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MADRAS HIGHWAYS

THE JOURNAL

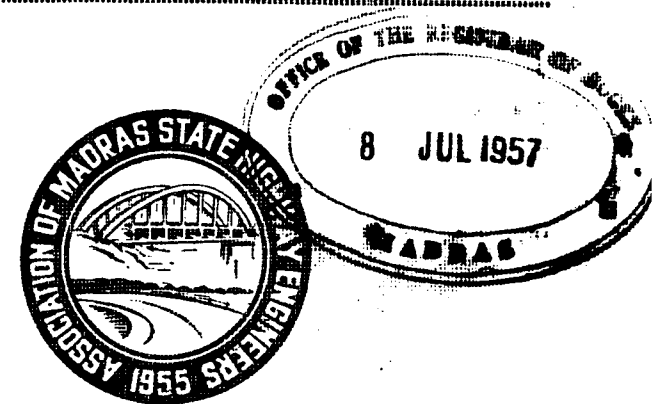
OF

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MADRAS STATE HIGHWAY ENGINEERS

Vol. II

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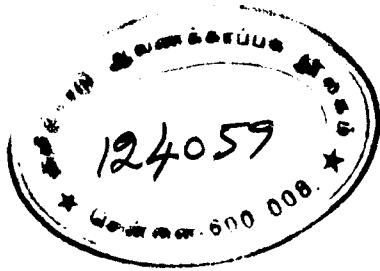
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The Second five year plan has been embarked and it is well known the programme of construction under this plan is very ambitious.

“There was a time when the substantial problems of highway administration stemmed almost exclusively from lack of money with which to accomplish the necessary demands of the day and of the days ahead. We are passing into what may be a period of more adequate financing and into new and greater responsibilities as well. The necessity for spending wisely and vastly increased construction funds for highway systems which will operate safely, economically, and efficiently adds to administrative burdens already heavy. Every highway administrator is aware of increasingly critical public demand for the systems in which those characteristics are inherent as contrasted with nothing more than additional miles of construction”.

Traffic operation, and not miles of concrete bituminous surface is what the motorist expects to buy with his tax money. Transportation, not just facilities alone is demanded. Geometric design which does not contribute as fully as possible to safe and efficient traffic operation on the existing system can not reasonably be defended on grounds of either economy or expediency.

The problems that confront a Highway Engineer in dealing with the above are the quality of materials, workmanship and the construction know how during discharge of his duties.

Though there had been specifications and codes of construction practice, it is very often noticed that construction work proceeding with little regard to standards result in extravagance and in inadequate facility. It is not uncommon to come across highway construction in different places being executed to different standards and specifications. In one stretch of road cutstone

edging for black top surfacing is used while in others they are dispensed with. In some stretches edge bundings in high banks are seen while in others they are entirely rounded off. A flat bank slope is used in some embankments while steep bank slopes are seen in others irrespective of soil conditions. Perhaps this lack of uniformity in standard of workmanship and design might have been due to the want of a suitable code of practice in the past. For the first time in our country an effort has now been made to draw up a comprehensive specifications for highway materials and construction in this state. Already Madras Highways Manual Volume I dealing with specifications for materials etc. and Vol. III dealing with type designs for Highway works have been published and these books are intended to serve the needs of men engaged in actual construction work. The outstanding characteristics of these volumes are simplicity and preciseness. All over, simple principles have been adhered to; such methods which have been most useful for ordinary run of work and most upto date way of doing work have been described. Other information have been sufficiently furnished in each section to make clear the science of road construction.

A code of practice such as the above represents a collective experience of many eminent engineers and as such every effort must be made to translate the specification requirements into practice. A faithful enforcement of specifications as envisaged in the manuals will not only result in structures suited to present day conditions but also will be most economical as the heavy waste of expenditure due to the old, outmoded trial and error methods of bullock-cart era can be completely eliminated.

Soil Stabilization work on Kovalam-Mahabalipuram Road

BY

Sri E. C. CHANDRASEKHARAN, B.E., M.S.E.,

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SYNOPSIS.

This article briefly describes the procedural methods adopted in the stabilization of a road connecting Kovalam with Mahabalipuram in the coastal region of Madras State.

The structural features and a list of plants used on the job are given.

The procedure adopted for arriving at the design mixes for base course and stabilization of the road is described in addition to cost particulars and findings.

A typical representation of the various stages of work from formation to stabilization of sand-clay base, is illustrated.

Location

Kovalam, an old Dutch settlement on the eastern sea coast between Madras and Mahabalipuram is a pilgrim centre for both Muslims and Christians with the existence of a famous Muslim Durga and an ancient Church built around 1850. Mahabalipuram is an all India tourist centre of great archaeological interest with its stone carvings dating to the 7th Century A. D. The existing road from Madras to Mahabalipuram crosses the Buckingham Canal from the east at 8/2 and runs west of the Canal before recrossing it at 35/8 to reach Mahabalipuram. With the undertaking of the bridge work across the Canal from Kovalam to Kelambakkam at 23/0 of the Madras-Mahabalipuram road, the need for the extension of the road from Kovalam to Mahabalipuram on the eastern side of the Canal for affording both a through link for the tourists to proceed to Mahabalipuram via Kovalam and a road communication to the

10 villages on route (one of which, *viz.* Thiruvadanthai is a pilgrim centre for the Hindus with the existence of the Nityakalyanaswami Temple) became apparent and the work was taken up for execution in June 1955. The map showing the location of the different places is given in Fig. 1.

The route originally proposed for the road was to pass through most of the villages and the low-laying areas on the west with a thick vegetation. During actual construction, however, the alignment was shifted on to the top of the ridge of a sand dune located on the east of the villages. This shift in the alignment made available an adequate land width free from the built up tenements, a greater facility for natural drainage for the road and an excellent panoramic view of the whole area from the road.

Structural Features

2. The subgrade soil was a fine to medium sand and this posed a problem for the construction traffic to negotiate the untreated surface, especially in the dry season. Transporting the conventional construction materials as gravel or stone available only from both the ends of the road was difficult and costly. Preliminary soil investigation in the nearby area showed the availability of a sandy clay within leads varying from $\frac{1}{2}$ to 6 furlongs and depths of 0 to 8 feet from the ground surface. Past experience in stabilized soil construction showed that a combination of the subgrade sand and the binder clay in suitable proportions (about 1 : 1) compacted to Proctor density for a thickness of 6 inches would serve effectively as a base course. The wearing course was of waterbound macadam 5 inches thick, to be laid in two layers of 3 inches and 2 inches thick, with gravel berms for the sides. A typical cross section of the road is given in Fig. 2.

Organisation

3. The formation work in heavy earthwork reaches (involving the use of mechanical aids as bull dozers) and the stabilisation work (still new to the contracting profession in the state) were undertaken departmentally, while the other items of work were entrusted for execution on contract.

Soil Stabilization work on Kovalam-Mahabalipuram Road 5

Equipments

4. The various plants used on the job, though not simultaneously were as follow :

1. Bull dozer	85	... 1 to 2 Nos.
2. Grader		... 1 No.
3. Seaman pulvimixer		... 1 No.
4. Smooth wheeled power rollers		
(three wheeled type)	...	1 to 2 Nos.
5. do (two wheeled)	...	1 No.
6. Tractor		... 1 to 3 Nos.
7. Lorry		... 1 to 8 Nos.
8. Water pump with connections		... 1 to 2 Nos.
9. Attachments to tractors :		
(a) Trailor	...	1 to 3 Nos.
(b) Sheepsfoot roller	...	1 to 2 Nos.
(c) Pneumatic tyred roller	...	1 No.
(d) Trial-Master grader with tooth harrows	...	1 No.
(e) Disc harrow	...	1 to 2 Nos.
(f) Disc plough	...	1 No.
(g) Water tank	...	1 to 2 Nos.
10. Field soils laboratory	...	1 No.
11. Tents for stores and crew	...	1 to 3 Nos.

5. Construction

5. 1. **Formation of the Road**—Jungle clearance of Palmyra and casurina plantations was made by a combination of manual labour and bull dozer, depending upon local conditions. The formation was done by Manual labour in fairly level portions and by bull dozer in others involving heavy filling or cutting. A ruling gradient of 1 in 30 was adopted in highly undulating terrain.

Collection of Clay

5. 2. The clay available from the nearest sources was collected and stacked on the subgrade at the sides leaving a central gap of about 8 feet for the construction traffic to pass through. The

clay was conveyed to the road side by head loads when the leads did not exceed one furlong. For longer leads tractors and lorries were used. The sand surface was kept specially prepared by spreading some vegetation covering or some metal sheets to facilitate easy movement of the vehicles on the sand surface.

Design of Sand-Clay Mix for Base Course

5. 3. Typical samples of the subgrade sand and the binder soil collected were obtained from each furlong and these were tested for their mechanical analysis and consistency limits. The sand was of medium variety and the sandy clay was medium plastic and susceptible to easy pulverization. Proctor density tests and bearing power tests with North Dakota Cone Penetrometer were conducted on a number of combinations of sand and sandy clay. The combinations that showed the maximum density and maximum bearing power were taken as the design mix for the respective furlong. The proportions varied from 2 sand : 1 clay to $\frac{1}{2}$ sand : 1 clay depending upon the plasticity characteristics of the binder soils collected in the different reaches. For the design mixes the proctor density obtained was more than 120 Lbs./cft. and plasticity index values were between 6 and 10. The bearing power, as determined by the North Dakota Cone penetrometer after soaking for 3 days was also more than 200 Lbs./sq. in. Most of the combinations for which maximum dry density and bearing power values were obtained did not possess gradings completely falling within the limits specified for sand-clay mixes in the A. S. T. M. specification. But past experience has proved that soils or soil mixes with gradation outside recommended limits but with good density and bearing power show satisfactory service behaviour. So gradation within the limits was not considered as an indispensable requirement and on the basis of maximum dry density and cone bearing power design mixes were arrived at.

Typical test results are shown in Table No. 1.

Stabilization

5. 4. The sand subgrade was brought to a camber of 1 in 36 and the clay from the stacks was spread to the required thickness (which varied from 4 to 8 inches) and to a width of 16 feet. The

clay was pulverised initially by a number of passes (about 8 to 10) of a disc harrow towed by a tractor, until the clods were not more than say 2 to 2½ inches in size. The material was further pulverised by a number of passes (about 4 to 6) of the pulvimixer with its tynes adjusted to suitable depths in two stages until the clods were not more than say 1 inch in size. The pulverized clay was then mixed with the sand in the subgrade below by further passes (about 4 to 6) of the pulvimixer with its tynes adjusted to a suitable depth in order to obtain the desired mixture of sand and clay. Requisite quantity of water was then added, the water being conveyed to site by means of a tractor-water tank combination, and the material was wet mixed with additional passes of the pulvimixer (about 4 to 6) until a uniform mix was obtained. Any undulations left on the surface by the pulvimixer was levelled off and the surface was brought to camber by 2 or 3 passes of the grader. The soil mixture was then compacted initially with a sheepsfoot roller (about 8 to 10 passes) later with a pneumatic tyred roller (or a grader) and finally finished with a smooth wheeled power roller, preferably of the tandem type. The surface was bladed a few times during these compaction operations in order to remove any undulations.

A diagrammatic representation of a typical sequence of operations adopted in the work is shown in Fig. 3.

Field Control Tests

5. 5. The compacted surface was subjected to density and cone bearing power tests (with a North Dakota Cone) as a part of the field control tests. During the mixing operations additional quantities of sand or clay were added to the mix, if in local spots such a material was found wanting due to one reason or another.

Deviations from the Typical Procedure

5. 6. The typical procedure described above was deviated from when conditions were unfavourable for its adoption. For example, when the pulvimixer was not available for use due to occasional repairs, a combination of the disc harrows and the disc plough was employed. This had, as compared with the use of the

pulvimixer, the disadvantage of not a precise control on the depth of pulverisation and mixing of the clay with the sand in the subgrade. In some reaches the disc harrow alone was used for both pulverising and mixing by controlling the inclination for the discs with the line of movement of the tractor. The finished product was quite satisfactory, especially when the binder soil was of a poorly plastic clay.

On occasions when the clay spread on the subgrade got soaked in rain water and conditions were not favourable for pulverising and mixing by the methods described (the binder soil having been rendered too soft and plastic), attempts were made to do the same in one operation by puddling by means of manual labour. A layer of sand was laid on top of the clay already spread, an additional quantity of water was added, if necessary, and the sand and clay were puddled together by stamping under foot as is customarily done for mixing sand and clay used for mud wall construction. The material was kept turned upside down frequently by means of mummutties. On obtaining an intimate and uniform sand-clay puddle, the material was allowed to dry out in sun and later subjected to compaction under more favourable conditions of weather.

Maintenance

6. The stabilized sand-clay surface was subjected to pneumatic tyred construction traffic of lorries and tractors engaged in the collection of materials for the wearing surface and side protection works. Continued use of the heavy laden and fast moving vehicles was found to leave signs of distress on the stabilized soil layer. This was particularly noticeable when the traffic used the wet surface immediately after the rains in the curved portions and in the beaten tracks. Traffic was then directed, as far as possible, to use the complete width of the stabilized surface.

Cost

7. The average cost of the sand-clay base for the road inclusive of the cost of soil materials was Rs. 10/- per 100 square feet by 6 inches thick.

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Wearing Surface

8. The stabilized surface was allowed to dry out in sun for a few days (at least 3 to 4 days) before the wearing surface was laid. Actually in this case the collection of materials for the wearing surface got considerably delayed due to one reason or another and the stabilized surface was exposed to weather and traffic for a longer time. The bottom layer of waterbound macadam was laid immediately after the collection of materials for that layer was over. This surface was then used by the construction traffic engaged in the collection of materials for the second layer. The second layer is being laid at the time of writing of this paper and the work is expected to be completed within a fortnight.

Edge Protection

9. Since the road runs on a sand subgrade, the sides are susceptible to heavy scour by rain water draining away from the road surface. The road edges and slopes were protected with clay bunds with openings for side drains at suitable intervals to channelize and clear away the surface water. The edge bunds and the drains were protected at their sides and bottom with turf. The portions thus protected have stood excellently well the monsoon rains, while the sides of the unprotected portions, especially those at high fills were gullied and eroded very badly.

Findings and Future Trends

10. Two significant findings that arise from the experience gained in stabilized soil road construction in the state in sandy areas are :

- (1) In the coastal areas of the state the surface soil is sand and negotiation of the untreated surface even by the construction traffic is almost impossible. In most of these places binder soil of clay is available in close proximity. Adoption of sand-clay stabilized foundation course in these places should therefore commend itself both for reasons of economy and constructional expediency.

