A Field Study on the Design and Construction of Roads in Waterlogged Areas

by

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1. Introduction

IN certain parts of India, it has been noticed in recent years that due to waterlogging, large scale damage is being caused on several roads. In order to have better understanding of the construction of roads in such areas, a series of experimental stretches were constructed at Palwal-Bye-Pass near Palwal (km 58) on Delhi-Mathura Road, National Highway No. 2 where water-table from 1 to 1·5 m remains throughout the year apart from stagnation of water on sides during rainy season.

On the whole 27 specifications were laid during 1958 and the performance of the same was observed for a period of about 8 years. The details of the experiments together with some data on their performance is presented in this paper.

2. Details of Experiments

For convenience, the 27 specifications adopted in the present tests are divided into four different series. Details of the various experimental stretches together with their objectives are as under:

SERIES I

Series 1 consists of eleven specifications with the following objectives:

(*i*) To study the effect of primer coat over the subgrade, in order to arrest the upward movement of moisture from subgrade to the road crust in waterlogged areas and to arrive at the optimum thickness of road crust required for the type of subgrade, traffic and other environmental conditions as existing at Palwal-Bye-Pass.

(*ii*) To compare the performance of stabilized soil base with that of conventional brick soling.

(*iii*) To compare the 15 cm thick cement soil base using $2\frac{1}{4}$ percent cement with the stabilized soil bases of varying thickness.

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In order to obtain information related to the above mentioned three objectives, under the conditions of this experiment eleven specifications were laid as detailed below:

Sl. No.	*Description*	*Length in metres*
(*i*)	8 cm thick flat brick soling on primed subgrade	17
(*ii*)	12 cm thick brick on edge soling on primed subgrade	15
(*iii*)	15 cm thick brick soling with two bricks on flat one over the other	15
(*iv*)	15 cm thick cement soil using 2½ percent cement	15
(*v*)	15 cm thick stabilized soil	15
(*vi*)	18 cm thick stabilized soil	15
(*vii*)	20 cm thick stabilized soil	15
(*viii*)	23 cm thick stabilized soil	15
(*ix*)	25 cm thick stabilized soil	15
(*x*)	30 cm thick stabilized soil	15
(*xi*)	35 cm thick stabilized soil	15

In all the cases, except cement soil specification, the trench was enveloped with a primer which is a proprietary material at the rate of 20 kg per 10 sq m. All the eleven specifications were covered with 12 cm water bound macadam together with bituminous premix surfacing on top.

SERIES II

Series II consists of three specifications with the following objectives of studying the performance of stabilized soil base of varying thickness in waterlogged conditions without using any primer at the subgrade.

To obtain information on the above mentioned objective under the conditions of this experiment, three specifications were laid as detailed below :

Sl. No.	*Description*	*Length in metres*
(*i*)	23 cm thick stabilized soil	15
(*ii*)	30 cm thick stabilized soil	15
(*iii*)	35 cm thick stabilized soil	15

All the three specifications were covered with 12 cm water bound macadam together with bituminous premix surfacing on top.

SERIES III

Series III consists of four specifications with the objective of comparing the stabilized soil wearing coat with and without graft stone and primer with that of water bound macadam as wearing coat.

In order to obtain information on the above mentioned objective, under the conditions of this experiment four specifications were laid as detailed below :

Sl. No.	*Description*	*Length in metres*
(*i*)	12 cm thick stabilized soil wearing course with grafting at the rate of 0·2 cu m stone (38 mm size) per 10 sq m together with premix bituminous surfacing on top using primer at the rate of 10 kg per 10 sq m	15
(*ii*)	Same as in one above, omitting primer for premix surfacing	15
(*iii*)	Same as in one above except grafting	15
(*iv*)	Same as in two above except grafting	15

In all the above four cases, after coating the trench with primer at the rate of 20 kg/10 sq m stabilized soil of 35 cm compacted thickness was used as base.

SERIES IV

Series IV consists of nine specifications with following objectives :

(*i*) To study the efficacy of some of the techniques as barriers for the capillary rise.

(*ii*) To compare the performance of stabilized soil of 8-10 P.I. with that of 5-7 P.I. in wearing coat and to further compare the performance of the above with that of water bound macadam as wearing coat.

