

ALTERNATIVE STABILIZATION METHODS OF FOREST ROADS FOR AN EFFICIENT AND GENTLE MECHANIZATION OF WOOD HARVESTING SYSTEMS¹

By

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1. Introduction

Forestry, as a scientific discipline as well as a practice of human activity, considers the issues of sustainability and multiple-use as the most important principles for its rationalization. The implementation of these principles has a long tradition, more than two centuries in Europe, because otherwise, the respective human needs from the forest resources can not be covered in the long term. Wood harvesting represents a dominating activity in the framework of utilizing the so called production or economical forests, but it causes many negative impacts to the forest ecosystems after the wood extraction. Some authors put the detrimental effects of logging in the second place after the forest fires. The most remarkable impacts of logging refer to the remaining stands (stems and roots) as well as to the soil changes (compaction, puddling, displacement) and to the hydrologic behavior of watersheds (run-off, infiltration rate etc), especially when careless wood harvesting operations are carried out (Grammel 1988).

In the last 10-20 years, the public and many governmental, non-governmental and international bodies have become aware of these detrimental impacts, which have led to the strengthening of the reactions by the ecological and environmental movement. These reactions have reached a critical and dangerous point of pressures in order to change or to abandon, in some cases, the whole forest management process. International conferences and resolutions by the United Nations, the Council of Europe and the European Union have been multiplied in the last 5-10 years in order to find measures and criteria for sustainable development, for sustainable forest management and for an effective environmental protection (processes of Strassburg, Helsinki, Rio, Santiago, Geneva, Montreal, New York etc.) (Efthymiou 1995a and 1995b).

The Joint FAO/ECE/ILO Committee on Forest Technology, Management and Training, as one of the most appropriate and active bodies on the problems of forestry operations and following the priorities set by its parent bodies (European Forestry Commission and Timber Committee) has organized many seminars and meetings on the topics mentioned above, as for instance in Louvain-la-Neuve (1989), Munich (1990), Feldafing (FORSITRISK) (1994), Prince George-Canada (1995) etc.

The experience gained from this intensive collection and exchange of expertise, with respect to the soil impacts, can be summarized as follows:

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- The movement of heavy machinery in the forest leads to major soil changes and damages, which negatively affect the growth potential of the trees. Some of the soil changes are irreversible.
- Soil compaction is a serious threatening factor, which should be taken into more consideration, regarding the conception and structuring of wood harvesting systems in the future.
- Ground - pressure values exceeding 30-40 KPa cause severe soil damages, especially if the machine has more than 3-5 passes on the same terrain point (Horvat 1994).
- Soil type and moisture as well as the tyre size and type play a very crucial role and the assessment of their interactions is not easy and not predictable.
- As a general rule or conclusion in order to avoid soil damages, the vehicle movements should be confined to roads and skin trails, which means that machines should not move inside stands. (FAO/ECE/ILO 1989).

These conclusions should probably be seen and tested on the basis of some characteristic ground-pressure values of the forest machinery, mostly used in wood harvesting operations, as they are given by Abeels (1995):

Machine category Engine Power (KW)	Ground - pressure min - max (kPa)
1. <u>Ordinary forest tractors derived from agriculture</u>	
< 36	15 - 70
37-55	15 - 100
56-120	20 - 120
> 120	20 - 130
2. <u>Specialized tractors (skidders, haulers etc.)</u>	
37 - 120	50 - 140
3. <u>Combined tractors and trailers (forwarders, processors etc)</u>	
25-36	30 - 70
37-55	30 - 180
56-80	30 - 120

These facts show that modern forest machinery of wood harvesting exceeds the permissible pressure values on the soil in the most cases, especially when the machines are loaded or they extract wood from the forest stand. On the other hand, their frequent movement on earth forest roads is not possible, because after a few passes under adverse conditions, the primitive forest road will not be in function due to its severe damages. All these facts lead to the need that a well stabilized network of forest roads represents a precondition for an efficient and gentle mechanization of wood harvesting systems.

2. Literature Review

Stabilization implies improvement of soil so that it can be used for subbases, bases and in some rare instances, surface courses.

Stabilization of roads started in its primitive form since the ancient times. The need for stabilization of forest roads became obvious in central European forestry in the last two centuries due to the adverse soil and climatic conditions of forest operations. The first approach took place 50 years ago and the principal materials that have been used for stabilization included lime, lime-flyash and lime-NaCl mixtures, Portland cement and RRP-235 (Yoder 1957).