- (2) Use of specialized machinery as pulvimixer has the advantage of efficiency and quality control in the work. But such plants are of maximum benefit only when the work is undertaken as a train operation with a number of such units. For the conditions obtaining in this country, especially regarding the high cost of investment involved in the use of such specialized machinery and the large mileage of low cost secondary roads to be provided for connecting the villages, it appears that mobile units of tractors with the necessary attachments (which are not costly) as trailers, disc harrows, sheepsfoot rollers, pneumatic tyred rollers, smooth wheeled stone or iron roller (without power unit) etc. may serve the essential purpose. The use of specialized plants is however essential for speed, uniformity of work and research on stabilization methods and procedures.

TABLE 1.—Typical Results of Tests Conducted on Soil Samples for Designing a Suitable Mix for Base Course for Kovalam—Mahabalipuram Road

Serial No.	Particulars of Tests	Sand from 0/7	Clay from Kovalam quarry	Proportion by Weight					Remarks
				$\frac{1}{2}$ sand + $\frac{1}{2}$ clay	$\frac{3}{4}$ sand + $\frac{1}{4}$ clay	$\frac{1}{2}$ sand + $\frac{1}{2}$ clay	$\frac{1}{4}$ sand + $\frac{3}{4}$ clay	$\frac{1}{2}$ sand + $\frac{1}{2}$ clay	
1	Liquid limit %	—	25.8	—	—	—	—	—	P.I. Values for mixes were calculated as per Hogentogter's formula.
2	Plastic limit %	—	11.0	—	—	—	—	—	
3	Plasticity index	—	14.8	10.1	8.9	7.8	6.2	5.2	
4	Passing A.S.T.M. Sieve	100	99.8	99.8	99.8	99.9	99.9	99.9	
		40	85.7	83.0	82.3	81.8	81.0	80.5	
		60	63.5	52.9	49.9	47.6	44.4	42.3	
		100	52.3	37.3	33.1	29.9	27.6	22.4	
		200	32.6	22.2	18.9	16.6	13.4	11.3	
5	Proctor density in lbs./cft.	—	111.0	117.0	122.0	124.0	120.0	—	
6	Optimum moisture %	—	15.3	13.4	11.0	11.1	13.0	—	
7	Cone bearing power soon after compaction in P.S.I.	—	—	—	600	700	400	—	
8	Cone bearing power after soaking in water for 3 days PSI	—	—	—	180	320	224	—	
9	Total moisture absorbed %	—	—	—	14.2	12.4	13.2	—	

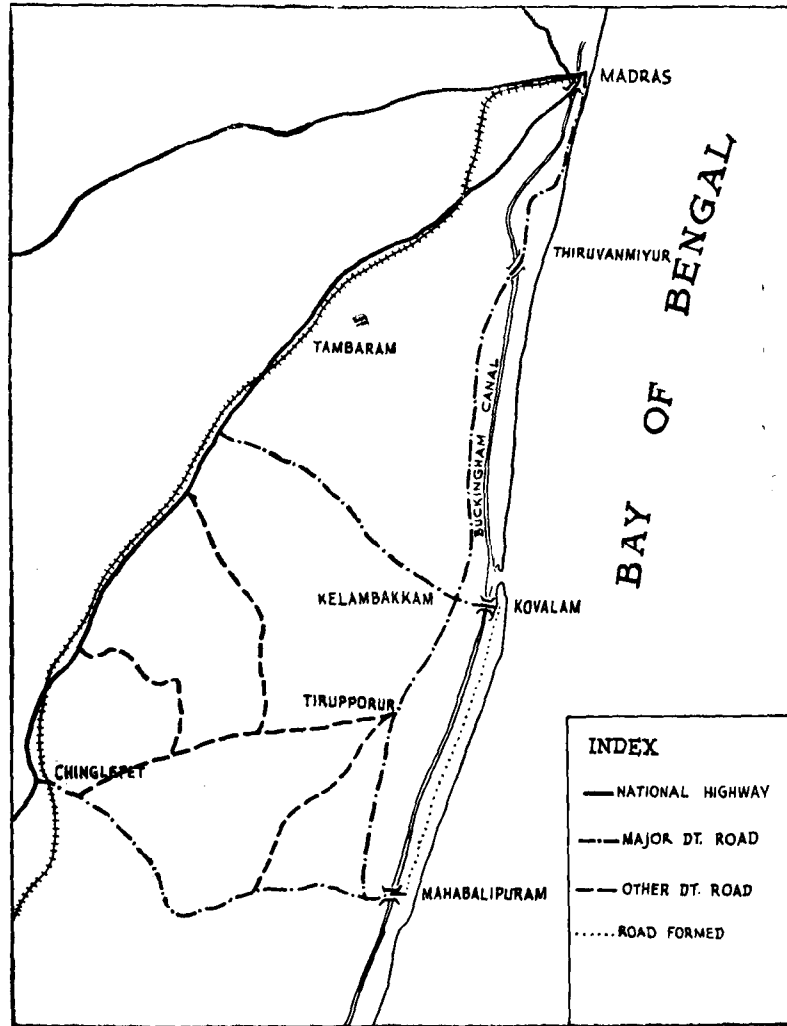


FIG. 1. MAP SHOWING THE LOCATION OF KOVALAM - MAHABALIPURAM ROAD

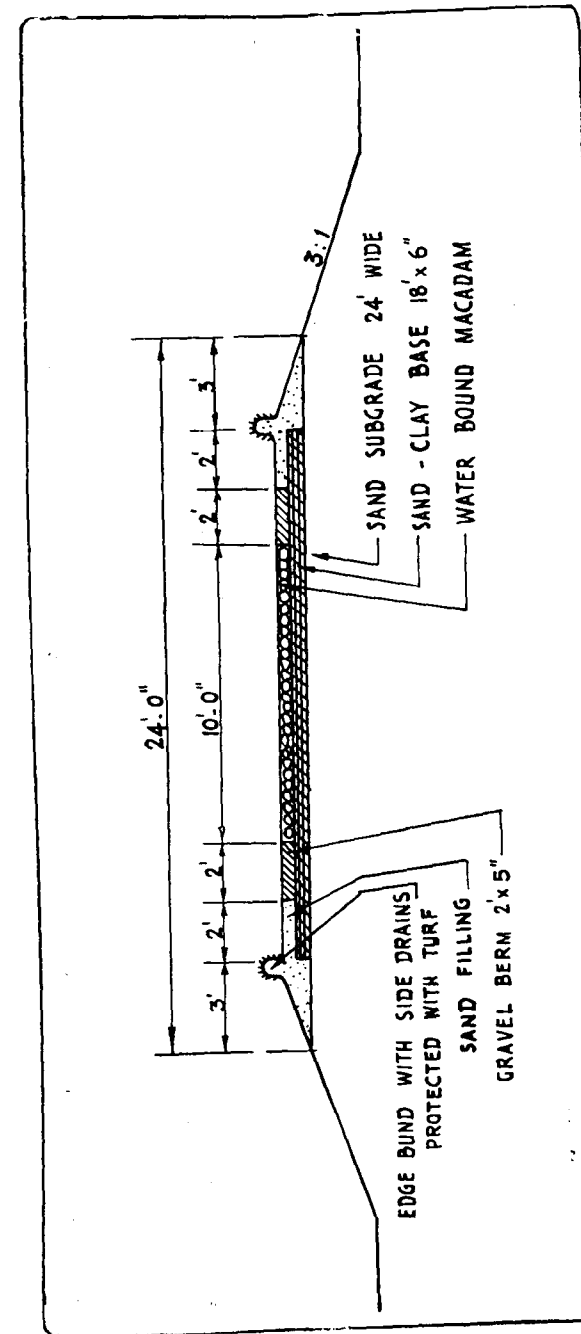


FIG. 2. SHOWING A TYPICAL CROSS SECTION OF KOVALAM - MAHABALIPURAM ROAD

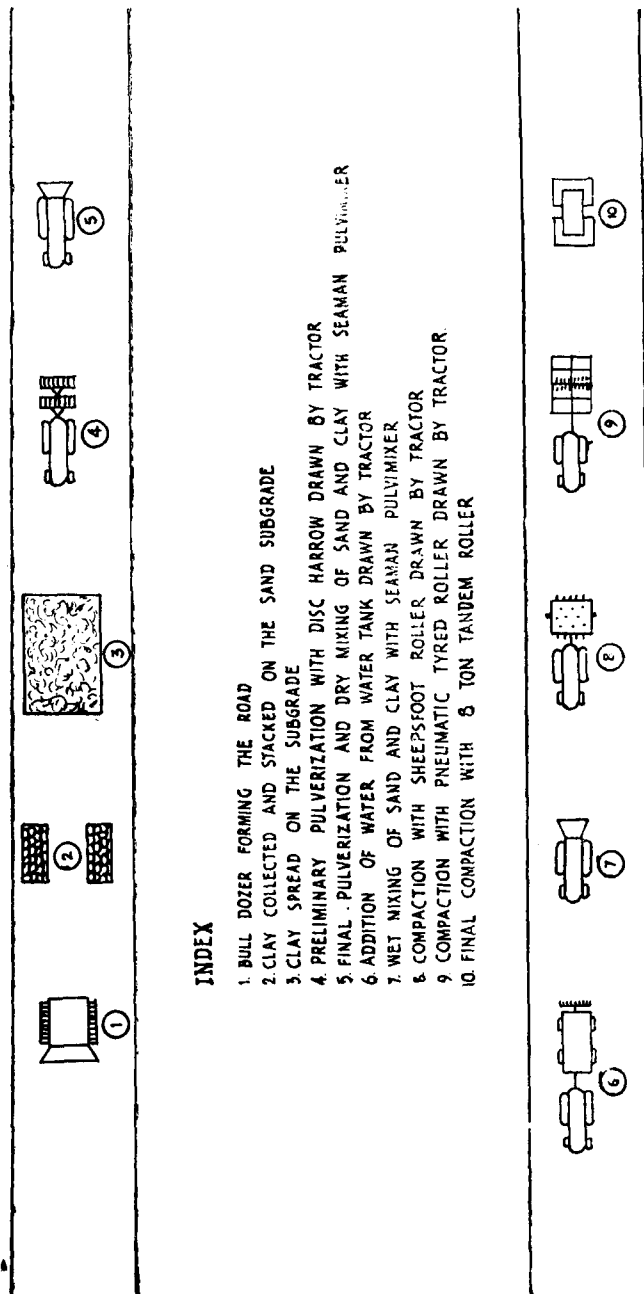


FIG. 3. SHOWING A TYPICAL REPRESENTATION OF THE VARIOUS STAGES OF WORK FROM FORMATION TO STABILIZATION OF SAND-CLAY, BASE ON KOVALAM - MAHABALIPURAM ROAD

NOT TO SCALE.

Granular Soil Stabilization

Contributed from Highways Research Station

The contents of this note on soil stabilization are divided into four parts :

1. Soil properties.
2. Soil compaction.
3. Soil stabilization.
4. Method of Testing.

As the article is intended for those who are not familiar with the subject it is suggested that the chapters be perused in the following sequence : 1, 4, 2 and finally 3.

The term soil stabilization means the improvement of the bearing power of the soil by means of compaction with or without added material. The technique of applying sand over muddy stretches of roads or clayey soil over sandy stretches is very old and is practiced by our engineers by "cut and try" methods. The modern methods of soil stabilization, which is allied to the science of soil mechanics, make scientific use of certain properties of soils, instead of the "cut and try" methods.

The widest application of soil stabilization is in highway and air port construction, and the following are some of its uses :

- (i) To provide a firmer subgrade than the ordinary subgrade.
- (ii) As an economical substitute for stone soling and base courses.
- (iii) As a surface course if the traffic is light and predominantly pneumatic tyred.

The chief types of soil stabilization are the following :

- (i) Using soil Mixtures :
 - a. Without admixture of materials other than soils.
 - b. With the addition of certain water retentive chemicals such as sodium or calcium chloride.

(ii) Using soils with special stabilizing Agent :

- a. Bituminous binder.
- b. Portland cement.
- c. Certain industrial waste products such as resins molasses etc.

(iii) Electro-osmosis :

Of these methods i (a) and i (b) and ii (a) and ii (b) are the most useful for the purposes of highway engineering. If suitable soils are available i (a) is the most feasible of all the above methods, and this has also been tried on a number of our important roads.

1. Soil and Soil Properties

1. 1. Soil. The materials that constitute the earth's crust are rather arbitrarily divided by the Engineer into two categories, *Soil* and *Rock*. Soil is a natural aggregate of mineral grains enclosing a network of pores or voids which is filled with air or water or both.

According to their origin, soils can be divided into two large groups, those which consist chiefly of the results of rock weathering, and those which are chiefly of organic origin. If the products of rock weathering are still located at the place of their origin, they constitute a *Residual Soil*. Otherwise they constitute a transported soil.

The term *Organic Soil* ordinarily refers to soil consisting of the products of rock weathering, with a more or less conspicuous admixture of decayed vegetable matter. Organic soils are generally unsuitable for Highway purposes.

1. 2. In order to understand the fundamentals of soil stabilization it is necessary that certain properties of the soil as an engineering material are properly understood. Soil properties are broadly divided into :

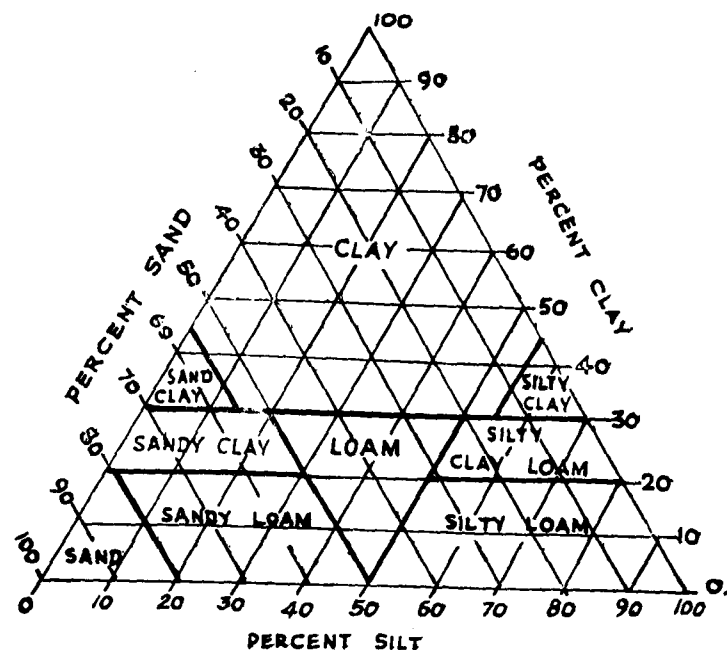
(i) Index Properties : These properties reflect the general character of a soil and help the engineer to discriminate between the different kinds of soils.

(ii) Hydraulic Properties : Permeability, capillary phenomenon, and drainage characteristics. To the highway engineer these assume importance in the design of subsoil drainage.