To obtain information on the above mentioned objectives, under the conditions of this experiment, the following nine specifications were laid :

Sl. No.	*Description*	*Length in metres*
(*i*)	8 cm cement-soil (as barrier for capillary rise) using 5 percent cement, 23 cm stabilized soil	15
(*ii*)	25 cm stabilized soil base, 12 cm stabilized soil wearing coat (8-10 P.I.) with grafting and premix bituminous surfacing	15
(*iii*)	Same as in (*ii*) above using stabilized soil of 5-7 P.I. in the wearing coat instead of 8-10 P.I..	15
(*iv*)	15 cm sand blanket (as barrier for capillary rise), 15 cm stabilized soil	15
(*v*)	Using primer envelope at the rate of 20 kg/10 sq m, 23 cm sulphate free local soil, 8 cm stabilized soil	15

(*vi*)	Using polyethylene as envelope 23 cm local soil 8 cm stabilized soil	15
(*vii*)	15 cm local soil 15 cm stabilized soil	15
(*viii*)	Using tar felt as envelope 23 cm local soil 8 cm stabilized soil	11
(*ix*)	Using sand asphalt as barrier for capillary rise together with bituminous primer on sides 23 cm local soil 8 cm stabilized soil	15

The details of the experiments are given in Figure 1.

3. Materials

CLAYEY SOIL

The soil available on top along the alignment is very silty, as such efforts were made to locate suitable clayey soil at selected places in deeper zones with a view to blend the same with fine and medium sand, borrowed from outside.

SAND

In order to obtain suitable workable soil mixes, the locally selected binder soil was blended with two different types of sand, i.e., fine and medium. The mechanical analysis of the fine sand obtained from km 51 and km 68 of N.H. 2 and the medium sand obtained from Badarpur quarry situated at about 3 km away from km 21 on N.H. 2, were conducted.

SILTY SOIL

In order to use sulphate free soil as base or sub-base, soils free from sulphates were taken from selected locations along the alignment. (The data about clayey soils, sands and silty soil are given in Table I).

BRICKS

Bricks and brickbats from local brick kilns with an impact value not greater than 40 were selected for use in these experiments. Bricks were used from brick soling whereas brickbats were used for making brick jelly to be used in the stabilized soil.

STONE METAL

Delhi quartzite with aggregate impact value of about 20 was used for water bound macadam, stone grafting and bituminous surfacing.

OTHER MATERIALS

Straight run bitumen of 80/100 penetration was used for premix surfacing.

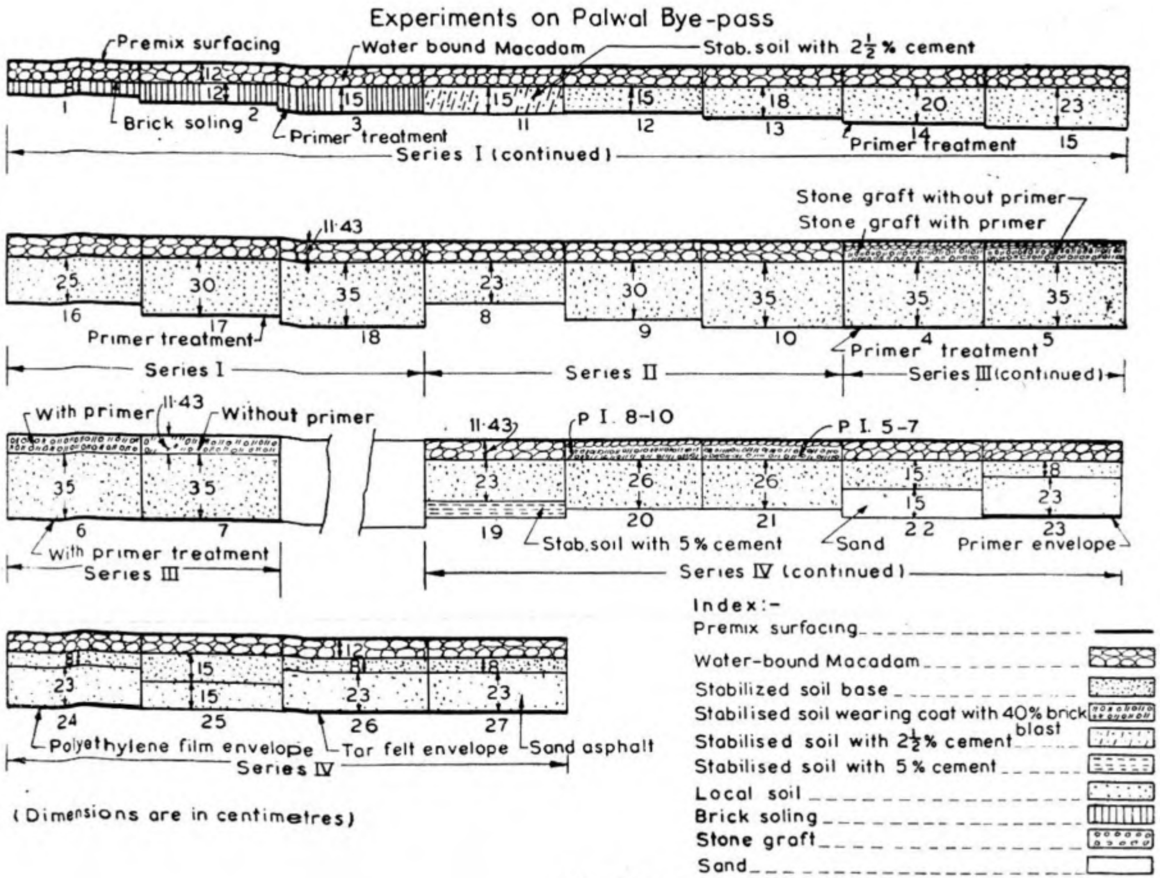
Experiments on Palwal Bye-pass
Premix surfacing
Water bound Macadam
Stab. soil with 2½ % cement
Brick soling
Primer treatment
Series I (continued)
Stone graft without primer
Stone graft with primer
11·43
Primer treatment
Series I
Series II
Series III (continued)
With primer
Without primer
P I. 8-10
P I. 5-7
With primer treatment
Series III
Stab. soil with 5% cement
Sand
Primer envelope
Series IV (continued)
Polyethylene film envelope
Tar felt envelope
Sand asphalt
Series IV
(Dimensions are in centimetres)
Index:-
Premix surfacing
Water-bound Macadam
Stabilized soil base
Stabilised soil wearing coat with 40% brick blast
Stabilised soil with 2½% cement
Stabilised soil with 5% cement
Local soil
Brick soling
Stone graft
Sand

