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SOIL STABILIZATION TECHNIQUES ADOPTED IN THE CONSTRUCTION OF ROADS IN THE ALLUVIAL PLAINS OF INDIA, WITH A VIEW TOWARDS REDUCING CONSTRUCTION COSTS

(Paper No. 160)

The paper describes various techniques of soil stabilization, using local soil and soft aggregates, adopted in the alluvial plains of India, with a view to reducing road construction costs. The model estimates enclosed in the paper indicate that a savings of around 40 to 50 per cent, as against conventional specifications for water bound macadam, can be effected for roads with light to medium traffic.

INTRODUCTION

1. India, with an area of about 1.2 million square miles, lies entirely to the north of the equator. From south to north it stretches from 8 degrees north latitude to 37 degrees north latitude, with the Tropic of Cancer cutting it roughly into two halves. West to east it stretches from about 66 east longitude to 97 west longitude.

2. From the agricultural point of view there are as many as 20 different types of soils, ranging in type from sand to black cotton soil and peat. Some of these soils occupy a small area, and therefore, from an engineering point of view, India can be divided into five major groups for purposes of utilizing local soil in road construction. One of the major groups, the alluvial soil, occupies almost the whole of northern India, i.e., a length of about 1,500 miles and a width of 150 to 200 miles. This covers almost the whole of Punjab, Uttar Pradesh, parts of Bihar, West Bengal and Assam, as shown in *Fig. 1*. The rainfall is moderate in the west but increases considerably towards the east.

CONVENTIONAL METHOD OF ROAD CONSTRUCTION IN INDIA

3. Water bound macadam has been accepted as a standard form of road construction. In the past, as traffic was comparatively light, the thickness of road crust generally provided was from 6 to 9 in. of stone soling in the base course and about 4½ in. of stone metal, consolidated to a thickness of 3 in. The wearing course generally comprises 2 coats of bituminous surface dressing. In places where stone is very costly, comparatively cheaper materials such as burnt brick are used to replace stone soling in the base course. The cost of such construction is about Rs. 25,000 (£A2380), without surface treatment as per details given in APPENDIX A.

4. The specifications mentioned were based mainly on experience, and no scientific consideration of the actual bearing capacity of the subgrade or the intensity of the traffic was taken, even though it was known that all areas were not equally dry

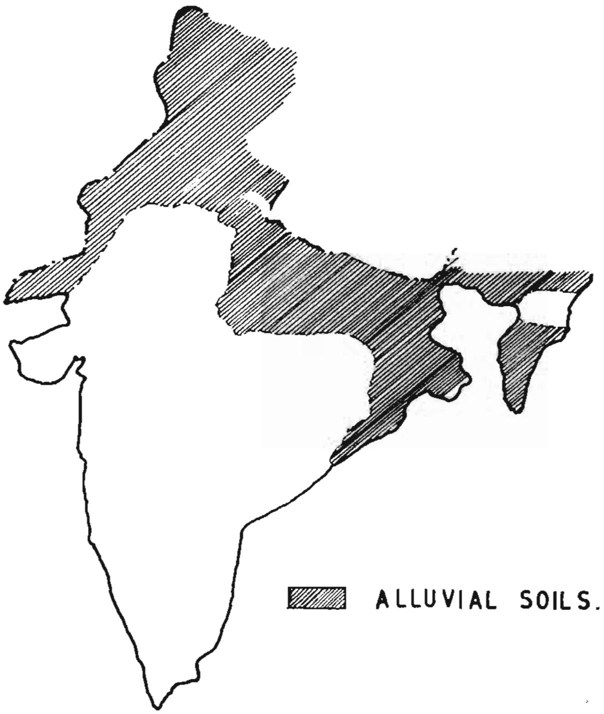

Fig. 1 — Showing alluvial plains of India

or wet and that the traffic intensity also varied considerably from place to place.

DIFFERENT TECHNIQUES OF SOIL STABILIZATION ADOPTED IN ALLUVIAL PLAINS

5. As a result of a traffic census it was observed that most of the roads, except main roads, carried light traffic. For roads carrying only light to medium traffic, in dry areas where the water table is not likely to come within 10 ft of the road surface, and where stone metal is costly because of long haulage, the following techniques have been successfully adopted.

STABILIZATION OF SOIL WITH SOFT AGGREGATE (MEHRA'S METHOD)

6. Although stone is not readily available in many areas, there are large deposits of kankar and moorum (weathered rock), and burnt brick bats are also available at low cost because the price of the coal used for burning bricks is controlled.

7. If these soft aggregates, which generally have an aggregate impact value of about 50, were to be used in the same way as stone metal, their sharp corners would be crushed; and with the loss of interlocking, the crust would fail. A number of attempts have been made in the past to improve the crushing strength of these aggregates by impregnating them with different chemicals, but none of these attempts have substantially improved their strength; furthermore, the processes are uneconomical.