The choice of the proper stabilizer to be used depends upon the particular case, the goal and the stress, but the quantity of stabilizer is determined by means of laboratory tests, or by strength tests.

Portland cement has been used with success to improve existing gravel roads, as well as to stabilize natural soils. The factors that affect the physical properties of soil-cement include soil type, quantity of cement, degree of mixing, time of curing and dry density of the compacted mixture.

Granular sandy, silty and loam clays soils can be stabilized with cement, but it cannot be used in organic materials (Yoder 1957).

Cement brings about a decrease in density and in liquid limit (WL) and an increase in the plastic limit with a corresponding decrease in the plasticity index (IP). The increase in plastic limits is accompanied by a corresponding increase in optimum moisture content (W). Also cement, at times results in decreased density γ_d (optimum dry), when compared to the natural soil and increases soil strength.

Lime is most efficient when used in granular materials and lean clays. Addition of lime to a soil results in decreased soil density, in changes of the plasticity properties and in increases of its strength.

For the evaluation of strength, it is desirable to test lime-soil mixtures using the unconfined compressive test. Insofar as minimum unconfined compressive strength values are concerned, the criteria presented for soil-cement (17 Kg/cm^2) can be used as a guide for soil-lime mixtures, if consideration is given to the fact that these latter mixtures show considerable gains in strength with age. (Thomson 1970, National Lime Ass. 1970).

The quantity of lime required to stabilize most soils will vary between 5 to 10 percent by weight.

In Greece, we have found that the sandy soils (GL-CL, SC-CL), sandy loam (GC-CL, SC-CL, SM-ML), sandy clay (SC-CL) and the loam sandy (SC-CL) from granite, gneise, mica, schist and calcareous sandstone are stabilized with cement and that clay soils (CL, CH), loam (CL, ML, SC-CL), sandy clays (SC-CL), sandy loamy (SC-CL, GC-CL) and clayloamy (CL,ML) from gabbro, peridotite, flyash and limestone are stabilized with lime. Special research required only for the sandy loam soils (Eskioglou 1991).

Flyash is generally high in silica and alumina; therefore the addition of flyash to lime stabilized soil speeds the pozzolanic action. Generally, however the quantity of flyash required for adequate stabilization is relatively high, restricting its use to areas that have available large quantities of flyash at relatively low cost. (Groney 1978, Marsellos 1988).

Flyash decreases the density and improves the optimum moisture content as well as the mechanical properties of the soil (decrease in plastic index), it increases also the strength of the soil.

Another category of stabilization includes some chemicals like RRP-235. RRP includes compounds that will render a soil hydrophobic. This chemical will decrease the rate of water sorption to a minor extent but, in general, it is very costly, thus limiting their widespread use. Any soil is suitable, except soil consisting entirely of sand with less than 15% fine constituents (0.06 mm). The more cohesive, the more clayey or loamy it is, the more easily can be stabilized with RRP. (Stergiadis, Eskioglou 1991).

The object of the RRP method is to alter the soil and the water binding forces (break of capillarity). If it has been given optimum compaction, it can carry even the heaviest loads. There are no limits in this respect.

3. Research methods and materials

Research on forest roads stabilization started in Greece ten years ago using lime, cement, flyash and RRP 235.

For the purpose of this research work we have taken soil samples from the forest districts of Aridea, Drama, Grevena and Xanthi (Northern Greece) as follows:

Applying random sampling (AASHTO-T 86), we have fixed the plot points from which we have taken the soil samples. The soil weight taken from each plot was 10 Kg and this has been separated into 10 subsamples for the experimental testing. The soil-types tested were clay soils (CL, CH), loam soils (ML), sandy clay to sandy loam soils (SC - CL) and sandy loam soils (GC - CL).

The experimental samples have been tested in the laboratory. As testing methods have been applied:

The particle size distribution (according to method AASHTO-T 27). The maximum dry density (γ_d) and the optimum moisture content (W) on the basis of the method AASHTO-T 190 and the Atterberg limits. Especially, in this paper, we estimated the change of plastic properties (WL= liquid limit and Ip= plasticity index) and the soils strength after stabilization with various stabilizers.