FIGURE 1.

TABLE I

Physical characteristics of clayey soil, fine sand, medium sand and resultant base course soil.

Sl. No.	Type of Material	Percent L.L.	Plasticity Index	Percent Passing Sieve No.						
				Sieve No. 10	40	60	100	200	Percent sand content	Percent C.B.R. O.M.C.
1.	Clayey soil I	34·5	13·6	—	—	—	—	—	8·6	
2.	Clayey soil II	33·4	*14·8*	—	—	—	—	—	*12·6*	
3.	Clayey soil III	37·0	16·5	—	—	—	—	—	7·2	
4.	Fine sand	—	—	99·1	98·6	98·4	97·7	17·7	—	**10·0**
5.	Medium sand	—	—	92·2	41·2	24·0	18·4	4·0	—	
6.	Silty soil	24·0	9·0	92·6	89·3	—	77·0	60·0	—	
7.	Base Course Soil: (*i*) Clayey soil 25% (*ii*) Fine sand 37.5% (*iii*) Medium sand 37.5%	—	7·3	97·6	83·9	79·3	77·3	38·9	—	
8.	Base Course Soil: (*i*) Clayey soil 30% (*ii*) Fine sand 40% (*iii*) Medium sand 40%	—	6·5	96·7	75.3	67·2	65·7	31·9	—	

Primer

Shell Primer No. I, a proprietary material containing 50 percent of 80-100 bitumen and 50 percent of solvent was used for arresting the capillary rise and for priming coat for bituminous wearing courses wherever specified.

Polyethylene Film

Polyethylene film of 0·1 mm thickness supplied in sheets of 17 m long and 10 m wide was used in the experiment.

Tar Felt

Heavy duty tar felt in rolls of 15 m length and 0·8 m wide was used for capillary cut-off. During the process of enveloping, wherever needed, the tar felt was joined by 85/25 hot blown bitumen.

Cement

Fresh Portland Cement conforming to I.S.I. specification for cement soil specifications.

4. Design

GENERAL DESIGN FEATURES

California Bearing Ratio method of design, using the design curves developed by the Road Research Laboratory, Harmondsworth, was used for the design of the pavement layers wherever applicable. The subgrade soils were tested for soaked C.B.R. value and an average value of 5 percent and 150 to 450 vehicles per day traffic was adopted for the design of the specifications.

Wherever an enveloping layer was used to study the efficacy of the layer under test, the material used in the envelope forming sub-base or base in the road crust was designed such that the relatively dry material encased, possess adequate strength to start with. Once due to the failure of the enveloping layer, if any, due to more moisture entering that part of the body of the crust, the material was supposed to loose its strength to such a degree that it showed distress of the pavement on top for the prevailing traffic on the experimental length.

Apart from covering the bottom and sides of the trench with different materials under test for cutting capillarity, premix surfacing was used as wearing coat in all test sections.

SOIL MIXTURES

The criteria adopted for the blended soil to be used as base course was as follows :

Sand content 50 percent or more
Plasticity Index 5 to 7.

The criteria used for the base coat was as follows :

Sand content not less than 33 percent
Plasticity Index 9-11.

In order to achieve the above mentioned requirements, the three soils, i.e., fine sand, meduim sand and the clayey soil were mixed and the resulting grading and P.I. are given in Table I.

5. Construction

GENERAL

In order to have uniformity of the sub-grade for the various test sections under each series, efforts were made to select suitable stretches along the bye-pass to locate the experimental sections. As a result of the field study, two stretches about 275 m and 140 m were finally selected which are hereinafter designated as site I and site II. Series I to III were located at site I whereas series IV was located at site II. The dry bulk densities on the prepared subgrade in site I varied between 1·6 to 1·75 whereas in case of site II, the variation in dry bulk densities was between 1·75 to 1·8 gm/cc. A general view of the sub-grade ready to receive base course is shown in Figure 2.