(iii) Structural properties : Compressibility, shear strength, stress-strain relationships, bearing strength etc. A knowledge of those properties is necessary for a proper understanding of all foundation problems, whether it be of a road, bridge or other structure.

1. 3. Such of these properties as have significance in relation to soil stabilization are listed below : The method of test for determining each property are also listed.

PROPERTY	NAME OF TEST
Index Properties	
Size of Soil Particles	Mechanical Analysis
Porosity, water content bulk density	
Limits of consistency	i. Liquid Limit ii. Plastic Limit iii. Plastic Index iv. Shrinkage Limit
Structural Properties	
Compaction	Proctor Compaction Test
Bearing Strength	One of the following : North Dakota Cone Penetrometer Proctor needle 30-inch plate California Bearing Ratio



CLASS	PERCENT		
	SAND	SILT	CLAY
SAND	80-100	0-20	0-20
SANDY LOAM	50-80	0-50	0-20
LOAM	30-50	30-50	0-20
SILTY LOAM	0-50	50-100	0-20
SANDY CLAY LOAM	50-80	0-30	20-30
CLAY LOAM	20-50	20-50	20-30
SILTY CLAY LOAM	0-50	50-80	20-30
SANDY CLAY	55-70	0-15	30-45
CLAY	0-55	0-55	30-100
SILTY CLAY	0-15	55-70	30-45

Fig 1. 4-a—Textural Classification of Soils

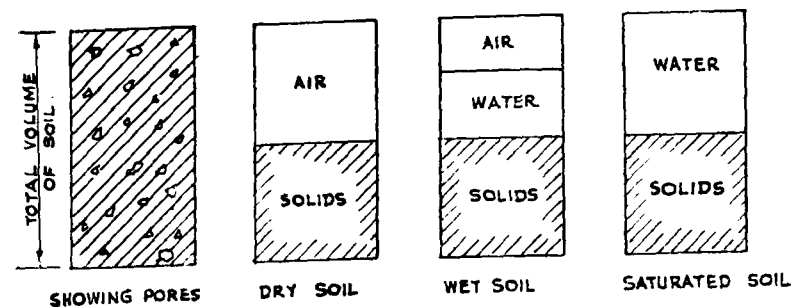


Fig 1. 5-a—Diagram Illustrating Pores and Solids in Soil Mass

Size of Soil Particles

1. 4. The size of soil particles range from less than 0.001 mm. to several mm. The process of separating soil aggregates into fractions, each consisting of grains within a different size range, is known as mechanical analysis. The larger fractions upto No. 200 sieve are separated by sieving, (article 4.2) and those passing the No. 200 sieve by hydrometer analysis. The A.A.S.H.O. standard method of mechanical analysis separates soils into six grain sizes having the following size names.

No.	Name	Passing ASIM Sieve No.	Retained ASIM Sieve No.	Limits of the size of Particles, mm.
1	Gravel	—	10	Over 2.0
2	Sand-coarse	10	40	2.0—0.42
3	Sand-fine	40	200	0.42—0.075
4	Silt	—	—	0.075—0.0075
5	Clay	—	—	Smaller than 0.0075
6	Colloids	—	—	Smaller than 0.001

Figure 1. 4-a shows a triangular chart showing the proportion of sand, silt and clay for different soil types such as sandy loam, loam, silty clay etc. This classification is based on the size of the soil grains and is termed textural classification. After performing the mechanical analysis on any soil sample it may be directly classified into one or other of the soil types with

the aid of this chart. For example if it is known that a sample contains 60% of fine sand and 30% silt and 10% clay, from the chart it is seen that the point representing these values falls within the area "sandy loam" and therefore the soil is a sandy loam.

The results of mechanical analysis, *i.e.*, the grain size distribution is represented on a semi-log chart, Article 4. 3.

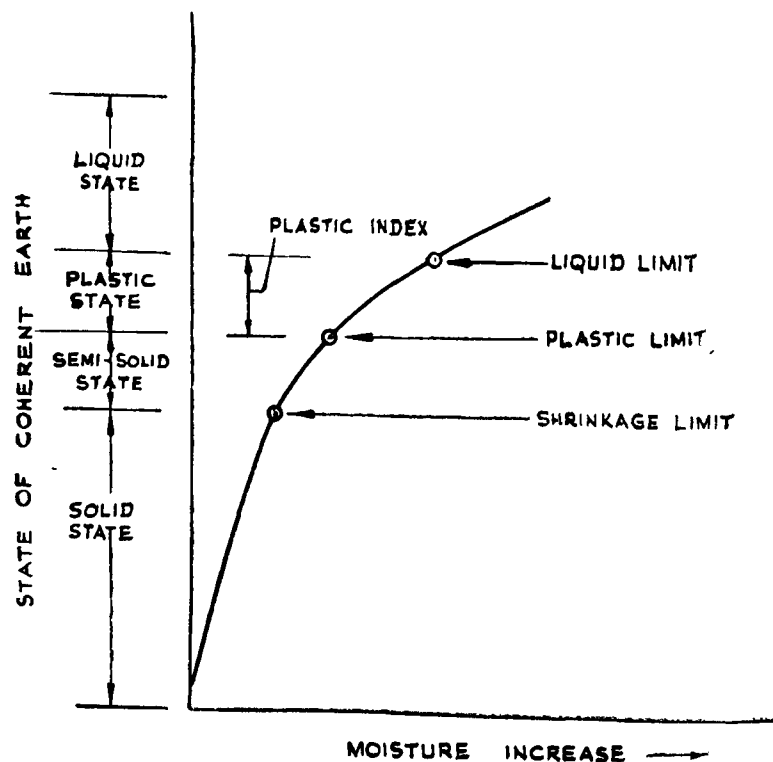


Fig 1.6-a—Limits of Consistency

Porosity, Moisture Content and Bulk Density, Porosity

1. 5. The porosity of a soil is the ratio of the volume of voids to the total volume of the soil. If porosity is expressed as a percentage, it is referred to as the percentage of voids. The ratio of the volume of voids to the volume of the solid substance is called the voids ratio, Figure 1. 5a.

Moisture Content

The moisture content of a soil is the ratio of the weight of water to the dry weight of the solids. It is usually expressed as a percentage.

Bulk Density

The bulk density of the soil is the weight of the soil (solids + water) per unit of volume. It is expressed in pounds per cubic ft. The value depends on the specific gravity of the solid constituents, the porosity of the soil, and its moisture content.

Limits of Consistency

1. 6. If the water content of a clay slurry is gradually reduced, the clay passes from a liquid state through a plastic state, and finally into a solid state, Figure 1. 6-a. The water contents at which different soils pass from one of these states into another are very different. Therefore, the water content at these transitions can be used for identification and comparison of different cohesive soils. These are called the Atterberg limits.

Liquid Limit

Liquid limit is that moisture content at which the soil just begins to flow when slightly jarred. Liquid limits vary from zero in the case of purely sandy soils to 100 or more for highly colloidal clays. Typical values are :

Sandy clays and silts	...	35 to 40
Normal clays	...	40 to 80

If the moisture content exceeds the liquid limit the soil begins to flow like a thick liquid.

Plastic Limit

Plastic limit is the lowest moisture content at which the soil can be rolled into threads one-eighths inch diameter without the thread breaking into pieces. It denotes the water content above which the soil will get plastic. Below this moisture content the soil will be in a semi-solid state. If the plastic limit is not determinable (as in the case of sand), the material is said to be non-plastic.

Plastic Index

Plastic Index of a soil is the numerical difference between the liquid limit and the plastic limit, Figure 1. 6-a. It is the range of moisture content at which the soil is still in a plastic stage. Light friable type soils have a low plasticity index and heavy clays which become greasy and water logged have a high plastic index.

Typical values are :

Highly plastic clay	... More than 40
Medium clay	... 20 to 40
Silty clay, sandy clay	... Less than 20

Shrinkage Limit

Shrinkage Limit of a soil is the moisture content at which a reduction in moisture will not cause a decrease in the volume of the soil mass, but an increase in moisture content will cause a corresponding increase in the volume of the soil mass. The shrinkage limit marks the boundary at which a moist soil changes from a semi-solid state to a solid state.

Compaction

1. 7. See Chapter 2, Soil Compaction.

Bearing Strength

1. 8. The bearing strength of a soil is its ability to support super-imposed load. It is associated with a certain amount of settlement and the allowable bearing pressure is always limited by the permissible settlement. The criterion in the choice of such settlement is that it should not have detrimental effects on the supported structure.

The bearing strength of a soil depends on its shear strength. Shear strength is a function of the internal friction and the cohesion or the bond strength between soil grains. Granular soils like pure sand have very little cohesion but have considerable internal friction. Pure clay on the other hand possesses no internal friction and its shear strength is derived from its

cohesion. The shear strength of a soil, and therefore its bearing strength can be improved by increasing the force with which the soil grains are pressed together, that is by increasing the compaction.

Different methods are used for determining a measure of the bearing strength of soils. Some of these are mentioned in Article 1. 3. In all these methods the soil is loaded by a suitable device and the deformation or settlement is measured. The result is usually expressed as bearing power in psi and is correlated with the settlement. The bearing values of the same soil obtained by the different methods will not agree, but some correlation is established between them. The method adopted in Madras uses the North Dakota cone Penetrometer (Article 4-8).

2. SOIL COMPACTION

Importance of Compacting Soil

2. 1. Soil compaction is important in the construction of embankments and stabilized soil bases and subgrades. In embankments made of well-compacted soil settlement after construction is greatly reduced, if not entirely eliminated, and earthworks built this way have greater stability.

Well-compacted bases and subgrades also possess considerably higher bearing strength than improperly compacted bases and subgrades. This additional strength enables a corresponding reduction of the necessary thickness of pavement.

Other objects aimed at in soil compaction are to decrease water absorption and obtain a material less subject to weathering.

Measurement of Soil Compaction.

2. 2. Compaction is measured by the amount of solid matter per cft. of material. This is also termed the dry density of the soil, and is expressed by the weight of soil solids per cft. It is determined from the bulk density of the soil after deducting the weight of moisture present, Article 4. 6.

Principles of Soil Compaction

2. 3. The factors influencing soil compaction are :

(i) The moisture density relations :

- (a) Moisture content.
- (b) Amount of compaction.

(ii) The type of soil.

(iii) Compaction under field conditions.

These aspects are briefly discussed in the following paragraphs.

MOISTURE DENSITY RELATIONS

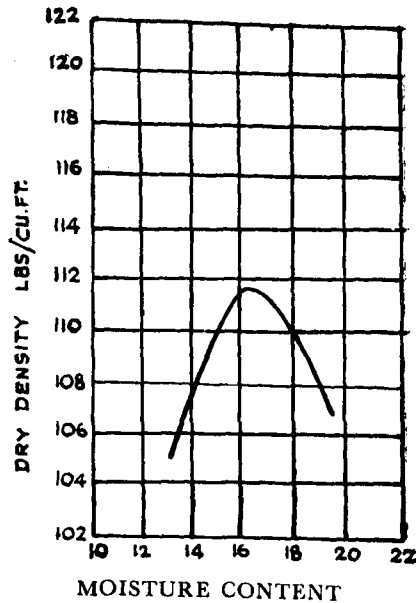


Fig 2. 4-a Constant Compactive Effort

Moisture Density Relation

2. 4. The moisture-density relation of a soil is usually determined by the Proctor Compaction Test, Article. 4. 6. The test was originally developed for moisture and density control in the compaction of earth embankments. Now its use has been extended to compaction of soil mixtures for stabilised soil bases and subgrades.

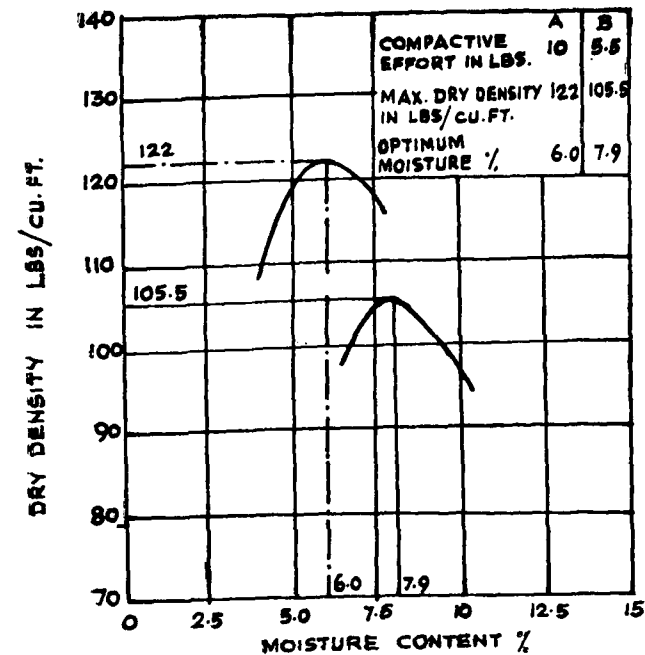


Fig 2. 4-b Two Different Compactive Forces

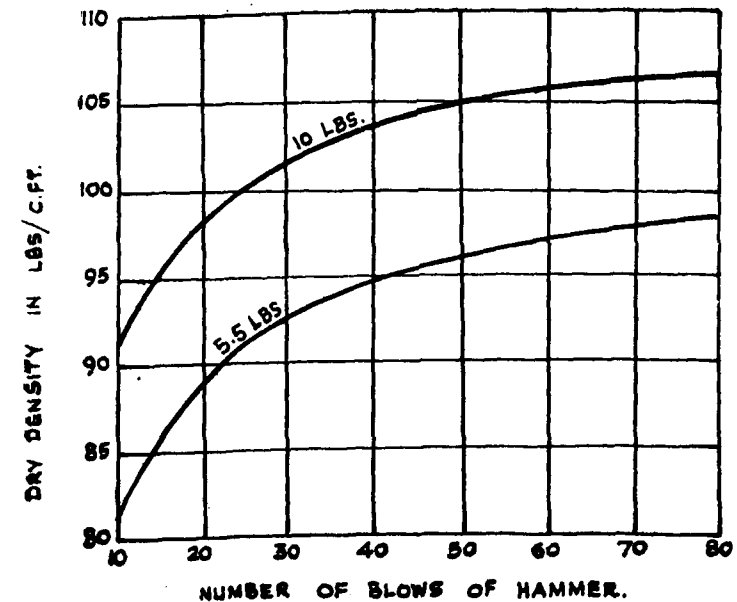


Fig 2. 4-c Constant Moisture Content but Increasing Compaction Effort

The bearing capacity of most soils increases with density and decreases with the moisture content. In a theoretical sense, for a high bearing capacity the soil should be dry and dense. Density increases with the amount of compaction, but a certain amount of moisture is necessary to obtain satisfactory compaction with any compacting equipment, and the presence of this moisture detracts from the bearing capacity. Therefore moisture should be limited to the minimum that is considered necessary from practical consideration.