Except the stabilization with lime and cement, we have also studied other materials, like RRP, flyash and NaCl, which improved or accelerated soils stabilization. The soils samples have been stabilized after the ASTM D/1632 and BS 1924 methods, with varying quantities of stabilizer.

Finally, we have compared the strength and the cost of the various stabilization options applied and tested.

4. Results and discussion

The data processing after the laboratory tests of the samples led to the set-up of the following results and tables.

4.1. Stabilization with lime

Table 1 indicates, for different percentages of lime, the compressive strength, the variation of soil Atterberg limits (WL and Ip) and the influence of stabilization enhancing on the optimum dry density (γ_d) and on the moisture content (W), for various mixtures after 7 and 28 days.

Table 1. Variation of the soil Atterberg limits (WL, Ip) moisture-density relationships and compressive strength of soil treated with different

percentages of lime, after 7 and 28 days curing (average of 10 samples). (1 Kg/cm²=98,066 kPa)

Soil type	W _L	I _p	Lime content %	Optimum dry density γ _d Kg/m ³	Optimum Moisture W %	Compressive strength Kg/cm ²	
						7 days	28 days
1. CL	35	17	0	1750	15		
	33	14	4	1720	16.2	7.2	7.8
	32	12	6	1670	17.1	7.6	7.6
	32	12	8	1680	18	8	9
2. SL-CL	27.1	9	0	1860	14		
	28	9	4	1720	15.2	8	9.2
	28.2	9.2	6	1600	17	8.5	9.7
	29	10	8	1510	18	9	10
3. ML	24	3.2	0	1790	14.5		
	25	3.5	4	1720	14.07	7	8
	26	3.6	6	1650	16.9	7.5	8.5
	26.1	4	8	1600	18	8.2	9
4. CL	40	21	0	1760	16.8		
	39	15	4	1680	17.6	6.8	9.5
	38	14.5	6	1600	18.2	8	10.2
	38	13	8	1580	19	8.9	12
5. CH	51	18	0	1500	23		
	47	15	3	1440	25	5.2	10
	46	14	5	1430	27	7.5	11
	40	8	7	1410	31	8	13
6. CH	62	39	0	1600	21.5	1.4	1.7
	57	30	3	1480	25.1	1.6	3.4
	56	20	6	1430	25.5	1.9	4
	56	18.5	9	1420	26.5	2.3	4.8
7. CL	35	20.8	0	1860	14.8		
	39	16	3	1730	18.5	2.6	4.5
	41	17	5	1690	19.7	4.4	6.2
	41	16.5	8	1660	20.2	4.8	7.5

4.2. Combined stabilization with lime and NaCl

Table 2 shows the results of the stabilization of clay soils treated with 1% NaCl and varying percentages of lime after 7 and 28 days of curing.

Table 2. Variation of the soil Atterberg limits, moisture-density relationships and compressive strength of clay soils treated with 1% NaCl and different percentages of lime after 7 and 28 days curing. (1KG/cm²=98,066 kPa)

Soil type	W _L	I _p	1% NaCL + lime content %	Optimum dry density γ _d Kg/m ³	Optimum Moisture W %	Compressive strength Kg/cm ²	
						7 days	28 days
5. CH	51	18	0	1500	23		
	46	14.5	3	1440	25	5.2	9.7
	46.5	14	5	1430	27	7.2	11.1
	42	7.8	7	1410	31	10	13.1
7. CL	35	20.8	0	1860	14.8		
	39	16	3	1730	18.2	2.6	4.4
	40	16	5	1690	19.5	4.5	6.2
	40	15.5	7	1660	20.2	4.8	7.3

4.3 Combined stabilization with lime and flyash

In Table 3 we have the variation of the clay soils treated with different percentages of flyash and soil lime 8% mixture.

Table 3. Variation of the soil Atterberg limits, moisture-density relationships and compressive strength of clay soils treated with different percentages of flyash and (soil lime 8% and flyash mixture) after 7 and 28 days curing.

Soil type	W _L	I _p	Flyash content %	Optimum dry density γ _d Kg/m ³	Moisture W %	Compressive strength Kg/cm ²	
						7 days	28 days
6. CH	62	39	0	1600	21.5		
	55	31	5	1550	23.3	1.45 (5.6)	2.17 (6.2)
	55	20	10	1527	23.6	1.50 (6.3)	2.25 (7.8)
	52	19	20	1500	24.7	1.54 (8.2)	2.85 (9.6)
	50	18	30	1470	25.5	1.65 (9.9)	3.00 (11.4)

We have studied the soil stabilization with flyash, due to the many quantities which are produced by the electric power factories.

