All Weather Low Cost Roads For India

BY

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Thesis

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF
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CERTIFICATE

Certified that the dissertation entitled " All Weather Low Cost Roads for India" which is being submitted by Sri Harion Prakash Sharma in partial fulfilment for the award of the Degree of Master of Engineering in Highway Engineering of University of Roorkee is a record of students own work carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other Degree or Diploma.

This is further to certify that he has worked for four and half months at the University of Roorkee for prepatation of his dissertation.

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A P P E N D I C E S

APPENDIX - I

TOPICS FOR FURTHER INVESTIGATIONS :- The author feels the necessity of carrying out the detailed investigation for following :-

1. Suitable design method, should be evolved for pneumatic tyred traffic, preferably on the basis of contact pressures (and not on wheel loads alone).

2. Further laboratory investigations on the effect of organic matter on cement-soil stabilization, to ~~find~~ differentiate between the active fraction of organic matter, and the total organic content, which includes even the insoluble organic matter. (Author's comments on page 88-89).

3. Further investigation to determine the effect of deviation from optimum moisture content on the strength of soil - cement mixtures, since the results reported by various workers have been contradictory. (Page 91-92)

4. Further investigations to find out the effect of partial replacement of cement, in soil-cement with flyash. Reports have been contradictory on this subject also. (Page 95-96)

5. In lime-stabilization of soils, contradictory results have been reported by various workers, (Page 104) on the

effect of Magnesium content of lime on the strength of stabilized soil. As such this also needs further investigations.

6. Generally only fat-lime has been tried both in laboratory and in field for stabilization purposes. Hydraulic lime also need be tried, beaause at some places fat lime may be many times costlier than the hydraulic lime.

7. Investigations, as to the economic possibility of using trace chemicals in improving strength of stabilized soil, should be carried out in details.

8. Further investigations for possibility of using industrial waste like sulphite liquor, lignin etc., should be thoroughly carried out.

9. Investigations for devising a suitable and economic method for thermal treatment of the soils.

APPENDIX - II

AMERICAN TENTATIVE LIMITS OF PARTICLE SIZE DISTRIBUTION FOR BASES AND SURFACING

(A.S.T.M.: D. 556 - 40T and A.S.T.M. : D. 557 - 40T)

Percentage Passing.

B.S* Sieve Size	Type A (Sand-Clay) Base or surfacing.	Type B (Gravel-sand-clay) Base 2" max. size	Type B (Gravel-sand-clay) Base 1" max. size	Type B (Gravel-sand-clay) Surfacing	Type C Base or surfacing.
2 in.	-	100	-	-	-
1½ in.	-	70 - 100	-	-	-
1 in.	-	55 - 85	100	100	-
¾ in.	-	50 - 80	70 - 100	85-100	100
3/8 in.	-	40 -70	50 - 80	65-100	-
3/16 in	-	30 - 60	35 - 65	55- 85	70-100
No. 7	100[x]	20 - 50	25 - 50	40- 70	35-80
No. 18	55-90	-	-	-	-
No. 36[+]	35 - 70	10 - 30	15 - 30	25 -45	25-50
No. 200[‡]	8 - 25	5 - 15	5 - 15	10-25	8 -25

* The nearest equivalent commonly used B.S.Sieves are given here.

\+ The fraction passing the No. 36 sieve shall have the following characteristics :-

For Bases -- Liquid Limit not exceeding 25 percent.
Plasticity Index not exceeding 6% for types A & B & 3% for type C.

For Surfacing -- Liquid Limit not exceeding 35 percent.
Plasticity Index between 4 & 9percent.

Ɨ The percentage passing the No. 200 sieve shall be not more than one-half of that passing the No. 36 sieve for bases, and two-thirds for surfacings.

x Type A mixtures may have upto35percent retained on the No. 7 sieve; the limits shown are those of the material passing the No. 7 sieve.

PROPOSED LIMITS OF PARTICLE SIZE DISTRIBUTION FOR BASES AND SURFACING WITH TOLERANCE.

B.S. Sieve size.	Percentage Passing.					
	Base.			Surfacing	Base or surfacing.	
	Nominal Maximum Size.			Nom. Maxm. Size.	Nominal Maxm. Size	
	3 inch	1½ inch	¾ inch	¾ inch	3/8inch	3/16-3/8inch
3 in.	100	-	-	-	-	-
1½ in.	80 - 100	100	-	-	-	-
¾ in.	60 - 80	80 - 100	100	100	-	-
3/8 in.	45 - 65	55 - 80	80 - 100	80 - 100	100	-
3/16in.	30 - 50	40 - 60	50 - 75	60 - 85	80 - 100	100
B.S. 7	-	30 - 50	35 - 60	45 - 70	50 - 80	80 - 100
14	-	-	-	35 - 60	40 - 65	50 - 80
25	10 - 30	15 - 30	15 - 35	-	-	30 - 60
52	- -	-	-	20 - 40	20 - 40	20 - 45
100	5 - 15	5 - 15	5 - 15	10 - 25	10 - 25	10 - 25

Notes :-

1. Not less than 10 percent should be retained between each pair of successive sieves specified for use, excepting the largest pair.
2. The two smaller sized material (3/8 in. and

3/16 in.) may have upto 35 percent of stones not larger than 1½ inch, provided that the material passing the 3/16 in. sieve ~~with~~ is within the limits specified.

3. The material passing the No. 36 sieve shall have the following characteristics (B.S. 1377: 1948) :-

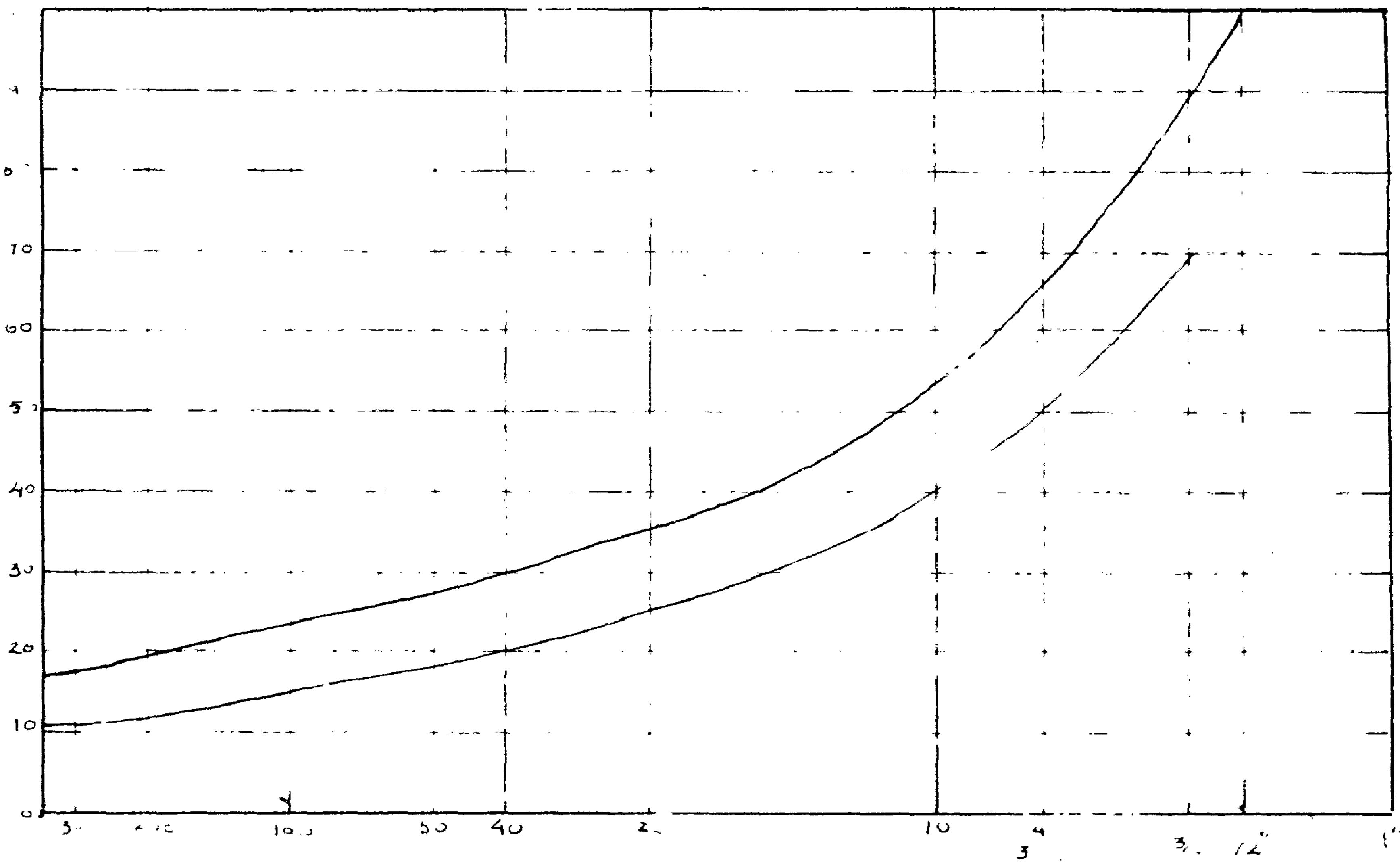
For Bases -- Liquid Limit not exceeding 25%.

Plasticity Index not exceeding 6%.

For Surfacings -- Liquid Limit not exceeding 35%.

Plasticity Index between 4 and 9%.

APPENDIX II iii



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SPECIFIED BY SWEDISH STATE ROAD INSTITUITE. STO[illegible]

APPENDIX --III

SAMPLE CALCULATIONS FOR THE COST OF BASE- COURSES - PER MILE PER 10 FT. WIDTH OF ROAD.

(1) 6" thick Hard Stone Soling :- Lead of 10 Miles for stone

Item	Quantity	Rate	Amount.
1. Collection of Hard Stone Soling AT SITE	5280 x ½ x 10 = 26400 Cft.	8.00 %cft)	)7022.40
Cartage of stone for 10 miles	26400 Cft.	18.60 %cft)	
2. Laying soling to template including hand packing etc.	26400 Cft.	3.75 %cft.	990.00
3. Consolidation of soling including watering, spreading earth etc., with lead of water upto 3 miles.	26400 Cft.	6.00 %cft.	1584.00
			9596.40
		SAY Rs.	9600.00

2. (2) 4" thick Cement Stabilized Soil - with 4% Cement Content.

1. Collection of Ordinary Soil including breaking clods (pulverization)	5280 x 10 x½ =			
		26400Cft.	15.00%cft	396.00
2. Collection of Cement at 4% of dry weight of soil. (roughly 90pc.ft.)	$\frac{26400 \times 90 \times 4}{112 \times 90}$ =	1056Cft	6.00/cft	6336.00
Carting of Cement for 10miles		42.4 Tons	5.80/ton	246.00
3. Dry Mixing of Soil and Cement in stacks.	26400 + 1056 =			
		27456Cft.	1.00%cft.	274.56
4. Watering and Wet Mixing		27456 Cft.	1.00%cft.	274.56
5. Laying and Levelling to Camber		27456 Cft.	1.00%cft.	274.56
6. Rolling with 8 Ton Power Roller.	5280 x 10 =			
		52800 Sft.	1.00%sft.	528.00
7. Curing for 7 days.		1 Mile.	100.00/mile	100.00
				8429.18
		SAY		Rs. 8430.00

(3) 4" thick Bitumen Stabilized Soil @ 6% Bitumen.

1. Collection of ordinary soil

including pulverization   5280 x 10 x ½ =

26400 Cft 15.00 %ocft. 396.0

2. Collection of Bitumen at 6% of

Dry Weight of soil.(Assuming

dry density of soil 90 p.c.f.) $\frac{26400 \times 90 \times 6}{100}$ =

= 142560lbs = 63.6 tons

@ 300.00/ton 19080.00

Kerosene for fluxing at 20% of

Bitumen (Assuming Sp.Gr. = 0.8) $\frac{142560 \times 20}{6.25 \times 0.8 \times 100}$ =

5750.25 Gall. =

12.7 Tons 1.50/Gall. 855.36

Cartage for Bitumen & Kerosene

for 10 miles. 76.3 Tons. 5.80/Ton 441.40

3. Addition of Optimum Moisture, Mixing and Aeration. 26400 Cft. 2.00%cft. 528.00

4. Laying and levelling to grade & Camber. 26400 Cft. 1.00%cft. 264.00

5. Rolling with 8 T. Power Roller 5280 x 10 =

52800 Sft. 1.00%sft. 528.00

22092.76

SAY Rs. 22100.00

APPENDIX -- IV

Sample Calculations for Base Coats and/or Surfacings.

(1) 3" thick W.B.M.

(i) Collection of 1½" gauge screened

Hard Stone Ballast 5280 x 10 x 3/8 =

19800 Cft. 12.00%cft. 2376.0

Cartage of 10 Miles. 19800 Cft. 18.60%cft. 3686.8

(ii) Collection of Binding Material

(Moorum, morrinda etc.) 1/5th of (i) =

3960 Cft. 4.50%cft. 178.00

Cartage for 10 Miles. 3960 Cft. 18.60%cft. 736.56

(iii) Consolidation of Stone Ballast, etc., with lead of water upto 3 Miles. 5280 x 10 x 3/8 =

19800 Cft. 15.00 %cft 2970.00

9947.36

SAY Rs. 9950.00 per mileS per 10 ft. width.

(2) Creteways with brick paving directly on subgrade.

Two strips of cement concrete each 2½'width,5"th. of 1:2:4c.c.

Flat Brick Paving of 1½" width on edges &2½' width in middle.

(a) Cement Concrete 1:2:4 per %cft, with 10 miles cartage for stone, sand etc.

Collection of Graded Metal upto

1½" size is (: Given rate of 1½"

size is 12.00 % cft or say 16.00 % cft. for graded)	96 Cft.	16.00) + 18.60)	%Cft.	33.20
Collection of Sand.	48 Cft.	6.00) + 18.60)	%Cft.	11.81
Collection of Cement.	1 Ton	150.00) + 4.40)	per Ton	154.40
Labour charges for mixing, placing and finishing etc.		L.S.		30.00
Joints etc.		L.S.		10.00
				239.41

Cost for Cretways 2 x 2.5 x 5/12 x5280 x $\frac{239.4}{100}$ = 26400.00(i)

(b) Flat Bricks per hundred sq. ft.

Cost of bricks	350 Nos.	30.00 ‰ Nos.	10.50
Cartage for 10 miles.		18.60 % Cft	4.65
Laying with Sand Blindage (180)		5.58 % Sft.	4.30
			19.45

Cost For Brick Paving (2.5 + 1.5 + 1.5) x 5280 Sft.

@ 19.45 % Sft. = 5720.00

Total 26400 + 5720 = Rs. 32120.00 per mile

10 ft. width.

(3) Single Coat Bituminous Surface Painting :-

1. Collection of ½" Gauge Stone Chips
etc. @ 5 Cft % Sft. $\frac{5 \times 10 \times 5280}{100}$ = 2640 Cft

@ 25.00%Cft.)
Cartage for 10 miles. 2640 Cft. 18.60%Cft.) 1151.0

2. Collection of Bitumen at 40 lbs.
per 100 sq.ft. $\frac{40 \times 5280 \times 10}{100}$ = 21120 lbs.

= 9.5 T. 300.00/Ton)
Cartage. 9.5 T. 5.80/Ton) 2905.00

3. Labour Charges for Single Coat
Surface Painting. 5280 x 10 = 52800 sft.

@ 2.50 % sq.ft. 1320.00

5376.00

SAY 5380.00 per mile per 10 ft. width.

APPENDIX -- V

Sample Calculations for Annunity Determination :-

(y) - For 30 years ; (x); with 3% Compound Interest (y)

$$a = 1 + \frac{y}{100} = (1.03)$$

(1) **W.B.M. only on Base :-**

(a) Initial Cost - of Base Course (Standard) = 8400.00

W.B.M. Base Coat 3 inch thick = 9950.00

18350.00

C_I = Cost at 30 years at 3% compound interest

$$= \frac{(1.03)^{30} \times 18350}{30} = 44600.00$$

(b) Annual Maintenance Cost = 500.00

∴ Maintenance Cost for 29 years = a

$$C_{A.M.} = 500 \times \frac{100}{3} \left\{ (1 + 3/100)^{30} - 1 \right\}$$

$$= 23800.00$$

(c) Periodic Maintenance Cost = 5000 - 500 = 4500 every 4 years (p)

Total number of renewals = 7 = $\left(\frac{n}{x}\right)n$

$$\therefore \text{Cost} = C_{PM} = C \times \frac{a^x - a^{x-p\left(\frac{n}{x}\right)}}{a^p - 1}$$

$$= \frac{4500 \times (1.03)^{30} - (1.03)^{30-28}}{(1.03)^4 - 1} = 4500 \times 10.84$$

$$= 48800.00$$

Total Cost = 44600.00 + 23800.00 + 48800.00 = 117200.00

Annunity = 117200/30 = 3907 SAY Rs. 3910.00

APPENDIX -- VI

Extracts From Schedule of Rates of Rajasthan P.W.D.(B&R) for Jaipur Circle.

A. Cost of Materials -

1.	Stone Ballast 1½" Gauge	12.00 % Cft.
2.	Burnt Bricks I Class	35.00 %o Nos.
3.	Stone Grit, ordinary variety ½" gauge to 1/8" graded.	25.00 % Cft.
4.	Bajri Sand.	6.00 % Cft.
5.	White Lime.	2.00 per maund.
6.	Cement.	6.00 per Cft.

B. Transportation of Materials -

1.	Carriage of building or road materials etc., upto ½ mile lead including loading and unloading.	5.00 % Cft.
2.	-do- upto 3 miles lead.	9.00 % Cft.
3.	Add extra cost for every subsequent mile upto 7 miles.	1.50 % Cft.
4.	-do- beyond 7 miles.	1.20 % Cft.
5.	Transportation of Bitumen or Tar full drum to site including loading and unloading with lead upto 3 miles.	3.00 per Ton.

6. Transportation of Bitumen or Tar full drums to site including loading and unloading with extra lead of each subsequent mile. o.40 per Ton

7. Carriage of Cement, Steel and other heavy material upto 3 miles lead including loading and unloading. 2.30 per Ton.

8. -do- Add extra for subsequent additional lead per mile. 0.30 per Ton.

Note :- 1. Add extra 1.00 per mile per % Cft for cartage in sandy or hilly area (on items 1 to 4)

2. -do- 0.40 per Ton per mile (on items 5 to 8)

C. <u>Earth work</u> -

1. Earth work in all sorts of ordinary soils including breaking clods, ramming, levelling, dressing in layers etc. with lead upto 100 ft. and lift 5 ft. 15.00 %o Cft.

2. -do- stiff clay or any other hardsoil- 22.00 %oCft.

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D. Collection of

1. Collection of Stone Soling etc., duly stacked(at quarry) 8.00 % Cft.

2. Collection of approved brick bats for soling duly stacked at site.of kiln 10.00 % Cft.

3. Breaking Ballast at quarry (labour) 4000 % Cft.

4. Supplying 1½" gauge screened broken stone ballast etc., duly stacked at quarry. 12.00 % Cft.

5. -do- 2" gauge -do- 10.00 % Cft.

6. Collection of Binding Material, Morrinda, Kankar, Moorum etc., duly stacked at source.

Morrinda	3.50 % Cft.
Kankar	5.00 % Cft.
Moorum	4.50 % Cft.

7. Collection of screened stone grit of approved quality etc, duly stacked (at quarry) size ½" to 1/8" graded. 25.00 % Cft.

E. Laying and Consolidation:-

1. Laying soling to template etc. 3.75 % Cft.

2. Consolidation of soling including watering, spreading earth etc., with lead of water upto 3 miles. 6.00 % Cft.

3. Consolidation of stone ballast etc., 15.00% Cft.

F. Labour Charges -

1. Labour charges for hot bituminous surface painting etc., I coat. 2.50 % Sft.

2. Labour charges for laying and consolidating hot premixed carpet ¾" thick complete in all respects. 4.25 % Sft.

3. -do- 1½" thick -do- 5.00 % Sft.

Rates for Rough Estimate of Roads. -

1. Surface Dressing with precoated chips ¾" thick. 11000.00 per mile per 10'lane.

2. A.M. to important roads of W.B.M. etc. 500.00 -do-

3. -do- other minor roads -do- 400.00 -do-

4. A.M. to important roads(Black-Topped) 400.00 -do-

5. -do- minor roads -do- 350.00 -do-

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APPENDIX -- VII.

Recent Researches in Highway Materials :-

Very recently a new constructional material has been developed in Germany, in which aggregates are suspended in a special type of plastic. Hollow blocks made of this material are then laid over cross beams for the road construction.

This type of construction is claimed to cost as little as half the conventional types and has got the further advantages of, providing space for underground utilities, quick constrüction etc. (182)

Also in Holland the wood waste from timber is pressed, treated and used as base for cheap roads in swampy areas, Such roads have also been found to serve very well to the traffic, with life nearly 10 years. (Details from 'Specifications for Roads' Amsterdam)

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3.10.62.