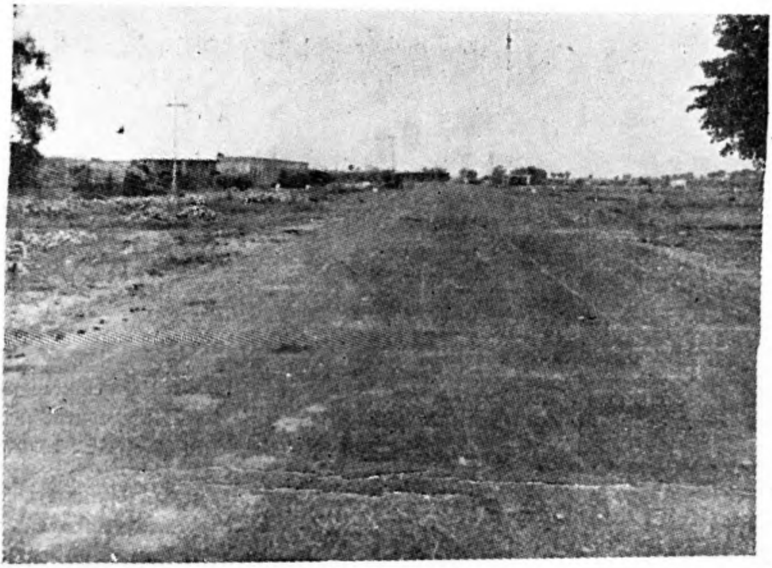

FIGURE 2 : Subgrade ready for takingover base course.

The salient features of construction of the various specifications adopted in the test sections are enumerated as under :

BASE COURSE

Placement of Primer Envelope

After clearing the loose soil from the compacted subgrade, the primer No. 1 was applied at the rate of 20 kg/10 sq m both on the subgrade and on the sides. There was 6 mm to 25 mm penetration of primer in the subgrade.

BRICK SOLING

On the primed subgrade after spreading 12 mm thick sandy soil, the different brick soling specifications were laid as per normal construction procedure for brick soling.

Construction of Base Course by the Use of Local Sulphate Free Soil

As per the structural requirement a base course of local soil having C.B.R. value of 20 percent in dry state was provided over different treatments. The idea was that as long as the ingress of moisture to the base is not there, the base being dry, there will be structural adequacy of the crust to the expected traffic. Sand or coarse material is not provided over capillary cut-offs as per recommendations of I.R.C. as the capillary cut-offs were to be evaluated and presence of sand layer would have affected the results. Figure 3 shows the polyethylene film laid on subgrade.

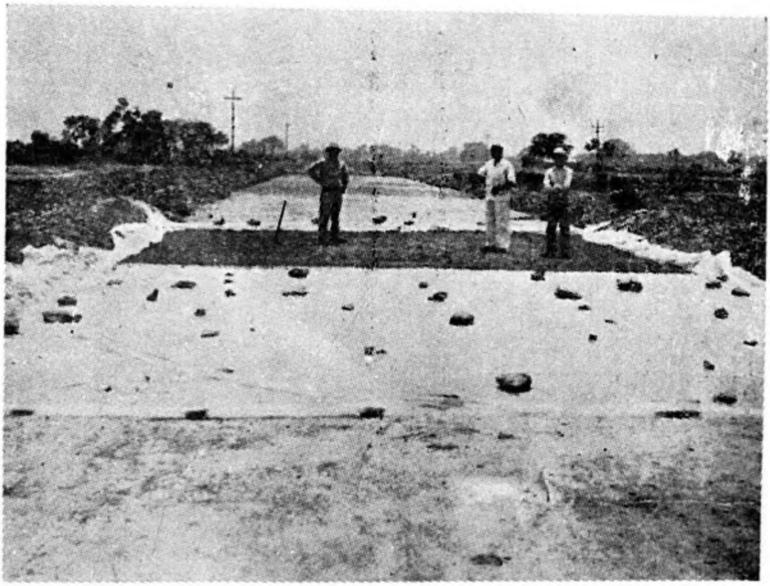

FIGURE 3 : Polyethylene film spread on subgrade.

Soil-Cement Base

Calculated quantity of cement layer was spread on the graded soil at 1 to 2 percent above optimum moisture and after mixing cement thoroughly in the soil, the mix was compacted. Figure 4 shows the soil layer ready to receive the cement from cement bags at predetermined intervals.

Sand Blanket Course

15 cm loose thickness of a coarse sand required according to Public Road Administration formula based on mean diameter method of calculation was provided on the subgrade, The sand layer was sprinkled with water and then compacted after laying a layer of stabilized soil over it.