For each kind of soil there is a maximum density which can be obtained with a certain compactive effort, and there is a particular moisture content corresponding thereto. When a soil is compacted with different amounts of moisture using the same compactive effort, the density increases with moisture upto a certain limit and thereafter decreases, Figure 2. 4-a. The percentage of moisture in a soil, based on its dry weight, at which the greatest density is obtained under a particular compactive effort is known as the *optimum moisture content*.

The maximum density is related to the compactive force, the greater the compactive effort the higher the maximum density which can be attained and the lower will be the corresponding optimum moisture content, Figure 2. 4-b. For this reason, the maximum density obtainable with a certain compactive effort at a certain moisture content can be attained with a larger force at a lower moisture content, and at constant moisture content a higher density can be obtained with a greater compactive effort, Figure 2. 4-c.

The Type of Soil

2. 5. For any method of compaction the maximum density and optimum moisture content vary with the type of soil and the Atterberg limits are useful guides as to the type of soil, Article 1-6. The optimum moisture content for standard compaction is roughly 2 to 5 percent less than the plastic limit of the soil. The plastic limit is therefore a useful rough guide as to the best consistence of the soil for compaction. Table 2. 5-a gives an approximate classification of quality of soils for compaction based on soil characteristics.

Table 2. 5-a Relation between maximum dry density and index properties of cohesive soils.

Quality of soil for compaction	Range of maximum dry density pcf.	Liquid limit	Plastic limit
Very Poor	70--100	65	22
Poor	100--110	50--65	19--22
Fair	110--120	32--50	16--19
Good	120--130	24--32	14--16
Excellent	130	24	14

Heavy clays have densities from 90 to 105 pcf. while silty clays run up to 105 to 115 pcf. Higher densities are obtained only with sand or gravelly soils in which there is little cohesion to resist compaction.

Well graded soils containing gravel, silt and clay in ideal proportion have a high maximum density and a low optimum moisture content.

The admixture of stone upto about 50 per cent has very little effect on the moisture density relationship of the soil mortar, the aggregate acting merely as a displacer.

Compaction Under Field Conditions

2. 6. In performing the standard compaction test under laboratory conditions all factors entering into it can be precisely controlled, but ordinarily this is not possible under actual construction conditions in the field. Further, the relationship between pressure resulting from the impact of the falling hammer of the compaction test and that developed by the weight of a roller moving horizontally is somewhat uncertain. Nevertheless experience shows that satisfactory performance can be expected if the soil is compacted to conform to the requirements of the Proctor Test. The *Relative Compaction* is a measure of the effectiveness of rolling and is defined as the percentage of the dry density

of the soil *in situ* to the maximum dry density as found in the Proctor Test. The following relative compactions may be considered reasonable.

Table 2. 6-a. Showing relation between maximum dry density and relative compaction.

Max. Dry Density, PCF.	Min. Relative compaction required per cent of Max. Dry Density.
90—100	100
100—110	95
110—120	95
120—130	90
130 and above	90

Compaction Equipment

The three chief methods used to compact soil in the field are (i) pressure, (ii) impact, (iii) Vibration, the object in all cases being to bring about closer packing of the soil particles and hence higher density. The usual types of field compaction equipment include:—

(i) Rollers.

- Smooth wheeled rollers.
- Pneumatic tyred rollers.
- Lorries and Pneumatic tyred equipment.
- Sheepsfoot rollers.

(ii) Rammers.

- Dropping weight type (manual).
- Internal combustion type.
- Pneumatic type.

(iii) Vibrators.

Smooth wheeled rollers and Pneumatic tyred rollers and equipment are effective on soils which contain a certain amount of clay so as to make them fairly cohesive. Soils that are well

suited for stabilization generally come under this class. Such rollers are not effective on sandy soils.

For cohesive soils such as clay and silty clay sheepsfoot rollers give the best results.

Ramming whether mechanical or manual is effective for both cohesive and non-cohesive soils. Mechanical rammers are very costly and not in common use.

Vibration is very effective on non-cohesive but not on cohesive soils. This is almost the only mechanical method suitable for compacting loose sand. An effective method for sand is to saturate it fully. This results in its consolidation and the excess water drains away.

Field Control of Compaction

In the field the aim is to attain the relative compaction given in Table 2.6a. The various steps in control are mentioned below.

(i) Determine the moisture content of the soil before compaction. The sample taken for this purpose should be as representative as possible.

(ii) If the moisture content is much in excess of the optimum for the soil, it is better that the soil is allowed to dryout sufficiently.

(iii) If the moisture content is less than the optimum, apply water uniformly to bring up the moisture content to very near optimum, and compact by means of suitable equipment that is available.

(iv) At intervals during compaction determine bulk density of the soil under process of compaction by means of the sand-bottle apparatus, Chapter 4.

(v) Determine the dry soil density and moisture content corresponding to the above bulk density.

(vi) Continue compaction and testing as above till the dry soil density is equal to the specified relative compaction.

A simplified procedure using the cone penetrometer is given in Article 3. 5.

Records to be kept

It will be useful to keep a record of the number of passes of the compaction equipment required to attain the relative compaction. When soil conditions are comparable, the same number of passes of the same or similar equipment will secure approximately the same compaction. A suitable form is given below :

Form 2. 6-a Compaction Record

Name of work :
Reach compacted :
Date of compaction :
Sub-grade soil :
Weather conditions :

Grading :

Retained on No. 10

No. 10 to No. 200

Passing No. 200

Maximum density, pcf.

Optimum moisture content

Relative compaction specified

Relative compaction attained

No. of passes of equipment :

Smooth wheeled roller

Pneumatic tyred rollers

Lorries etc.

Sheepsfoot Roller

Details of compacting equipment :

3. SOIL STABILIZATION

3. 1. GRANULAR SOIL STABILIZATION

Principles

3. 1. 1. Granular soil stabilization or mechanical stabilization involves the use of natural soils and soil mixtures only. The aim of granular soil stabilization is to increase the shear strength and thereby its bearing strength by proper grading of the soil and adequate compaction, Article 1. 8.

The object of proper grading is to ensure that the soil contains sufficient amount of granular material to impart internal friction and cohesive soil to impart the necessary bond between the particles. A well graded soil contains different sizes of particles from the largest size down to materials passing the No. 200 sieve. From the analogy of concrete, a well graded soil may be viewed as one in which the voids of gravel are filled by sand, the voids of the sand with silt, and the voids of the silt with clay. When such a soil is compacted the resulting soil mass will have a very high density because of the close packing and interlocking of particles, and a high density generally indicates good bearing power, Article 2. 1.

There are several formulae for the grading curves of soils to produce the maximum density. Because we have to use the natural soils that are available at a reasonable cost a rigorous adherence to these theoretical curves is impracticable, and a certain amount of working margin is necessary. Figures 3. 1. 1-a and 3.1.1-b. show the limiting curves for well graded soils. Figure 3. 1. 1-a applies to gravel sand mixes and Figure 3. 1. 1-b. to sand clay mixes.

The Atterberg limits, Article 1-6, are indicative of the type of a soil, and the suitability of a soil for compaction depends upon the type of soil. Therefore the index properties are a useful rough guide as to the suitability of a soil for compaction, Article 2. 5. Since compaction is an important factor in mechanical soil stabilization, among the criteria which determine the suitability of a soil mixture for soil stabilization are its Atterberg limits.

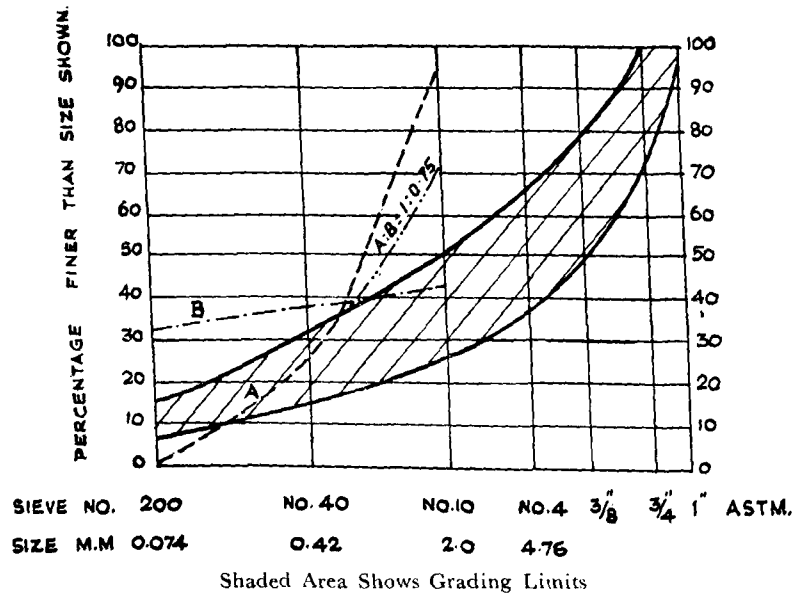


Figure 3. 1. 1-a. Limits of grading for gravel-sand mixes for Base Course

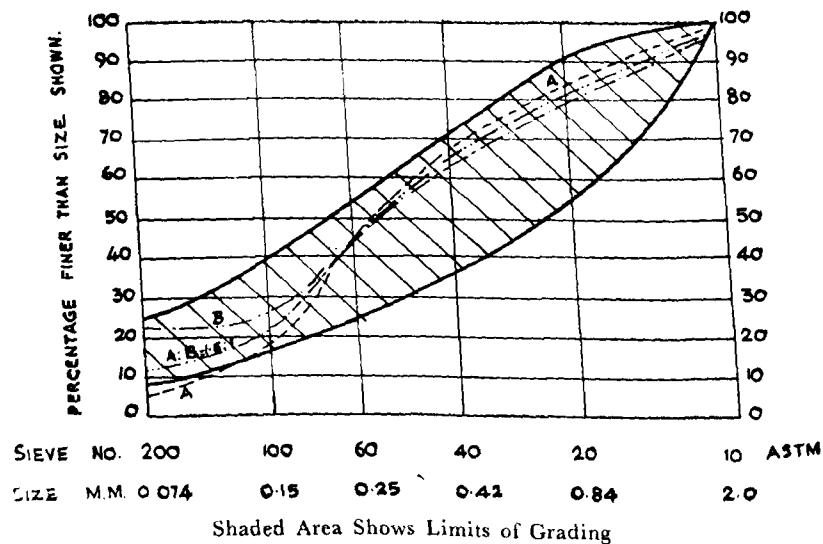


Figure 3. 1. 1-b. Limits of grading for sand-clay mixes for Base Course

This aspect is provided for by fixing suitable limits for the plastic index of the soil. The desirable limits of plasticity index for base courses are 3 to 6.

No single soil may satisfy the requirements of grading and plastic index, but these properties can be improved by suitable admixtures with other soils. The technique of soil stabilization consists in designing such soil mixes, testing them for their bearing power and compacting to desirable relative compaction with suitable equipment at optimum moisture content, Article 2. 6. The procedure is explained with illustrations in the succeeding Articles.

Design of Stabilized Soil Mixtures

The problem in the design of stabilized soil mixtures is to produce from given soils the densest possible soil mixture having its plasticity index within the desirable limits. As a few routine tests are involved the problem is usually tackled in a soil laboratory. The various steps in the design are :

- (i) Determine the grading, liquid limit, plastic limit, plasticity index and bearing power of the soil samples by performing the respective tests, chapter 4.
- (ii) Choose the desirable grading with reference to the curves, Figure 3. 1. 1-a or 3. 1. 1-b whichever is applicable.
- (iii) With the help of the triangular chart, Figure, 3.1.2 determine the approximate proportions of the soils which will yield the desired grading.
- (iv) Calculate the plastic index of the proposed mix by formula.

$$P_m = \frac{P_a \cdot S_a \cdot D_a + P_b \cdot S_b \cdot D_b}{S_a \cdot D_a + S_b \cdot D_b}$$

in which P = Plastic index, S = percentage of each soil passing the No. 40 sieve, D = Proportion of each soil in the mix, and the suffixes a, b and m refer to the soil samples A, B, and the mixture respectively.

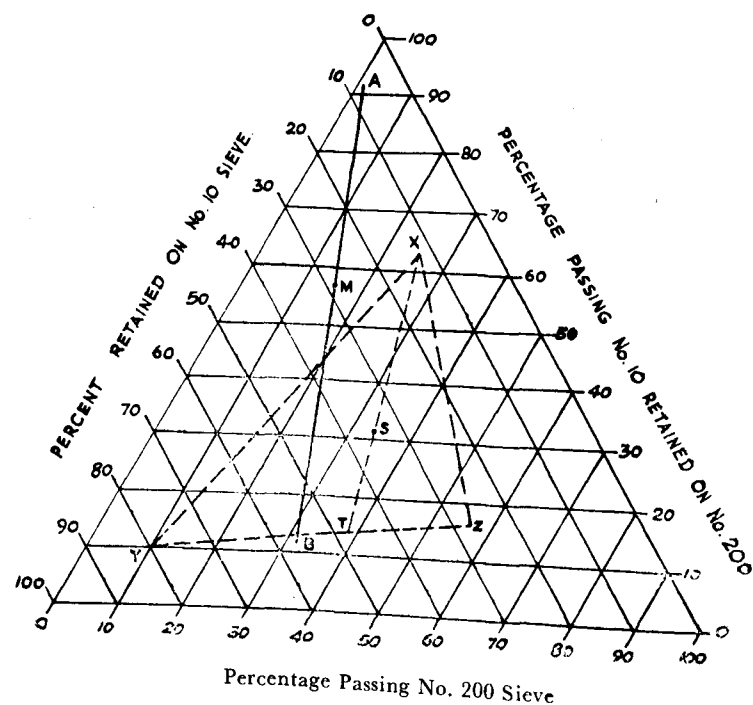


Figure 3. 1. 2-a. Triangular Chart for proportioning of Stabilized Soil Mixtures

Note

1. For mixing two soils, see Article 3. 1. 4.
2. For mixing three soils X, Y, Z, to produce a mixture S: Mark points X, Y, Z, representing the grading of the three soils. Mark point S to represent the desired grading of mixture S. If the point S falls within the triangle XYZ, it will be theoretically possible to produce the desired mixture. Then join X (Y, or Z) with S and produce the line to cut the opposite side in T. Point T represents the mixture of Y and Z that may be combined with X to produce mixture S. The proportion of X, Y & Z in S may be calculated from:

In mixture T:— Y : Z = TZ : YT

In mixture S:— T : X = SX : TS

(If the trial mix is not determined by ii and iii, determine the same from consideration of plastic index).

(v) Calculate the grading or particle size distribution of the proposed mix by formula.

$$G_m = \frac{A.G_a + B.G_b}{A + B}$$

in which G = percentage passing a given sieve,

A = proportion of soil A in mix,

B = proportion of soil B in mix,

and the suffixes a, b, and m, refer to the soils A, B, and the mix respectively.