ALL WEATHER LOW COST ROADS.

CHAPTER - - I.

INTORDUCTION -

I - INTRODUCTION.

1.1 MEANING OF LOW COST ROADS AND THEIR SIGNIFICANCE FOR INDIAN CONDITIONS :- The conventional meaning of Low Cost Roads is that they are cheap roads constructed from cheap materials such as soil and low grade aggregates, by using cheap construction methods.

However a truely low cost road should be cheap not only in initial construction but in subsequent maintenance and vehicle operation as well. That means least cost per ton mile. But then this definition will included all the correctly designed roads. For example even a well designed concrete road if provided for a heavy traffic of 1500 Tons per day or so, shall give least cost per ton mile and shall be known as "Low Cost Road". Such roads however are very few and most of the roads to be newly constructed, shall have very light traffic in the early years of their life. The traffic in such cases does take a couple of years to reach to its full intensity. Provision of high cost roads such as W.B.M.Road with bituminous carpet or Cement Concrete road, in the very initial stage of such cases is likely to give very high cost per ton mile.

Thus the best way out is to provide such roads which have low initial cost, as well as low maintenance cost, to successfully cater with the present day traffic(with due allowance for the increase in traffic by the end of a certain period say three years or so), and are capable of improvement in stages, to cope with the traffic that will develop at the end of a certain period(design period) after the construction of road.

The present thesis has been aimed at this problem, viz., how to construct a large mileage of roads, with a very limited amount of funds, and yet successfully cater for the traffic with minimum of operation and maintenance cost.

Coming to the facts and figures of our Five Year Plans and Twenty Year Road Projects, we plan to get 2,52,000 miles of main roads and 4,05,000 miles of other roads by the end of 1981, giving a network of 52 miles of roads per 100 Sq. miles of land, against the present figure of 26 mile today. This programme is expected to cost about 5,200 Crores of Rupees(97 & 98). The data of 1961 is 1,23,000 miles surfacedand 2,08,000 miles unsurfaced roads. Then we have to construct about 6,450 miles of surfaced and about 10,000 miles of unsurfaced roads every year, assuming a uniform development. The allotments for road construction were Rs. 130 Crores in First Five Year Plan and about 250 Crores in Second and Third Five Year Plans. That means nearly 50 Crores every year, while the anticipated expenditure is 260 Crores per year(or 5,200 Crores for twenty years).

The plan allocation are thus quite insufficient to fulfill our 20 year Road Development Plan targets, if we stick to our conventional specifications of W.B.M. roads. What is the solution then?

The very obvious solution is to reduce the initial cost of construction, so that we may be able to meet the immediate demand of a closely connected road network, which is so essential fo the devlopment of our Rural Economy.

Low Cost Roads then come to our rescue. The extent to which low cost roads, would economize the road construction, can be visualized from the fact that surfaced W.B.M. costs something like Rs. 58.00 per 100 sq. ft., as against Rs. 38.00 per 100 sq. ft., for surfaced soil stablized stone grafted road (Chapter IX), which has proved to be good enough for traffic upto 800 Tons per day under favourable soil and climatic conditions. With the recent advanced knowledge of soil science, the low cost roads, utilising stabilized soil or soft aggregates as their main constituent, can be adopted for most of the local soil, climate, and traffic conditions in India.

1.2 STAGE CONSTRUCTION :- These low cost roads essentially have traffic limitations, and can not withstand a very high traffic intensity, without suitable wearing surfaces. A high cost pavement can then be divided into a convenient number of stages and improvements made at the end of each stage.

In general following stages are encountered in practice, and the choice has to be made by considering the immediate and ultimate traffic characteristics, as well as the local conditions of soil and climate:-

Road Pavements - Life and Traffic Capacity.

Stage.	Type	Useful Life	Traffic Limit T/day
I	Earth Roads.	Less than One Year.	Upto 30
II	Mechanically Stabilized Soil Roads (No additive) with Bituminous Surface treatment. OR	Surface life 3 years.	30 - 250
	Additive Stabilized Soil Roads (Cement, Bitumen etc.) with Surface treatment.	Surface life 3 years	upto 500
III	Brick Paved or W.B.M. with Bituminous surface treatment. OR	Surface Life 3 - 4 years	250 - 500
	Bituminous Premix Carpet. OR	12 Years	500 - 1500
	Cement Concrete	30 Years	1000 - 1500

has got to be provided where a very high intensity of traffic is expected to develop immediately after the construction of the road. But in case, a high intensity of traffic is to come upon the road after some time, say ten years, the "Low Cost Road" can form the beginning of a planned programme of prgressive stage construction.

The stage construction , as applied to roads, means providing layersof increased strength to the pavement with the corresponding increase in traffic. This is feasible, because the basic difference between a high cost and low cost road lies, not in the design of base or subbase, but in design of surfacing only. A road which is to be developed in future by stage construction, need be designed withthe idea of future improvement in mind at the initial stage itself.

For a successfull stage construction process one should carefully decide upon the traffic characteristics that would develop at the end of a forseeable period of time (design - period). The design of geometrical elements of road viz., grade, camber, curves, crossings, road widths, and formation widths, as also the design of cross drainage works shall be governed by this traffic, while the initial structure of the road shall depend upon the traffic, that the road will have to bear immediately. The design

Example :- Let us consider a road that is to be constructed for connecting a very small village with a big town; the alignment passing through a cultivable land. Design period - Ten Years.

Now let us first consider the probable development in traffic. With the construction of road more people will be attracted towards rural life, and passenger traffic will increase. The Rural Industries of poultries and dairies will develop, and more land will be exploited for cultivation. Mines and jungle products(Timber etc.), if available are liable to be exploited.

As such quite heavy traffic (about One thousand Tons per day) can be expected to develop at the end of our design period. All the curves, crossings and C.D. works shall be designed for this traffic.

The construction of the road itself can be conveniently divided into stages as follows:-

Stage I :- First Three Years- Meagre Traffic of Carts, very little passenger traffic say upto 50 Tons per day. --- Earth Roads.

Stage II :- Six Years Afterwards- Development of cultivation Dairies and Poultries. Farm and Dairy products carried to city for quick disposal. Jungle resour-

~~xxx tapped,~~ ces tapped, new quarry opened. More social contacts and hence more passenger traffic. Traffic say upto 500 Tons per day. --- W.B.M. or Stabilized Soil Road with Bituminous Surface Treatment.

Stage III:- Ten Years Afterwards- Cultivation and Rural Industries in full swing. Village gradually developing into a town. Industries like Sugar Milla and Flour Mills starting at village. More activities in the village. Traffic - Heavy- Say 1000 Tons per Day. --- Bituminous Carpet $1\frac{1}{2}$" thick over W.B.M.

In this manner the road is improved as necessitated by the devalopments in traffic, and hence stage construction is particularly useful for the construction of access roads like farm to market roads, village roads, and district roads. This is because these roads will essentially have meagre traffic to cater with in the beginning.

The special point in favour of stage construction is that a road improved in stages in a suitably planned way, is most economic of all. This is because full utilization is made of the road at each stage.

For this reason low cost roads can be initially provided even for those alignments, which will be carrying very heavy traffic at the end of the design period. The low cost road shall have been improved by that time in stages, the final stage being that of the high cost pavement necessary to carry that heavy traffic.

1.3 TYPES :- For our purpose, then, the low cost road will mean only stabilized soil roads, or soft aggregate roads, or brick paved roads. The high cost road on the other hand will mean bituminous premix or stone sett or cement concrete road etc.

1.4 SCOPE:- These low cost roads, have soil or other soft material in their bulk and as such are not capable of resisting abrasion due to traffic (particularly of steel tyres) and destructive effect of weather, particularly Monsoons. They must be provided with a bituminous surface dressing if a trouble free, dust free, durable, and all weather road is desired.

Provided with a suitable wearing coat, a well designed low cost road constructed of stabilized soil or soft aggregate is as good as any of the costlier pavements like bituminous carpet or cement concrete for traffic upto 500 Tons per day. For traffic heavier than this they can successfully serve only as base courses for higher types of pavements.

1.5 OBJECT OF THE THESIS :- The object of this presentation has been to analyze the different structural and economic aspects of these low cost pavements by utilizing stage construction procedure.

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C H A P T E R - II.

DESIGN OF LOW COST ROADS --

II DESIGN OF LOW COST ROADS.

A road must be properly designed for its geometrical as well as structural elements if it has to carry the traffic loads safely, with minimum of expenditure and inconvenience.

The geometrical design includes the design of road width, grade, curves, camber, super elevation etc. The structural design includes the design of road crust.

2.1 DESIGN OF GEOMETRICAL ELEMENTS:- The geometrical design is governed mainly by the speed and size of the vehicles that will be plying on the road. Since the size of vehicles has already been fixed by the I.R.C., we need consider the speed only.

I.R.C. has recommended 30 m.p.h. (50 k.p.h.) as designed speed for all important roads in plain or rolling country. This speed although reasonably high, is rarely maintained by auto drivers. In personel interviews with the truck and car drivers at Dausa on N.H.W. No. 11 the author was informed that the speeds maintained are round about 40 m.p.h. and 50 m.p.h. for trucks and cars respectively. Further more the present trend is towards still higher speeds, which is essential for economy and competition with Railways. In America trucks and truck-trailer units usually ply at 50 m.p.h., thus saving time; and time is money these days. The same age shall soon come to India as well. As such it would be very reasonable to adopt higher design speeds for the geometrical standards, with due consideration of the anticipated traffic conditions after ten years or so.

Correct estimation of traffic that would develop after the design period is very important, because unlike the structural elements, the geometrical elements can not be changed every now and then, without entailing an excessively high expenditure and have got to be fixed in the initial stage.

As regards the type of traffic it has been established universally that whereever finance permits, seperate roads should be provided for iron tyred vehicles and pneumatic tyred vehicles, if economy is to be achieved. This is so because the design requirements of the two types of the traffic are entirely different. However since under the present economic tightening it may not be possible for us to provide seperate lanes for slow moving iron tyred vehicles and fast moving pneumatic tyred vehicles, it would be desireable to limit the slow traffic on the berms made of stabilized soil. About 14 feet wide sand clay berms on either side of the carriageway have been found to serve very well in Burma(51), and same may be tried in India as well.

2.2 STRUCTURAL DESIGN :- The structural design of low cost roads includes the design of various structural elements of the road crust. The various structural elements of the pavement are:-

1. Wearing Coat.
2. Base Course.
3. Sub Base Course.
4. Sub Grade,

and their design requirements are as follows:-

1. Wearing Coat:- Wearing coat is the top most layer over the main road structure or base, specially designed to resist attrition, abrasion, crushing, suction, and other forms of damage to the riding surface and to prevent the entry of water into the base from above. It must be strong and resilient enough to prevent permanent deformation and cracking, and should be able to resist stripping from the base course due to weathering and horizontal shear caused by traffic.

Wearing coat is not always provided, for example in a simple gravel road, where the main road structure or base performs temporarily the duties of the wearing coat also. But in most of the cases where the soil as such, or modified by stabilization forms the bulk of the road structure, an impervious wearing coat need be immediately provided, to prevent the change in strength of base course due to access of moisture.

When the wearing coat is very thin and serves the purpose of water proofing only, it is more correctly called "Surface Treatment" and then it is considered not as a seperate layer, but as a part of the base course it self.

2. <u>Base Course:-</u> Base Course or base alone forms the body of the road and serves the function of dispersion of applied traffic loads safely over the layers underneath. It must be designed so as to be able to disperse the applied loads to such an extent that the ultimate pressures transmitted to the subgrade, are less than the safe bearing capacity of the subgrade under all anticipated conditions, without causing any permanent deformation in itself, at any time during the yearly cycle.

3. Sub Base Course:- It is a layer of selected material palced between the subgrade and basecourse for further reduction of vertical stresses due to traffic. Its necessity arises when heavy loading and poor subgrades of very low bearing capacity are encountered. Although the sme effect can be obtained by providing an additional thickness of basecourse, but it is more economic and mere scientific to adopt a thin base course of superior material underlain by a varying thickness of relatively inferior(and hencecheaper) material.

A sub base course may also be required for cutting off the capillary rise of under ground water. A sandy blanket layer may be needed in silty subgrades, and a clay cut-off in fine sand regions. Hessian impregnated with bitumen may serve for both.

4. Sub Grade :- It is the natural ground prepared to recieve the base or sub base, as the case may be, immediately over it. This is the most important part of the road, since it has to ultimately bear the traffic stresses.

It is very essential to have the bearing values of subgrade known under all conditions of traffic and moisture. Money spent in improving a poor subgrade is always well spent, because it helps in reduction of roadway cost not only by reducing the required thickness of road crust, but also by reducing the future maintenance cost. A bed subgrade is always a liability, and can not be cured by patching or resurfacing in top layers; some times the addition of top layers may result in even more speedy deterioration of the road. It must be kept in mind, that a faulty base can be remedied more easily and with much less expenditure than a faulty subgrade, containing areas of inferior material, whose rectification may even be virtually impossible.

As such in areas of weak subgrade, all efforts should be made to improve it by ramming, draining, and in extreme cases by providing suitable sub base course.

2.22 COMMON CAUSES OF ROAD FAILURE :- Thus we see that every layer of the road crust must be suitably designed to safegaurd against the failure of road. Generally the failure of road may be due to one or more of the following reasons:-

Most common cause of failure, particularly in low cost roads, where the soil forms the bulk, is due to differential change in moisture content of base, sub base, or sub grade, that results in a change in their shear strengths. Due precaution against the access of moisture and proper design for thd worst condition are the likely remedies.

According to Sri Rangachari(15) another important reason attributing to failure of roads is the placing of materials of widely different elasticity in adjecant layers. It is normally aggreed upon, that in flexible pavements materials with increasing shear strength (or C.B.R.) should be placed from bottom upward for safety foras well as economy.

Another reason for the failure of WsB.M. roads is the direct placing of stone soling on the fine grained soils. The fine soil of subgrade becomes soft and plastic with an increase in water content, which may be either due to capillary rise of water from bottom or entry of water through the pavement(in case of unsurfaced W.B.M.) or some times even due to reduced evaporation of water from the subgrade(due to impervious surface in case of surface painted W.B.M.). Under the traffic loads, then the fine soils work up in the interstices of the solingstone,which in turn sinks down. More and more materials are added during maintenance just to sink down in the silty or clayey subgrades, as the case may be.

The remedy of-course is to provide a permeable coarse-grained layer between the soil and soling. Although an inverted filter would form the ideal layer, but that is pretty costly. A 4" sub-base of fine granular material (river sand etc.) or of lime stabilised soil may be provided to undo this sinking of the soling.

As to the size of these sub-base materials the U.S. Army Corps of Engineers(185) has introduced a term known as ' piping ratio ' which refers to the size of pore spaces through which drainage shall take place. According to them _

$$\text{Piping Ratio} = \frac{15\ \%\ \text{particle size of sub-base}}{85\ \%\ \text{particle size of subgrade soil}} \not> 5$$

In general this may be interpretted to mean that the smallest size of particle in the sub-base should not be more than 5 times the coarsest size of the particle in subgrade soil. Then for clay subgrades, flyash of coarse sand passing 3/8 inch sieve should be satisfactory.

Also the subgrade and sub base should be given asuitable cross slope (Camber) say 1 in 48, for effective flow of drain water out.

In addition to the above mentioned reasons, following ones have also caused road failures in many cases:-[4]

i) Bad Design,

ii) Faulty Specification & Imperfect Supervision,

iii) Faulty Subgrade Preparation,

iv) Inadequate Pulverization & Mixing Where applicable.

v) Inadequate Equipment, and

vi) Work carried out at Wrong time of the year.

However if the road is properly designed and constructed under strict supervision in accordance with correct specifications, there remain little chances of road failure. Proper design means, the design of road thickness for safely carrying the traffic loads with due consideration of all anticipated influencing factors.

2.23 FACTORS INFLUENCING DESIGN:-[3] The important factor that influence the design of a road crust are, traffic characteristics, soil characteristics, drainage facilities, climate and cost.

(1) Traffic Characteristics:- Both the amount and type of traffic influences the design of road crust. For the proper design we must know the maximum wheel load as well as the frequency of its application.

Tendency of modern transport is towards heavier loads. A controversy hence arises; while the highway engineers want to limit the wheel load so as to not over stress the pavement, the transport people want stronger roads to suit their heavier loads. A reasonable upper limit should hence be fixed for the wheel loads. (Present limit is 9000 lbs.)

As a matter of fact it is not only the wheel load that counts, but the inflation pressure as well as the tyre size are equally important. As such Statutory Limits should be fixed for Maximum Wheel Load, Maximum Inflation Pressure and Mimimum Tyre Size. If in certain special cases, wheel load has got to be exceeded, the inflation pressure should be correspondingly decreased to bring the stresses within safe limits.

In case of wholly empirical methods, generally the design method itself takes care of the repetition of load and impact In more rational methods, the repetition is generally taken into account by correspondingly increasing the static wheel load. In many methods however the impact allowance is usually dispensed with, because modern roads rarely have such serious irregularities so as to cause appreciable impact effect.

The iron-tyred bullock cart traffic of India poses a great threat to the road structure, if the same is not designed suitably for the high shearing stresses that are induced by the bullock cart tyres. The best solution of this problem, lies of course in replacement of iron-tyres with pneumatic tyres, or fixation of Statutory Limits for maximum laden weight, and minimum diameter and width of the tyre of the cart, so as to keep the stresses within limit.

However till these steps can be put into practice, we have to design our roads to carry bullock cart traffic also. A complete and thorough investigation is hence necessary to determine the character and amount of present day traffic, as well as of the anticipated traffic at the end of the design period.

(2) Subgrade Characteristics and Drainage:- The subgrade has got to bear the traffic loads ultimately. Hence the value of the subgrade strength should be known under all possible conditions of moisture and density that may occur in the yearly cycle. As the subgrade stregths may vary widely with changes in its moisture content, it is very essential to know the drainage conditions also well in advance, so that the correct estimation of the subgrade under worst possible conditions may be made.

This needs complete analysis of the subgrade soils and the determination of their engineering properties.

(3) Climate:- The design of road shall also be governed by the climatic conditions. For example excessive rains or no rains, too much temperature variations, freeze and thaw conditions etc. will be the influencing factors in design, since they tend to change the strength of subgrade and bases etc.,

(4) Cost:- This is the last, but not in the least, important factor governing the design of road. A very careful study has got to be made of all possible alternatives and most economic design is to be adopted. In many cases it would not be possible to make the " 30 year cost", the basis of choice, since the immediate availability of funds is most important factor. In most of the cases, a cheap road made of low grade aggregates and soils, with a plan of progressive stage construction may have to be adopted.

2.24 DESIGN METHODS :- With all these necessary informations regarding traffic, subgrade soil, climate, cost etc., available with us, there are as many as fifty different methods, each one differing from the other either in the assumptions made or in the results arrived at. Each one has got its own merits and limitations. In general these methods can be grouped under four sub heads:-

(1) Purely Empirical Methods- Using No Soil Strength Tests. They are based mainly on experience and soil classification tests such as particle size and plasticity characteristics.

Example :- Group Index Method.

(2) Empirical Methods Using A Soil Stregth Test. The tests for such methods are usually bearing or penetration tests and generally applicabele only to its associated design method. These methods are also partly based on past experience.

Example :- C.B.R. Method.

(3) Methods Based Partly on Theory and Partly on Experience. In these methods fundamental stress- strain properties of subgrade soil and sometimes of base also, are determined by bearing or shear tests and results employed in a simplified or modified theory of stress distribution, having some experimental evidence.

Example :- Westergaards Method.

(4) Wholly Theoritical Methods. These are based on theoritical analysis of the stresses and strains throughout the pavement and subgrade and the true stress-strain characteristics of the materials.

Example :- Burmister's Analysis.

As a matter of fact in past design methods were mostly empirical, because the behaviour of soil towards the applied loads was most uncertain and unknown. This can now be predicted with sufficient accuracy by recently developed new techniques such as, displacement of buried glass beads, distortion of thin layers of white and coloured powders and X-ray shadow graphs(80), that gives the shape of failure zones, moisture cells that give the state of moisture content at various depths and at various parts of the year, and electronic devices that can measure the soil density at any depth very quickly, the exact mode of failure of the subgrade can be precisely ascertained.

Aided by these advancements, scientists are at work for developing a rational methodd of design. Till then, however the more empirical methods have got to be used.

The most widely accepted design method for flexible and semi-flexible pavement is the California Bearing Ratio Method and its various modifications. For the semi-rigid pavements also C.B.R. method is widely used.

Rational design methods particularly for stabilized soil roads have recently been developed by Harris(121), Vokac(83) etc.. Another method has been developed in Russia which takes the deformation of various layers as the basis of design.