8. As a result of work carried out by the senior author, it was found that crushing of weak aggregates could be prevented by

suspending them in a mass of soil with a particular plasticity index. The strength of the resultant mass after compaction is due not to interlocking of the aggregate but to the strength of the soil mortar, which separates the aggregate and holds it in place. The mixture used for this method of protecting the weak aggregates is that of 2 parts of properly blended soil to 1 part of brick aggregate, kankar or laterite, measured by volume. This particular mixture, besides withstanding surface abrasion, also has increased load-bearing capacity, as shown in *Fig. 2* (the k value of soil without aggregate being only 200).

9. Due to the dry condition of the subgrade for which this technique is recommended, the CBR under natural density and moisture is usually between 25 and 35 per cent, so that not more than 6 in. of crust is required for light to medium traffic.

10. The details of the technique finally adopted for different intensities of traffic are described under the following categories.

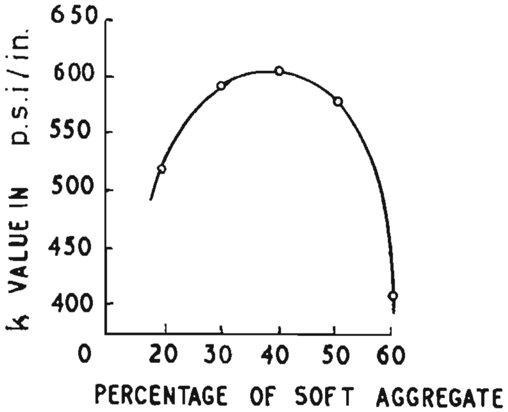

Fig. 2 — Relation between percentage of soft aggregate in the upper course of a stabilized soil road crust and the k value in a plate bearing test

SCOPE

11. The specifications are for the following climatic and traffic conditions:
Rainfall: up to about 50 in. per year.
Subsoil water level: not less than 10 ft below ground level.

Maximum traffic: (a) unsurfaced roads: about 50 tons per day, average mixed traffic; (b) surface treated roads: about 200 tons per day, average mixed traffic; (c) stone graft and surface treated roads: about 500 tons per day, average mixed traffic.

NOTE: mixed traffic normally implies not more than about 30 per cent iron-tyred traffic.

MATERIALS

12. Without bituminous surface treatment:

(a) Base course.

Soil: PI* 4.0 to 7.5; sand content not less than 50 per cent (fraction between 40 and 200 A.S.T.M. or 40 and 8 I.S.I.); sulphate content (deleterious salts) 0.15 per cent (including the sulphate content of the water to be used for construction).
Aggregate: nil.

(b) Wearing course.

Soil: 2 parts; PI* 9.0 to 11.5; sand content not less than 33 per cent (fraction between 40 and 200 A.S.T.M. or 40 and 8 I.S.I.); sulphate content 0.15 per cent (including the sulphate content of the water to be used for construction).

Aggregate: 1 part (10 per cent to be kept for spreading on the surface); aggregate crushing value 35 to 50 (the 10 per cent to be spread on the surface should have an aggregate crushing value of not more than 35); size: 100 per cent passing 1¼-in. screen, 20 per cent passing through ¼-in. screen.

* PI: the lower PI to be used where natural soil of that PI, with given sand content, is available. The higher PI to be used when a high plasticity clay is to be used in the moisture.

NOTE: ordinary hand broken aggregate normally satisfies the above grading.

13. With bituminous surface treatment:
(a) Base course.

Soil: PI* 4.0 to 7.5; sand content not less than 50 per cent (fraction between 40 and 200 A.S.T.M. or 40 and 8 I.S.I.); sulphate content 0.15 per cent (including the sulphate content of the water to be used for construction).

Aggregate: nil.

(b) Upper course.

Soil: 2 parts; PI* 7.5 to 9.5; sand content not less than 33 per cent (fraction between 40 and 200 A.S.T.M. or 40 and 8 I.S.I.); sulphate content 0.15 per cent (including the sulphate content of the water to be used for construction).

Aggregate: 1 part (10 per cent to be kept for spreading on the surface); aggregate crushing value of 35 to 50 (the 10 per cent to be spread on the surface should have an aggregate crushing value of not more than 40); size: 100 per cent passing 1¼-in. screen, 20 per cent passing through ¼-in. screen.

NOTE: ordinary hand broken aggregate normally satisfies the above grading.

(c) Surface dressing.

Primer: 30 per cent bitumen 80 to 100 penetration; 70 per cent furnace oil; rate of spread 20 lb per 100 sq. ft.
Binder: a tar, bitumen or cutback considered suitable for ordinary surface dressing.

Grit: aggregate crushing value of 30; stripping value of 15 to 20.

NOTE: grits found by experience to be good for surface dressing work may be used without testing.