(vi) Mix the soil in the given proportion and determine the grading and plasticity of the mixture as a check on the calculations.

(vii) Perform the Proctor Compaction Test on the trial mix and determine its maximum density and optimum moisture content, Article 4.6.

(viii) Perform the bearing test on a slab 3' × 3' prepared with the above soil mixture and determine its bearing value by the cone penetrometer, Article 4.8.

(ix) Subject the slab to three-day soaking and again determine the bearing value. This test is expected to provide for the worst conditions of saturation under field conditions.

(x) Repeat tests vi to ix on two more trial mixtures with slightly varying proportions of the constituent soils.

(xi) Select the mix which gives the best bearing value after the three-day soaking test.

Ordinarily the first trial mix itself will give the most satisfactory results. Generally the maximum density will correspond with the maximum bearing value. In case of disagreement, adopt the mix which gives the best bearing value.

If facilities for bearing tests are absent, the mix that gives the highest density and desirable value of plastic index may be adopted.

Design of Thickness

3. 1. 3. The required thickness of the base or sub-base may be determined reference to Chapter VI, Design of Pavement thickness.

3. 1. 4. The method of design of stabilized soil mixtures is illustrated in the following examples.

Example 1. A stabilized soil base course is to be provided for Dammenu Lankalakoderu Road miles 4/0 to 7/1 in a typical black cotton area in West Godavari District. Investigation shows that good muram (A) and sand (B) are available within easy reach. Design the stabilized soil mix.

This is an example of a gravel-sand mix.

Design of Mix

Step i. The mechanical analysis and the plasticity index as determined in the laboratory are shown in Table 3.1.4-a.

Step ii. Plotting the grading curves of soils A and B in Figure 3.1.1-a it is seen that neither of the soils is really suitable for stabilized soil work, because soil A contains too little of material passing No. 200 sieve and soil B contains too much of it. Also soil A contains a very high percentage of material passing the No. 10 sieve. From these consideration it is evident that it will not be possible to produce a mixture lying fully within the grading limits with the soils A and B. Therefore all that is possible here is to suggest the best possible use of these soils. The best proportions are worked out in the next step.

Step iii. For determining the proportion by means of the triangular chart the control sizes are sieve Nos. 10 and 200. The percentages of soils A and B passing these sieves are :

TABLE 3. 1. 4-a. DATA PERTAINING TO EXAMPLE 1

DAMMENU LANKALAKODERU ROAD		PROPERTIES OF SOILS AND DESIGN DATA				
A—Sand from Vadapalli Quarry		B—Muram from Badampudi Quarry				
SOIL PROPERTIES		A	B	Trial Mixtures		
		A	B	A + $\frac{1}{3}$ B	A + $\frac{2}{3}$ B	A + B
Plastic Index	...	—	9.0	3.8	4.7	5.4
Grading : Percent passing No. 10	...	93	43	76	71	68
" " " 40	...	25	37	29	30	31
" " " 60	...	8	35	17	20	22
" " " 100	...	3	33	13	16	18
" " " 200	...	2	32	13	15	17
Maximum Dry Density Pcf	...	104	120	122	134	134
Optimum Moisture Content Per cent	...	6	—	8.5	7.8	8.0
Bearing power Soon after Compaction psi	...	—	317	440	700	600
Bearing power After 3-days soaking psi	...	—	180	290	440	360
Moisture content After 3-days soaking Per cent...	...	—	12.3	11.2	9.5	10.2
REMARKS. Design Mix Adopted	...	—	—	—	A + $\frac{2}{3}$ B	—

	SAMPLE A	SAMPLE B
Percent passing No. 10 ...	93	43
Percent passing No. 200 ...	2	32

To facilitate use of the chart these values may be written down as follows :

	SAMPLE A	SAMPLE B
Percent retained on No. 10 sieve.	7	57
Percent passing No. 10 and retained on No. 200 sieve ...	91	11
Percent passing No. 200 sieve...	2	32

On the triangular chart, Figure 3.2-a mark points A and B to represent the percentages shown above and join them by a straight line.

Points along AB represent mixtures of soils A and B. As the mix should not contain more than 15 percent passing No. 200 sieve Figure 3.1.1-a mark point M on AB such that M has 15 percent passing No. 200. The point representing the desirable mix must now line between M and A. As we approach A, the percent passing No. 10 sieve increases rapidly and even point M represents nearly 70 percent ($55 + 15$) passing No. 10 sieve. All considered, point M represents the best possible mix in this case. The proportion of A and B is given by the ratio of lengths BM : AM. By scaling off these lengths, $A : B = 1 : \frac{3}{4}$.

Step iv. Plastic index by calculation.

$$P_m = \frac{P_a \cdot S_a \cdot D_a + P_b \cdot S_b \cdot D_b}{S_a \cdot D_a + S_b \cdot D_b}$$

$$= \frac{0 + 9 \times 37 \times .75}{25 \times 1 + 37 \times .75} = 4.7$$

This value is within the permissible range of 3 to 6.

Step v. The calculated grading of the mixture $A : B = 1 : \frac{3}{4}$ is shown in Table 3.1.4-a.

Step vi. Omitted.

Steps vii, viii and ix. The result of the different tests are given Table 3.1.4-a.

Step x. The tests under vi to ix are repeated for two different mixes $A : B = 1 : \frac{1}{2}$ and $A : B = 1 : 1$. The results are shown in Table 3.1.4-a.

Step xi. Final choice. It is seen from the tabulated results that the first mix $A : B = 1 : \frac{3}{4}$ is not only the densest, but also has the highest bearing value. So this mix is adopted. It has the following control values.

Proportion	= $A + \frac{3}{4} B$
Max. dry Density	= 134 pcf.
Optimum moisture content	= 7.8 percent.
Bearing power soon after compaction	= 700 psi.
Bearing power after 3-days soaking	= 440 psi.

Example 2. This example concerns the work of forming a road from Ramnad to Mandapam 0/0 to 21/4, NH 49. The soil for the embankment in a particular stretch is sand (A). It is proposed to stabilize the top layer of sand to a certain depth with clayey sand (B) which occurs 3 to 6 feet below ground level, so that the subgrade may have adequate stability. Design the soil mixture.

This is an example of a sand-clay Mix.

Step i. The grading and plastic index of A and B as determined in the laboratory are shown in Table 3.1.4-b.

Step ii. Even from a cursory examination of the grading curve, Fig. 3.1-b of soils A and B it is seen that they are almost similar, except for the much larger amount of material passing No. 200 sieve in soil B, and that by mixing them in any proportions the grading is not going to be materially altered for better or worse. The significant fact in this is the very large plastic index of soil B. By mixing soil B with soil A-a mixture can be produced which has a more desirable plastic index and which can be compacted better. Therefore a fairly clear indication of the desirable proportions of A and B may be had from considerations of plastic index. This is done in Step iv.

Step iii. Omitted.

TABLE 3. 1. 4-b. DATA PERTAINING TO EXAMPLE 2

RAMNAD MANDAPAM ROAD		PROPERTIES OF SOIL AND DESIGN DATA			
A—Sand from Subgrade at 1/6		B—Sandy Clay at 4 ft. Depth from Fields at 1/6			
SOIL PROPERTIES		Trial Mixtures			
		A	B	A + B	1½A + B
Plastic Index	...	0	16.8	8.0	5.1
Grading : Passing No. 10	...	99	99	99	99
Grading : Passing No. 40	...	67	63	66	67
Grading : Passing No. 60	...	45	43	44	44
Grading : Passing No. 100	...	17	26	22	20
Grading : Passing No. 200	...	6	22	14	11
Maximum Dry Density pcf.	...	—	110	117	117
Optimum Moisture Content percent	...	—	15.0	11.5	11.4
Bearing power soon After Compaction psi	...	—	1000	440	360
Bearing Power After 3-days Soaking psi	...	—	150	216	320
Moisture content After 3-days soaking	...	—	—	—	—
REMARKS. Design Mix Adopted	...	—	—	—	1½A + B

Step iv. Plastic index and proportions of the mixture by calculation :

$$P_m = \frac{P_a \cdot S_a \cdot D_a + P_b \cdot S_b \cdot D_b}{S_a \cdot D_a + S_b \cdot D_b}$$

$$= \frac{0 + 17 \times 63 \times D_b}{67 \times D_a + 63 \times D_b}$$

Two or three trial values of D_a and D_b are substituted in this equation and the P_m calculated. If $A : B = 3 : 2$, $P_m = 6.4$. As this is very close to the desirable value, the trial mixture may have a proportion $A : B = 1\frac{1}{2} : 1$.

Step v. The calculated grading of the mixture $A : B = 1\frac{1}{2} : 1$ is shown in Table 3.1.4-b.

Step vi. Omitted.

Steps vii, viii, and ix. The result of the different tests required under these steps are given in Table 3.1.4-b.

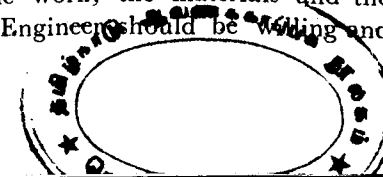
Step x. The tests under vi to ix are repeated for two different trial Mixes $A : B = 1 : 1$ and $A : B = 2 : 1$. The results are shown in Table 3.1.4-b.

Step xi. Final choice. It is seen from the tabulated results that the first trial mix $A : B = 1\frac{1}{2} : 1$ is generally the most suitable and this is adopted. It has the following control values :

Proportion	= $1\frac{1}{2} A + B$.
Maximum dry density	= 117 pcf.
Optimum moisture content	= 11.4 percent
Bearing power soon after compaction	= 360 psi.
Bearing power after 3-days soaking	= 320 psi.

Construction Methods

3. 1. 5. The method of construction of stabilized soil bases and subgrades is briefly described below, as far as possible in accordance with the sequence of operations. The details will depend upon the nature of the work, the materials and the available equipment, and the Engineer should be well and



able to modify details and improvise methods to suit the actual conditions. Stabilized soil work may be done with manual labour or with the aid of costly equipment or by economical combinations of both. At present there is a dearth of mechanical equipment specially designed for stabsoil work, and therefore for some time to come Engineers must try to carryout stabilized soil work with manual labour assisted by available equipment such as rollers.

Collection of Materials

i. As far as possible local materials are used short of making unsightly pits on the roadside. Stabilized soil methods have very little chance of making headway unless they are established as a more economical substitute for other types of road foundation such as stone soling. Therefore collection of suitable soils from long distances paying considerable sums on freight is not advisable.

In collecting soils, due allowance is made for the bulking when in a loose condition. Taking Example 1 for illustration, the following calculations will apply for one furlong, 4 inches $\times$ 18 ft. wide base.

$$\begin{aligned}\text{Total weight of mixed soil} &= 660 \times 18 \times \frac{1}{4} \times 134 \\ &= 5,18,600 \text{ lbs.} \\ \text{Weight of sand} &= 518600 \times \frac{4}{7} \\ &= 2,96,300 \text{ lbs.} \\ \text{Weight of Gravel} &= 518600 \times \frac{3}{7} \\ &= 2,22,300 \text{ lbs.}\end{aligned}$$

Uncompacted sand weighs 86 pcf.

Uncompacted muram weighs 96 pcf.

$$\begin{aligned}\text{Quantity of sand to be collected} &= \frac{296300}{86} = 3445 \text{ cft.}\end{aligned}$$

$$\begin{aligned}\text{Quantity of muram to be collected} &= \frac{222300}{96} = 2316 \text{ cft.}\end{aligned}$$

Breaking Clods

ii. In order to facilitate thorough mixing of the soils the clods are thoroughly broken and pulverized. The presence of even small clods of clay in the soil mixture tends to defeat the purpose of stabilization. In soils generally used for stabilization clods can be broken by means of heavy wooden hammers or rammers, if better means are not available.

Collection of Materials

Where a binder, soil of clay is to be used the clay in the quarry is dug or ploughed into chunks. If the clay is wet and is not easily susceptible to pulverization it is allowed to dry in the sun until the moisture content gets suitably reduced. The chunks are then pulverized by manual labour or by passing a 6 to 8 Ton roller on the clay bed. The pulverized material is screened through a No. 8 sieve and the powder is collected and conveyed to the road side.

Forming Continuous Stacks or Windrows

iii. Forming of the soils into continuous stacks is a prelude to mixing and its purpose is to facilitate thorough mixing and spreading to uniform depth. The soils are stacked in two rows one on either side of the centre line, each row containing the soils in requisite proportions. Referring again to Example 1 and the calculations in para (i) for illustration, total quantity of soils per furlong

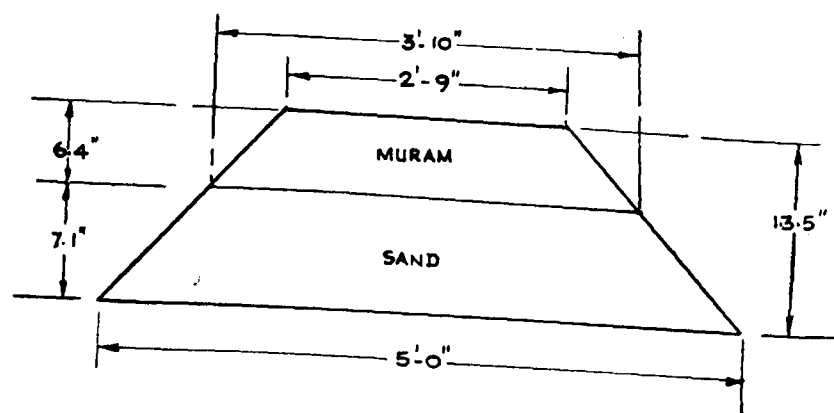
$$\begin{aligned}&= 3445 + 2316 \\ &= 5761 \text{ cft.}\end{aligned}$$

If the soils are formed in two windrows, the quantity per windrow

$$= \frac{5761}{2} = 2880 \text{ cft.}$$

$$\text{Cross section of each windrow} = \frac{2880}{660} = 4.36 \text{ sft.}$$

The dimensions of each windrow for a cross sectional area of 4.36 sft. is shown in the sketch below :



The cross sectional area for sand = $\frac{3445}{2 \times 660} = 2.61$ sft.

The cross sectional area for muram = $\frac{2316}{2 \times 660} = 1.75$ sft.

If sand is kept at the bottom, it will occupy a depth of 7.1 inches and muram will occupy a depth of 6.4 inches. These details are also shown in the above sketch.

Dry Mixing

iv. This may be done by working the stacks by such simple tools as mummities. After thoroughly mixing, the mixture is restacked into windrows and shaped into a convenient number of equal bays for adding water.

Adding Water

v. Before adding water, the moisture content is determined, and the further amount to be added for optimum moisture content calculated on representative samples from the stacks. Referring to Example 1 by way of illustration.