Seperate design methods have been forwarded for the iron-tyred bullock carts, which howeger have not been universally accepted sofar;

A critical review of the more common methods with a passing reference to the methods themselves, and a little detailed dealing of the methods applicable to low cost roads in particular is hereby given:-

(1) Group Index Method:- This design method, developed by U.S.Highway engineers is based on a purely empirical value known as Group Index of the material, which is an inverse measure of the strength. The higher the Group Index, the lower is the strength, and higher the thickness of road crust needed over it. Materials with Zero Group Index (well graded gravels and sands) form the best subgrades and need minimum of built up road thickness over them.

The Group Index value is a function of particle size, liquid limit and plasticity index of the soil.

Design curves relating the thickness of bases and sub bases to the Group Index of the subgrades have been developed for various traffic intensities. The two basic assumptions of this method are:-

(a) Compaction of the subgrade to be not less than 95% of that determined by standard A.A.S.H.O.Test and compaction of base and sub base not less than cent per cent.

(b) The subgrade should be sufficiently high above the ground water table to enable proper compaction of the subgrade prior to the placing of base or sub base, and soil drainage or sufficient embankment height, or some other suitable cut off to be provided where necessary to keep the water table at least 3-4 feet below the road surface.

Comments:- The chief advantage of this method lies in its extreme simplicity, needing no intricate testing or formula work. The results are obtained quickly by conducting very simple physical tests only. The values obtained by this method have been found to be fairly safe in the investigations carried out by R.R.L.Harmondsworth(60), provided that the assumptions regarding compaction and drainage hold good. Under present conditions the assumptions of compaction and drainage are hardly cared for in India, the subgrades being never compacted and drainage being cared for only in extreme cases.

Another draw back of this method is that it does not differentiate between the flexible and rigid pavements and does not take into account the pavement properties.

Any way since the importance of subgrade compaction has been universally accepted and agreed upon, and proper drainage is also an essentiality for trouble free service of the road, the Group Index method may form an acceptable method of pavement design.

What is actually needed, is that the values given by G.I. method should be checked against the existing roads and formula modified to suit the local conditions. Seperate design curves need be developed for bullock cart traffic.

The present trend is towards this method of d
The present trend is towards using this method of design for less important roads only, the more rational method being used for important roads.

(2) C.B.R.Method:- C.B.R. value of a material is the load required to penetrate a cylinderical plunger 3 sq. in. in end cross section, 0.1 in. or 0.2 in. at 1/20 in. per minute in that material expressed as a percentage of the standard load.

The method was developed by California State Highway department which came to know by experience that the materials having a certain C.B.R. value required a minimum thickness of road construction over it. Design curves were then developed, based on experience, for the design of base and surfacing, for different C.B.R. values and wheel loads.

Comments:- This method has also got the advantage of simplicity, no intricate calculations being involved in the design. As far as its soundness is concerned, a series of tests conducted by R.R.L.Hardmondsworth have shown that the C.B.R. method gives quite accurate values

This method being the most widely accepted one all over the world, due to its merits mentioned above, deserves adoption in India as well. However it would be more scientific to take into account the local factors also, on the lines of the modifications made by the highway departments of Wyoming State (U.S.A.), Colorado State (U.S.A.), and Australia (157).

Some research workers have also tried to apply the C.B.R. method to the design of road for the bullock cart traffic also, which will be discussed at length at a later stage.

Reader will find the table given hereby interesting for having a general idea of subgrade evaluation

SUBGRADE EVALUATION (5)

Description of the Soil	Classification	Group Index	Subgrade Bearing Values	C.B.R. Value percent.
Sand- Clay- Gravel- Well drained.	Excellent	0	40 -80 psi.	35 - 100
Sandy Soils with not more than 35 % passing No. 200 seive. Good Drainage.	Good	0 - 4	20 -30 psi.	13-22
Clayey Soils but not heavy Clays. Good Drainage.	Fair	4-10	15-20 psi.	10-13
Heavy Clays with more than 50% Clay Uncertain drainage. Poor.		10-15	10-15 psi.	6 - 10

for the design of pavement and the values are quite safe (16).

However a controversy exists as to the conditions under which the C.B.R. test should be conducted. The U.S.Corps of Engineers uses a test sample soaked in water for four days prior to testing, a condition ~~fairly~~ rarely met in practice, and hence unnecassrily higher thicknesses. It is hence very important that the worst conditions to which the subgrade may be subjected during its service period, should be accurately ascertained and sample tested for C.B.R. under these conditions only also it must be ascertained that the subgrade and the base(ifof soil or soft aggregate) do not have moisture variation departing seriously from the moisture content used at the time of strength test. This is so because even small variations in the moisture content of soils may cause relatively serious changes in the bearing values. The strength test should be carried out at a moisture not varying from the critical moisture content of the subgrade(which must be exactly determined to nearest one percent) by more than one per cent. So much is the effect of change of moisture content on the strength of subgrade that some workers have recommended the application of a thin coat of bituminous material blinded with granular material to the formation, immediately after its preparation(183), to seal it against any ingress or egress of moisture in service time.

Heavy Clay soils - Poor drainage.	Very Poor	15-20	5 - 10 psi.	2 -6

(4) <u>Design of Semi - Rigid Pavements:</u>- As already referred to, there are two distinct type of pavements, one flexible type, that do not have any beam or slab strength and another, rigid type which have appreciable slab strength and can bridge over small irregularities of the subgrade surface. In between these two types of pavements lies a distinct group of semi-flexible or semi-rigid type of pavements which generally includes additive stabilized- soil roads.

The pavements to be included in this catagory should have sufficiently low Modulous of Elasticity and Co-efficient of thermal expansion, so as to reduce the temperature expansion - contraction and warping to such an extent that jointing is not necessary. It has been observed that in cement-stabilized sand-shell mixtures the ultimate strength limits for semi flexibility are 200 p.s.i. and 1200 p.s.i., and that no objectionable cracking occurs between these limits(121). Similar, though not exactly the same, limits exist for other types of stabilized-soil roads also.

For design purposes semi-flexible pavements may be defined as those constructed of bases having appreciable slab strength, but not sufficient slab strength to ensure that the subgrade soil will not be over stressed under the traffic loads.

The design of these roads will hence consist of two parts:-

(a) Determination of base thickness required to prevent development of tensile stresses in the slab in excess of the allowable flexural strength, like that of rigid pavements, and

(b) Determination of the base thickness required to prevent over stressing of the subgrade soil or any other underlying layer of the pavement.

This is accomplished by first designing the pavement as a flexible type, and then applying a thickness reduction in proportion to the slab strength.

The slab strength is determined by Hveem's Stabilometer-

$$\text{Slab Strength} = \frac{MY}{I} = \frac{C}{45.4}$$

where,

M= Failure Moment,

Y= Distance of Extreme fibre from Neutral Axis,

I= Moment of inertia of the sample,

C= Failure load under standard conditions.

The reduction in thickness is obtained by referring the Nomograms(121).

Comments:- This method appears to be more scientific and rational than the others discussed before hand, and possesses the advantag of being quite simple also. This method, as such should form the basis of design of roads such as cement or cement-lime stabilised bases, or any other chemically stabilised base that has got appreciable rigidity.

Yet many of the low cost roads shall fall outside this category, examples being that of the bitumen-stabilised or mechanically stabilised roads, which are purely flexible types. Thus this method has got only limited application.

(5) Other Design Methods:- A method suggested by Vokac (83) for the design of stabilised soil or gravel pavements utilizes the bearing strength of subgrade as basis of design.

The formula forwarded is -

$$h = \frac{b}{2}\sqrt{\frac{P}{R} - 1}$$

where,

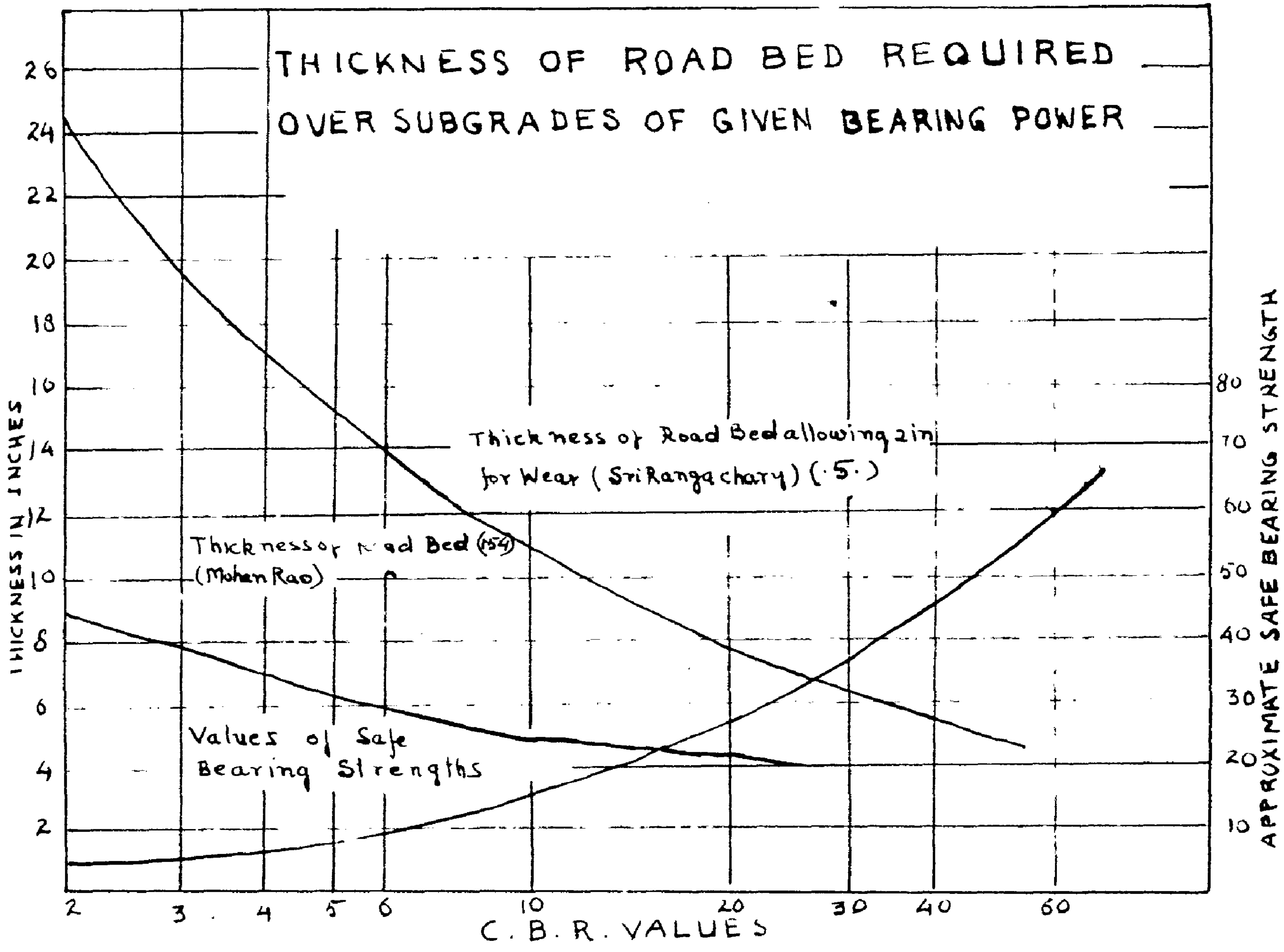
h= thickness of the road structure in inches including the bituminous surfacing, if any.

b= diameter of the tyre contact area in inches.

P= contact pressure of vehicle tyre on surface, p.s.i.

R= bearing capacity of the subgrade soil.

Vokac's method has been widely used in North Carolina (U.S.A.). The special thing about this method is that while other methods, even the most theoritical ones like Westergaard's utilize the maximum wheel load as the design factor, this method utilizes the contact pressure for design, thus having a more direct approach


THICKNESS OF ROAD BED REQUIRED
OVER SUBGRADES OF GIVEN BEARING POWER
THICKNESS IN INCHES
26
24
22
20
18
16
14
12
10
8
6
4
2
C.B.R. VALUES
2
3
4
5
6
10
20
30
40
60
APPROXIMATE SAFE BEARING STRENGTH
80
70
60
50
40
30
20
10
Thickness of Road Bed allowing 2in for Wear (Sri Rangachary) (·5·)
Thickness of Road Bed (154) (Mohan Rao)
Values of Safe Bearing Strengths

bullock cart traffic need be tackled as effectively as possible for the time being. Proper design of roads to carry the bullock cart traffic successfully is even more important for the low cost roads, which often have wearing course of low crushing and shearing strength.

The bullock cart loads normally vary from 1200 lbs. to 1700 lbs, while the width of tyres vary from 1.5"(4cms) to 3.5"(9cms). Various workers have shown that for cart loads of 1600 lbs. a contact pressure of 600 p.s.i. can be safely assumed for design purposes(158 & 154). The assumption made by Sri Rangachary(4) of 100 p.s.i. contact pressure does not seem to be very correct.

Pressure Distribution - The pressure distribution by the road crust differs very widely in iron tyre and pneumatic tyre. The contact pressure of a 9000 lbs. pneumatic tyred wheel is round about 60 p.s.i., whereas it is 600 p.s.i. for a 800 lbs. steel tyred cart wheel. The pressure intensity for pneumatic tyred wheel load at a depth of 5" or more is higher than that for a steel tyred cart load.

This means that while the proper design for steel tyred wheel necessitates the provision of a lesser thickness of road crust with top or wearing course having very high shearing and crushing strengths, the design for pneumatic tyred wheel necessitates the provision of much greater thickness of road crust, the top of which need not have too much strength. And a road for combined traffic must have a very strong wearing course as well as a sufficiently thick base course for suitable distribution of the wheel load pressure to the safe bearing values of the subgrade.

As such, it will be generally more economic to seggregate these two types of traffic by providing seperate lanes for them.

Design curves have been developed by Sri Rangachari (4) for bullockcart traffic on the basis of C.B.R. curves by using an approximate relationship between the C.B.R. values and ultimate bearing capacity as determined by a 30 inch diameter plate bearing test, for a soil deformation of 0.15 in., to 0.2 in. This method is based on the assumption that the roads fail in shear under the bullock cart load, and penetration test being a measure of shear resistance, should form a justified method of design.

Another curve is that given by Mohan Rao (158) which has been extrapolated from existing C.B.R. design curves. A minimum thickness of 2 inches of Asphaltic Concrete or Cement Concrete or 4 inches of W.B.M. as wearing coat is suggested over the properly designed base, which may be of low cost type.

Comments:- The curves given by Sri Rangachari (4) are based on Safe Bearing Value which itself is not an absolute value, depending to the problem.

There is still another method of designing the soil stabilised and other flexible pavements in Russia, which is based on Modulus of Deformation (Further refer to Specifications for the flexible pavements for roads V.I.103-57 Moscow,1957.)

(6) Design for steel tyred bullock cart wheels:-

The iron tyred wheels of bullock cart which are so common in India pose a serious threat to the successful behaviour of our roads towards traffic. The wheel load itself is usually not excessive in case of bullock carts, but on account of narrow width of the steel tyre, very high pressure intensities, which have a crushing effect on the road, and very high shear stresses due to sharp edges of tyres, which have a cutting effect on the road, are created. These two things viz., high crushing and shearing stresses, combined with various other factors such as absence of springs, bent axles, and wobbling of wheels, result in rapid deterioration of the road structure.

Various suggestions have been made by Central Road Research Institute,India,(154), and others, that include replacement of steel tyres with pneumatic tyres, restriction on the tyre width and tyre diameter to a certain minimum, and providing self aligned wheel axle system etc., All of these will still take decades for full implementation, and as such the problem of suitable roads for upon various factors such as shape and size of the loaded area, in-situ soil conditions etc.. The contact pressure assumptions also do not appear to be very reasonable. The first factor can however be eliminated by adopting standard test procedure, and conducting the in-situ test under precisely known conditions of subgrade, particularly moisture content and state of compaction. The thicknesses given by this method have also been found to be much in excess of those found safe in practice.

On the other hand Mohan Rao's curves are found to approximate more closely with the thicknesses found satisfactory in service.

Both of these methods suffer from the defects that

a) no consideration is given to the strength of the wearing course,
b) the wearing course is not rationally designed against crushing and shear, and
c) little consideration is given to the conditions under which the strength of subgrades should be determined, which should be same as the most critical condition, as regarding the state of compaction and moisture content, that the subgrade may have to encounter any time during the yearly cycle.

At present however Mohan Rao's curves appear to be better than the other existing mehtods of design.

2.25 PRESENT POSITION OF DESIGN METHODS :- Inspite of such a large number of design methods advanced so far, none has been universally accepted. An ideal design method would consider not only the subgrade strength, but also the strength and properties of all the layers forming the road structure together with the true distribution of stresses. This method would be based on tyre contact pressure instead of wheel load alone(Since the tyre sizes are usually standardized, the upper limit on contact pressure can be fixed by putting an Statutory Limit on Inflation Pressure and Wheel Load both, and not on the wheel load alone).

In absence of such an ideal design method, C.B.R. method with modifications such as, dispending with of four days soaking procedure, incorporation of actual anticipated conditions in the test, and modification in C.B.R. curves with contact pressure replacing the wheel load, should form the best method for the design of flexible bases, such as W.B.M., Stabilized Soil, Gravel roads etc.

Harriss(121) concept of semi rigid pavements has got limited application viz., to soil cement roads only, and deserves an experimental trial in field.

Vokac's (83) method is also in infancy and needs further support from both laboratory and field evidences.

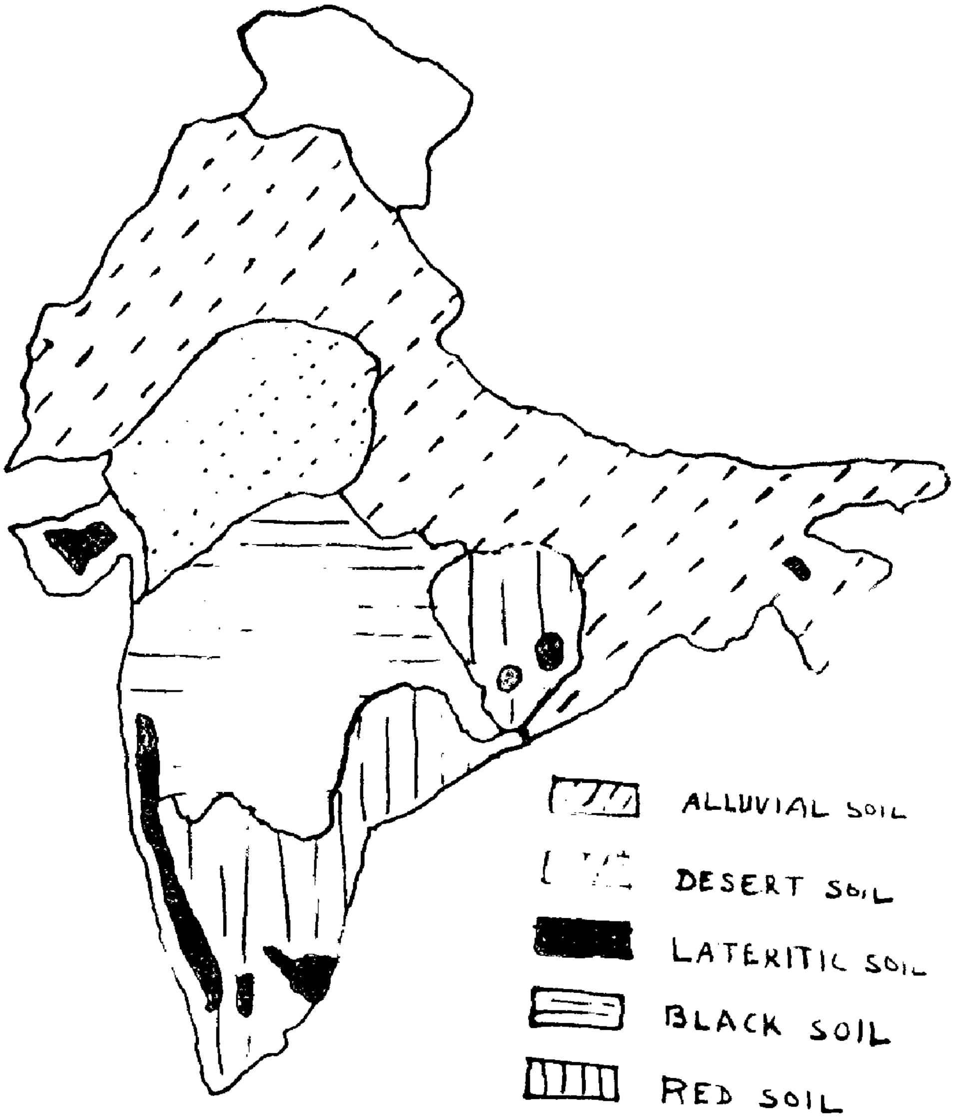
Group Index Method with modifications to suit the Indian conditions should form a quick and convenient design method for less important roads e.g., village roads and other district roads.