Soil Stabilized Base Course

As no natural soil having P.I. 5-7 and sand content more than 50 percent was available, blended soil was prepared by adding requisite quantities of clayey soil with fine and medium sand. The optimum moisture and maximum laboratory densities for soil mixes were 8·5 to 10 percent and 1·96 to 2.04 gm/cc respectively. The required thickness of stabilized soil bases were compacted at optimum moisture and dry bulk densities from 1·90 to 2·10 gm/cc were achieved. The dry bulk densities were quite consistent on comparing the maximum laboratory densities for the respective mixes. Figures 5 and 6 show nail drag in action and finished base coarse surface respectively.

BASE COAT

Stabilized Soil Base Coat

Stabilized soil base coat with grafting and without grafting was laid according to Mehra's method of soil stabilization.

FIGURE 4 : Mixing of cement in base course soil.

FIGURE 5 : Nail drags in action.

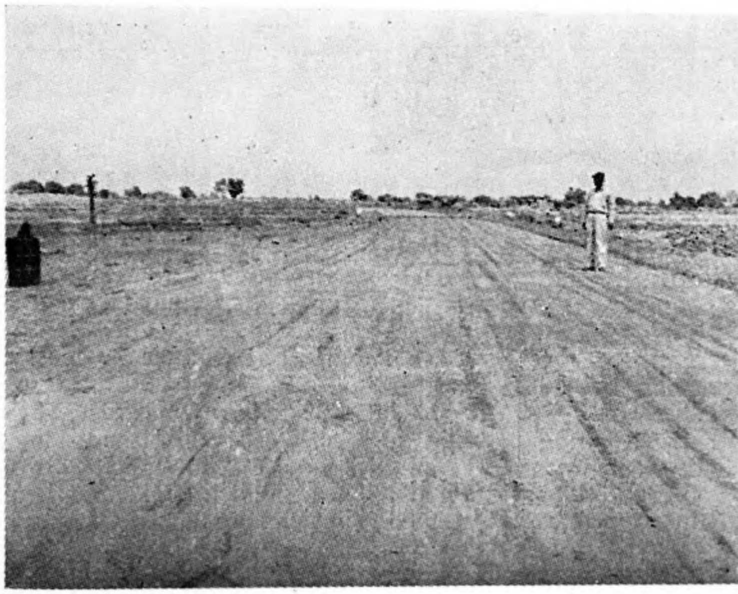

FIGURE 6 : Finished base course.

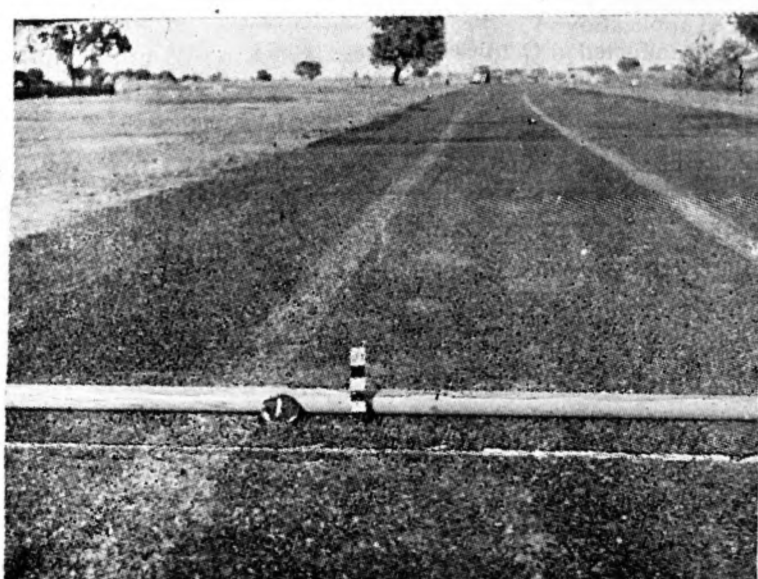

FIGURE 7 : Completed premix surfacing.

Water Bound Macadam

A 12 cm thick water bound macadam was constructed using granular moorum as filler in the two layers of 8 cm loose thickness.

BITUMEN SURFACING

The premix bituminous surfacing consisting of two sizes of aggregates, i.e., 0·17 cu m of 12 mm size and 0·11 cu m of 6 mm size coated with 1·4 kg and 1·6 kg 80/100 bitumen respectively for 10 sq m were laid after applying tack coat @ 10 kg 80/100 bitumen per 10 sq m. Figure 7 shows typical sections with premix surfacing at the top.

6. Observations on the Performance of Different Specifications

There was not much traffic on Palwal-Bye-Pass after the construction of experimental stretches in June 1958 till the completion of the remaining portions in November 1960. The remaining length was constructed by PWD by providing conventional specifications, i.e., two layers of stone soling 15 cm and 8 cm, two layers each of 12 cm thick loose WBM followed by two coats surface dressing. There was about 300 heavy vehicles traffic per day in the beginning but it increased to about 500 vehicles per day by October 1962.