Optimum moisture content = 7.8 per cent by weight. Suppose on a particular day the moisture content is found to be 1.0 per cent, water is to be added to the extent of 6.8 per cent. If the bays are 10 ft. long.

Weight of soil per bay = $\frac{5,18,600}{2 \times 66} = 3929$ lbs

Weight of moisture = 39 lbs.

Dry weight of soil = 3890 lbs.

Weight of water to be added = $3890 \times \frac{6.8}{100} = 265$ lbs.

Volume of water to be added per bay = 26.5 gallons or 4.24 cft.

The required quantity of water is uniformly applied over each bay. The water may be added in the evening preceding the wet mixing and spreading and allowed to soak into the soil overnight so that evaporation losses may be minimized.

Wet Mixing and Spreading

vi. The wet soil is thoroughly mixed and spread in a uniform layer not more than 6 inches over the subgrade which is previously sectioned and prepared to receive the soil mixture. After spreading the surface is shaped to camber by means of a suitable camber board. The camber to be provided is the same as the camber specified for the surface course. The profile is checked by means of boaring rods and all irregularities corrected by addition or removal of material as necessary.

Compaction

vii. As soon as the surface is prepared as above the soil should be compacted. The type of roller or other compacting equipment that is suitable depends upon the nature of the soil, Article 2.6. Rolling should commence at the edges and work toward the centre in successive overlapping trips. The surface is checked frequently and uneven spots corrected promptly.

Compaction Control

At intervals during compaction the bearing value is frequently checked by means of the Cone Penetrometer when the bearing power reaches the control value or thereabout the bulk density of the soil is determined by means of the sand bottle apparatus chapter 4, and also its dry density and moisture content. The density determination should be sufficiently representative and is

generally made at about four places in a furlong. The values obtained should satisfy the relative compaction requirements, Table 2. 6-a.

As a further check the bearing power at typical points after three-day soaking is determined, and this should be within 10 percent of the control value.

In the absence of facilities for determination of bearing power the compaction may be controlled by density measurements alone, Article 2. 6, but this is a somewhat more tedious process.

Curing

viii. The surface is allowed to dry out for 2 or 3 days or even more if the weather conditions are unfavourable, during which iron-tired traffic is to be excluded.

Laying Surface Course

ix. After the period of curing the specified surface course is laid in conformity with the methods applicable to the same.

Alternative Methods

3. 1. 6 A condition that is frequently met with necessitates the mixing of a borrow material with the existing subgrade soil in order to improve its properties. Except in matters of detail there is no essential difference between this and the preceding method.

The surface is shaped to proper camber and profile by cutting high places and filling low ones and the width to be stabilized is marked off. The unit weight of the subgrade soil is determined and the depth to which it should be dug up to give the requisite quantity for the mix calculated. The surface is then dug up to the calculated depth, the clods broken up and pulverized. The clods in the borrow material are also broken up and pulverized and the soils are formed into windrows, Para 3. 1. 5 (iii), for mixing etc. or the subgrade soil may be levelled after breaking of clods and the borrow material spread over it and the two thoroughly mixed *in situ*. This is followed by watering and other operations, Article 3. 1. 5.

3. 2. Soil-Cement Stabilization

In the introduction to this article reference was made to methods of soil stabilization involving the use of special stabilizing agents. This section deals with such a method in which cement is the stabilizing agent used. This type of construction is generally employed in the formation of base courses, usually with thicknesses varying from 4 to 6 inches. It may serve as a base for a thin wearing surface which will be subjected to light or medium traffic, or as a support for a high-type flexible or rigid pavement. It may also be used in the construction of shoulders, parking areas etc.

Description of Soil-Cement

3. 2. 1. Soil-cement is a thorough mixture of soil and Portland cement compacted while in a moist condition and before the cement has hydrated to form a stable paving on hydration and hardening of cement. For reasons of economy and for facility in construction the soil most commonly used is that which occurs in the surface of the road. The percentage of cement required to produce a satisfactory soil-cement mixture varies with the characteristics of the soil used. In general, the finer the texture of the soil, the more the cement required to harden it to a satisfactory degree, but certain fine colloidal clays and peaty soils are unsuitable for soil-cement construction.

PRINCIPLES OF SOIL-CEMENT

The Function of Soil

3. 2. 2. Material passing the No. 4 sieve, when mixed with cement, provides most of the strength and durability of the compacted mixture. It is found that not more than 45 per cent of the soil should be retained on a No. 4 sieve, unless the soil is uniformly graded from coarse to fine, in which case as much as 50 to 55 per cent of the material may be retained on a No. 4 sieve.

As the presence of large pieces tends to reduce compacting pressures and resulting densities by increasing the effective size of tamping foot of the sheepfoot rollers and by causing smooth rollers to bridge over adjacent areas, it is necessary that the maximum size should not exceed 3 inches

An important factor in determining the suitability of a given soil for soil-cement construction is the ease with which the soil may be pulverized. Soils which contain large amounts of clay will be more difficult to pulverize, will require more cement, and will demand more careful control during construction.

Unlike granular soil stabilization, the gradation requirements of soil-cement are very broad, and permit the use of an extremely wide range of soil. The sub-grade soil naturally existing in the road bed will usually be suitable for stabilization. However, in many cases, especially where the existing soil contains large amounts of silt or clay, economies may be effected by the use of carted soil to improve the gradation and reduce the plasticity of the soil which is to be stabilized. A procedure of the sort might well result in a reduction in the cement content required for stabilization. The relative economy of using carted soil in order to improve the characteristics of the soil to be stabilized, as compared with the use of more cement, can only be determined by laboratory study supplemented by knowledge of local materials and cost factors.

Function of Cement

In granular soil stabilization the clay content of the soil provides all the binding but in soil-cement this function is performed much more efficiently by the cement. This is the reason why gradation of the soil is not so important in the case of soil-cement. The cementing, hydration and hardening action of Portland cement in soil-cement is similar to the same action in concrete. Water is needed for this action. There is an initial and final setting time for cement, and recognition must be given to these factors in the process of construction.

Function of Water

The water in a soil-cement mixture performs the two functions of lubricating the mass to facilitate compaction and of hydrating the cement. The optimum moisture content determined in accordance with Article 4.9 provides the quantity of water required for these two functions. Any considerable excess over this quantity will hinder compaction and is unnecessary for the

hydration of cement. As in the case of concrete, the surface of the compacted soil-cement mixture should be protected to prevent the excessive evaporation of water during the first few days so as to facilitate the hydration of the cement.

Function of Compaction

The soil and cement grains are brought into close contact by compaction. The greater the compaction, the more efficiently will the cement hold the mass together. Without adequate compaction cement will not be able to perform its function as a binder satisfactorily.

Design of Soil-Cement Mixtures

3. 2. 3. The requirements of soils and soil-cement mixtures are set forth in table 5.3-a. The problem in the design of soil-cement mixtures is to produce a suitable admixture of the soil and cement that satisfies the mixture properties set forth in Table 3.2.3-a, and also to determine the three factors which determine and control the quality of soil-cement, *viz*

1. Proper cement content uniformly mixed throughout the soil.
2. Proper moisture content uniformly mixed throughout the mixture.
3. Proper density uniformly attained throughout the mixture.

After having performed a soil survey of the road, Article 4.1 and having obtained samples and prepared a soil map of the road, the step by step procedure in design is described below.

(1) Determine the grading, liquid limit, plastic limit and plastic index of the sample (section 4). If the results satisfy the requirements of table 3. 2. 3-a, the soil may be considered as suitable for soil-cement work and further tests taken up as indicated below.

(2) Determine the moisture-density relations of raw soil, article 4.6.

(3) With the information obtained from (2) as background, cement contents to be used in the preparation of trial mixtures may then be established. For example, it may be decided that mixes may be prepared using 8, 10 and 12 per cent of cement. Since the influence of cement in the mixture depends on the water cement ratio, the strength increasing as the ratio decreases, a low optimum moisture content indicates a low cement content as well, but to produce like results with a soil having a high optimum moisture content a larger quantity of cement will be required.

In general, most soils will have a satisfactory hardness and durability with cement contents ranging from 8 to 12 percent. Corresponding optimum moistures may vary from 9 to 25 percent and densities vary from about 90 to 135 pcf. The lower cement and moisture contents occur with the higher densities.

(4) Moisture-density relationships for soil cement mixtures containing the selected amounts of cement are then determined, using the procedure set forth in Article 4. 9, which is practically the same as that employed in standard compaction test, article 4. 6. From these relationships the density and optimum moisture content of each of the different soil-cement mixtures are determined.

(5) Next the percentage of cement required for satisfactory stabilization is determined after performing one or other of the two series of durability tests, *i.e.*, wet-dry or freeze-thaw test, and finding the leanest mix that satisfies the requirements of the test. The durability specimens for each of the selected cement contents are prepared by compaction at optimum moisture content, the necessary information being furnished by (4). The test procedure is described in article 4. 10.

(6) Although the cement requirements are principally established on the basis of the results of the durability tests, the selected mix should be tested for compressive strength. If the mix does not exhibit the specified minimum compressive strength (table 3. 2. 3-a), a richer mix which satisfies all the durability test and compressive strength requirements should be selected.

TABLE 3. 2. 3-a
REQUIREMENTS OF SOILS FOR SOIL-CEMENT STABILIZATION

TYPE OF SOIL	Sandy	Silty	Clayey
Properties of Soil:			
Gradation : Passing 3-in sieve	100	100	100
Retained on No. 4 sieve	0-45*	0-45*	0-45*
Liquid limit	Less than 50		
Plasticity index	Less than 25		
Properties of Mixture:			
Normal cement content (Dry weight basis)	6 to 10%	8 to 12%	10 to 14%
Minimum compressive strength	250 lbs per sq. in at 7 days		
Durability test:			
Permissible loss during 12 cycles of either wet-dry or freeze-thaw test	14%	10%	7%
Permissible volume change	2%	2%	2%
Maximum moisture content	Optimum moisture content		

* Note:—May be raised to 55% for well-graded soils.

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(7) The field control factors mentioned earlier, *i.e.*, cement content, moisture content, and density of the selected mix for the representative soil samples are now established, and the gradation limits of each soil-cement mixture, the corresponding cement content, optimum moisture content, and the density may be marked on the soil profile map for use during construction.

Construction Methods

3. 2 4. The method of construction in soil-cement is not greatly different from granular soil stabilization. The description of construction methods given in section 3 primarily related to the road-mix process using manual labour with rollers and small tools. The method of construction described below is the road-mix method using mechanical equipment.

Equipment for Construction

A list of equipment capable of producing from 1000 to 2000 linear ft. of 20-ft. roadway per day is given below. On large works equipment is frequently operated in complete units, each containing several machines, which are often termed "trains".

- 1 — Subgrade roter (adjustable scarifier on power grader will reduce equipment needs).
- 2 — 9-ft. Offset disc harrow equipped with cleaners, minimum diameter of discs 24-in. Offset disc harrows are necessary for pulverizing heavier textured soils, and are good mixing tools. Where soils are easily pulverized, substitute one additional heavy duty cultivator and one 6-ft. rotary tiller.
- 6 — 1½ ton truck or equivalent.
- 3 — 35-40 h.p. track type tractor (one tractor equipped with street plates).
- 1 — 15 h. p. smooth rubber tired tractor.
- 1 — 30 h. p. rubber tire tractor.

- 1 — 8 ft. or wider heavy duty spring-tooth or stiff-tooth field cultivator with teeth back of wheels, power lift, depth control mechanism, 4-in. double-pointed shovels on each standard.
- 1 — 6 ft. rotary tillers. (Rotary tillers are mixing machines with rapidly rotating axles on which curved teeth are mounted; these are used as mixing tools on soil-cement projects where the percentage of large rock is low).
- 1 — 3 or 4 bottom heavy duty gangplow, 14 to 18 in. mould board with power lift and adjustable depth levers.
- 3 — 1,000 gal. pressure distributor for water. (Minimum water-spreading requirements should be considered as averaging 100-gal. per minute during water spreading. This will require that a 1,000 gal. pressure distributor be filled and then emptied on the roadway, at a rate of 200 gal. per minute, once every 10 minutes. A feeder tank can be equipped with a 200 gal. per minute pump and appropriate valves and spreading bar to provide a satisfactory, inexpensive pressure distributor. Water spreading will become slow and expensive unless critical attention is given to water supply and spreading).
- 1 — Motor grader, 12 ft. blade (tandem or 4 wheel drive preferred).
- 2 — Double-drum sheeps foot roller, types to be dictated by soil conditions. Range of foot pressure to be approximately as follows:

Sandy soils, specify unit pressures of 50 to 100 lb. per sq. in. with tamping feet of 10 to 12 sq. in. area. Sandy loams and light clay loams, specify unit pressure of 100 to 200 lbs. per sq. in. with tamping feet of approximately 7 sq. in. area.

More plastic soils and soils containing considerable aggregate, specify unit pressures of 200 to 400 lbs. per sq. in. with tamping feet of 5 to 6 sq. in. area.

- 1 — Tandem self-propelled smooth wheel roller sizes to be dictated by soil conditions.

Sandy soils, specify 3 to 5 tons.

Sandy loams and light clay loams, specify 5 to 8 tons.

More plastic soils and soils containing considerable aggregate, specify 8 to 12 tons.

- 1 — Multiple-wheel pneumatic roller or equivalent.

- 1 — 10 ft. spike-tooth harrow. Teeth not more than $1\frac{1}{2}$ in. apart.

- 1 — Broom drag.

- 1 — Nail drag.

Field Testing Equipment

The field tests to control moisture and density are fundamentally important and should not be neglected. The following items will equip a field laboratory adequately. Each item is important and fills a definite need on the job.

1. Portable shed 8×10 ft. (converted trailer makes an excellent field laboratory).
2. Two burner stove.
3. Split moisture-density $1/30$ cu. ft. mould and sleeved 5.5 lbs. rammer.
4. Overhead triple beam balance with weights, 500 gram capacity, sensitive to $1/10$ gram.
5. Sensitive balance with weights, 15 lb. capacity, sensitive to $1/100$ lb.
6. Set sieves 3-in. $\frac{3}{4}$ -in. Nos. 4, 10 and 20.
7. Field density determination apparatus, article 4-7.
8. 3-in. diameter soil auger and shovel.
9. Quantity of sand of known dry weight per cu. ft.

10. Hammer and 1-in. mason's chisel.
11. Dozen tin pie plates and dozen $\frac{1}{2}$ -gal. syrup pails.
12. Two fry pans, 10-in. diameter.
13. 100 ml. glass graduate.
14. 10-in. butcher knife, 12-in. steel straightedge and 10-in. trowel.
15. 12 ft. pail, two large spoons and 2-in. paint brush.
16. Maximum and minimum thermometer.
17. Wet and dry bulb thermometer with relative humidity chart.
18. Slide rule.
19. 5×5 ft. canvas sample cloth.
20. Ruler, 50-ft. metallic tape and 100 ft. chalk line.
21. Notebook, graph paper, scratch pad, pencils, etc.