Whereever bullock cart traffic is encountered, the road must be carefully designed and provided for with a base coat of 4" of W.B.M. or 2" of asphaltic concrete of 3" of cement concrete. If finance permits, seperate lanes should be provided for cart traffic and truck traffic.

The roads if thus designed properly, will have little chances of failure and hence give a safe and trouble free long service with minimum of expenditure.

C H A P T E R. - - III.

MATERIALS FOR LOW COST ROADS --



SOIL MAP OF INDIA

III MATERIALS FOR LOW COST ROADS.

As already emphasized, the low cost roads embody all types of stabilized soil roads, soft aggregate roads, brick paved roads and creteways. The materials for them are naturally then:-

1. Soils,
2. Soft Aggregates,
3. Bricks,
4. Additives for stabilization purposes like cement, lime, bitumen, etc.

3.1 SOILS :- Soil being the member that will support the traffic loads ultimately and hence serve as foundation, is very important for roads, and more so for low cost roads, where it forms x the bulk of road itself, either as such or after being stabilized by various techniques.

3.11 Soil Types :- For general purposes the soils are divided in four ffactions:-

1. Gravel Fraction -- Particles between 60 mm. and 2.0 mm. equivalent particle diameter.
2. Sand Fraction:- Particles between 2 mm. and 0.06 mm. equivalent particle diameter.

3. Silt Fraction -- Particles between 0.06 mm. and 0.002 mm. equivalent particle diameter.

4. Clay Fraction-- Particles below 0.002 mm. equivalent particle diameter.

Further sub divisions exist embracing coarse, medium and fine fractions for both sand and silt.

(1) Gravels :- They are coarse particles resulting from the disintegration of rocks, and may be calcareous (then known as kankar, jhajhra, morrinda and nodule etc.), or sileceous or ferrogeneous (then known as red moord), depending upon the parent rock. They usually form the best materials for low cost roads as such, or after stabilization, which does not present any serious problem.

(2) Sands :- They usually consist of quartz or silica particles and are either pit-borne, river-borne, or wind-borne. The pit and river sands may be coarse and well graded but the wind-borne or dune sands, as occuring in deserts (Western Rajasthan for example) are very fine and single sized. They rarely create problems in stabilization and are often suitable for most types of additive stabilization. They lack cohesion.

(3) Silts :- They are physically and chemically similar to sands except for their smaller size, and are very susceptible to

frost heave. They have high permeability and capillarity, while having negligible internal friction and cohesion. Silts, having no strength of their own, are more costly to stabilize than sands.

(b) Clays:- The clay particles differ from the other coarser types of soils both physically and chemically. Physically, unlike the sands and silts, they are flat and elongated, having much larger surface area and hence the property of plasticity.

Chemically, they consist of hydrated alumino-silicates, which are formed during the leaching process to which the coarser particles of the primary rock are subjected.

The clays have cohesion only and no internal friction. They pose great problems in road construction . As a subgrade, they tend to cause subidences & cracks in the road, due to change in its moisture content, which changes its bearing capacity very much, and causes it to swell or shrink.

As a material for stabilization, they pose still greater problem due to the difficulty in their pulverization, and very high plasticity characteristics as well as due to their chemical and electro-chemical characteristics.

Black cotten-soil, a type of very heavy clay occuring predominently in Maharashtra and nearby states and in patches in other places also has got all these detrimental characteristics at their limit.

The soils have been classified more scientifically, considering their gradation and plasticity characteristics etc by various instituitions and organizations. More important of these classificat-ions for Engineering purposes are- United States Public Road Administration Classification, Cassagrande Classification and Unified System of Classification.*

All these soils have their own properties, depending upon various factors, which have an important effect on their use as subgrade and /or constructional material for road work.

3.12 <u>SOIL CHARACTERISTICS</u> :- Various soils have their own characteristic properties depending upon, grain size, chemical composition, moisture content, densification, organic content etc. The important soil characteristics that effect their use in Engineer-

* Details of these classification system can be read from any Standard book on Soil Mechanics.

ing purposes are:-

(1) Internal Friction:- This the resistance to the displacement of particles due to their mutual interlocking, and is a major factor determining the strength of soil. It is maximumin sands and minimum in clays. Moisture content has got a remarkable effect on internal friction, due to its lubricating effect on the particle surfaces.

(2) Cohesion :- It is the resistance to the displacement of particles due to binding forces of films of water. Cohesion is maximum in clays and least in sands. Cohesion in clays is ~~due to~~ of two types both of course depending upon water, one due to surface tension forces at the air/water interfaces within the soil structure, and another due to interaction between the soil particles or soil particles and water molecules.

Cohesion is hence greatly effected with changes in moisture content, and increase ~~the~~ in moisture content may totally destroy the cohesion.

(3) Suction:- Suction forces are mainly due to particle

hydration in case of clays and due to surface tension incase of sands and silts. Suction is important for Road Engineer, because it may cause a rise in moisture content of subgrade or base course by capillary action, and hence change the strength.

(4) Swelling:- It is an effect associated with particle hydration in clay soils. The soil swells on an increase in moisture content by the gradual increase in thickness of adsorbed water films, till the suction pressure in the water equals the over burden pressure on the soil. Such soil will settle instantaneously on an increase in over burden pressure, by a reduction in thickness of adsorbed layers of water, a phenomenan explaining the settlement of road or building foundation in clay soils.

(5) Shrinkage:- It is also a property of clay soils and may result partly from external loading, but mostly due to moisture changes occuring with evaporation or transpiration by vegetation.

(6) Plasticity:- This is due to the lubricating effect of the water films between adjecant particles in the soils, and is thus dependent upon the size and shape of the individual particles and

the chemical nature of their surfaces. This property is associated with clays only.

(7) Permeability:- It is the property mainly associated with grain size and the density of the soil. This property influences the drainage very much. Coarse-grained soils are more permeable and hence more easily drained then the fine grained soils.

(8) Compaction:- This is the packing of particles more closely through a reduction in air voids and depends upon the lubrication of soil particles with moisture films. Gradual addition of moisture to dry soils results in lubrication of points of contact of the soil particles and hence enables them to come closer and closer when force is applied. After a certain limit however, voids become full of water and any further increase in moisture tends to displace the particles, giving rise to ~~denser~~ less denser state.

This limit of moisture at which a certain amount of compactive force applied to a certain soil results in maximum densification(measured by dry density) is known as Optimum moistur-e content for that soil under the given conditions.

Compaction causes an improvement in the desireable engineering properties of the soil such as bearing strength, permeability and susceptibility to effect of moisture changes.

(9) Salt Content:- Presence of various water soluble salts in soil effect the soil properties a lot. Particularly in case of clay soils, the electrolytic salts, that cause base-exchange phenomenon to take place, have a major influence on soil properties. Thus the sodium clays have very high swelling and plasticity characteristics, while calcium clays have much less.

The soluble salts also effect the road structure by -- (a) attacking concrete and other materials containing cement, (b) disrupting the porous materials such as the soil itself by crystallization and, (c) by attacking metals.

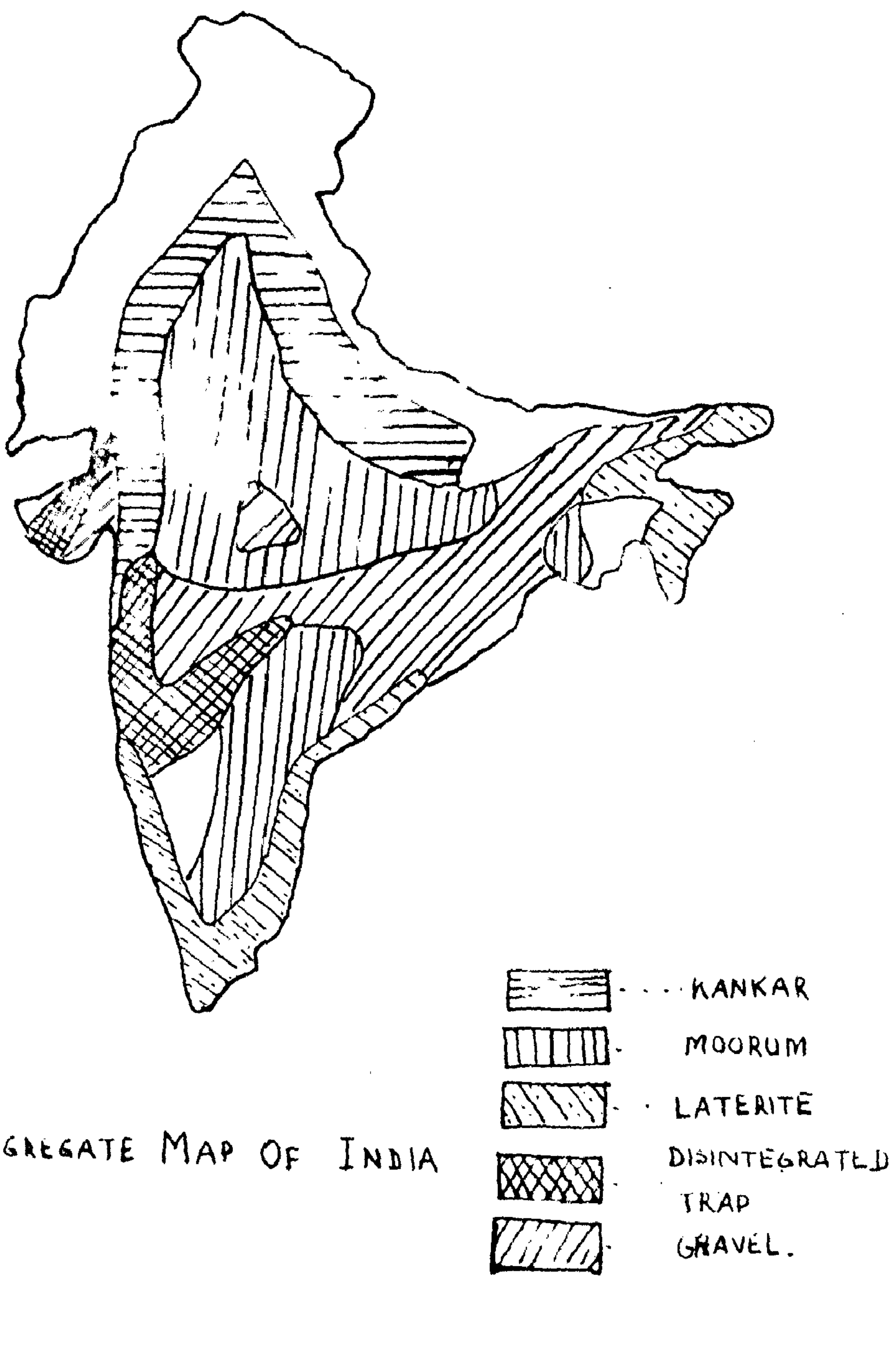
The principal salts concerned are sulphates of sodium and magnesium, which are highly soluble in water. Sulphates have a very detrimental effect on cement matrix, probably due to the formation of calcium sulpho-aluminate, which breaks the cement matrix due to expansion in its own formation-

As such sulphates are very dangerous in stabilization processes and more so in cement stabilization.

(10) Organic Content:- Organic matter which finds its access to the soil through the decomposition of plant or animal remains, is an undesireable element. It results in an open, spongy, and mechanically weak soil. It has also got very undesireable effect on stabilization techniques, particularly lime and cement stabilization, due to its acidic characteristics.

(11) Ph Value:- The Ph value, a measurement of the hydrogen ion concentration in soils is of importance in soil stabilization process. Thus for cement stabilization the soil should not be acidic or Ph $>$ 7, while for stabilization with natural resins the soil should not be alkaline or Ph $<$ 7. Ph has got similar influence on other types of stabilization processes also like lime and bitumen stabilization.

The Ph is generally governed by the presence of electrolytic salts in soils, and may have to be regulated in some cases for reasons mentioned above.



SOFT AGGREGATE MAP OF INDIA

These soil properties, thus have got a great bearing on the strength of the soil, as well as on the stabilization processes, and the successful utilization of soil as subgrade or as base after suitable processing is solely controlled by these characteristics.

3.2 SOFT AGGREGATES:- Soft aggregates are materials such as Kankar, Moorum, Morrinda, Laterite, Bricks, Porous Volcanic Rocks, Gravels, Furnace Slag etc. and any other form of soft and disintegrated rocks, which are hitherto regarded as unsuitable for permanent road construction due to their low strength.

These aggregates offer great possibilities in economising road construction, if suitably utilised. This is so because they occur locally in abundance at most of the places.

Although most of them will not satisfy the usual test standards of hard stones, yet some have given values comparable, to or even higher than the hard stone. Such aggregates can be used in higher type of pavements as such. The other weaker types can be used only after suitable treatment in stabilized roads.

3.21 Types & properties:- The various types of soft aggregates that occur abundantly in India are:-

1. Kankar - also known as Dhandla, Jhajhra, Gravel and Nodular Kankar. They are siliceous nodules of concretionary deposits of limestone occuring usually in layers of few feet(2-5) below the ground level. They vary in strength from stone hard to clay soft. Occur profusely in U.P. and Rajasthan.

2. Moorum - siliceous (Grey Moorum) ferrogeneous(Red Moorum or Iron Stone Gravel) or calcereous(Disintegrated Limestone) occurs like kankar; strength lesser than that of Kankar; generally soil fraction more in quantity and plastic. Occurs chiefly in M.P. Rajasthan and Andhra.

3. Morrinda - calcareous surface deposits having both soil and gravel fraction. Properties intermediate between kankar and moorum. Occur commonly in East Rajasthan.

4. Gravel - river borne or pit borne; calcareous or argillaceous; usually with plastic fine fraction. Occurs mainly in M.P., Orrissa, Bihar, Assam, Gujerat and Rajasthan.

5. Laterites - disintegrated ferrogeneous rocks, having porous and cellular structure. Generally brick hard. Common in Assam, Andhra, Mysore, Madras and Kerala.

6. Bricks - described seperately vide para 3.3 .

7. Blast Furnace Slag - This is a waste product obtained from blast furnaces. With the steel industries coming up its production is likely to go very high. Properties vary with composition.

8. Disintegrated Trap - as the name indicates it is derived from gradual weathering and disintegration of trap rock, which is otherwise a very good road material. Regular quarries of this material exist in states of Maharashtra, Gujerat and Andhra.

3.22 CHARACTERISTICS;- In general the soft aggregates occurin nature mixed with soil, with a varying proportion of coarse (> 2 mm size) and fine fraction (< 2 mm size).

Coarse Fraction has got no resistance to crushing, abrasion, attrition and impact in general with a few exceptions (like over burnt bricks and some specimens of kankar) which are comparable to hard stone.

Most of them give quite high C.B.R. values and Modulus of Subgrade Reaction when suitably graded. Properties are adversly effected with the presence of water. Aggregate Impact Value (both dryand wet) is considered a suitable measure for their evaluation.

Fine Fraction- usually has moderate plasticity and good gradation and compaction characteristics.

3.23 Classification of Soft Aggregates :- As obvious from paras 3.21 and 3.22 the existing classification that is by name only, is not suitable for Engineering Purposes. A better classification based on the physical properties such as gradation, plasticity etc. has been proposed by C.R.R.I. (21). According tothis the soft aggregates are divided in four groups as follows:-

i) Materials having - percentage retained on U.S.Seive No 10 equal to 35 - 90, and P.I. of the fine fraction equal to 5 - 10 %

ii) Materials having - percentage retained on U.S.Seive No

10 equal to 0 - 35, and P.I. of the fine fraction equal to 5 - 10 %.

iii) Materials having - percentage retained on U.S. Seive No. 10 equal to 35 - 65 and P.I. of the fine fraction equal to 11 - 25 %.

iv) Materials having - percentage retained on U.S. Seive No. 10 equal to 0 - 35 and P.I. of the fine fraction equal to 11 - 25 %.

This classification, although considers the important properties like gradation and plasticity of the finer fraction, does not give any idea about the quality of the coarse fraction. In author's view some test like A.I.V. should be incorporated in the classification suggested by C.R.R.I. and sub groups prepared.

3.24 Scope of Soft Aggregates: Most of the soft aggregates that occur commonly in India, either as such, or after suitably blending with other soils, or after treatment with some stabilizer, can be successfully utilised in road construction. They effect the economy of road construction a lot, and hence all attempts should be made to explore their possible uses in road work.

3.3 BRICKS:- Bricks are generally made by winowing the suitable sandy-clay earth, moulding and burning in kilns to about 1000° C. They are used either as aggregate or as paving material for the roads.

3.31 Limitations:- The bricks are not preferred in road construction for two reasons; firstly they behave as individual members under a wheel load, and hence less bearing strength, and secondly they have very low crushing and abrasion strength, and high porousity and absorption.

3.32 Merits :- The merits of brick paved roads are good riding qualities, pleasing appearance, low maintenance cost, easy access for undergground utilities, high salvage value, and comparatively low cost in clayey regions.

3.33 Improving the Quality:- Attempts have been made since long for improving the strength characteristics of bricks and following have been found effective:[4]

a) Selection of suitable soil type.

b) Repressing the cut pug (181) that reduces absorption and increases density.

c) "Deairing", the pug by subjecting it to a strong vaccumm (181) that increases hardness, toughness, abrassive resistance, density and compressive strength (25000 psi compared to 10000 psi of ordinary bricks). Too much de-airation makes the brick brittle.

d) Burning at high temperature - this vitrifies the bricks increases hardness, strength and reduces absorption. It needs temperatures round about 1200 - 1500° C. Admixture of 0.5 % felspar as flux reduces the fusing temperature to 1000°C.

e) Annealing or gradual cooling of bricks results in better surface properties.

3.34 <u>Scope</u>:- Brick pavement has been found to serve well after bituminous surface treatment (180) and it is accepted that with the introduction of new precesses, as mentioned above, will make it an ideal paving material for our roads.

The improved brick aggregate may successfully be utilised in stabilized soil as well as W.B.M. roads.

3.4 MATERIAL FOR STABILIZATION:- There are innumerable materials which are being used or proposed to be used in stabilization processes. They fall under following heads:-

1) Cheap Chemicals such as Lime, Cement, Bitumen, Calcium and Sodium Chlorides etc.

2) Industrial products like Sulphite Liquor, Lignin, Resins, Flyash, Molasses, Linseed Oil Cake, Waste Oil etc.

3) Trace Chemicals like Arquad H-2, Phenols, Aniline, Furfurol, Phosphorous Penta Oxide, Higher Organic Compounds etc.

These will be described in detail alongwith their theory of stabilization in Chapter V.

This study of materials and their properties will help much in the clear understanding of the way in which they help in stabilization of the soils.

C H A P T E R -- IV.

COMPACTION - -

IV C O M P A C T I O N

4.1 INTRODUCTION:- Compaction or densification is a process by which the particles of the soil are forced to come closer and closer through the reduction of air voids, generally by mechanical means.

The effect of compaction on almost all types of soil is an improvement in their desireable properties such as, increased unconfined compressive strength and bearing value, and reduced water absorption and permeability which are so important for the road purposes. The improvement in subgrade bearing strength, gained by compaction has been as much as 150% in some cases. By compaction density is increased and hence greater resistance to deformation. Other properties like compressibility, permeability, swelling pressure etc. are also improved to a great extent.

Compaction increases dry density and as such dry density serves as a measure of degree of compaction.

4.2 FORCES RESISTING COMPACTION:- For carrying out compaction successfully, it is necessary to first consider the forces that resist compaction. They are -

1. Internal Friction of Grains and Capillar Tension of Inter Granular Water.
2. Arching or Interference in movement of Big Particles by Smaller Particles in case of Cohesion less Soils.
3. Viscosity of the adsorbed Water layer, which prevents sliding of Particles, particularly in Clays.
4. Pore Pressure of Water present in voids, that displaces the particles apart. It comes into action when moisture content is more than optimum.

And hence the compaction will be effected by the type of soil, amount of moisture present, and the amount and type of compactive effort used.

4.3 FACTORS INFLUENCING COMPACTION:- The various factors are :- i) Soil type,

ii) Moisture,

iii) Amount of Compaction,

iv) Type of Compaction, and

v) Temperature.

i) Soil Type:- The degree of compaction that can be achieved with a certain amount of compaction shall vary from one soil type to another depending upon texture, gradation and plasticity characteristics. For example a well graded sand-clay mixture can be compacted to higher density than pure snad by applying same amount of compaction. As such an attempt should be made to get a well graded soil for obtaining maximum compaction with least effort.

ii) Moisture:- For each soil type there exists a critical moisture content at which a certain compactive effort would give maximum dry density. Upto this limit water aids in lubrication, but beyond this limit, it fills the pores causing the pore water pressure to force the soil particles apart and hence lesser compaction. This moisture content is known as Optimum Moisture Content.

iii) Amount of Compactive Force:- In general compaction increases with an increase in compactive effort. Field tests done at New-York(159) have shown that depth effected increased with the weight of compaction equipment used. A 50 ton roller was found to compact upto 10 ft. depth, while a 30 ton roller was found effective only upto 6 ft.