As per the specifications generally followed an open textured premix surfacing comprising 0·17 cu m of 12 mm gauge precoated grit per 10 sq m followed by 0·11 cu m of 6 mm gauge precoated grit was compacted. Due to the pervious nature of the surfacing, different specifications specially with water proofing layers had a set back in the beginning but a seal coat comprising 10 kg/10 sq m 80/100 bitumen and fine grit was provided in July 1962.

Apart from the periodical observations about the movement of moisture in different layers of the various specifications, and patch work done before application of seal coat and after seal coat, a detailed investigation was conducted in October 1964 and again observations taken in June 1966 for evaluating different objectives.

CONDITION SURVEY

The behaviour of different specifications observed in June 1966 alongwith percent patch work before application of seal coat and after seal coat is given in Table II.

FIELD INVESTIGATIONS

The following field tests were conducted at each of the selected specifications during the beginning of October 1964.

(*i*) *Field C.B.R.*

Field C.B.R. tests were conducted at the top of the base course, local compacted soil layer and at different depths of the subgrade.

(*ii*) *Dry Bulk Density and Moisture Content*

The different layers of stabilized soil base course local compacted soil, subgrade at different depths were tested for dry bulk density and moisture content.

(*iii*) *Miscellaneous Observations*

(*a*) Percentage moisture in the soil of stabilized soil base course.

(*b*) Percentage moisture above and below primer layer, Polyethylene Film, Tar felt and Sand Asphalt.

(*c*) Percentage moisture in sand asphalt.

(*d*) Condition of Polyethylene layer and Tar felt after 6 years.

(*e*) Observations about the settlement of different layers.

TEST RESULTS

The data on various tests conducted, are given in Table III.

7. Discussion of Results

Based on the data collected (as enumerated above) the performance of each specification, objective-wise is discussed in the following sections.

SERIES I

(*i*) *To study the effect of Primer Coat over the Subgrade in order to arrest the Movement of Moisture to the Road Crust in Waterlogged Areas and to see the Optimum Thickness of Road Bed required to meet the Soil and Traffic Conditions existed at Palwal*

Out of eleven specifications in series I, ten specifications received primer treatment out of which three specifications are of brick soling and the rest seven are with stabilized soil base.

The data collected on moisture contents at different depths during different seasons are presented in Figures 8 to 11.

With a view to study the effectiveness of primer layer for enveloping the stabilized soil base, the related moisture data for both enveloped and non-enveloped specifications of the stabilized soil for specification Nos. 5, 17 and 10 have been plotted in Figure 10. Out of the three specification Nos. 5 and 10 are of same thickness but one is with primer envelope and the other without the primer envelope. It is revealed that there is no significant difference between the variations of moisture recorded from samples taken from subgrade and stabilized soil base whether there is bituminous envelope or not.

Again when the data is pooled as given in Figures 8 and 9 for studying the moisture variation from top of the base to the subgrade extending to a depth of about 45 cm it is seen that the moisture in the various specifications reveal that in general the moisture increased from top to bottom. This observation indicates that the moisture movement is from bottom to top, i.e., due to capillarity.

Regarding the optimum thickness of the crust required for conditions covered by the experiment and taking specifications 12-18 which range in thickness of stabilized base from 15 cm to 35 cm, it is seen that the strength tests carried out just after the withdrawal period of monsoon in 1964 i.e., after 3½ to 4 years traffic use, indicated in situ C.B.R. of about 6. Whereas the in situ C.B.R. of the stabilized soil base at the same time was

TABLE II

Performance of different Specifications Patch Work before and after Seal Coat.

Sl. No.	Specification No.	Percent patch work before seal coat	Percent additional patch work after seal coat	Performance	Remarks
1.	1	47·5	16·5	There is settlement (about 2·54 cm) which has been made up by premix surfacing. Brick soling settled towards centre in the form of slope.	Seal coat was applied in July 1962.
2.	2	13·0	13·0	Surface has pot holes, cracks and has settled.	
3.	3	6·6	7·0	Surface has pot holes, cracks and has settled. Maximum settlement under the wheel is 9·3 mm.	There was free water at 45 cm to 50 cm depth of subgrade.
4.	4	17·0	12·0	Surface uneven, patched and settled, base course was quite strong. Behaviour was better than Nos. 6 and 7 specifications.	Primer appears to be dispersed in subgrade, water-table at 0·9 m. There is no difference between the behaviour of specifications 4 & 5 and 6 & 7.
5.	5	5·5	14·5	Surface uneven, patched and settled.	
6.	6	28·5	35·5	Same as above with more patch work.	
7.	7	14·0	50·0	Same as above. The failure appears to be due to poor surface drainage.	
8.	8	6·0	54·0	Settled but on side near the culvert is satisfactory after patch work.	
9.	9	7·0	34.0	Slightly cracked and patched. In general not much settlement and behaviour is not bad.	
10.	10	Nil	37·0	Same as above.	
11.	11	33·0	44·3	Due to initial settlement, the patch work has been done. At present the behaviour is quite O.K. except a bit depression in the centre.	
12.	12	69·0	Nil	Heavily patched, settled and cracked.	