Sequence of Operations

The sequence of operations in soil cement construction assuming that the subgrade beneath the base requires no special treatment or has previously been brought to the desired condition, is as follows :

- (1) Pulverizing of the soil which is to be processed.
- (2) Mixing of the soil with the stipulated amount of cement.
- (3) Addition of the required amount of water and its incorporation with the soil-cement mixture.
- (4) Thorough compaction, including final rolling and finishing.
- (5) Curing of the completed soil-cement base. If best results are to be secured, the processing operations should be carried on in a planned sequence, with

little time elapsing between separate steps. Thus, pulverization, "dry" mixing, the addition of water and "wet" mixing, and compaction should follow step by step with little lost time or motion. Careful control must be exercised to see that a uniform mixture of the proper proportions of soil, cement, and water is secured and that the mixture is adequately compacted. Prompt mixing and laying of the mixture are necessary in order to insure final compaction before appreciable setting of the cement occurs.

Pulverization

(1) Before cement is added, the soil which is to be used must be thoroughly pulverized. If the existing soil is to be used it must be scarified to the desired depth, usually by the use of a subgrade rooter or a scarifier attachment on a blade grader. If imported material is being used, it must be hauled in and spread on the existing soil to the required depth. The soil is then pulverized by the use of offset disc harrows, gang plows, or rotary mixers. Sheepsfoot rollers are also good clod breakers. It is generally required that the soil, with the exception of gravel or stone, be pulverized until at least 80 per cent will pass a No. 4 sieve.

A soil that does not contain clay or colloids can be pulverized rapidly and easily with a wide variety of equipment under a wide range of moisture contents from air-dry to about the liquid limit. Such soil requires no particular experience or soil knowledge to successfully pulverize. Equipment developments continue to simplify this problem and increase the types of soils that can be pulverized readily.

Clay in soils, together with moisture films and moisture conditions, produces the glue that holds the soil grains together. Below the plastic limit, clay soils form into hard clods and at the shrinkage limit the clods are so hard they can be broken only with a hammer. Above the plastic limit the clay particles can be separated easily but they are so wet that they glue back together on contact with little or no pressure. Experimentation with these soils will demonstrate that at a water content near the plastic

limit (which is also near optimum moisture content) they may be broken up with reasonable effort and will not recompact readily.

Therefore, the key to success in pulverizing clayey soils is to bring them to a suitable water content, when needed, by wetting or drying and then applying pulverizing effort in such a way as to avoid recompressing the soil. The most efficient method of pulverizing each soil can be determined by experiment and experience and by observing the methods and procedures followed by farmers.

As previously noted, soils that do not contain clay or colloids pulverize readily. As the clay content increases it decreases the range in moisture contents where the soil can be pulverized. A sandy roadway with only a small amount of clay present will pulverize readily at the higher moisture contents near the plastic limit. Although it may appear quite hard after dry weather and traffic has ironed it out and a rooter may be needed to loosen it at first, once loosened, it pulverizes readily, and adding even a little water will make it quite friable.

Some soils are best pulverized by drying below the shrinkage limit and then adding water.

Many combinations of sand, silt and clay occur in nature and each soil has its own pulverizing characteristics. Knowledge that variations in the moisture content of a soil governs its pulverization characteristics, which is the key to soil pulverization, will make it practical to readily pulverize most soils that are economical to use.

A field test to determine the practicability of pulverizing clayey soils consists of placing a hard dry clod in a glass of clear water. In a very short time, grains of soil should begin falling from the clod which finally slakes to a mound. Such soils should pulverize economically. Some soils are best pulverized by drying below the shrinkage limit and then adding water.

Incorporation of Cement

(2) Before spreading cement the moisture content of the pulverized raw soil should be determined. Under the average wind, temperature and humidity conditions, the moisture content

in the roadway after the cement has been dry mixed with the pulverized soil will be about two percent below the moisture content in the raw soil at the start of cement spread. Therefore cement may be spread and mixed whenever the moisture content of the raw soil does not exceed the optimum moisture content of the soil-cement mixture by more than two percent. If the raw soil is wetter than this it should be brought to the desired condition by drying.

The proper amount of cement may be spread upon the surface of the pulverized soil either by hand methods or by mechanical means. Very frequently bags of cement are "spotted" by hand along the surface in rows of pre-determined spacing. The calculations for cement spotting are readily made as illustrated below.

Example: Calculate the spotting of cement bags for a soil-cement base course 20 ft. wide, 6 inches thick compacted, with a cement of 10 percent of volume of compacted mixture. Assume that a bag of cement contains 110.5 lb. of cement measuring 1.2 cft. apparent volume.

One bag or 1.2 cft. of cement will be adequate for 1.2×10 or 12 cft. or 24 sft. of compacted soil-cement. That is each bag can take care of an area 6 ft. $\times$ 4 ft. The bags may be spotted in rows 6 ft. apart, each row containing 5 bags at 4 ft. intervals. The first and last bag in each row will be placed 2 ft. from the edge of the road, the first and last row in each reach under processing will be 3 ft. from the ends of the reach, the reach being selected so that its length is a multiple of 6 ft.

The bags after being spotted are opened and the cement spread in uniform transverse rows, also by hand. Spreading is completed by the use of a spike-toothed harrow. When spreading of the cement has been properly completed, dry mixing is ready to begin.

Mixing

(3) The mixing of the soil and cement is accomplished by the use of such tools as gang plows, disc harrows, spring-tooth cultivators, and rotary tillers. Careful control is necessary during this operation in order that the mixing be carried to the proper depth

and that a uniform mix be secured. The equipment available for this purpose will generally be operated in a train, with additional units being added to the train as construction proceeds, to supply water and complete the wet mixing operation. In many cases dry mixing and wet mixing are not essentially separate operations but are carried along together in an integrated series of operations. The proper amount of water is added, generally by means of pressure distributors, and the soil, cement, and water are thoroughly blended to a uniform mixture, ready for compaction. A complete train of equipment, capable of both dry and wet mixing, will usually include spring-tooth cultivators, gang plows, blade grader, rotary mixers, water distributor and a spike-tooth harrow. Several passes of the train are usually necessary for the complete mixing operation. The amount of water added is generally enough to increase the moisture content to 1 or 2 per cent more than the optimum desired for compaction. This is done because of the loss of water which may occur during field mixing operations, as compared with laboratory mixing. In other words if a slight excess of water is incorporated during mixing, the soil may then generally be expected to be very close to optimum by the time compaction, is ready to begin.

Compaction and Finishing

(4) Initial compaction of a soil cement base is generally achieved by the use of sheepsfoot rollers. After the base has been compacted to within two or three inches of the surface, the layer is brought to shape with a motor grader. Rolling then generally continues until satisfactory density has been secured to within about one inch of the surface. In very sandy soils, of course, compaction may not be possible with sheepsfoot rollers, and densification may then be accomplished by the use of pneumatic-tired rollers. After the soil-cement mixture has been compacted as described, the rollers are taken off and the surface brought to final shape. The final shaping is done by using a spike-toothed harrow or nail drag to remove the compaction planes left in the surface by the rollers, followed by a broom drag. A rubber-tired roller may then be used again, the surface shaped by a blade grader, and compaction planes finally removed by the nail drag. Final compaction is then secured by rolling with steel rollers weighing from

3 to 12 tons, depending on the soil involved. Rolling is continued until a tightly packed surface is secured. In some cases additional final rolling has been done by pneumatic rollers to secure a tightly knit surface. During all the rolling operations which have been described it is essential that the moisture content be maintained at optimum. Frequent checks on the density and moisture content are, of course, necessary, and this is done in accordance with method described in article 4. 7.

Curing

(5) The water contained in the soil cement mixture is necessary to the hardening of the cement, and steps must be taken to prevent loss of moisture from the completed base by evaporation. A protective covering of from two to four inches of soil may be placed over the base, or hay or straw may be used. As soon as the cover is placed it is moistened so that evaporation takes place from the cover and not the underlying soil-cement. Only enough water should be added to the cover to moisten it thoroughly without free water running into the surface of the compacted soil-cement. Protection of this sort should be continued for at least seven days, after which the base may be opened to traffic for a brief period prior to the application of the wearing surface.

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(To be continued)

ITEMS of interest

THE BATTLE OF THE STRUCTURES

I received a great thrill when I had the honor to introduce the president of the Empire State Building to the president of the Eiffel Tower. This historic meeting took place at the Eiffel Tower, when Mr. William J. Keary, of the world's tallest building, went to pay his respects to M. Pierre Charles Raffegeau, the director of France's greatest landmark. As the only newspaper man present I can report that both men behaved in impeccable fashion, and after their exchange of warm greetings and salutations the bond between the two structures is now stronger than ever.

It is only natural when two great men come face to face that they exchange notes on thier respective enterprises. And so it was with Mr. Keary and M. Raffegeau. The latter, who speaks no English, called in M. Alexis de Gunzburg, the largest stockholder of the Eiffel Tower to accompany us on a tour.

M. de Gunzburg revealed that the Eiffel Tower is owned by the City of Paris and leased to his company on a rental-plus-percentage basis. Eiffel Tower stock is listed on the Bourse, and anyone can buy it.

Mr. Keary said his building was owned by a syndicate which recently brought a controlling interest from the Raskob family.

Mr. Raffegeau said the Eiffel Tower's major source of income is tourists, who pay 400 francs (\$ 1.20) to go to the top, 250 francs (\$.71) to go to the second floor and 100 francs (\$.28) to go to the first floor of the structure.

Mr. Keary said his tourists pay \$ 1.20 to visit the 102nd floor of his building. The main source of income from the Empire State Building is rentals, of course, but tourist business is a very profitable sideline, accounting for three quarters of a million dollars a year.

M. de Gunzburg proudly pointed out that last year 1,250,000 people visited the Eiffel Tower, a record surpassed only by the first year's operation in 1889, when 1,850,000 visited it during the Paris Exposition. The Eiffel Tower, M. Raffegau added, recently played host to its 25,000,000th visitor.

Mr. Keary pointed out that the Eiffel Tower is much older than the Empire State, which can account for only 15,000,000 people. But last year, 1,00,000 people came up to the 102nd floor, also a record.

M. Raffegau said his structure has a television antenna on top that beams programs all over France.

Mr. Keary said the Empire State Building has seven television stations broadcasting from its antenna and he expects two more to come in shortly.

M. de Gunzburg asked Mr. Keary how much he receives in rentals from his television tower, and when the latter mentioned a figure over half a million dollars, M. de Gunzburg looked depressed.

M. Raffegau said that the Eiffel Tower rents souvenir concessions on a yearly basis and also collects rent from two restaurants on the first and second floors. Receipts from concessions come to \$ 31,000 a year.

Mr. Keary said the Empire State Building runs its own souvenir and post-card shops, which net \$250,000 a year.

Both Frenchmen shook their heads in disbelief.

Mr. Keary said his building is now air-conditioned.

M. de Gunzburg said the Eiffel Tower has always been air-conditioned.

For the first time he was one up on Mr. Keary.

M. Raffegau said the Eiffel Tower is the safest structure in the world, built in such a way that even if an earthquake struck it would hold its ground.

Mr. Keary pointed out that engineers say if a ninety-mile gale blew steadily for nine hours against the Empire State Building it would move the tower only one and one half inches.

As an impartial observer I tried to bring up the question of suicides.

Mr. Keary said the suicide problem at the Empire State Building has been solved by building a fence around the observation tower.

M. de Gunzburg and M. Raffegau said nothing.

From what I observed, Mr. Keary had gotten the best of the afternoon, but the Frenchmen had not played their ace yet.

After the tour was over, Mr. Keary presented to M. Raffegau a souvenir reproduction of the Empire State Building which stood seven and one half inches high.

M. Raffegau returned the gesture by presenting Mr. Keary with a souvenir reproduction of the Eiffel Tower *Ten inches high*. It was a small thing, but anyone who saw it had to give the nod to the Frenchmen in the end.

—From Art Buchwald's *Paris*.

THE SHRINKAGE OF CONCRETE

When a concrete building 275 ft. long was built without joints at Rochester, New York, U. S. A., in the year 1939, electric strain meters were inserted in the four floor slabs and in the columns. After sixteen years the shrinkage has been about 0.6 in. in the floor slabs. Details of this test were given in a paper read by Mr. Robert R. Sheridan and Mr. Morgan B. Klock at the annual convention of the American Concrete Institute held at Philadelphia in February last.

—Extracted from *Concrete and Constructional Engineering*, Vol. LI, No. 8.

NEW JAPANESE CEMENT

A research scientist of the Ministry of Construction is credited with the discovery of a new type of cement, said to be very cheap, highly waterproof once it has set, and proof against temperatures up to 400 deg. C. The cement is made from limestone and blast-furnace slag, pulverised separately and mixed equally or in the ratio of 40 to 60. The cement is said to be slower in hardening than portland cement, making it easier to handle. Its use is not considered suitable for ferroconcrete works, since it corrodes iron faster than ordinary cement.

—*Extracted from Highways and Bridges and Engineering Works, dated 28-11-'56.*

* * *

It is regretted that in the last issue Jhon Loudon McAdam has been Printed as Jhon London McAdam.

JULIUS
from other
Journals

MOVING A FOUR-STORY BUILDING

In the re-organisation of the factories at Oissel of the Compagnie Francaise des Materieres Colorantes a comparison of the estimated cost of constructing a new building and the cost of moving an unused building from another part of the site showed a considerable saving in favour of the latter scheme. The building is a four-story structure about 326 ft. long by 35 ft. 6 in. wide, built of reinforced concrete flat-slab construction and weighing about 5000 tons. A joint across the width of the building divided it into halves; one half was successfully moved during 1955, and the second half will be moved after the installation of machinery in the first half.

Fig. 1 shows the complete building. The total length of movement was about a kilometre and included a 3 per cent fall over a length of 680 ft., a rise of 2 per cent, over 250 ft., and rotational movements of 44 deg. and 65 deg.

Each half of the building is supported by 55 columns equally spaced in five rows. In order to support the building on two lines of rails transverse stiffening frames were built between the first and second stories across each line of columns, as shown in *Fig. 3*. These frames were supported under the first internal rows of columns, cantilevering beyond them to carry the external columns and carrying the central row of columns in the middle of their spans. The first-floor slab formed the lower boom of the frames, the second-floor slab the upper boom, and the diagonal members were steel struts. Because of the cantilevers the upper boom was in tension and prestressed ties were used across the second floor to avoid high tensile stresses in the slab. The diagonal struts were also prestressed by hydraulic jacks at their lower ends. A vertical tie was used between the upper and lower booms at the central columns.