As such heaviest practicable equipment should be used for compaction, but it should not be so heavy as to crush the surface by shearing. Generally for road work use of 10 to 12 ton roller is recommended for compaction of soil in 12 inches layers.

iv) Type of Compactive Effort:- Every soil has got its own favourite compaction technique. For example, vibration is most suitable for cohesionless soils; Stato-dynamic compaction in different proportion is suitable for sandy to clayey soils ; and pneumatic tyred rollers are suitable for heavy clayey and silts(16).

v) Temperature:- The temperature during the process of compaction is also supposed to effect the compaction, although its exact effect is yet unknown (16).

4.4 TYPES OF COMPACTION:- Various types of compaction equipments used in field for road purposes are -

1. Static Compaction.
2. Dynamic (Vibration)
3. Static and Dynamic Combined.
4. Vibro -floatation.

1. Static Compaction:- In this process the particles are brought closer by application of static pressure, and aided by the presence of moisture that lubricates the contact surfaces of particles. It successfully over comes the forces of viscosity. Various types of rollers come under this heading. The smooth steel tyred rollers, Pneumatic tyred rollers and sheeps foot roller are the commonly used ones. Of these, steel tyred rollers are best suited for crushed rock, gravel and coarse sands, and pneumatix tyred rollers are suitable for fine grained soils. Previously sheeps foot rollers were considered to be more suitable for cohesive soils, but the tests carried out at R.R.Laboratory (16) have conclusively shown that they are in fact least effective.

They are more effective if heavier in weight.

2. Dynamic Compaction:- In dynamic compaction the forces of internal friction and arching are overcomed by vibration. The soil grains are made to arrange themselves more closely by vibrations. Vibration equipment of various frequencies and amplitudes are used. This type of compaction has been found to be most suitable for all

types of sands, the frequency of vibration being adjusted according to the natural frequency of the soil to be compacted.

3. Static and Dynamic Combined:- This process utilises the mechanism of both static and dynamic processes and hence gives better results for most of the soil types. In many cases soils poured in a single layer of 3.5 ft. depth have been compacted to more than 95 % of Proctor Density down to two and often to three feet and deeper. (118) . Thus a clear economy can be effected by adopting compaction in single layers of 2 ft. and more.

Equipment:- Modified crawler type tractor or rubber tyred vehicles with multiple wheels, combined with a mechanical two - mass oscillator will be the only equipment. The Static load will be transmmitted through the wheels and can be further increased by putting surcharge weights on the vehicle. The dynamic compaction will be obtained by oscillator. Thus any ratio of static and dynamic compaction can be fixed as found suitable for thesoil concerned.

Operating Frequency:- Dynamic force vector in the range of 15 to 40 c.p.s. adjustable to the critical frequencies of the vibrating system : compactor soil.

Compaction speed is governed by speeds available for the tractor. Magnitude of force vector will depend upon the type of dynamic compacting act, that is , whether sinusoidal or impact characteristica are desired.

In no case the maximum compact pressure must exceed the breaking through pressure on the soil surface due to shear failure.

Limitations- many soils such as with highly elastic cohesive and viscosity characteristics are not compactable with this method.

Natrajan and Palit (101) have carried out extensive experiments on vibratory compaction. The results are -

a) For a given frequency of vibration, there is an optimum value of static load to give maximum compaction by vibration which depends upon factors, such as soil type, moisture content, frequency of vibrator etc..

b) Applying the static load in increaments and vibrating the soil after each increament, indreases the density considerably. thus the use of lighter roller would be advantageous in initial stages, gradually introducing heavier rollers on a sort of "stage compaction".

c) Optimum moisture for this type of compaction seems to be hundred per cent. However even a dry sand gives nearly maximum values. But low values of moisture content are found to prevent inter granular slippage by the introduction of apparent cohesion in sands.

Thus it is quite important that before performing the field trial, the laboratory experiments should be conducted to decide the optimum static load, moisture content and the vibrating frequency etc.. Recent investigations at C.I.T. (184) have indicated that by proper combination of these three parameters, even cohesive sandy soils could be successfully compacted. However it is still a matter of investigation, as to what limit of cohesion in the soils, the stato-dynamic method could be successfully used for compaction purposes.

4. Vibrofloatation:- The process of vibrofloatation can
(127)

be defined as a method of introduction of suitable liquids into a granular mass under simultaneous vibration of the mass. This process counter acts the forces of internal friction and arching and is hence good for frictional soils only.

In this procedure the vibrofloat, a hollow needle like structure, is introduced inside the soil by hthe vibrating action of the device. At the same time, the water issuing from the bottom of the vibrofloat in an upward direction makes the sand temporarily quick, thus making the sinking of the vibrofloat easier and quicker. During lowering, a precompaction of the surrounding material occurs. When a vibrofloat has reached the prefixed depth, the direction of flow of water is changed from bottom upwards to top downwards, so that the sand is now under the influence of downward flow pressure, and the vibrofloat is taken out gradually.

As the vibrofloat is taken out, the increased soil density offers a resistance to it, and hence the energy required to pull it out provides a mean of measurement of compaction.

Vibrofloat compacts a soil volume of spherical shape of diameter at least 8 - 10 feet, depending upon grain size and the characteristics of the machine.

Limitations:- This method is useful for coarse grained soils only, (snds with not more than 20% passing B.S.S. No. 200).

4.5 MEASUREMENT OF COMPACTION:- The degree of compaction is usually expressed as a percentage of the maximum compaction or dry density achieved in standard compaction tests such as Proctor's or Modified AASHO's test. The compaction in field is measured by either core- cutter method or by sand- pouring cylinder method. A new method has been devised at C.R.R.I.?, New Delhi, which utilises graduated jar and a highly viscous oil for determination of in situ bulk density.

A formula for determining maximum Proctor's density and O.M.C., without actually performing the test has been put forward by Rowan and Graham (109), based on seive analysis and plasticity and shrinkage tests which runs as follows:-

$$\text{Proctor's Density} = \frac{6250}{S\,(B/A - 1) + 100/R}$$

$$\text{O.M.C.} = S\,(B/A)$$

Where, R = Shrinkage Ratio,
S = Shrinkage Limit,
A = Soil Percentage passing U.S.S.No. 4,
B = Soil Percentage passing U.S.S.No. 40.

It has been shown by Calhoon and Baymen (109) that if averages obtained by two plasticity tests and five shrinkage tests, are used in this formula, the results are as accurate as the actual laboratory test.

A new push-button nuclear device for determination of the density and moisture content in soils, aggregates and pavements has been developed, known as Hydro-Densimeter and is available with Viatec Division of Tellurometer Inc. This instruement takes only about 60 seconds for determination of both density and moisture content (189).

4.6 CONCLUSION:- It has been tried to emphasize in this chapter that, compaction plays a major role in increasing the desireable engineering properties of the soils. The compaction of subgrades and embankment will not only effect the economy by directly reducing the pavement thickness required over it, but also indirectly bu minimising the moisture susceptibility of the subgrades and hence lesser risk of faliure of the road. Compaction is a stabilizing process in itself, and is an indispensible part of all the stbilization techniquees. Generally it is aimed that compaction in field should not be less than 95% of the Proctor's density.

The choice of compaction equipment is influenced by following factors :-

1. Soil Characteristics.
2. Maximum Compaction Desired.
3. Available Equipment.
4. Economy

Actually the degree to which a subgrade need be compacted should be such as to prevent failure due to settlements in future, and hence should be compacted at a stress higher than the stress under worst anticipated conditions.

The compaction equipments generally suitable for the common soils are as follows:-

Type of Soil	Suitable Compaction Equipment.
Coarse Grained Soils	Vibration, Vibrofloatation and Stato-Dynamic Rolling.
Graded Sands and Loams	Flat Steel Tyred Roller and Pneumatic Tyred Rollers.
Silts and Clayey Soils	Pneumatic Tyred Rollers.
Clays	Pneumatic and Sheep's Foot Rollers.

Generally 10 - 12 passes of the smooth field wheeled and pneumatic tyred rollers are found sufficient in field compaction and beyond this there is very little gain in compaction. Hence it is not economic to give higher number of roller passes.

C H A P T E R -- V.

THEORY OF STABILIZATION PROCESSES --

V THEORY OF STABILZATION PROCESSES

5.1 INTRODUCTORY:- As already stated in preceding chapters stabilized soil is the most common constuctional material for Low Cost Roads. Soil stabilization, so common a term, may be defined as " any process aimed at maintaining or improving the performaance of a soil as a constructional material, usually by the use of admixtures".

The admixtures may be a selected soil, a soft or hard aggregate, cement, lime, bitumen, tar,or some industrialwaste or a combination of two or more materials.

However the most common types of stabilization are:-

1. Using only soil or soft aggregate as admixture - Mechanical Stabilization.
2. Using additives like - (i) Cement,
   (ii) Bitumenous Material,
   (iii) Lime, and
   (iv) Other Chemicals.

In some cases the soil is stabilized ~~by adm~~ not by admixtures but by Electrical, Electro Chemical, or Thermal means, but these processes are very costly and hence rarely used.

Thus there are a number of techniques by which the soil can be stabilized, each having its own mechanism of action.

A study of the mechanism or theory of the more important types of stabilization processes, and the factors influencing there upon, shall now be described.

5.2 MECHANICAL SOIL STABILIZATION:-

5.20 General:- Mechanical soil stabilization is a process of improving or maintaining the stability of soil with or without the admixture of soil material only, by adopting mechanical means like compaction anddrainage etc. In nut shell it consists of properly grading a soil and then compacting it under optimum conditions of moisture.

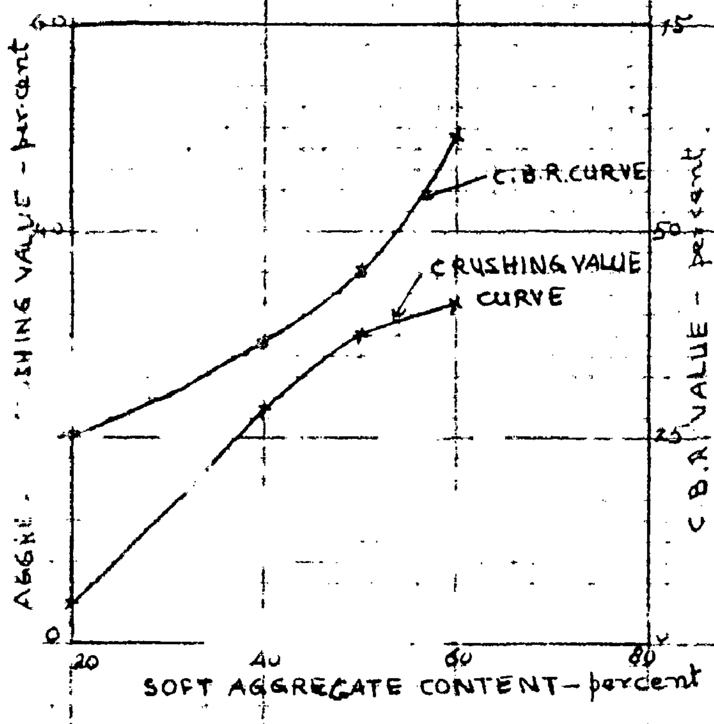
5.21 Theory:- The fact, that soils derive their shear strength from two basic properties that is internal friction and cohesion, and that the bearing capacity of soils increases with increase in their dry density, forms the back bone of Mechanical Soil Stabilization.

The fact that most of the soils have both these properties of internal friction and cohesion is utilized in this process. Coarse grained soils like sands have high internal friction and poor cohesion while fine grained soils like clays have high cohesion and poor frictional strength. In Mechanical Stabilization we aim to get maximum cohesion and maximum internal friction by adding to the soil, the fraction in which it is defficient, clay being added to sands and sand being added to clays.

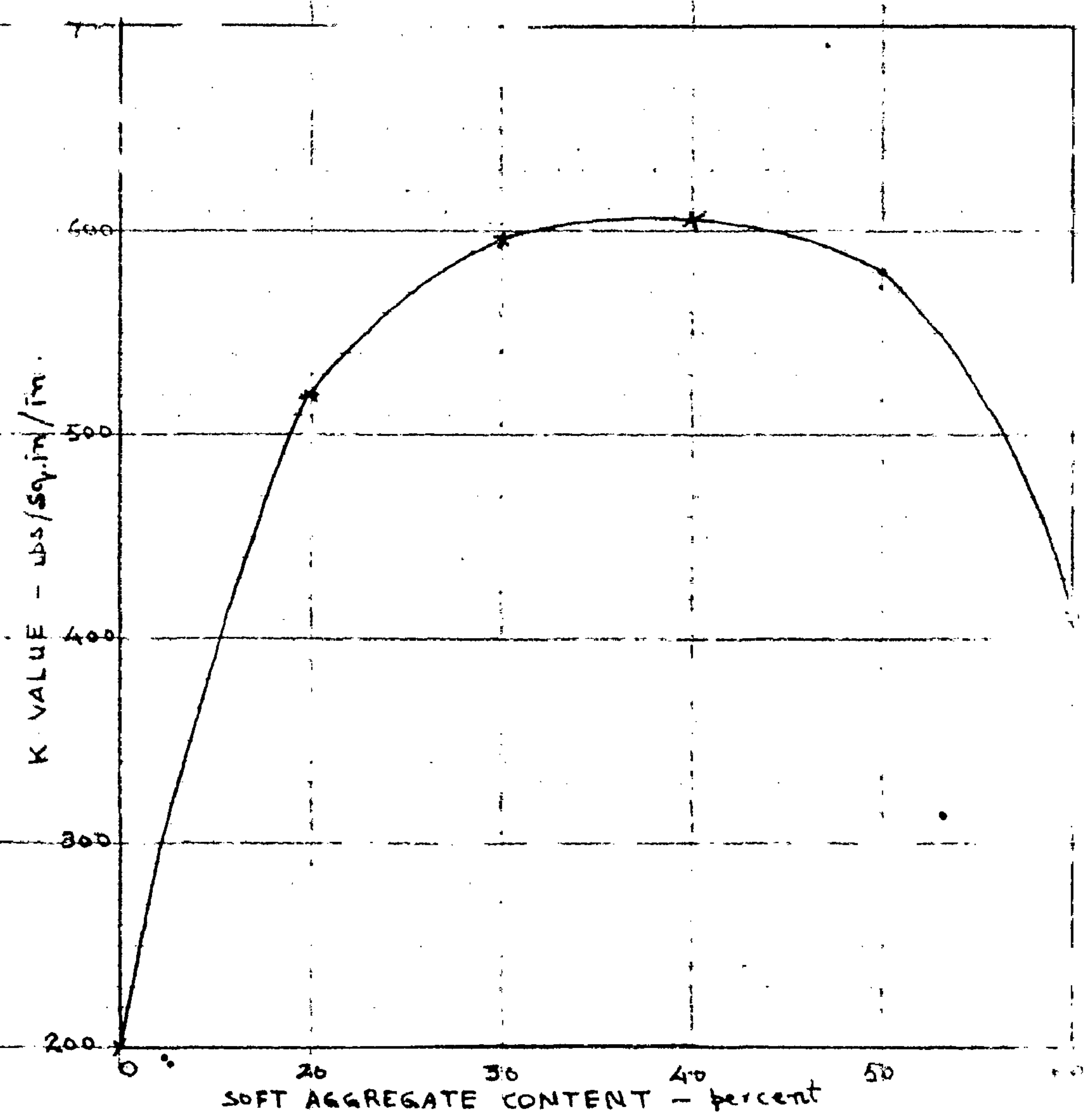
The second aspect of Mechanical Stabilization that is, getting maximum dry density for maximum bearing power, is fulfilled by properly grading the soil and then compacting it under optimum conditions of moisture. In a properly graded soil, the voids in the coarser particles are filled by the next finer size and so on, till all the voids are filled and the soil gets into its densest state, which has got maximum bearing value also. Maximum dry density also means lesser absorption of water and increased resistance to softening action of water.

5.22 <u>Theory of Mehra's Method</u> :- This is a type of Mechanical soil stabilization developed by Shri S.R.Mehra. Director C.R.R.I., which utilises soft aggregates and graded soil in the process of stabilization.

In this method the road crust consists of ~~ywp~~ two layers; the lower layer or base course consisting of graded soil having more sand and less plasticity, and the upper layer or base coat consisting of graded soil mixed with soft aggregates in the proportion 60 : 40. The graded soil in the top layer has lower



RELATIONSHIP BET... SOFT AGGREGATE CONTENT AND THE CBR VAL... AND AGGREGATE CRUSHING VALUE (32)



RELATIONSHIP BETWEEN SOFT AGGREGATE CONTENT AND THE COEFFICIENT OF SUBGRADE REACTION ...

sand content and medium plasticity.

The soft aggregates used in this process, usually have very low crushing, abrasion and impact characteristies and get crushed immediately under the traffic loads, if used in road construction as such. The principle of Mehra's method is to provide a protective coating of graded soil around each and every piece of soft aggregate, so as to prevent its deterioration by crushing, impact or attrition under the traffic loads.

Such a graded soil- aggregate mixture, when compacted under optimum moisture conditions to maximum dry density, has got high stability as determined by C.B.R. and Plate bearing tests (32).

The exact proportion of the graded soil and soft aggregates in the mix for maximum stability has been found to be 60 : 40 by actual experimentation in the laboratory (see the tables). Probably at this ratio, the soil matrix is just enough to coat the soft aggregates and fill in the voids between them when compacted at optimum moisture. As such the mix is more dense and provides maximum stability.

The results of experiments on road crust of 3 inches base course of graded soil and 3 inches upper course of soil aggregate mixture are given in table over leaf:-

Effect of Soft Aggregate Content on Aggregate Crushing value and C.B.R. of Resulting Road Crust. (32)

S.No.	% Brick Ballast	Aggregate Crushing Value	% C.B.R.
1.	20	4.65	25
2.	40	23.48	36.5
3.	50	30.03	46.5
4.	60	33.05	64.0

Effect of Soft Aggregate Content on Co-efficient of Subgrade Reaction (K). (32)

S.No.	% Brick Ballast	K. Value lbs/sq.in./in.	Remarks.
1.	0	200	K values are for a crust thickness of 6".
2.	20	520	
3.	30	594	
4.	40	604	
5.	50	579	
6.	60	411	

5.23 <u>Factors Effecting the Mechanical Stability</u>:- The factors that will influence the stability of the soil can be readily inferred from the theory of stabilization. They are -

(i) Mechanical Strength of the Aggrgate (Gravel Fraction)

(ii) Mineral Composition of the Materials

(iii) Particle Size Distribution (Gradation)

(iv) Properties of the Soil Mortar (Fraction Passing U.S.S. No. 40 or ISS No. 40 Seive)

(v) Compaction.

(vi) Adequate Protection against Moisture Changes.

(i) Mechanical Strength of the Aggregates:- The strength of the aggregate (usually measured by its crushing strength) influences the stability to a great extent. A weak aggregate is liable to get crushed under the traffic loads. Generally crushing strength over 12,000 psi., (Aggregate crushing values below 40) are considered good enough for use in Mechanical Stabilization. (16)

Even weaker aggregates if embeded in a properly graded and thoroughly compacted mass may serve the purpose. This fact has been utilised in Mehra's method of soil stabilization.

In some cases very weak aggregate have given good results, probably because they break under compaction to give a grading, more closely approaching to that required for maximum density on compaction (16).

In general attempt should be made toget the aggregate of sufficient Mechanical Strength to retain their original size distribution during compaction and subsequently under traffic loads during service.

(ii) Mineral Composition of the Materials:- The effect of this factor is only in relation with weathering and in general all aggregates, which are resistent to weathering, are suitable for Mechanical Stabilization. Aggregate susceptible to weathering are liable to lose their strength in due course of time and as such, require proper protection against weathering.

Most of the commonly occuring hard and soft rocks are free from this defect.

Mineral composition of the finer fraction of the soil(portion passing U.S.Seieve No. 200) has got great effect on the soil properties like cohesion, compressibility, swelling, and shrinkage etc.. Presence of Montmorillonite type of clay mineral, and Micas is very undesirable. The sodium clays are most undesireable while calcium clays are not so harmful. The presence of sodium salts in the clay fraction results in a deterimental effect on stability by causing disruption of the surface by crystallization.

So that the stabilized soil may not lose its strength by shrinkage and expansion during the service behaviour of the road, the silica-sesqui-oxide ratio of the clay content should not be more than 2.00 (1).

The presence of chlorides of calcium and sodium are desireable in the fine fraction, since they help in maintaining the stability, due to their hygroscopic properties.

Thus the mineral composition of both coarse and fine fraction of the soil has got a remarkable effect on the Mechanical Stability of the soil.

(iii) Particle Size Distribution (Gradation):- Proper gradation(that is procuring such a soil mixture which contains soil particles of all sizes from coarsest to finest, in such proportion, that the voids in coarser particles are filled with next finer size and so on, forms the back bone of Mechanical Stability. Such a well graded soil on compaction will result in a dense compact mass.