13.	13	39·5	25·5	Same as above.	
14.	14	21·0	12·0	Same as above.	Settlement of subgrade 3·75 cm in 45 cm.
15.	15	Nil	32·0	Same as above.	
16.	16	2·3	1·3	Though slightly patched and cracked yet settlemenr is not much.	
17.	17	Nil	4·1	Not much settlement or patch work in general it is O.K.	No settlement of subgrade.
18.	18	2·0	5·4	Same as above.	
19.	19	43·0	Nil	After initial patch work and seal coat the behaviour is satisfactory.	
20.	20	15·0	Nil	There is not much unevenness or deformation but it is cracked and settled at some points.	
21.	21	52·5	Nil	Except a few differential settlement points and also cracking, the general behaviour is satisfactory.	No settlement in subgrade, base course or base coat.
22.	22	84·5	Nil	At present after patch work and seal coat the behaviour is O.K., a few cracks and differential settlement points here and there.	There is settlement of the sand layer due to settlement of subgrade 3·75 cm to 5 cm under the wheel path.
23.	23	67·0	Nil	At present after patch work and seal coat, the behaviour is O.K., a few cracks.	Settlement towards centre.
24.	24	69·0	11·0	Same as above.	Settlement towards centre in local soil layer.
25.	25	58·0	15·0	Same as above.	No settlement in different layers.
26.	26	85·0	Nil	Same as above.	Local soil got compacted more on inner side, difference about 2·54 cm.
27.	27	18·0	63·0	Same as above.	No settlement in the layers.

1 ft =0·3048 m ; 1 in. =2·54 cm.

TABLE III

D.B.D. percent moisture, C.B.R. at different layers of various specification existing and required thicknesses.

Sl. No.	Speci-fication No.	Subgrade						CBR at			Sub-base			Base Course			W.C.	Existing thickness in cm	Thickness required in cm	Remarks
		D.B.D. and % moisture at																		
		0 cm depth		23 cm depth		45 cm depth		0 cm depth	23 cm depth	45 cm depth	DBD	Moisture %	CBR %	DBD	Moisture %	CBR %	Moisture %			
		DBD	Moisture	DBD	Moisture	DBD	Moisture													
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1.	1 Primer 8 cm brick 12 cm WBM surfacing	1·81	15·5	1·76	18·2	1·60	22·2	—	3·8	—	—	—	—	—	—	—	—	19	43	
2.	3 Primer 15 cm brick soling 12 cm WBM surfacing	1·70	18·4	1·67	18·4	1·62	22·7	—	7·2	—	—	—	—	—	—	—	—	26	31	
3.	6 Primer 35 cm base course 12 cm Mehra's base coat with graft	1·87	14·9	1·65	21·9	1·48	31·1	—	2·6	—	—	—	—	2·07	8·2	52·0	11·3	46	55	

4.	9 30 cm base course 12 cm WBM	1·85	14·7	1·60	22·2	1·54	28·6	—	2·4	—	—	—	—	1·99	10·6	36·5	—	41	55	
5.	11 15 cm soil cement (2·5%) 12 cm WBM	1·81	14·7	1·67	18·8	1.39	28·4	12·5	4·6	—	—	—	—	1·90	12·2	50·0	—	26	55	
6.	14 Primer 20 cm graded soil 12 cm WBM	1·82	16·8	1·78	16·8	1·72	19·7	8·7	6·9	—	—	—	—	2·10	9·9	43·6	—	31	31	Moisture above the primer layer 10%
7.	17 Primer 30 cm graded soil 12 cm WBM	1·91	13·9	1·76	17·8	1·75	18·2	24·3	5·4	—	—	—	—	2·05	10·9	32·7	—	41	35	Moisture above primer layer 11·1%
8.	19 8 cm 5% cement soil 23 cm graded soil 12 cm WBM	1·80	17·3	1·70	18·5	1·64	21·0	4·1	2·2	—	1·90	10·6	100	1·96	11·0	33·5	—	40	58	
9.	21 26 cm base course 12 cm W.C. Mehra's method	1·76	16·1	1·70	19·2	1·64	24·4	10·8	4·8	—	—	—	—	2·05	9·9	34·2	—	38	38	
10.	22 15 cm sand 15 cm graded soil, 12 cm WBM	1·87	15·5	1·76	17·6	1·70	20·9	16·8	1·6	—	—	6·0	30·2	2·08	9·0	41·8	—	41	23	