14. With stone graft and bituminous surface treatment:

(a) Base course.

Soil: PI* 4.0 to 7.5; sand content not less than 50 per cent (fraction between 40 and 200 A.S.T.M. or 40 and 8 I.S.I.); sulphate content 0.15 per cent (including the sulphate content of the water to be used for construction).

Aggregate: nil.

(b) Upper course.

Soil: 2 parts; PI* 7.5 to 9.5; sand content not less than 33 per cent (fraction between 40 and 200 A.S.T.M. or 40 and 8 I.S.I.); sulphate content 0.15 per cent (including the sulphate content of the water to be used for construction).

Aggregate: 1 part; aggregate crushing value of 35 to 50; size: 100 per cent passing 1¼-in. screen, 20 per cent passing through ¼-in. screen.

NOTE: ordinary hand-broken aggregate normally satisfies the above grading.
(c) Graft stone.

Aggregate crushing value not more than 25; size 1 in.; rate of spreading 7 to 8 cu. ft per 100 sq. ft.

(d) Surface dressing.

Binder: a tar, bitumen or cutback considered suitable for ordinary surface dressing.

Grit: aggregate crushing value of 30; stripping value of 15 to 20†.

NOTE: Grits found by experience to be good for surface dressing work may be used without testing.

DESIGN

15. The total thickness of crust is calculated by the CBR method or any other usual method for flexible pavement design. The thickness of the upper course is kept 3 in., the remaining thickness being the base course.

*See footnote on page 568.
†Vide paper On laboratory investigation of stripping bituminous binders, C.R.R.I. Paper No. 18.

CONSTRUCTION PROCEDURE

16. The procedure specified below relates to work carried out by manual labour. The use of machinery for pulverizing, mixing and watering has been successfully adopted recently in a few cases, and a standardized procedure for this will evolve in due course as a result of experience.

Preliminary soil survey

17. A visual identification of soils along the entire length of the existing earth road or proposed alignment is carried out, keeping in view the probable behaviour of different lengths under traffic, in different weather conditions. Topographical data and figures of rainfall, etc., are also collected. The object of the survey is to fix the specifications.

Soil sampling

18. As a certain amount of banking is necessary to keep the road immune from flooding, the soil for stabilization purposes normally must be borrowed from areas outside the formation width of the road.

19. In the alluvial plains of India, the characteristics of the soil deposits change at short intervals, and therefore soil samples are taken from fixed points which can be located when soil is to be actually borrowed.

20. Soil samples are taken at points a quarter of a furlong apart and 70 ft from the centre line of the road*. A 1-ft deep (the specified depth of borrow pits) sample of the soil is taken after removing the top 1 to 2 in. of foreign matter, which may be grass or any other loose matter. A representative sample, weighing about 5 lb, is obtained by quartering, after mixing the entire quantity of soil dug out from a hole 1 ft wide by 1 ft deep. A numbered peg is left to locate the test hole for subsequent borrowing of soil.

21. In addition to sampling at regular intervals, a few more samples of admixtures like heavy clay and sand, if available at economical distances from the road, are taken to facilitate blending.

22. Samples of local aggregate such as brick bats, kankar, laterite, shale or coarse moorum, etc., are also collected. Samples of the water that will probably be used for construction are collected in glass bottles.

Dispatch of samples

23. The soil samples are put in paper bags to avoid loss of fine materials. These in turn are enclosed in cloth bags to which tags are tied describing the exact location. Similar information written on a paper is also enclosed in the bags themselves. The samples are then dispatched to the field laboratory for testing.

Testing of samples

24. The following routine tests are carried out:

(a) Sieve analysis through No. 200, 40, 8 I.S.I. Standard (10.40, 200 A.S.T.M.).
(b) LL.
(c) PL and PI.
(d) Sulphate content.

Subgrade formation

25. If the formation is already existing, then the top 6 in. of the subgrade are raked, pulverized and then rolled back with an 8 to 10-ton roller at near optimum moisture. In the case of a new formation, the top 12 in. of the embankment are compacted in loose layers of not more than 9 in., in the same manner as that mentioned above. The desired moisture may be attained by flooding the borrow area.

Collection of soils

26. Soils, as specified in the designed mixtures, shall be dug out and collected in

* This distance should be fixed, keeping in view the area available for borrowing. The aim of having a fixed distance is to be able to conveniently locate the spots from which samples were originally taken, so that soil can be borrowed from the same places.

stacks in required quantities every quarter-furlong.

Pulverizing of soils

27. The soils are then pulverized separately with the backs of spades to a state of fineness at which about 80 per cent of the soil is under 5/16-in. size. With hard heavy clays the pulverization can be more conveniently carried out if the clods are wetted a day or two in advance.

Dry mixing and stacking

28. The different soils, in the case of the base course, or the soils with the aggregate, in the case of the wearing course, are then mixed in the dry state by turning them over with spades and shovels. After this, stacks about 15 in. high are made and carefully levelled on top.