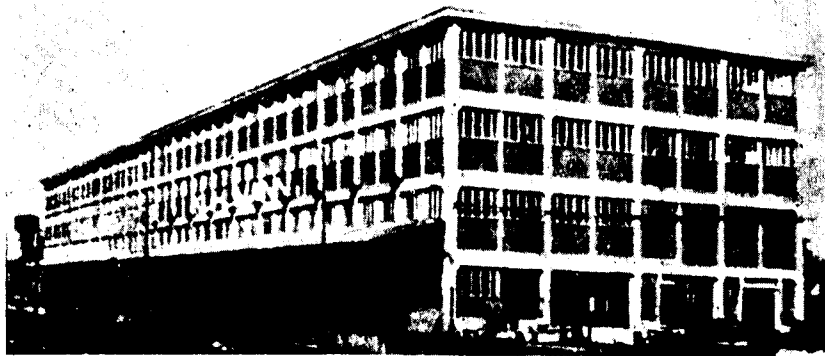


Fig. 1.—Building Before Removal.



Fig. 2.—Underside of Building During Removal.

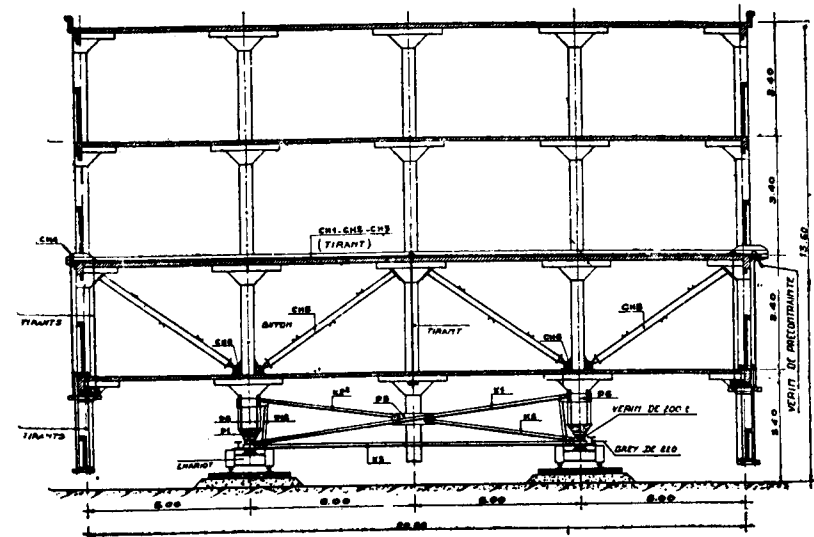


Fig. 3.—Cross Section showing Bracing and Trollies.

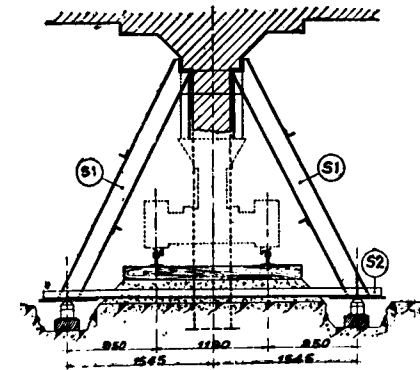


Fig. 4.—Method of Lifting Structure on to Trollies.

Each of the eleven frames was supported on two jacks of 200 tons capacity carried on four-wheeled trollies travelling on rails. The jacks were connected in groups so that it was possible to alter the relative level of groups and so control the forces in the structure during movement. The method adopted to mount the structure on the trollies is shown in *Fig. 4*. At each of the twenty-two columns an A-frame was formed of steel struts and a tie-bar ;

these struts were supported on small hydraulic jacks on each side of the rail-tracks so that the loads could be transferred from the bases to the A-frames. When this was done the columns could be cut away from the bases, the rail tracks laid, and the trollies positioned under the columns. The loads were then transferred to the trollies and the building was moved when the ties of the A-frames were cut and the struts removed. The completed arrangement is shown in *Fig. 2*, in which can be seen the cross bracing to stiffen the structure.

Hydraulic jacks clamped to the rails and thrusting against the trollies were used to push the building along the tracks. Six jacks were used giving a total horizontal thrust of 300 tons; the thrust required varied from 75 tons to 300 tons depending on the inclination of the track. The pumps for the jacks were carried on trollies at the rear of the building. Telephones were used for communication between the men operating the pumps and those guiding the building and checking the movement.

The most difficult operation was to turn the building; this was done by lifting the structure by auxiliary jacks, on concrete bases, on to the eleven lines of curved track, then using jacks clamped to the rails to obtain the rotary motion. At the end of the curve the procedure was reversed.

The total time taken to move the structure was six months, of which four were for the actual movement. Along a straight line a speed of between 3 in. and 6 in. per minute was possible, the greatest distance traversed in a day being about 185 ft. It is estimated that, with the experience gained with the first half, moving the second half will take only 2½ months. The work is fully described by M. Kurt Olsen and M. Jacques Prevost in the French journal "Travaux" for February, 1956. Messrs. Christiani et Nielsen, who developed the methods, were the contractors.

—(Extracted from "Concrete &
Constructional Engineering".

*

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THE ROTAPARK

A compact and efficient system of Off-Street parking.

It is becoming increasingly evident that if complete blockages in the streets in central areas of big cities are to be avoided there will have to be a total prohibition of kerbside parking. This would be tantamount to the prohibition in these areas of private cars used for business or shopping unless adequate off-street parking facilities are provided.

Sooner or later this demand will have to be met and the design of suitable premises, while presenting many problems, at the same time offers considerable scope for ingenuity in design and artistry in architectural treatment.

The most important requirement is that a given area of land shall accommodate the maximum possible number of cars, its provision only possible with multi-storey garage. The next point is that the cost of construction per unit car space shall be cut to the lowest possible limit, thus enabling parking fees to be set at a level which is low enough to ensure that the facility is used to capacity.

There are, of course, many other requirements to be considered such as speedy disposal of vehicles in their parking spaces and equally speedy removal.

All these essentials appear to be satisfied in the ingenious "Rotapark" system introduced by Messrs. Griggs Rotapark, of 56 Victoria Street, London S. W. 1. and illustrated in the accompanying drawings.

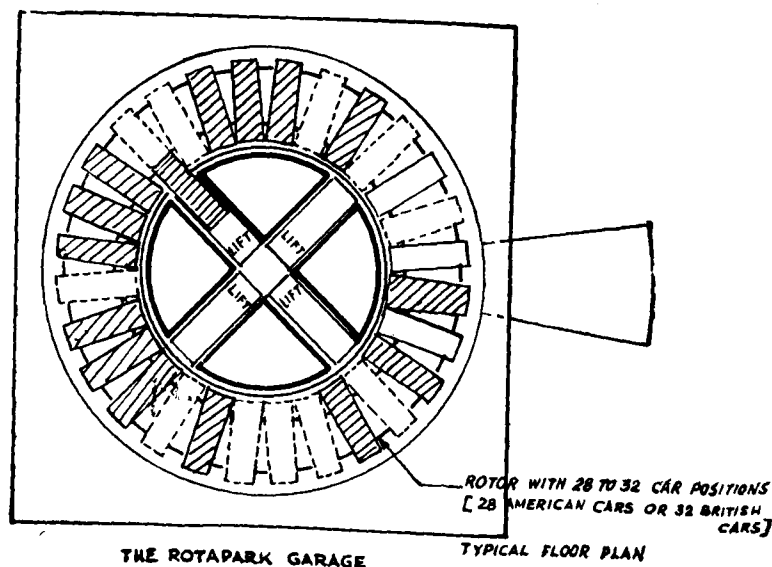
The main structure can be designed with any number of floors within the limits of local by-laws and soil conditions at the site, and it is circular in plan. The building may consist of an open-sided frame, or may be walled-in as required. The parking spaces are arranged radially round the outer part of the circular structure and four lifts are located 90 degrees apart in the centre, giving access to the inner circumference of the parking area. A unique feature is that the circular floors can rotate, thus bringing any particular parking space into alignment with the nearest lift. Normally the maximum rotation needed would be 45 degrees, but as a safeguard against possible emergencies the floor can be turned through 360 degrees.

The procedure in parking is to drive the car on to a turntable which rotates into a position in line with a lift. A patented "dolly" or fork, integral with the lift, emerges therefrom and grips the vehicle behind the tyres of the front wheels. The car is raised slightly and pulled into the lift which then rises to the appropriate floor. The latter, mean-while will have rotated to bring a vacant stall into line with the lift door, whereupon the dolly ejects the car gently into its parking position. The lift then descends in readiness for the next car and the average time occupied in this entire procedure is only 53 seconds.

On a site 100 feet by 100 feet, each floor of the Rotapark can accommodate 32 cars, 8 in each quadrant served by one lift. A reservoir space is provided on the ground floor to prevent congestion at the entrances and it is possible by electronic devices to render the working entirely automatic under the charge of one attendant.

It is stated that the cost of construction using this system is approximately £ 500 per car space.

—Extracted from "Highways and Bridges and Engineering Works", 28—11—'56.



BASE COURSE AND BITUMENOUS PAVEMENT REQUIREMENTS

Hand-placed Telford bases are in fairly general use in European countries, but are seldom considered for use on American airfields. This probably is due in part to the time-consuming job of placing the Telford stone and to our aversion for hand methods. A Telford base was included in the test section constructed at Marietta, Georgia by Waterways Experiment Station personnel. One layer of Telford stones was embedded in a sand cushion, keyed with spalls, and choked with screenings. The total thickness of base was 16 in. of sand and 10 in. of stone. This base was paved with 2 in. of asphaltic concrete and tested with 20,000 to 30,000 lb. single-wheel loads and 40,000 to 60,000 lb. dual-wheel loads. Contrary to the expected behaviour, the performance of this Telford base was much poorer than would have been anticipated from an equal thickness of crushed-stone base built by normal practices.

—Extract from "The Proceedings of the American Society of Civil Engineers", March, 1954.

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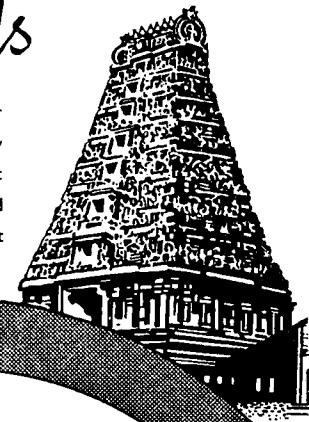


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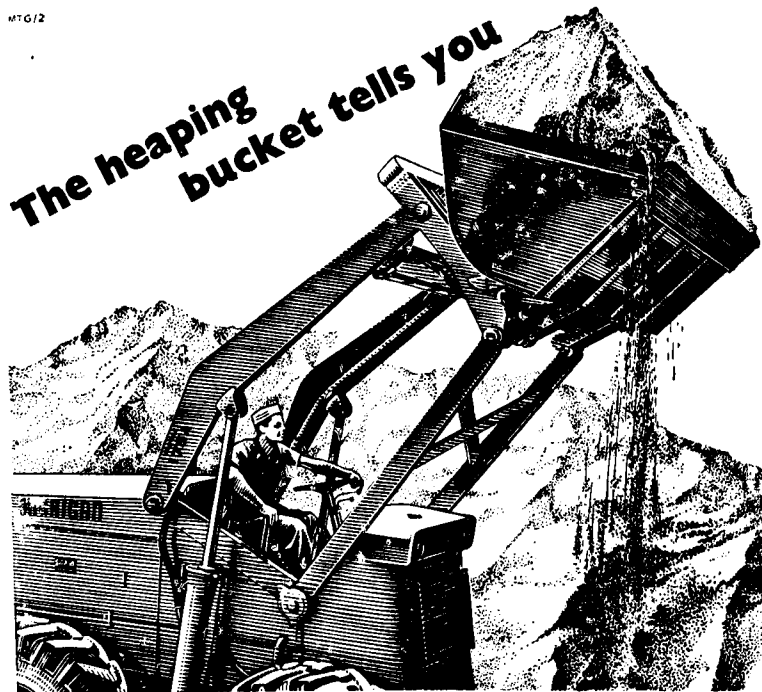


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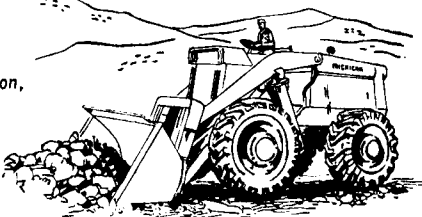
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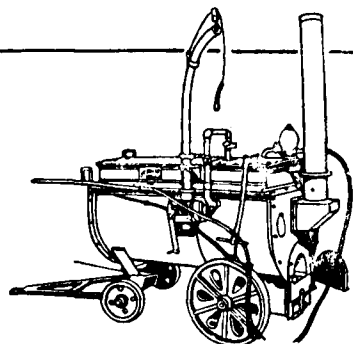


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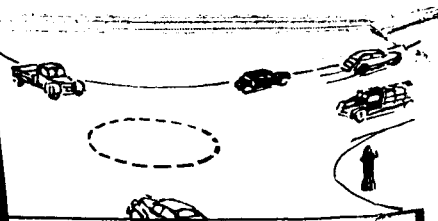
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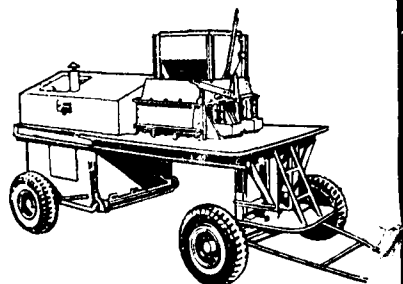
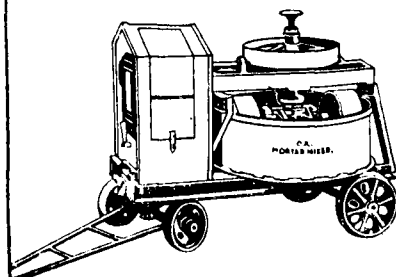


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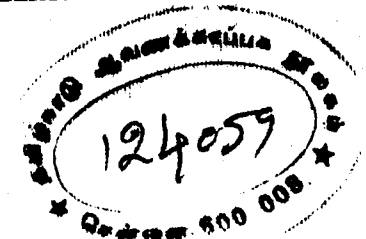
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XX XX XX In Science men have discovered an activity of the very highest value in which they are no longer, as in art, dependent for progress upon the appearance of continually greater genius for in science the successors stand upon the shoulders of their predecessors; where one man of supreme genius has invented a method a thousand lesser men can apply it. No transcendent ability is required in order to make useful discoveries in science; the edifice of science needs its masons, brick layers and common labourers as well as its foreman, master-builders and architect. In art nothing worth doing can be done without genius; in science even a very moderate capacity can contribute to a supreme achievement.

—BERTRAND RUSSEL.



22
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