'Fuller' has given a formula for this purpose-

$$\text{Percentage Passing any Seive} = 100\sqrt{\frac{\text{Aperture size of that Sieve}}{\text{The size of the largest particle in soil.}}}$$

In practice, a little more of material passing No. 200 B.S.Sieve is needed than that given by this formula, for high degree of stability, particullarly for surfacings.

In most of the cases, it is an uneconomic venture to attain the exact Fuller's grading. For this reason various charts and curves have been develpped by different organisations permitting slight deviations from Fuller's curve. The general principle kept in view in these grading specification is, that the base should have both internal friction and cohesion for strength, and also enough permeability for check of capillarity and good drainage. As such, lesser fine fraction, is needed in base course material. The wearing course on the other hand, must have more cohesion and impermeability and hence more of fine fraction.

The exact attainment of Fuller's grading being difficult, and uneconomic also, other grading charts may be adopted with due consideration of the following factors:-

a. Grading of local available materials,

b. Cost and delay in procuring more desireable materials,

c. Volume and nature of traffic that will use the road,

d. Climatic conditions.

Grading charts of Swedish State Road Institute Stockholm, R.R.Laboratory,Harmodsworth and A.A.S.H.O. are usually considered as standard ones. (Refer Appendix)

For Mehra's method Shri Mehra has given his own specifications which are very flexible and hence economic to attain. (Refer Appendix)

(iii) Properties of Soil Mortar :- The fraction of the soil passing No. 40 U.S.Sieve is known as soil mortar. It is primarily responsible for moisture effects and binding properties. Practically all the water added to the soil or soil mixture is absorbed by this fraction. Hence this portion is also called the 'Active Portion' of the soils .

For successful stabilization the moisture films of the particles should not change their thicknesses, which means lesser volumes changes under adverse weather conditions. It has been shown by soil scientists at Ohio (186) that these volumetric changes decrease with decreasing P.I. of the soil. For this reason all organizations have specified limits for L.L. and P.I. for the soil mortar fraction of the graded soil. In general it is recommended that for base courses soil mortar should have L.L. $\ngtr$ 25%, P.I. $\ngtr$ 6%, while for surfacings it should have L.L. $\ngtr$ 35% and P.I. $\ngtr$ 4 to 9 %.

Each binder soil has got an optimum sand ee percentage at which it gives highest density. This sand content generally varies from 55 to 70% of the soil mortar (187).

The sum of the percent of soil fines and P.I. of the same should not exceed 40, to ensure a material, that will not get unduly slushy and sloppy in wet weather (14).

The base exchange capacity of soil binder has direct bearing on the service behaviour of the new surfaces. In surface courses the binder soil can be classified as having high, medium or low base exchange capacity. Generally binder soils with medium values of base excahange (1.2 to 2.1 m.e./100 gms. of sample) are reported to be satisfactory for surface courses (187).

(iv) Compaction:- Compaction of the soil results in a dense mass having more shearing strength, higher C.B.R., lesser compressibility and permeability, and lesser susceptibility to moisture changes. Compaction is best carried out at optimum moisture content. It is better to compact slightly on lower side of it than on higher side. Adequate compaction is a 'must' for stable base construction.(It has been dealt in details in Chapter IV.)

(v) Adequate Protection against Moisture Changes:- A stabilized soil base may lose part or whole of its stre-ngth, if moisture gets an access to it, even when properly compacted during construction. Actual experiments have shown that as much as 1% variation in the moisture content of compacted material may necessitate a higher design thickness by 3" (188). As such stabilized bases must be well protected against access of moisture, both from top(surface to be bitumen treated) and bottom (coarse sand cut off to be provided). Adequate drainage should also be provided to prevent access of moisture from the sides of the road.

5.24 Limitations:- As would be obviously inferred from the theory of Mechanical Stabilization, it can be used at its best in dry areas. In moist climate it can be used only as a base course with suitable wearing course.

It has got traffic limitations also, and will not survive the bullock cart traffic. For iron tyred bullock cart traffic it does need a stonger base coatse like W.B.M., concrete etc., while this Mechanically Stabilized pavement would act as base course.

The roads made with Mehra's method with stone grafted and bitumen treated surface, are said to stand traffic upto 500 tons per day in favourable climatic=conditions. With no stone grafting it is good enough for mixed traffic of 150 tons per day. Another method for soil stabilization in wet areas by Mehra's method has been developed at C.R.R.I. in which lime or cement is incorporated.

5.3 ADDITIVE STABILIZATION:- The additive stabilization is necessitated either when suitable blending soils are not economically available or climatic conditions are adverse or relatively high strengths are desired. It embraces all sorts of stabilization processes in which admixture other than soil or aggregate is used.

An ideal additive or more correctly the stabilizer should meet the following requirements:-

a) It should have applicability to a wide range of soils.

b) It should be reasonably cheap.

c) It should have permanent stabilizing effect.

d) It should be readily available in large quantities.

e) Stabilizing effect should be obtained with small amounts of stabilizer, to keep the transportation cost low.

f) It should present no serious storage, transport or construction problems.

g) It should be relatively non-toxic and non-corrosive.

Some soils like black cotton soils and organic soils need special treatment for stabilization.

There are innumerable substances, which are being used as stabilizers, either in field or in experimental stage. They can be classified in three groups based on their stabilization techniques:-

1. Those which stabilize the moisture content of the soils, e.g., hygroscopic chemicals like calcium and sodium chlorides, resins, bitumenous products, linseed oil cake etc.

2. Those which change the chemical or physical properties of the soil such as base exchange, aggregation etc.. Examples are, lime, polycationic organic compounds, cement (in cement modified soils only) etc.

3. Those which impart strength to the soil by solidification, cohesion or proper bond formation, e.g., cement, lime, bituminous materials, sodium silicate, calcium chloride, aniline, furfurol etc.

Out of the materials of first group, the resins and bituminous materials etc., maintain the moisture content of the soil by water proofing it. Any access or egress of moisture ~~is~~ from the soil is thus prevented, and the soil maintains its initial state of high stability after compaction.

The chlorides of calcium and sodium absorb water from atmosphere equal to many times their on weight. This moisture maintains cohesion in the surface course and hence stability. (Calcium Chloride is effective in maintaining the soil moist only when the relative humidity of the atmosphere is more than 31%) (17).

The materials of second group react with soil in some complex manner. Probably there occurs some surface phenomenon like exchange of adsorbed ions, that changes the properties of the soil. Main change is brought about in the plasticity and shrinkage characteristics and the particle size. In addition to ion exchange, some action with the reactive silica is also expected.

The materials of this group that have reckoned stabilizer value are lime(5 - 15 %), cement (upto 2 %) and higher organic compounds like DMAEM-poly-βdimethyl-amino-ethyl-methacrylate hydroacetate.

The materials of the third group have most wide acceptance as good stabilizers. They form bondswith the soil.

which may be either physical or chemical. The physical bonds are reversible to a certain extent, where as the chemical bonds are more rigid and hence irreversible. (160)

The properties of stabilized soil depend upon the reaction of the densified matrix to the forces that operate upon it. The qualitative characteristics of the response depend essentially upon the chemical structure of the matrix, whereas the actual values depend both on its chemical structure as well as on its geometrical structure, that is distribution through the soil mass.

Thus in bituminous stabilisation, where the internal structure or molecular structure consists of physical bonds, the response will be elastic, viscous, or elastic followed by viscous (The response is however effected by many other factors also like temperature, loading characteristics etc.). On account of the flexible and reversible nature of physical bonds, the bitumen soil can be densified even afterwards, and can even be reworked if so found necessary.

On the other hand cement which forms 3-D chemical bonds with soils, gives rise to rigid matrix. This will not densify afterwards and hence the necessity of maximum compaction at optimum conditions once for all. Also the structure if once broken, can not be reworked.

The rubbers and higher polymers are supposed to form combined physical and chemical bonds with the soil.

The theory of additive stabilisation having been discussed here in nutshell, shall now be dealt with in details for each of the more important stabilisers.

5.4 THEORY OF CEMENT SOIL STABILISATION:-

5.40 General:- Cement soil stabilisation comprises all the proccesses in which a stable material is obtained by using Portland cement as main additive to soil. The so-called soil cement is an intimate mixture of measured amounts of cement, pulverised soil, and water, adequately compacted to high density to form a hard, durable and stable mass and has got its own peculiar characteristics of strength, water resistance, and rigidity.

Soil cement is different from cement modified soil, in which a very small amount of cement, generally upto 2% is used to change the properties of the soil.

5.41 Mechanism (Theory) of stabilisation with cement:- The exact manner in which cement reacts when mixed with soil in presence of water is yet indefinite.

In the opinion of Housel(39), cement when mixed with soil, forms a granular soil structure with little more than enough cement paste to join the particles at their points of contact. The soil structure is spot welded, so as to speak.

Neat cement consists of three main compounds viz., $3CaO.SiO_2$, $2CaO.SiO_2$,& $3CaO.Al_2O_3$. On hydration or addition of water the resulting compounds are, hydrated di-calcium silicate, hydrated tri-calcium silicate, hydrated tri-calcium aluminate and free lime. Of these first three are insoluble and form the major cementitious components. These products cannot difuse through the soil (being insoluble) and hence adequate stabilisation is possible only when there is suffidient amount of cement, uniformly distributed in the whole soil mass. The fourth and last product viz., lime is deposited as a separated crystalline structure.

The bonds between cement and soil are according to Murray(160), of 3-D chemical type, and hence most rigid. When once formed, these bonds will not rearrange after destruction, and the structure will not gain any strength on remoulding. This hypothesis lays stress on placing of soil cement under most optimum conditions only.

These rigid bonds formed between the soil particles and hydrated cement, are solely responsible for the strength and moisture resisting properties of soil cement. In case of clayey soils, on account of a large number of small particles with normal amounts of cement it is not possible to connect all the soil particles with rigid bonds. The soil cement structure then consists of a combination of rigid cement bonds, whose strength is uneffected with the presence of water, and plastic clay bonds, which loose their strength in presence of water. In clean granual-ar soil a cement bond is usually formed between the individual particle, making such soil more strong, rigid and water resistant

Thus this hypothesis is able to explain the abnormally high cement requirements of clay soils compared to sandy soils.

In case of cement-modified soils, the action is said to be a surface phenomenon, associated with the change of ions and water adsorbed at the surface of clay particles. This change, brings about a marked change in the soil properties like Liquid Limit , Plasticity Index, Shrinkage and water absorption etc. The effect of cement is also to cause aggregation by bringing individual particles of soil closer, to increase the average particle size of the soil. This confers newproperties to the soil , which are independent of the structure of the soil cement as a whole (163). The exact process is however not fully understood as yet.

The soil cement difers widely from cement concrete in its properties, and the reason is obvious; in soil cement it is the cement which is coated by the soil particles, while in concrete the coarse aggregates are coated by cement-sand mixture.

5.42 Factors influencing the quality of soil cement:- Properties of soil cement are effected by variation in one or more of the following factors:-

1. Soil type.
2. Cement content and type.
3. Mixing.
4. Compaction.
5. Curing.
6. Admixtures.

1. Soil type:- The effect of soil type on soil cement characteristics is primarily as to its particle size distribution, plasticity characteristics, and chemical composition.

(i) Gradation and plasticity- well graded coarse soils need minimum cement for satisfactory stabilisation. Clay content upto 10 percent is considered to be tolerable for this purpose. Soils having an excess of highly plastic and fine fraction effect economy, not only by difficulty in pulverisation, but also due to higher cement contents required. In general, all soils that can be pulverised easily (L.L.$\not>$ 35 and P.I. $\not>$ 15) can be successfully stabilised with cement. With heavier clays some sort of pretreatment such as mixing of lime or sand is essential.

Various institutions have framed their own specifications for gradation and plasticity characteristics for cement stabilisation. H.R.B. recommendations are -

Gradation-	Maximum particle size	3 IN.
	Passing No.4 U.S. sieve	50%
	Passing No. 40 U.S. sieve	15-100 %.
	Passing No. 200 U.S. sieve	50 %.
Plasticity characteristics-	Liquid Limit	40 %.
	Plasticity Index	18 %.

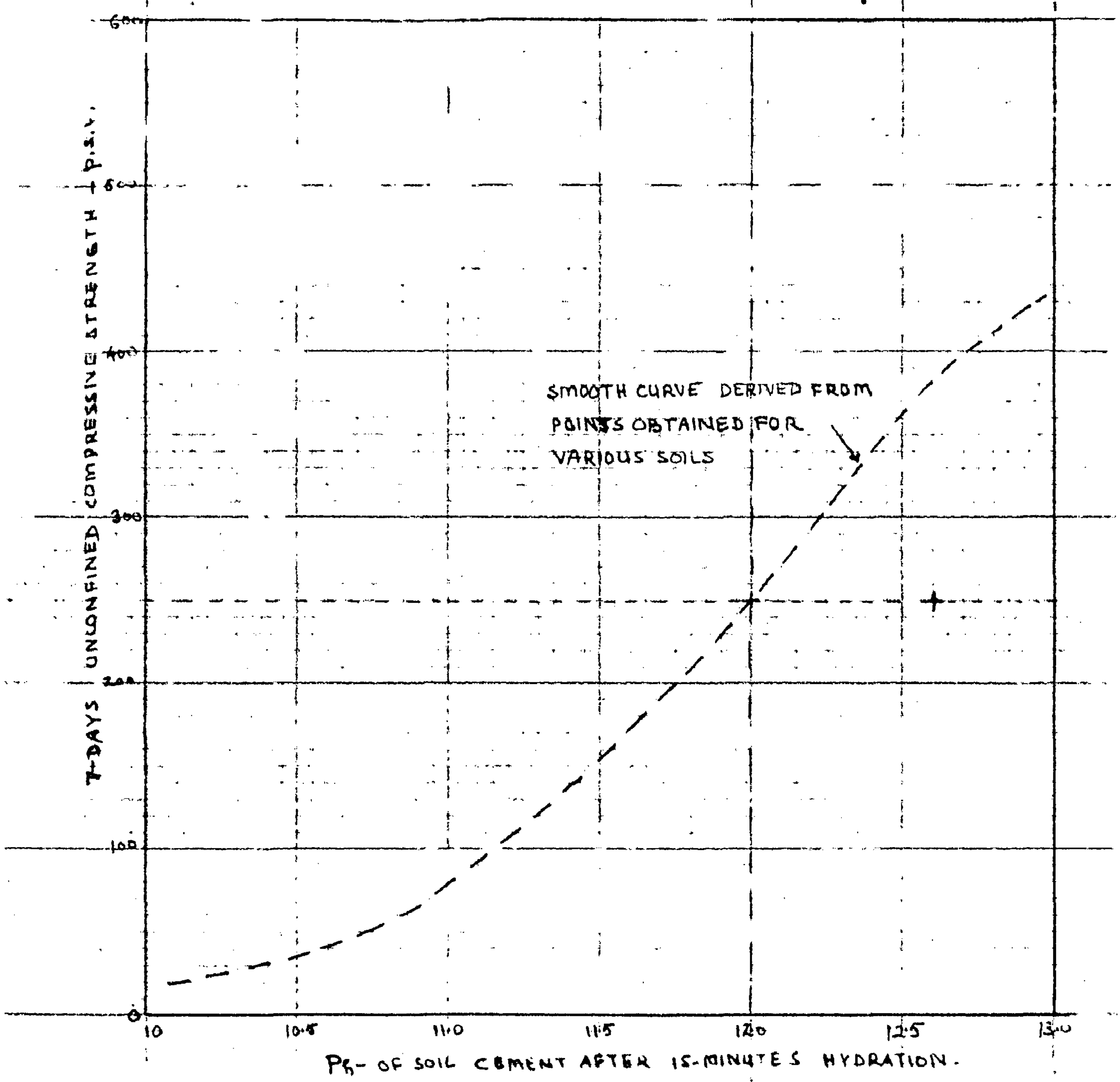
(ii) Salts- The presence of salts in soils or in mixing water has got undesirable influence on the strength of soil cement. The carbonate and sulphates of sodium, magnesium, calcium etc., have direct chemeical action with the cement inhibiting proper gain in strength in soil cement. The sulphates are most dangerous as they form calcium sulphate with free lime and lateron calcium-sulpho-aluminate, a compound which crystallises on drying causing expansion and ultimate disintegration in soil cement(192).

The other salts also, if present in appreciable quantities cause disruption of soil cement due to expansion during the process of crystallisation. Generally salt content should not exceed 0.2 % (146). Chlorides salts are generally beneficial in stabilisation if present in amounts less than 0.2%.

(iii) Organic content- Organic content in soils has also got very deletrious effect on cement-soil stabilisation, by inhibiting the process of hydration of cement. Clare and Sherwood(58) have suggested that organic matter(the water soluble content only) absorbs the Ca^{++} ions liberated during the hydration of cement. The concentration of Ca^{++} ions thus falling low, the formation of calcium silicates and aluminates is reduced, and hence the lesser strength of soil cement. Maclean and Sherwood(193) have further investigated that the organic compound that takes active part in retardation of hydration is probably of 'hydroxy-quinone' type.

According to this hypothesis then, the addition of Ca^{++} ions from outside in form of $CaCl_2$ should give results. This is actually so, the $CaCl_2$ solution has been found to reduce the deletorious effect of organic matter. On the other hand lime will not give equally good result due to its lower solubility (0.17 gms compared to 0.73 gms in 100 c.c of water for $CaCl_2$.)

Normally organic content should not exceed 2 %, but soils with organic content anything between 0.5 % and 4 % have been sucessfully stabilised with cement. In author's view



EFFECT OF Ph- ON 7 DAYS UNCONFINED COMPRESSIVE STRENGTH OF SOIL CEMENT. (194)

there cen be two reasons for this anamoly. Firstly the organic matter as a whole, as determined by laboratory tests, may not be active. The varying effects may be due to the varyihg percentage of the active fraction.(This needs further investigation). Also in the laboratory methods of determination of organic content, there is no distinction made between water soluble and insoluble fractbons of organic content which, in author's view, deserves serious consideration. Another possible reason may be the presence of other chemicals in the soil (like calcium salts) which might be counteracting the effect of organic matter.

(iv) Ph value- The hydrogen ion concentration of the soil has also got bearing on the strength of soil cement. The measurement of Ph in early stages of hydration (upto 3 hrs) is an indication of, whether or not the mixture would subsequently harden. If the Ph is more than 12 the soil cement would attain strengths higher than 250 p.s.i., otherwise not(141).

2. Cement content and type:- Cement content required to give satisfactory strengths may vary from about 5 % for graded sands to about 25 % for clays. Normally cement contents more than 12 % are uneconomic.

Higher cement content definitely results in higher ultimate strengths, but the improvment is more significant at lower values. Research has also shown that all soils improve in abrasion with higher cement contents, but the abrasive resistance tends to become independent of soil type at higher cement contents (15 % or above), an interesting conclusion (140).

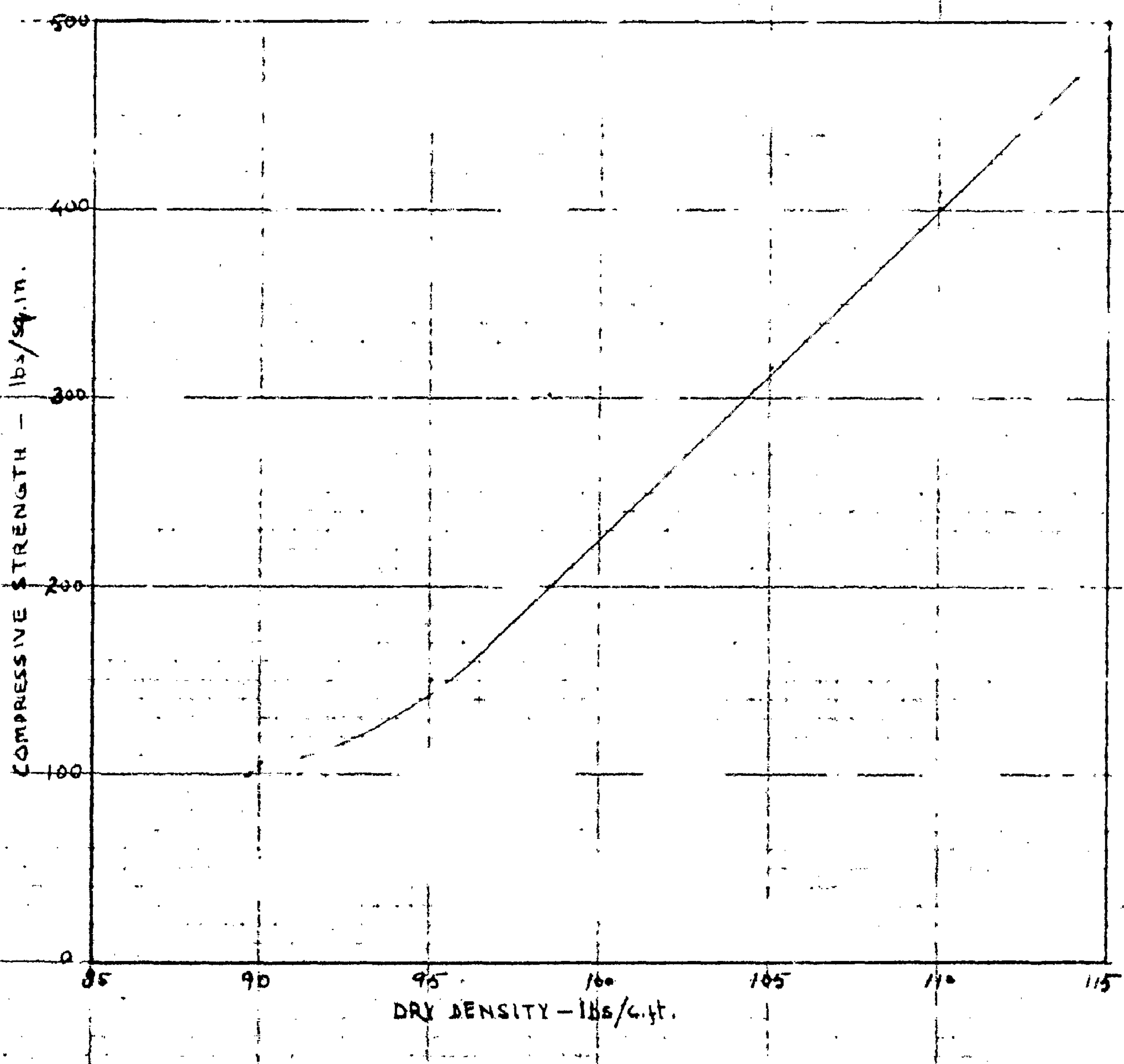
Much work has not been done on the effect of type of cement on the quality of soil cement. However, on the basis of effect of cement types on cement concrete, some effect can be expected here also. The use of sulphate resistant cements has not been found to be of any use to prevent the effect of sulphates in soils, a property differing from that of concrete(146).