Checking of mixed stacks

29. A representative sample is taken from the mixed stack and checked in the field laboratory for correctness of PI and sand content. Any serious departure is set right by adding the requisite admixture.

Addition of moisture

30. Optimum moisture is determined in the field laboratory and water carefully poured over the stacks, after small earth sides have been provided to retain the water. The water is added towards evening to stacks earmarked for laying next morning and allowed to soak down overnight. To ensure uniform distribution of water each large stack is divided on the surface into a number of substacks with raised earth sides.

31. Necessary allowance is made for evaporation losses and absorption by brick aggregate, as determined by experiments from time to time. Since optimum moisture is determined on weight basis it is necessary to determine the average weight of soil per cu. ft. This is generally 70 to 80 p.c.f.

Laying and rolling

32. After remaining in contact with moisture for several hours, the wet base course mixture is sliced off from the stacks in small lots, mixed as required and laid on the prepared subgrade with the help of templates, to a cross slope of 1 in 24 for unsurfaced and 1 in 48 for surfaced roads. (The mixing can be done mechanically with equipment such as the rotavator.) The rolling is done with a 6 to 8-ton flat roller, to attain a minimum dry-bulk density of about 1.8 g/cu.cm.

33. The wearing course is also rolled with a 6 to 8-ton power roller. Rolling is continued till the wheels of the roller make no appreciable impression on the surface. A heavy sprinkling of water is then given to the road and left overnight. In the morning the surface is again rolled to finish.

34. Where stone grafting is specified the following procedure is adopted.

35. On the first day the uncompacted upper course, together with the layer of stone, 1-in. gauge, spread on the surface at the rate of 7 to 8 cu. ft per 100 sq. ft, is rolled two or three times over the whole length and then sprinkled thoroughly with water and left till the next day.

36. The next day, without adding any more water, the surface of the road is rolled thoroughly for at least 6 passes. The surface is again thoroughly watered and left for the rest of the day.

37. On the third day the surface of the road is again rolled, after spreading some wet soil to blind the surface, without any addition of water, and this is continued until the road is thoroughly compacted. The rolling and re-rolling on the second day should be the heaviest.

Curing

38. The road is kept closed for traffic for 4 or 5 days and heavily sprinkled with

water during this period. After this, water sprinkling of a lighter nature is continued for another 10 to 14 days and controlled traffic allowed to run over the road, beginning with motor traffic only, and gradually extending to all kinds of traffic.

Surface treatment

39. The crust is allowed to dry to a moisture of about 4 or 5 per cent before bituminous surfacing is applied, which is done according to the practice prevailing in the area.

Cost of work

40. Since the construction is done mainly by manual labour, the actual cost will depend upon local conditions of labour prevailing in each state. A model estimate is given in APPENDIX A for general guidance; the cost of water bound macadam paving is given in APPENDIX B for purposes of comparison.

Maintenance for unsurfaced roads

41. The maintenance of this type of stabilized road is different from that of the conventional gravel road in that it does not need periodical grading with mechanical graders. All that is required is to remove the wearing course wherever a failure occurs, mix a little water and molasses (in the ratio of 3:1) to bring it up to near optimum moisture, and ram it back with a hand rammer. Molasses is used to give a little extra strength to the soil, to compensate for the impracticability of determining the exact optimum moisture for each patch, or of curing small patches before opening them to traffic.

BEHAVIOUR

42. About 300 miles of such roads have been constructed in different parts of India where alluvial soils are met with. These roads are reported to be giving satisfactory service.

43. The unsurfaced road, which is recommended for villages, gives a satisfactory performance, except that the surface is slightly dusty in the dry season. The slight rutting that may take place during dry weather tends to be automatically smoothed by traffic during the wet season. The road thus remains almost free of ruts and potholes, and the whole section wears uniformly. The crust generally wears at a rate of ½ in. per year, and so has a life of about 6 years. It would therefore appear to be more economical to surface-treat such roads, and provide regular maintenance, than to re-lay the upper crust every sixth year.

COST

44. It will appear from the model estimates given in APPENDICES A and B that stone grafted roads for medium traffic cost about 60 per cent, ungrafted roads, recommended for light traffic, almost 50 per cent, and unsurfaced roads about 40 per cent of the conventional specifications for the unsurfaced water bound macadam road.

45. This technique also has the advantage that no special road machinery is required, so that it is better suited for less developed countries. Another advantage of this method for less developed countries is that it provides a lot of employment, as most of the construction is done by manual labour.