We have used ash from the factory of Ptolemaida with 36% Calcium oxide (CaO) and with high efficiency in clay soils stabilization.

With a mixture of lime (8%) and flyash (30%), we have a decrease of the maximum dry density and an increase of the moisture. With an increase of the flyash content in the soil, we have a substantial improvement of all the above mentioned factors. The great quantity of CaO is responsible for the strength of the stabilized soils. We have not seen good results in soils, which have been stabilized without lime, but only flyash had been added.

From the soil stabilization with lime, we have realized that the soil became non-plastic, it increased the optimum moisture content, it increased the dry density and increased the compressive strength, when stabilizer percentage is about 7%. Possible mixture with flyash can improve all the properties, but strength cannot reach at 17 Kg/cm².

In gravel soils we have satisfactory results with a mixture of 9% lime and 30% flyash. With a mixture soil-flyash and with an addition of NaCl, we have not satisfactory results in the acceleration of soil stabilization.

4.4. Stabilization with cement

For the research of the non-clay soils stabilization with cement, we have used the Greek standard (norm) 0164.

The compressive strength results of soil treated with varying percentages of cement, after 7 and 28 days curing, are shown on Table 4.

Considering the soils which have been stabilized with cement, only the loamy soils (SC-CL) from flyash and the sandy clay (SC-CL) from granite show unsatisfactory strength results. For this reason they were stabilized with lime.

Soil stabilization with cement has resulted to :

1. Decreasing of the plasticity less than the lime.
2. Increasing of the strength more than the lime.
3. Increasing of the angle of internal friction and of true cohesion.

Taking into account the triaxial compressive strength and the angle of internal friction for a homogeneously plastic gravel soil, under normal moisture conditions, we estimated an increase of the angle from $\phi=40^\circ$ (cement 0%) to $\phi=55^\circ$ (cement 8%).

Also, the soil cohesion without cement, increased from $c=0.4 \text{ Kg/m}^2$ to $c=3 \text{ Kg/m}^2$ with a 8% cement addition. This increase is relatively lower in the loam soils.

Table 4. Compressive strength results of soil treated with 5%, 7%, 9% cement after 7 and 28 days.

Soil type	Cement content %	Compressive strength Kg/cm ²	
		7 days	28 days
1. SC-CL	5	16	19
	7	22	24
	9	27	32
2. GC-CL	5	22	26
	7	25	28
	9	30	34
GC-CL	5	27	31
	7	29	38
	9	33	49
4. SC-CL	5	20	26
	7	27	36
	9	32	47
	5	21	27

5. SM-ML	7	26	34
	9	30	44
6. SC-CL	5	13	16
	7	16	17.7
	9	17.7	18.5

4.5. Stabilization with RRP-235

In this paper also, it has been studied the way of action of an organic manifold, RRP, regarding its stabilization abilities into the soil. The results have shown that the material which was worked out with RRP, withholds less water, it is significantly less deformed when applying pressure on it, and it has shown that its behaviour is changed from a material with cohesive properties to one with cohesiveless properties.

The influence of RRP content (Kg/100m²) on physical properties and the change of the strength in an unconfined compression are shown on Table 5. The change of the strength in an unconfined compression, in connection with the content of the soils in lime and cement 7% and in 5 Kg RRP/100m² are shown in Table 6.

The results have shown that only in clay soils, which have been stabilized with RRP, indicate higher strength, compared to the same soil which was stabilized with lime or cement.

Table 5. Physical properties and unconfined strength of the soil which was used in the experiments.

Soil type	W _L	I _p	Kg RRP/100m ²	Optimum Moisture W %	Optimum dry density γ _d Kg/m ³	Compressive strength Kg/cm ²
CL	26	12	0	14	2038	2
	22	7.5	5	13	2102	12

Table 6. Change of the strength in an unconfined compression in connection with the comprehensive of the soil in lime and cement 7% and 5 Kg RRP/100m².