High early strengths in soil cement can be obtained by the use of finely-ground cement(84).

Metallurgical cements are understood to give higher bearing values at relatively lower strengths, while Portland cement gives higher bearing value at relatively higher strengths, (194).

A more detailed investigation on the effect of cement type on soil cement characteristics appears to be necessary.

3. <u>Mixing:-</u> Uniform mixing is indispenable for full develop-



TYPICAL RELATIONSHIP BETWEEN DRY DENSITY AND COMPRESSIVE STRENGTH OF SOIL-CEMENT CUBES (16) ment of the strength of soil cement. It has been found(149) that -

(i) O.M.C for mixing is slightly less than that for maximum density.

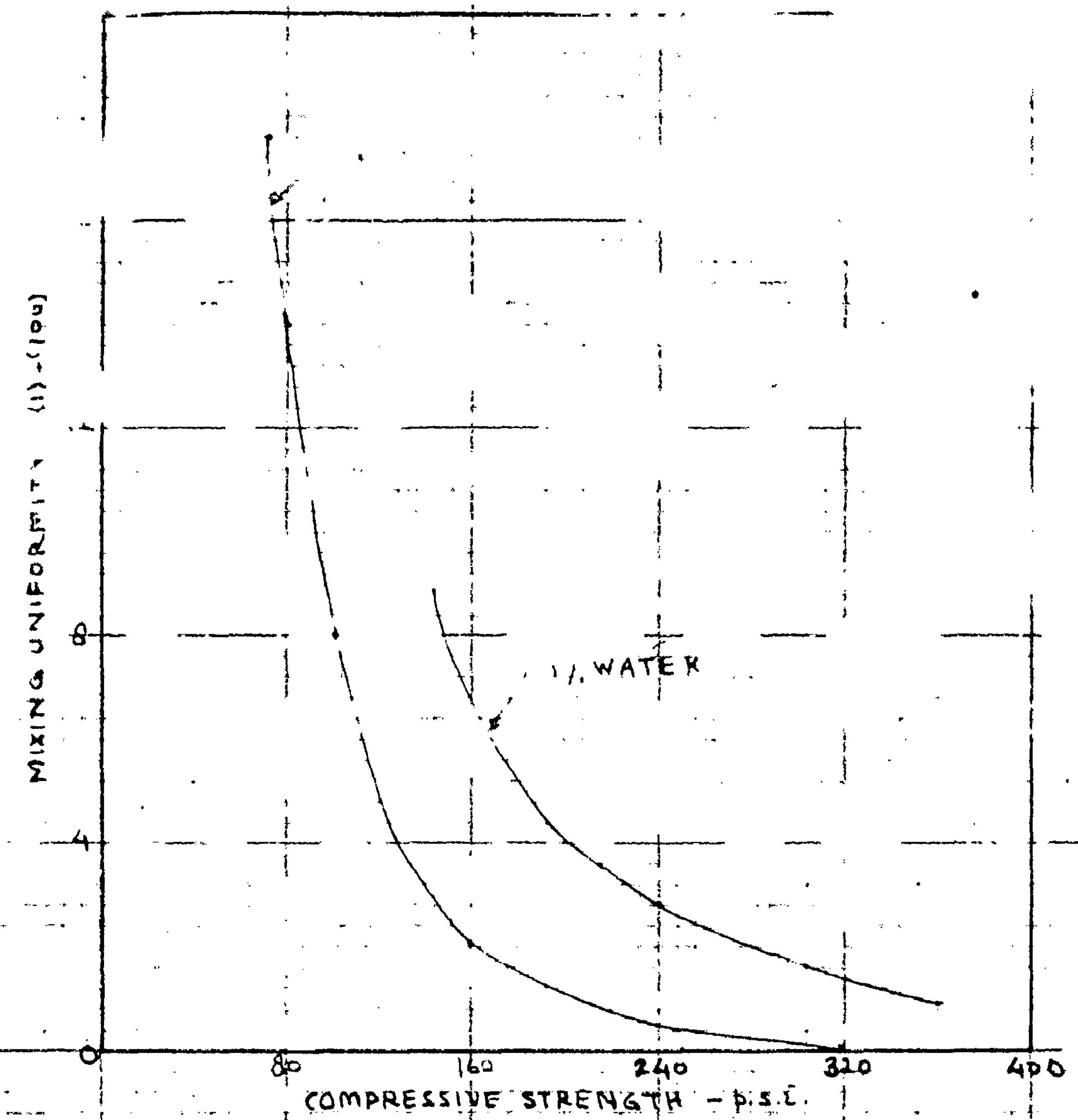
(ii) Strength of soil cement varies as the log of mixing uniformity.

(iii) Strength also varies as the log of mixing time or as the log of accumulative mixing energy upto the ultimate mixing uniformity, of the mixer.

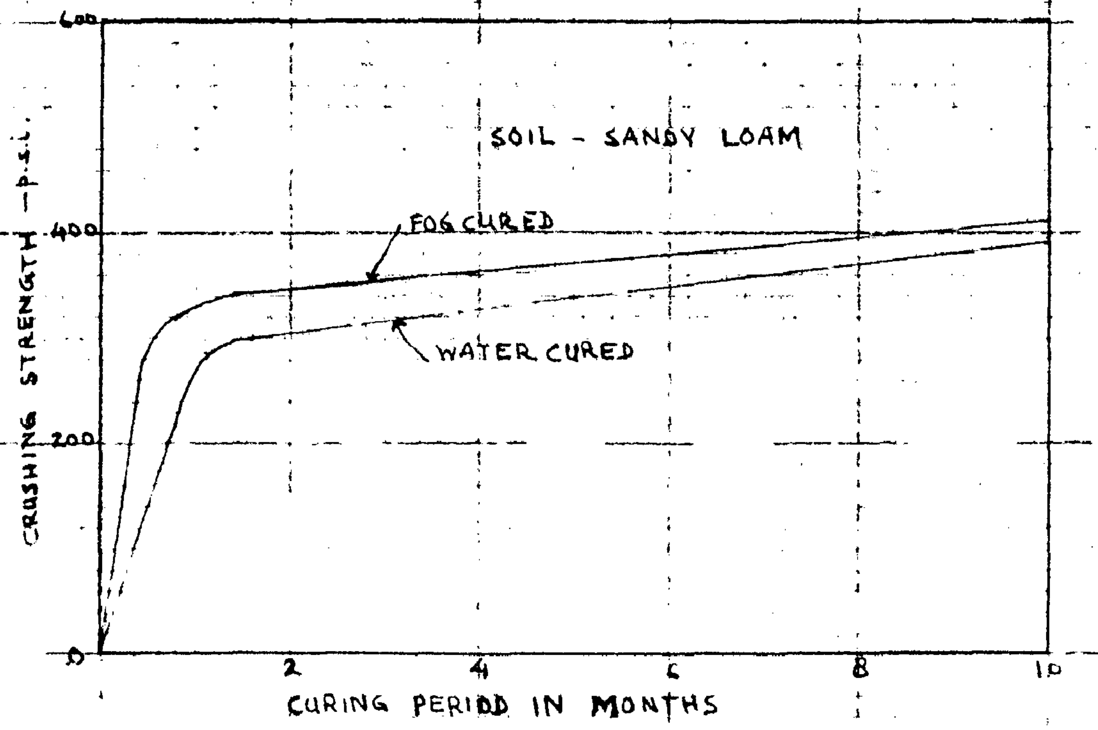
Regarding the effect of mixing in field, experiments(16) have shown that with an ordinary agricultural plant in mix-in-place methods, the field strengths are 40 to 60 % of laboratory values, while with efficient rotary tillers these values are 60 to 80 %.

The uniform mixing is hence essential for development of full strength provided that the moulding of soil cement is completed before the cement starts setting.

4. <u>Compaction</u>:- To obtain satisfactory strength in soil cement adequate compaction is essential. It has been established beyond doubt that maximum dry density should be aimed at, for maximum compressive strengths. A slight decrease in dry density results in relatively greater loss in compressive strength(16). However, Dutron(194) has reported that maximum strength is obtained at a moisture content equal to or slightly less than Proctor's optimum moisture, with



RELATIONSHIP BETWEEN UNCONFINED COMPRESSIVE STRENGTH AND MIXING UNIFORMITY INDEX FOR CEMENT CONTENT ABOUT 10% (149)



STRENGTH INCREASES WITH INCREASE IN CURING PERIOD (140) negligible loss of strength upto 2 % higher moisture contents. As such the results are contradictory.

Best mixing is carried out at a moisture content slightly above than the O.M.C. for compaction while highest compressive strengths are obtained at moisture slightly lower than the O.M.C. for compaction. In durability tests, best results are obtained at moisture slightly above than the O.M.C. for compaction.

The data for most suitable moisture content being thus non-conclusive, the laboratory tests should be carried out to find the most suitable moisture content which will satisfy all the requirements to a reasonable degree.

The effect of moisture content in soil - cement is different from that in cement concrete, in that the percentage of water effects only the compaction of soil cement while the water cement ratio in concrete effects the strength directly.

It should also be kept in mind that the time taken in all the processes since the addition of cement upto the final compaction should not exceed the initial setting time of cement.

5. <u>Curing and Ageing</u> :- The soil cement gains strength with age, provided that proper curing is done (16). The purpose of curing is to retain the minimum moisture necessary for the complete hydration of cement. The curing may be done either by creating a damp atmosphere

by keeping the surface saturated with water, or by preventing the evaporation of water by putting an impervious layer over the surface. Most of the strength is gained in first fourteen days. The rate of hardening depends upon the type of soil and type of cement and also upon the curing conditions. The fog-cured specimens show higher early strengths than water cured specimens, but they tend to equalise in later stages (140). The bitumenous cover material has been found useful for curing the soil cement specially when a bitumenous coat is to be finally provided (140). A slight surface disintegration is noticed in curing ~~the~~ with the bitumenous cover materials probably due to the penetration of bitumenous material into the soil cement, thus hindering the proper hydration of cement (16). An application of the water on the finished surface of soil cement prior to the application of such cover materials, has been found to be useful in preventing the penetration of these materials in the soil cement (140 & 151). Road tars, emulsions and cut backs at about 0.2 gall/sq.yds. or water proof paper may be used for curing in areas scarce in water. Moist curing is preferable, where water is available in plenty.

It is recommended that curing should start immediately after moulding and should continue at least for 21 days afterwards.

6. Admixtures:- Admixtures have got a major influence on theproperties of soil cement and are classified as under according to the purpose served by them;-

a) Pozzolanic materials added to effect partial replacement of cement and hence effect economy. Example Surkhi and Flyash.

b) Chemical compounds that increase the strength of soil cement. Example Alkalie metal compounds.

c) Chemical compounds that extend the use of cement to otherwise unsuitable soils. Example Lime, Calcium Chloride and Sodium Sulphite.

Detailed description of the influence of various admixtures being beyond the scope of this thesis, only summarised description is given here with.

Group a) :- i) Surkhi - well burnt surkhi has been found to be able to replace cement upto 10% or so without causing any reduction in the strength (140), although longer curing is required.

i The reason for higher strehgth is attributed to the reaction of surkhi with the free- lime liberated during the hydration of cement, with the formation of hydrous mono- calcium silicate, which is a stable compound possesing cementing properties.

The reaction further tends to accelarate the hydration of cemant and brings more calcium ions into solution, which causes better diffusion of the cementing meta-silicate and aluminate through the soil. The higher curing period in this case can be brought to normal by using rapid hardening cements.The savings effected may be upto 10 % .

ii) flyash - it is a waste material from coal furnaces having pozzolanic properties. The replacement of cement with flyash in part, has been found to result in an increased strength in all soils except the very plastic ones(142). In loess and clays part replacment of cement with flyash results in low initial strength but an equal or even a higher strength at 120 days, due to reduced shrinkage and cracking. The effect may be due to pozzolanic activity of the flyash and hence the reaction with lime liberated during the hydration of cement.

However other workers have found the partial replacement of cement with flyash as highly detrimental to the compressive strengths and durability of soil cement may be beneficial only when the soil lacks infine fraction e.g.,indune sands. However the same effect could be obtained by addition of any other friable filler.

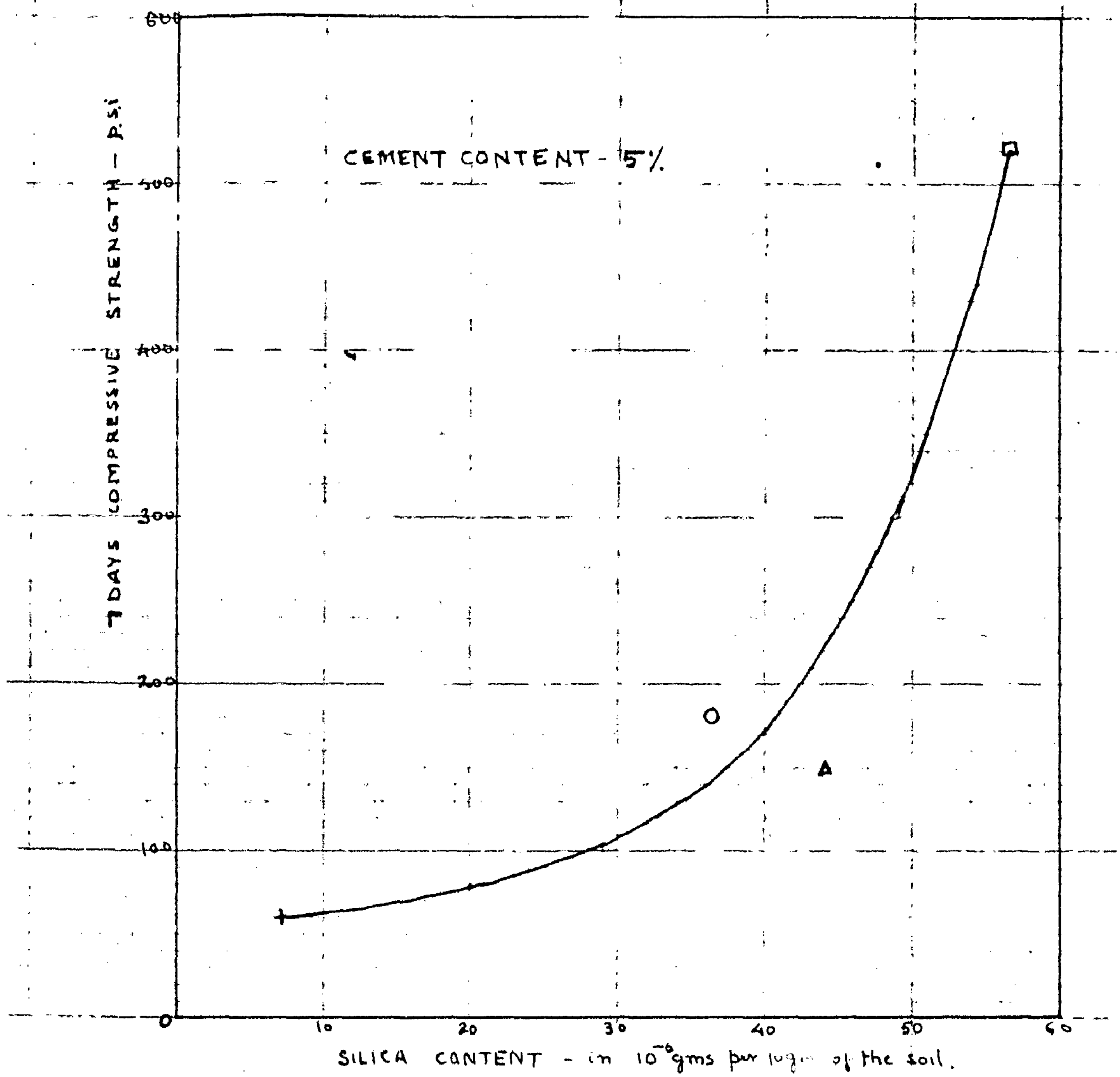
Thus the results are contradictory. In author's view this is probably on account of the variations in the properties of the flyash and hence needs further investigations.

Group b)~~iii~~ Alkalie metal compounds :- Much work has been done in America and England to study the beneficial effect of certain chemicals on soil cement. Research has been carried out in India as well.

The results in general conclude that the hydroxides and weak acid salts of any alkalie metal of cation, which yield soluble silicates or aluminates have very promising (57).

In some soils the additives result in an increase in the strength of soil cement by as much as 400% while in some other soils the effect is to make the otherwise unsuitable soils, fit for cement stabilization. Sodium compounds which form insoluble salts with calcium have been found to be relatively better than others. The efficacy of additives varies with the soil characteristics, particularly the plasticity and organic content. Upto moderate amounts of organic matter sodium hydroxide is beneficial. Sodium Sulphate is also suitable for organic silts and sands. Sodium meta silicate is best for clean sandy soil, while sodium aluminate is suitable for clayey soils. Sodium hydroxide is very beneficial for soils having high soluble contents (56, 57 & 140).

The effect of additives is more or less permanent. The optimum cement content for these additives is somewhere between 5 - 10% with lesser effect at higher cement contents.



EFFECT OF EXTRACTABLE SILICA CONTENT ON THE INCREASE IN COMPRESSIVE STRENGTH OF SOIL-CEMENT TREATED WITH ONE PERCENT OF SODIUM HYDROXIDE. (57)

Also for each soil type and cement percentage evry additive has got its own optimum value(normally less than One percent by weight of soil), at which its effect is most marked. The effect of Sodium compound has been found to be more marked in soils having higher reactive silica content.

Thus the over all picture at present is that the use of sodium compounds will not only economise the soil cement construction, by reducing the cement content, but will also extend its applicability to the otherwise unsuitable soils like organic soils and soils containing high soluble content. The amount of chemicals required is very small (0.5 - 1%) , while the reduction in required cement content is quite significant, thus economising the material handling and processing also.

Group c) :- i) Calcium Chloride - has been found very beneficial for organic soils which otherwise can not be successfully stabilized even with cement contents upto 10% (55). Its effect is negligible on those soils which can be satisfactorily stabilized with cement alone.

ii) Hydrated Lime - admixture of lime is particularly beneficial in reducing the platicity of heavy clays and hence the cement requirements.

Lime can also partly replace the cement (upto 30%) without any loss in compressive strength or durability(140).

However a longer curing is needed, probably due to the slowsetting properties of the lime.

The lime is supposed to react with the free reactive silica and alumina in the soils, to form the cementitious silicates and aluminates. Theyadd to the strength of soil cement. It is hence obvious that the effect of lime will be more pronounced with soils having significant amount of reactive silica and alumina.

The lime also reduces the acidity of the soil, thus producing a favourable media for successful cement stabilization.

5.43 <u>Limitations of Cement Soil Stabilization:</u>- The cement stabilization,inspite of its wide applicability,has got following limitations-

1. Only those soils, that can be economically pulverised, are suitable for cement stabilization.However addition of hydrated lime makes even the heaviest clay fit for cement stabilization.
2. Soils containing high organic content(2 % or more)are unsuitable for cement stabilization. However about one percent of Calcium Chloride or Sodium Sulphite makes them fit for this purpose.