USE OF COMPACTED SOIL IN LOWER LAYERS OF ROAD PAVEMENT

46. Large areas in the alluvial plains are becoming water-logged due to a rise of the water-table into the subgrade of roads. This has resulted in considerable reduction of the bearing capacity of these roads. The CBR of the subgrade, which originally used to range between 25 and 35 per cent, has fallen down to almost 2 to 3 per cent. The situation is further aggravated by the rapid increase of traffic, both in weight and intensity, as a result of recent industrialization

TABLE I

EFFECT OF INCREASED DENSITIES ON SOAKED CBR VALUES

Sl No.	LL	PI	Fraction coarser than 200 B.S. Sieve	Dry bulk density (g/cu. cm)	Percent CBR (Soaked)
1.	21	3	73	1.5	1.8
				1.6	4.13
				1.68	8.32
				1.80	14.40
2.	25	7.5	50	1.6	2.6
				1.72	4.0
				1.86	20.0
				1.94	39.0
				2.00	50.0
3.	35	14	23	1.6	1.7
				1.7	2.90
				1.8	5.12
				1.9	12.8

of the country. These conditions have necessitated the provision of thicker road pavements, of nearly 30 in., on National Highways, State Highways, and major district roads.

47. As a result of research work (Ref. 2) carried out at the Central Road Research Institute, New Delhi, it has been shown that all the soil types of the alluvial plains, when compacted at optimum moisture, improve in CBR under saturated conditions, which correspond to the water-logged conditions that occur in the alluvial plains.

48. The effects on the soaked CBR of increased compaction of some typical alluvial soils are given in TABLE I. It will appear from the results given in this TABLE that, with all types of soils tested, soaked CBR increases with the increase in dry bulk density. The effect of compaction varies from soil to soil depending upon their grading. The effect is more pronounced in the case of graded soils, such as those having a PI of 7 to 9 and fraction coarser than 200 U.S. Standard Sieve of about 35 per cent, s compared to predominantly sandy or ayey soils. This will require a rapid method of locating suitable soil during the survey.

49. For a preliminary soil survey the following device has been found very helpful (*Fig. 3*). This device is a metal tube 6 in. long and about 1 in. in diameter. To one end is fitted a cap with 2 or 3 holes, of ⅛-in. diameter, and through the other end a piston moves. To determine the approximate PI of a soil, a small quantity is wetted and made into a ball. This is put into the tube after removing the cap, which is then replaced. The piston is then pushed and the soil is forced out through the holes in thread-like lengths. It has been observed in a large majority of cases that when the PI of the soil is below 6 no threads are formed. Threads with a rough surface are formed with soil having a PI of 7 to 9, and if the PI is more than 12 threads with a glossy surface are formed.

50. Referring back to TABLE I, it will appear that a soaked CBR of 10 can be safely assumed for almost all types of soil met with in alluvial plains, when they are compacted at optimum moisture to a dry bulk density of 1.85 g/cu. cm. This has a far-reaching effect on designing road pave-

TABLE II

Sandy Loam	LL	PI	Fraction coarser than 200 B.S. Sieve
1.	19.8	5.3	56.7
2.	25.1	9.2	35.5
3.	28.6	10.2	14.3
4.	37.2	16.8	10.5

ments for heavy traffic in water-logged areas. As already stated, a thickness of 30 in. is required for heavy traffic over saturated subgrade. Since properly compacted soil can have a CBR of 10, a compacted thickness of 18 in. can be provided of local soil as part of the total required thickness of 30 in. This method has been adopted for all main roads to be constructed in the Twenty-Year Road Development Plan of India (1961-1981), resulting in huge savings in the estimated cost of the plan.

Fig. 3

STABILIZATION OF SOIL WITH LIME

51. Lime has normally been recommended for improving clayey soil in different parts of the world. However, not much research work has been carried out on the stabilization of alluvial soils with lime. From a study of literature on alluvial soils (Ref. 3), it will be found that the clay fraction of such soils is complicated, but that illite is the most important mineral, montmorillonite and kaolinite being of minor importance.

52. Research work on the stabilization of some of the typical alluvial soils such as those mentioned in TABLE II has been carried out in one of the State Laboratories (Ref. 4) in India. The effect of lime stabilization on the soaked CBR of the first three soils mentioned in TABLE II was determined with increasing percentages of lime. Tests were carried out both at optimum moisture content and at saturation. The results are produced in *Fig. 4*.

53. It appears that the maximum rise in CBR is produced only with 2 to 3 per cent lime, and that with further increase of lime the CBR values fall. At saturation there is a slight fall in the CBR values. The soaked CBR with optimum concentration of lime rises to 70 for sandy loam and about 40 for loam soils.

54. Advantage of this study has been taken in actual road construction. Above the compacted soil subbase, another 6 to 9 in.

of soil stabilized with lime (the thickness depending upon the CBR that is attained) can be provided as a base course. 100 cu. ft of compacted lime-stabilized soil costs Rs. 28.00 as against Rs. 50-55 for stone soling, as per details attached in APPENDIX C.