Soil type	Stabilizer	Compressive strength Kg/cm ²		
		7 days	28 days	35 days
CL	cement	4	9	12
	lime	5.5	8	8.5
	RRP	5	12	14
	cement	27	31	35

GC-CL	RRP lime	6 3	8 3.5	12 4
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4.6. Cost and strength

The last stage in this research was the comparison of strength and the cost of stabilizing soils.

For the strength estimation we have used the "Benkelman beam" in experimental surface with CBR=5 and allowable deflection $D_{zul}=185 \cdot 10^{-2}$ mm.

We have found that :

- For layer thickness 20 cm with sand-gravel, the Benkelman beam deflection has been reduced to $dm=528 \cdot 10^{-2}$ mm.
- For layer thickness 20 cm with 7% lime and 30% flyash, we have estimated $dm=349 \cdot 10^{-2}$ mm.
- For layer thickness 20 cm with 7% cement, we have estimated $dm=240 \cdot 10^{-2}$ mm.
- For layer thickness 20 cm with 7% cement and 20% flyash, we have estimated $dm=200 \cdot 10^{-2}$ mm.

From these, we have estimated the strength layer coefficients: a) $a=0.1$, b) $a=0.14$, c) $a=0.2$, d) $a=0.2$, respectively.

We have realized that a layer with cement and flyash shows a deflection 2.6 times smaller than the same layer of sand-gravel, and 1.7 times smaller than a layer with lime and flyash.

Table 7 indicates the cost and the relevant strength of layers which have been stabilized with various stabilizers. The cost figures show small differences but this should be compared and evaluated with the respective strength layer coefficients, which show bigger differences and they play an important role in the decision-making process.

Table 7. Cost and strength of stabilized layers

Types of stabilized layers	Cost in Drachmas per 15 cm layer*	Strength layer coefficient
Clay soil stabilized with 7% lime	1674	0.14-0.16
Clay soil stabilized with 7% cement	1592	0.13
Clay soil stabilized with 11% cement	1815	0.15
Sandy-loamy soil stabilized with 7% lime	1674	0.13
Sandy-loamy soil stabilized with 7% cement	1592	0.18
Sandy-loamy soil stabilized with 11% cement	1815	0.22

* This includes material, labor and construction cost.

5. Conclusions

Modern wood harvesting systems have to respect the fundamental forestry principles of sustainability and multiple-use management. Heavy logging machines (tractors, forwarders, processors, harvesters etc), should mostly circulate on forest roads and skid trails, in order to minimize the detrimental soil changes and damages on the stand growth areas. In this framework more forest roads have to be improved and stabilized for the accomplishment of an efficient and gentle mechanization of harvesting operations.

From the above discussion of research results on some alternatives of stabilization methods, we come to the following conclusions :

1. Plastic soils can be successfully improved after stabilization with lime, cement and flyash.
2. Soils of fine - element composition are well stabilized with 6-8% lime, as achieving with these percentages :
 - Improvement of the optimum moisture and decreasing of the dry density.
 - Soils become non-plastic.
 - The Benkelman beam deflection is reduced.
 - California Bearing Ratios (CBR) are increased.
 - We observed an increase of strength, which does not reach the limit of 17 Kg/cm².
3. Addition of flyash in the mixture soil-lime improves the strength values but this does not have any other positive effects (moisture and dry density).
4. Addition of NaCl in the mixture soil-lime increases the stabilization cost without any further improvement.
5. The treatment of very plastic clays with lime leads to a decrease of the liquid limit, which is increased in the less plastic ones. In case of a plasticity index decrease, we have a rapid improvement of soil processing ability, while the soil stability limits are improved. These properties are very important for the clay soils, as they contribute to maintain the soil strength and its volume from the influence of water, frost and traffic load in acceptable limits.
6. More specialized research is needed for sandy-loamy and silty-sandy soils, because stabilization changes their unstable state and makes them to high quality and strengthened materials. In this case the strength values of layers (a_j) are increased becoming higher of the respective values for sand-gravels at the best quality.
7. Stabilization of roughly structured soils with cement changes the soil Atterberg limits to a minor degree but it improves more the strength, compared to the lime stabilization. It is also increased the internal angle of friction and the cohesion.
8. The optimum addition of cement ranges at 7%, because at a higher percentage the whole construction work renders to be very expensive.
9. In soils which could be stabilized either with lime or with cement, the latter solution should be preferred (cement), up to a percentage of 10%. If a higher quantity of cement is needed, then lime should be applied as a more cost-effective option.