3. Soils containing high soluble salt content are also unsuitable for cement stabilization. However about one percent of sodium hydroxide makes them suitable for it.

Thus we see that sement stabilization has got practically no limitations except that of cost. As such it is likely to be replaced by cheaper methods of stabilization.

5.5 THEORY OF LIME STABILIZATION;-

5.50 General:- Lime has been used as stabilizer since 1924 or even earlier, but its scientific and rational background has come up only recently, through the researchwork done mainly in U.S.A., U.K., U.S.S.R., India and Israel. It has got its popularity, mainly because of its easy availability and well known use in building construction.

It is more commonly used in conjunction with other materials like cement, flyash, etc for higher strengths and more durability.

Incorporation of lime in soil generally brings about following improvements in its physical properties:-

(i) Liquid Limit - A substantial decrease inliquid limit has been reported by Bose (170) and Uppal and Bhatia (169) on addition oflime to black cotton soils. Spangler and Patel (114) have reported similar results from U.S.A.. On the other hand Clare and Cruchley (114) have reported that lime does not bring about any significant drop in liquid limit.

The data being inconclusive nothing can be said positively about the effect of lime on L.L.. Probably the reason of anomoly lies in the varying chemical composition of the limes used in testing.

(ii) Plastic Limit - In general it is agreed upon that lime brings about an increase in plastic limit.

(iii) Plasticity Index - As could be seen from para i & ii the P.I. may or may not decrease with the addition of lime. Generally heavy clays show a decrease in P.I. with increasing lime content, but how much of it is retained afterwards is still a matter of investigation (46). Woods and Yoger (27) have reproted an increase in P.I. of silty soils with the addition of lime.

Thus on the whole it can be said that the changes in P.I. of soils mainly depend upon the characteristics of the soil itself.

(iv) Shrinkage Limit - Generally soils improve in shrinkage characteristics with addition of lime. (169).

(v) Compaction Characteristics - Incorporation of lime generally reduces the maximum dry density and increases the optimum moisture content (47).

(vi) C.B.R. - Generally soils improve in C.B.R. with addition of lime. This is most significant with heavy clays.

(vii) Unconfined Compressive Strength - The lime - treated soil particularly heavy clays improve in strength, which goes on increasing with age like cement concrete. Values as high as 780 p.s.i. have been obtained in some cases (171).

Thus in general it can be said that the addition of lime is beneficial to soils, particularly to heavy clays. The efficacy of treatment is probably influenced mainly by the characteristics of soil and lime.

5.51 <u>Theory of Mechanism of Stabilization with Lime</u> :- A number of theories have been proposed, from time to time, to explain the action of lime on the soil in stabilization process. The more important of them are,

1. Flocculation or Agglomeration of soil particles changing the soil structure.
2. Base exchange that is replacement of sodium ions of clay with calcium ions of lime, which changes the soil properties. The fact that calcium chloride, a stronger

electrolyte does not have the same effect as lime, contradicts this theory.

3. Calcium Carbonate formation by reaction with atmospheric carbon di oxide. This is contradicted by the fact that soil lime mixtures sealed away form atmosphere have given even higher strengths than the unsealed ones.

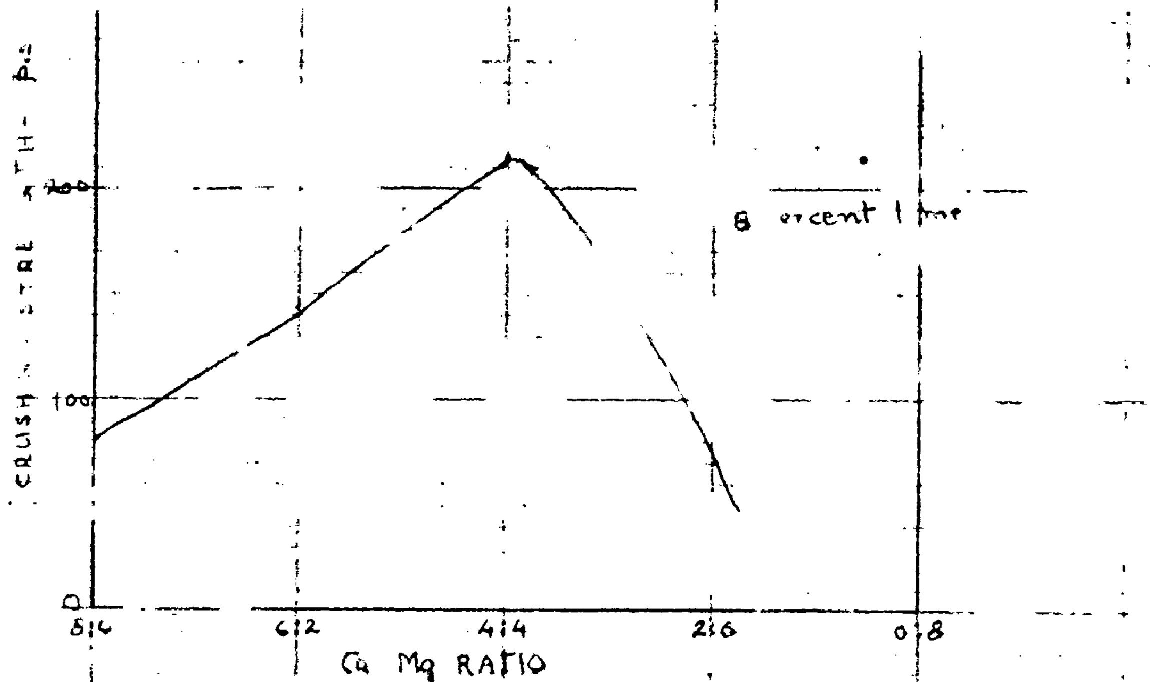
4. Formation of hexagonal crystals of Calcium hydoxides This is contradicted by the fact that soil lime mixture gain in strength even when the conditions are not favourable for the formation of such crystals.

Generally it is agreed that lime reacts in two ways. One is the electrolytic action combined with flocculation, which results in an immediate drop in plasticity, changing the soil to a dimensionally stable, free-draining composition.

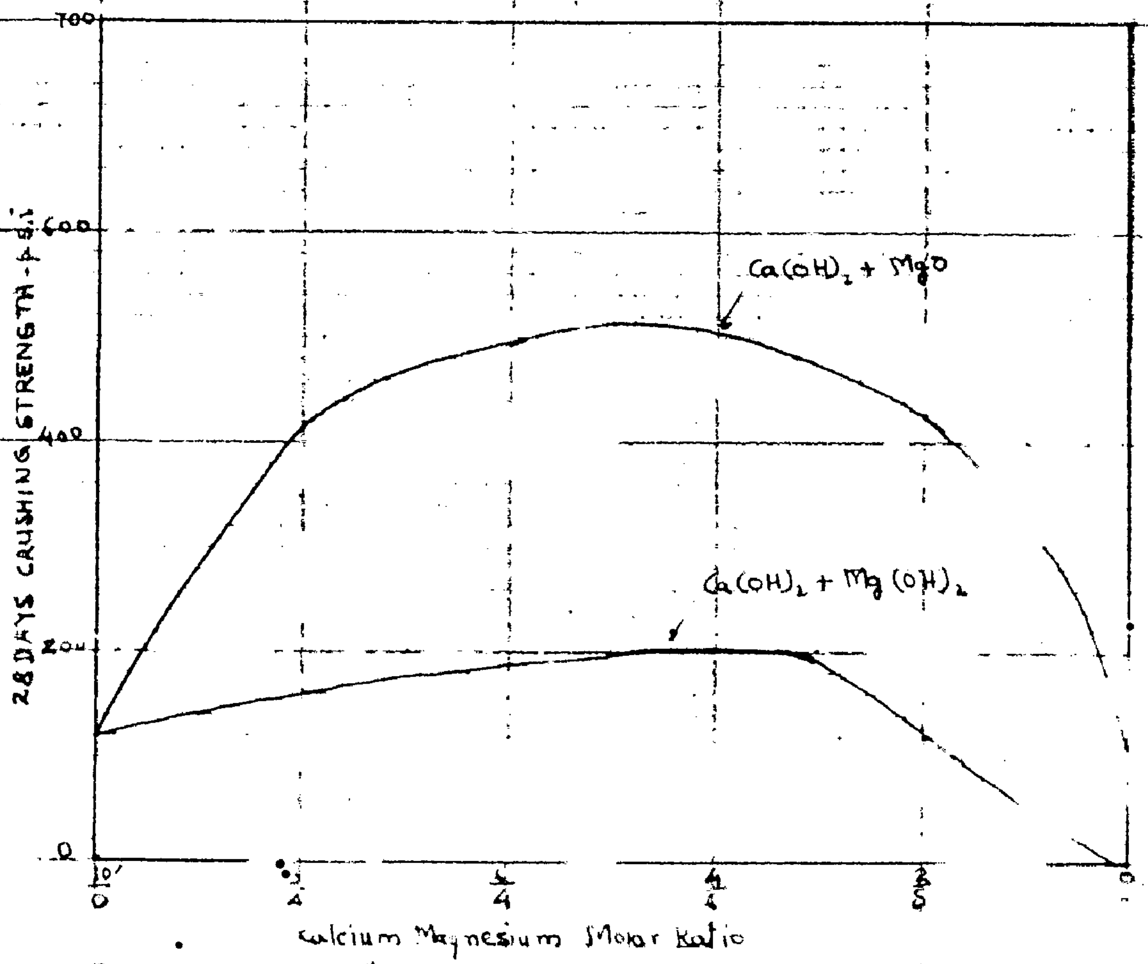
The other action is between the lime and hydrous reactive silica and alumina of the soil resulting in the formation of cementing alumino-silicate compounds of calcium (composition varying from $CaO.\ 10\ SiO_2$ to $2\ CaO.\ Si\ O_2$ in case of silicates). (115). This action is very gradual and takes years together for completion. This theory has recieved recognition from most of the workers now. On account of the slow rate of this reaction, the gain have been tried, and mostly found to respond favourably to the treatment with lime. Organic soils are not suitable for lime treatment. The efficacy of the treatment is probably governed by the amount of reactive silica and alumina present in the soil.

b) Amount and Type of Lime - Generally an increase in lime content results in higher strengths of soil-lime. However every soil has got its own optimum lime content beyond which further addition of lime is not very effective and hence uneconomic. For most of the soils itis 5 to 8% (116). (This is probably the lime required to satisfy the electrolytic requirements and the reaction with reactive silica and ~~alumi~~ alumina.)

The effect of composition of lime, mainly as to its magnesium content is significant on the properties of soil-lime. The results are however non-conclusive. Lu and Coworkers (172) have concluded that molar ratio of calcium and magnesium should be unity for maximum strength. This has been confirmed by research at C.R.R.I. (136). On the other hand Lambe and coworkers at M.I.T. have concluded that pure



EFFECT OF MOLAR RATIO OF Ca : Mg IN LIME ON THE CRUSHING STRENGTH OF LIME-STABILIZED SOIL (136)



EFFECT OF Ca Mg RATIO ON IMMERSED COMPRESSIVE STRENGTH calcitic limes are best for silts. Thus probably the effect of magnesium content varies with the soil type and needs further investigation.

c) Mixing - The effect of mixing is almost smae as in case of soil cement.

d) Compaction - As usual, maximum compaction results in greater strengths.

e) Curing - It has been generally realised that longer curing under humid conditions results in higher strengths. (115). Davidson and co-workers (48) have concluded that curing at high temperatures results in high early strengths.

f) Additives - The compounds that are commonly used in conjunction with lime in stabilization are of two types; first are those which are added only in traces (about one per cent or so), and the other are those which are added in large amounts (like 30 percent or more).

The additives of first group like sodium compounds although added in traces, cause a significant improvements in strengths. Particularly hydroxide and meta silicate of sodium are very beneficial(47).

The action of sodium salt is probably either to increase the amount of reactive silica (Sodium meta silicate) are to cause a more uniform distribution of silicate ions (soluble sodium silicate is first formed, diffuses through the soil and later on reacts with calcium ions, when the Ph goes down, to form cementitious calcium silicates.) (47)

The other group consists of materials like flyash, powdered shale, cement, wood-tar, molasses etc.,

Flyash - is the most commonly talked admixture for lime-soil. It is the powdery residue left after the burning of coal in power plants and primarily consists of silica and alumina with varying percentages of other compounds. Suitability of flyash for stabilization is judged by its carbon content which should not exceed 10% by weight (147). The incorporation of flyash in lime soil results in, significant improvement in strength and durability at early ages, applicability of lime stabilization to a wider range of soils, and improvement in shrinkage and consistency properties.

Flyash is understood to increase the formation of silicates of calcium and hence higher strength. Chu and co-workers (81) have shown that every soil has got its own optimum percentage of lime and flyash, for best results. Strengths as high as 1130 psi. have been obtained after 28 days moist curing at 70°F.

Looking to the economy possible with incorporation of flyash in lime-soil, further investigations seem to be desireable.

Cement - The combined use of limeand cement in stabilization results in easy pulverization and a strong water resistant material (49), (152).

Expanded Shale - Dawson and co-workers (48) have shown that by addition of 7.5 to 12.5 % of burnt and pulverized shale aggregate, a considerable improvement in strength can be achieved.

Wood Tar - Wood tar, a waste product of tar industry or any other bitumenous material can be used alongwith lime to induce waterproofing qualities in lime soil. The optimum percentage is about 4 (169).

Molasses - These are byproducts of sugar industry. They increase compressive strength of lime-soil by adding to the cohesion, but the strength gained is liable to be lost in presence of water. Optimum percentage is about 5. (43).

5.53 Limitations:- The principal limitations of lime stabilization are -

1. It is not applicable to organic soils..

2. Reduction of plasticity does not occur in all soils. Some soils have even shown adverse effect. Also the retention of the reduced plasticity in future in presence of water is also not definite.

3. Lime stabilization is not very useful for coarse-grained soils like sandy or gravelly ones.

4. Inspite of the high compressive strength of lime stabilized soils they have got high water absorptions and hence are liable to lose strength in presence of water. An impervious top course is hence necessary for them.

5. Only fat lime has been tried so far for the stabilization purposes. Unavailability of this type of lime in some areas may result in excessively high transportation cost.

On the whole, it can be said that lime stabilization is suitable for heavy clays only.

5.6 THEORY OF BITUMINOUS SOIL STABILIZATION :-

5.60 <u>General</u> :- The bituminous stabilization of soils includes all stabilization processes in which a bituminous materials (cut back, emulsion or foam, tar or bitumen) is used as the main stabilizing material. The function of bituminous material in soil bitumen is to add to the strength of the soil by water proofing the soil and providing cohesion to the soil grains. The various types of bituminous processes generally differ only in the medium used for coating the soil grains with bitumen or tar; emulsions using water, cut backs using distillates of petroleum, and foam asphalt using air bubbles as carrier for bitumen or tar.

It may be understood that there is no basic difference in an asphalt and bitumen, while tar differs from them in origin, properties and composition. Asphalts are products of petroleum distillation while tars are products of the distillation of Coke, coal , wood etc. The effectiveness of both is the same as far as the stabilization is concerned, but tars being cheaper, decision should fall in their favour. Tars are more adhesive and rapid hardening than the asphalts, and can be mixed better with alltypes of soils.

The demerits of tar are its toxicity and susceptibility to temperature changes. The rapid hardening property of the tars is also a disadvantage. The hardening effect may be dueto following reasons:-

i) Loss of oils by evaporation, which can be reduced by using higher boiling tar distillates for flucing.

ii) Chemical action of atmospheric oxygen, which can be reduced by, removing the phenolic constituents with caustic soda or by preoxidation of tars by blowing air at 75°C.in presence of 1-2 % of caustic soda (to act as catalyst) under controlled Conditions.And,

iii) A change in the structure of tar aftersome time,such as crystallisation of some compound, which can be prevented by addition of 10 % by weight of hard-grade bitumen to it, or by cooling and filtering the fluxing oils of cut backs and then using the filterate as flux.

Thus probably tar can economically replace the bitumen in stabilization process.

The processes in bituminous stabilization,in general are, pulverization of soil, mixing with bituminous material ~~xxxxxxxxxx~~,with or without moisture, aeration, and compaction to required density and then curing for the specified period.

5.61 Theory:- Every soil owes its strength to two ~~in~~ fundamental properties that is internal friction and cohesion. The purpose of bituminous material is to increase the second of them viz., cohesion, owing to its sticky nature. As such they are most suitable for coarse grained soil which has high internal friction and low cohesion. The fine grained soils presents difficulty in pulverization and uniform coating due to the presence of like charge on asphalt and soil particles(as shown by electro- phoretic measurements) which causes mutual repulsion. (111)

For successful stabilization, the bituminous material should form a continous matrix with all the soil grains embeded into it, and should be just sufficient for this purpose. Higher amounts shall, cause loss of stability by lubrication.

The bonds formed in soil-bitumen are of 3-D physical type according to Murray (160) and are hence of a most flexible and even reversible nature. The response to the external forces in case of soil-bitumen is elastic or viscous or elastic followed by viscous. Further densification of stabilized soil, when once compacted, is possible with the gradual evaporation of oil or water, and asphalt film taking their place due to drying stresses of asphalt. As such soil-bitumen can be placed at density lower than the optimum for further densification under traffic. Even it can be reworked and remoulded after initial compaction without any loss of stength.

It may be noticed that the coating of the soil particles by asphalt is a surface phenomemnon and hence can be influenced by the use of surface active additieves. (89).

The stability of soil is maintained in its high state by inducing the waterproofing quality also. In case of oiled earth surfaces, the spreading of oil on the surface induces waterproofing qualities as well as some cohesion and thus serves as dust palliative also.

In cutback stabilization the bitumen is carried in the media of distillates (flux),till the soil particles are well coated with it. In curing the distillate evaporates, leaving the bitumen coating on the particles. The uniform coating of particles is difficult when the soil is very wet or is very fine grained. In such cases a suitable additive like cement or lime may be neccessary to ensure the proper coating.

In emulsion stabilization, the bitumen is carried in the media of water. After proper mixing, during aeration and curing, the emulsion breaks leaving the bitumen coating on the soil particles. The water ~~is~~ gradually evaporates off. Suitable control on the breaking of emulsion is essential for proper coating of the particles. Also the stabilized soil should not lose its strength in presence of water due to residual emulsifier.

Hence the emulsifier should be selected such that,

(a) It would permit sticking of asphalt particles to soil even in presence of water.

(b) It would improve the tenacity of soil asphalt bond.

(c) It would not exhibit the undesireable effects of residual emulsifier after curing.

Certain anti- stripping additives or 3-5% of cement when used in conjunction with asphalt in stabilization have been found to give good results.

In stabilization with foam asphalt, the coating of soil grains is most perfect due to low viscousity and appropriate surface tension of the foam bubbles (107). Very little moisture is needed to produce a bubble. When a foam bubble, in-coating a mineral particle, collapses, the entraped water vapour escaped and the residual asphaltic cement rapidly regains its original properties.

Thus in all types of asphalt stabilization, the ultimate effect is to induce cohesion and water proofing qualities in the soil.

5.63 Factors Effecting Bituminous Stabilization :- The impportant factors that influence the quality of soil-bitumen are :-

1. Soil type.

2. Type and amount of Bituminous Material.

3. Moisture Content.

4. Mixing.

5. Aeration.

6. Compaction.

7. Curing.

8. Weather during construction.

9. Temperature during aeration and curing.

10. Additives.

1. Soil Type :- The soil characteristics effect the properties of bitumen soil maximum. In general coarse grained soils with which pulverization, mixing, and uniform coating of the particles is easy can be successfully stabilized. Well graded coarse grained soils are generally best. Single sized coarse grained soils often need some filler like 2 to 3 % of cement or powdered lime stone for high strengths (90). S

Silty soils usually create problems because they have negligible internal friction and cohesion. Very careful control of fluids content (water + bitumen) is essential to provide desireable cohesion, but not lubrication (that makes the soil spongy and unstable).

Clays which have high cohesion at low moisture contents and loose most of it at high moisture contents, need bitumen only for the purpose of waterproofing. Very thin grades of bitumen are required for effective coating of the particles where as additives are necessary to ensure permanancy of this coating.

Organic soils can not be stabilized with bitumen till treated with special agents.

The asphalts commonly available spread more readily in acid media, and soils having higher ph(basic soils)are rarely suitable for asphalt stabilization.(111)

For general guidance H.R.B. has suffested the following limits for the soil for bituminous stabilization :-

Maximum size of material - Less than one third the compacted thickness of the crust.

Material, passing 3/16 B.S.Sieve - greater than fifty percent

passing No.36B.S.Sieve - 35 to 100 %.

passing No.200 B.S.Sieve - 10 to 50 %.

Liquid limit - less than 40%,Plasticity Index - less than 18%.

2. Type and Amount of Bituminous Material:- The selection of correct type of bituminous material with reference to soil type, moisture, climate,availability of equipment etc.,is of great importance for the success of the stabilization process.