55. The above technique has been applied in the construction of roads in water-logged areas in Punjab, and is reported to be giving satisfactory service.

STABILIZATION OF SOILS WITH CEMENT

56. To impart durability to a soil-cement mix, a concentration of about 6 to 8 per cent cement has normally been recommended in the U.S.A. and the U.K. Since blending of soil is possible in alluvial plains, it has been shown that as little as 2.5 to 3 per cent cement can stabilize such soils, when compacted to a dry bulk density of about 1.9 g/cu.cm. The soil stabilized in the above manner satisfies all the durability tests specified by A.S.T.M. Even though the soil, when stabilized with 2.5 to 3 per cent cement, attains a compressive strength of 250 p.s.i., higher concentrations of cement, to attain even higher strengths, may still be necessary to resist the high stresses caused by non-tyred traffic of bullock carts.

57. In one of the projects of road construction carried out in water-logged areas in West Bengal, the following specifications were adopted. The design was based on the soaked CBR and unconfined compressive strength.

Subgrade: rolling with flat roller to attain a CBR of 3.

6-in. subbase: soil with a PI of 5 to 7 and sand content not more than 50 per cent, compacted to a CBR of 6.

3-in. base course: soil with a PI of 5 to 7 and sand content not less than 50 per cent, mixed with 2.5 per cent cement, on the weight of the soil, compacted to a CBR of 30.

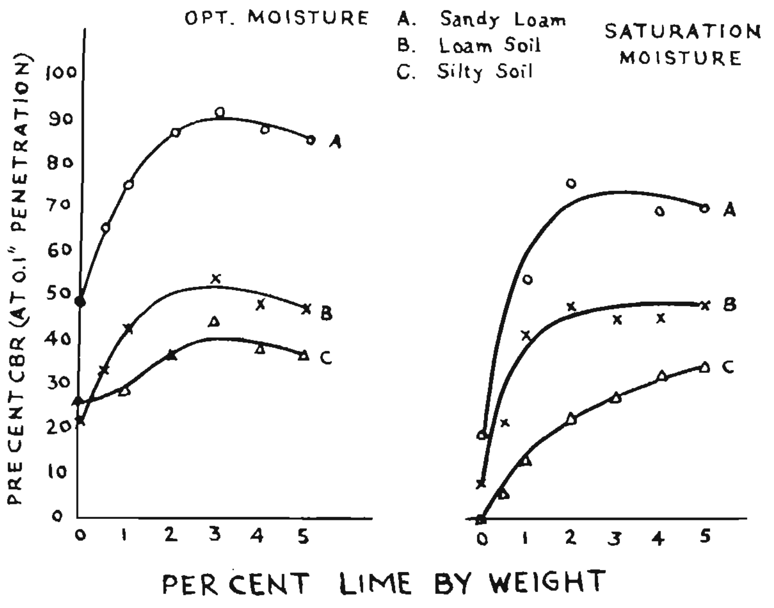

Fig. 4

4-in. base coat: soil with a PI of 8.5 to 11 and sand content not less than 33 per cent, with 6 per cent cement, with stone grafting at the rate of 12 cu. ft per 100 sq. ft, compacted to a CBR of 100.
Surface finish: 1 in. premix bituminous carpet.

58. The above specifications cost Rs. 63,130.00 per mile of 12-ft wide road, as against Rs. 100,299.00 for a conventional specification of similar thickness using stone metal: thereby saving about Rs. 37,000.00 (£A3,500) per mile. The details of cost are given in APPENDICES D and E.

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APPENDIX A

COST OF CONSTRUCTION OF WATER BOUND MACADAM ROAD (CONVENTIONAL SPECIFICATIONS IN THE STATE OF PUNJAB)

	Cost per mile of 12-ft wide road in Rs.*
(a) 3 in. burnt brick soling (flat layer)	
i. Collection of slightly overburnt bricks: 17,820 cu. ft @ 1,400 bricks per cu. ft = 249,480 bricks @ Rs. 35.00 per 1,000 bricks	8,732.00
ii. Laying charges: 17,820 cu. ft @ Rs. 5.50 per 100 cu. ft	980.00
Total for soling coat	9,712.00
(b) Base coat (3 in.)	
i. Collection of stone metal, 1½-in. gauge, including 8 per cent free supply of chips: 21,120 cu. ft @ Rs. 60.00 per 100 cu. ft	12,672.00
ii. Laying and consolidation of 21,120 cu. ft @ Rs. 7.50 per 100 cu. ft	1,584.00
Total for base coat	14,256.00
Add 5 per cent for contingencies for soling coat and base coat	1,200.00
Total for soling coat and base coat	25,168.00

(c) Two coats of surface dressing can be done at an additional cost of Rs. 10,150.00

*10.568 Rupees to £A1.0.0

APPENDIX B

COST OF CONSTRUCTION OF STABILIZED SOIL ROAD (MEHRA'S METHOD) IN THE STATE OF PUNJAB.