10. The stabilization of forest roads represents an environmentally friendly process, as using materials of nature, which are abundant and they provide the basis for improved road constructions, from the biological, technical and economical points of view. The stabilization of forest roads, combined with a sufficient density of roads network (opening up - system) must become a high priority in the forestry of the future, in order to meet the needs and the requirements, not only those of forest operations, but also in order to keep the forests healthy, productive and attractive for the future generations, which have the right to live in a better natural environment.

6. Literature

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**FOR AN EFFICIENT AND GENTLE MECHANIZATION OF WOOD HARVESTING
SYSTEMS**

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A problem continually facing a forest-engineer is that dealing with procedures and techniques by which otherwise unsuitable soils may be improved by stabilization. In many instances subgrade soils that are unsatisfactory in their natural state can be altered by admixtures, by the addition of aggregate, or by proper compaction and thus made suitable for subgrade construction. In its broadest sense, soil stabilization implies improvement of soil so that it can be used for subbases, bases, and, in some rare cases, surface courses. As in all engineering design problems, the economics of the problem in light of the benefits derived from the stabilization process determine whether it is warranted.

In any discussion of admixture stabilization, it is necessary for the user to keep in mind the purpose of the stabilization process. The intended use of the stabilizer, coupled with the mechanics of the stabilizer process, forms the basis for the selected type and quantity of stabilizer to be used.

Listed below are several reasons for using stabilization :

1. Poor subgrade conditions
2. Borderline base materials
3. Moisture control
4. Construction of superior bases.

Stabilization can be used to improve poor subgrades and thereby cut down on required pavement thickness. Many times borderline base materials with high plasticity are encountered and these can be made suitable for use by reducing the plasticity index by adding lime, cement, fly ash, RRP-235 and NaCl. Also admixture stabilization can be used to "dry up" some of the extremely wet soils.

The choice of the proper admixture to be used depends upon the use for which it is intended. The quantity of stabilizer is generally determined by means of laboratory tests, which simulate field conditions of weathering and other durability process, or by strength tests. In some cases, the addition of chemicals to a soil may increase the cost of construction to such an extent that it is more economical to improve the soil by densification, addition of better soils, or addition of aggregates.

MECHANICS OF STABILIZATION

The various types of stabilization have been categorized according to the properties imparted to the soil and their behaviour is vastly different of each from the others; each has its particular use, and, conversely, each has its own limitations.

The principal materials that may be used include Portland cement, lime, lime-flyash mixtures, RRP-235 and NaCl.

Portland cement has been used with great success to improve existing gravel roads, as well as to stabilize natural soils. It can be used in granular soils, silty and lean clays, but it cannot be used in organic materials.

Lime(Kalk) increases soil strength primarily by pozzolanic action, which is the formation of cementitious silicates and aluminates. This material is most efficient when used in granular materials and lean clays; the quantity required for proper hydration generally is relatively low.

Flyash is generally high in silica and alumina; therefore, the addition of flyash to lime stabilized soil speeds the pozzolanic action. Generally, however, the quantity of flyash required for adequate stabilization is relatively high, restricting its use to areas that have available large quantities of flyash at relatively low cost.

Cement and Kalk change the water film on the soil particles, modify the clay minerals to some extent, and decrease the soils plasticity index.

Another category of stabilization includes some chemicals, like NaCl, that increase rate of water sorption.. Sodium chloride lower the vapor pressure of soil water and lower the freezing point of the soil water as well.

Thus it can be used as a construction expedient to retard evaporation of the soil water during compaction or, in some cases, to prevent freezing of the soil water.

Others chemicals, like RRP-235, are available for stabilization. This include compounds that will render a soil hydrophobic. This chemical will decrease rate of water sorption to a minor extent but, in general, are very costly, thus limiting their widespread use.

CEMENT STABILIZATION

Stabilization of soil with cement to produce hardened soil cement consists of adding Portland cement to a pulverized soil, and permitting the mixture to harden by hydration of the cement.

The factors that affect the physical properties of soil-cement include soil type, quantity of cement degree of mixing, time of curing and dry density of the compacted mixture.

Most fine-grained soils, except those containing organing matter, can be stabilized with cement.Sandy soils generally are stabilized readily.Often, cement is incorporated in rela tively well-graned granural materials.