(a) Base Course (3 in. compacted)

i. Collection of base course soil including pulverization:

$$\frac{5,280 \times 12 \times 9}{24} = 23,760 \text{ cu. ft}$$

Soil (70 per cent of above):

$$\frac{23,760 \times 70}{100} = 16,632 \text{ cu. ft}$$

@ Rs. 6.00 per 100 cu. ft	Rs.* 998.00

Sand (30 per cent of above):

$$\frac{23,760 \times 30}{100} = 7,128 \text{ cu. ft}$$

@ Rs. 10.00 per 100 cu. ft	713.00
ii. Dry mixing, stacking, levelling and watering of soil stacks: 23,760 cu. ft @ Rs. 2.00 per 100 cu. ft	475.00
iii. Wet mixing of above: 23,760 cu. ft @ Rs. 1.25 per 100 cu. ft	297.00
iv. Pouring of base course, including spreading to camber: 23,760 cu. ft @ Rs. 1.25 per 100 cu. ft	297.00
v. Rolling of base course in one layer by flat roller at optimum moisture content: 5280 x 12 = 63,360 sq. ft @ Rs. 0.75 per 100 sq. ft	476.00
Total cost of base course	Rs. 3,256.00

(b) Base Coat (3½ in. compacted)

i. Collection of soil for base coat, including pulverization and stacking (80 parts of total soil-aggregate mixture):

$$\frac{5280 \times 12 \times 9}{24} \times \frac{8}{10} = 19,008 \text{ cu. ft}$$

Soil (80 per cent of above): 15,206 cu. ft @ Rs. 6.00 per 100 cu. ft	912.00
Sand (20 per cent of above): 3,802 cu. ft @ Rs. 10.00 per 100 cu. ft	380.00
ii. Collection of first class brick ballast from well burnt bricks, 1¼ in. sieve, including stacking 35 per cent of total: 8,316 cu. ft @ Rs. 30.00 per 100 cu. ft	2,495.00
iii. Supplying stone metal, 1-in. gauge, at the rate of 8 cu. ft per 100 sq. ft: 4,500 cu. ft @ Rs. 60.00 per 100 cu. ft	2,700.00
iv. Dry mixing of soil, sand and brick ballast (19,008 + 8,316) @ Rs. 2.00 per 100 cu. ft	546.00
v. Levelling, stacking and watering of soil-aggregate mixture: 23,760 cu. ft @ Rs. 1.00 per 100 cu. ft	238.00
vi. Wet mixing of aggregate and soil: 23,760 cu. ft @ Rs. 1.50 per 100 cu. ft	357.00
vii. Pouring of base coat soil including stone grafting over top: 23,760 + 4,500 = 28,260 cu. ft @ Rs. 1.50 per 100 cu. ft	424.00
viii. Compaction of wearing course with power roller: 63,360 sq. ft @ Rs. 2.00 per 100 sq. ft	1,267.00

*10.568 Rupees to £A1.0.0

ix. Curing of the crust for a week: 1 mile @ Rs. 120.00 per mile	120.00
Total cost of base coat	Rs. 9,439.00
Total cost of base course and base coat	Rs. 12,695.00
Add 5 per cent contingencies	635.00
Total cost	Rs. 13,330.00

Two coats of surface dressing can be given at an additional cost of Rs. 10,150.00.

(a) The cost of a soil stabilized road with stone grafting and surfacing is Rs. 23,480.00, as compared to a water bound macadam road, which costs Rs. 35,318.00 per mile.

(b) The cost of a soil stabilized road without stone grafting finished with two coats of surface dressing is Rs. 19,909.00, as compared to a water-bound macadam road, which costs Rs. 35,318.00 per mile.

(c) The cost of an unsurfaced road without stone grafting and surface dressing is Rs. 9,759.00, as compared to a water-bound macadam road without surfacing, which costs Rs. 25,169.00 per mile.

APPENDIX C

SAMPLE ESTIMATE FOR LIME TREATED STABILIZED SOIL BASE COURSE WITH TWO PER CENT LIME

(a) Wt. of 100 cu. ft of soil at 120 p.c.f. density = 12,000 lb
(b) Wt. of lime @ 2 per cent for 12,000-lb mixture = 240 lb
(c) Loose volume of 12,000 lb of soil from borrow pit areas = 150 cu. ft

COST ANALYSIS

(a) Cost of 150 cu. ft of soil @ Rs. 4.00 per 100 cu. ft	Rs.* 6.00
(b) Cost of 240 lb of lime @ Rs. 0.048 per lb	11.60
(c) Dry mixing of soil and lime @ Rs. 1.25 per 100 cu. ft and stacking	1.87
(d) Levelling and watering of stacks including water charges @ Rs. 1.00 per 100 cu. ft	1.50
(e) Wet mixing of soil @ Rs. 1.00 per 100 cu. ft	1.87
(f) Pouring of soil mixture and spreading to camber @ Rs. 1.25 per 100 cu. ft	1.87
(g) Rolling with flat roller @ Rs. 1.00 per 100 sq. ft	2.40
(h) Curing of lime-soil mixture	0.50
Cost of 100 cu. ft compacted soil-stabilized crust with 2 per cent lime	Rs. 27.61

*10.568 Rupees to £A1.0.0

APPENDIX D

COST OF SOIL CEMENT ROAD CONSTRUCTION AT SHEAKHALA-JAGJIBANPUR ROAD IN HOOGLY DISTRICT

Sl No.	Description of item	Rate (Rs.)*	Quantity	Amount for 100 sq. ft (Rs.)*
1.	Box-cutting	1.25 per 100 sq. ft.	100 sq. ft.	1.25
2.	Construction of sub-base: 9 in. loose compacted to 6 in. (local soil + 50 per cent sand)	4.75 per 100 sq. ft.	100 sq. ft	4.75
	Cost of sand	24,00 per 100 cu. ft.	37.5 cu. ft 100 sq. ft	9.00 8.25
3.	Construction of base course 4½ in. loose compacted to 3 in. with 2.5 per cent cement.	8.25 per 100 sq. ft.	18.75 cu. ft	4.50
(a)	Cost of sand (50 per cent of the total quantity of soil-sand mixture).	24.00 per 100 cu. ft.	100 sq. ft	24.00
4.	Construction of base coat with 6 per cent cement, 6 in. loose, completed to 4 in.	24.00 per 100 sq. ft.	15 cu. ft	3.60
(a)	Cost of sand 30 per cent of the total quantity.	24.00 per 100 cu. ft.	12 cu. ft	13.20
5.	Supply of stone material @ 12 lb per sq ft	110 per 100 cu. ft.	20 lb	3.57
	Primer treatment @ 20 lb per 100 sq. ft.	@ 400.00 per ton	100 sq. ft	0.50
	Labour charges for above	@0.50 per 100 sq. ft.	100 sq. ft	27.00
6.	1 in. premix carpet	27.00 per 100 sq. ft.		99.62

Total cost per mile of 12-ft wide road = Rs. 63,130.00

NOTE: The work was executed for a length of 2 miles and 6 furlongs by the contractor, and the above rates are according to the lowest quotations offered by him.

*10.568 Rupees to £A1

APPENDIX E

COST OF CONVENTIONAL TYPE OF ROAD CONSTRUCTION IN WEST BENGAL

Sl No.	Description of the item.	Rate in Rs.*	Quantity for 100 sq. ft	Cost for 100 sq. ft in Rs.*
1.	Flank dressing.	5.00 per 1,000 sq. ft	100 sq. ft	0.50
2.	Supply of double brick soling	70.00 per 1,000 bricks.	576 bricks	40.32
3.	Labour charges for double brick soling.	6.50 per 100 sq. ft	100 sq. ft	6.50
4.	Supply of 6 in. Jhama	71.50 per 100 cu. ft	50 cu. ft	35.75
5.	Labour charges for 6 in. Jhama consolidation.	11.00 per cu. ft.	50 cu. ft	5.50
6.	Supply of 4 in. Stone (2 in. to 1½ in).	115.00 per cu. ft	33.3	38.33
7.	Labour charges for stone metal consolidation.	15.50 per 100 cu. ft	33.3 cu ft.	5.16
8.	One coat of stabilization	7.70 per 100 sq. ft	100 sq. ft	7.00
9.	One coat of surface dressing	16.00 per sq. ft	100 sq. ft	16.00
10.	Supply of brick on end for edging (480 bricks required for 100 running ft).	70.00 per 1,000 bricks	40 bricks (for 12-ft wide road).	2.80
11.	Labour charges for brick edging.	4.00 per 100 running ft	8.33 ft.	0.33

Total cost for 100 sq. ft — Rs. 100,229.00

Total cost for 1 mile of 12-ft wide road — Rs. 100,299.00

*10.568 Rupees to £A1

DISCUSSION

S. GOTTLIEB, Gippsland Cement Ltd., Victoria

59. It is understood that adequate uniformity of blending can be achieved between 3 per cent cement and soil, if such work is done by manual labour. However, with the progress of soil stabilization, presumably more and more roads will be built. Would not manual labour then have to be replaced by machines for spreading cement and blending it with soil; are there any mechanical means available in India to perform these functions satisfactorily?

AUTHORS' CLOSURE

To S. GOTTLIEB, Gippsland Cement Ltd., Victoria

60. So far manual labour is plentiful and therefore the need for mechanical spreading and blending has not yet arisen. Partial mechanization with light machinery has, however, been started in places where labour is scarce.