TABLE III (*Contd.*)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
11.	23 Primer 23 cm local soil 8 cm graded soil 12 cm WBM	2·02	13·0	1·90	15·3	1·57	20·0	20·9	21·1	—	1·93	13·1	26·7	2·03	11·0	—	—	41	18	
12.	24	1·82	16·5	1.76	19·3	1·68	21·4	21·5	5·7	—	1·97	13·1	26·8	2·1	8·7	32·4	—	41	35	Moisture above film 13·9 and below 16·5%
13.	25	1·77	16·3	1·77	20·0	1·62	23·8	15·3	9·1 5·9 8·1 } *	—	1·92	14·4	17.3	2·07	8·5	38·2	—	26	29	
14.	26	1·87	16·0	1·62	22·2	1·70	20·9	14·6	11·0 8·4	—	1·97	14·4	29·6	2·15	8·7	37·8	—	41	29	Moisture above tar-felt 14·4 and below 16·0%
15.	27	2·03	15·7	1·61	22·5	1·67	20·2	18·6	10·5 6·5 4·6	—	1·94	15·7	24·6	2·07	8·7	34·2	—	41	40	Moisture above sand asphalt 14·9% and below 15·5 % There was 4·5% moisture in sand asphalt.

* 8 cm depth
13 cm depth
23 cm depth

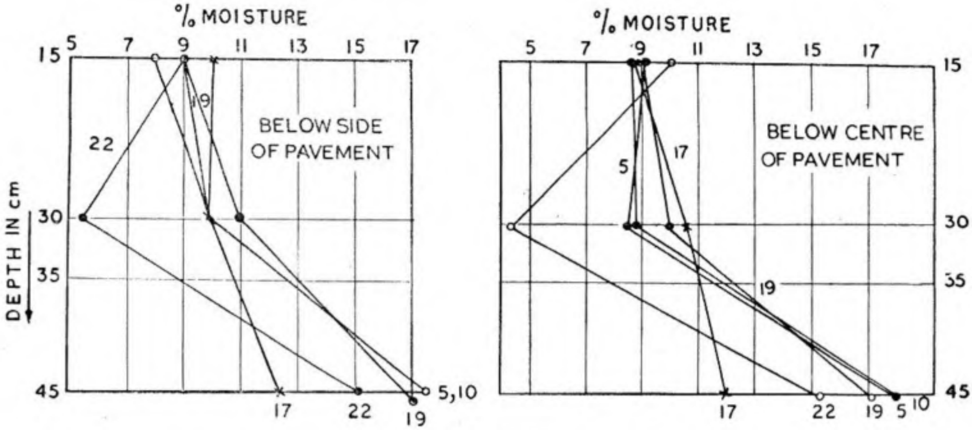

FIGURE 8.

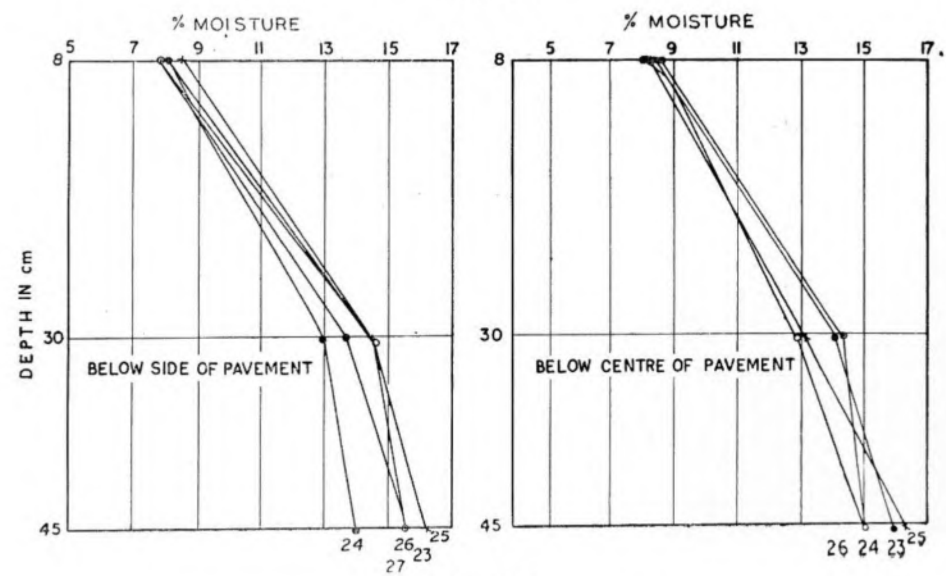

FIGURE 9.

between 33 and 43 percent. The traffic census taken during 1961 and 1964 revealed the traffic as 300 and 500 heavy vehicles per day respectively. The performance data as assessed by visual examination based on the extent of patch work and the settlements, it is seen that the performance of the specification with 25 cm stabilized soil base course and above are satisfactory even after about 5½ years under traffic. The thicknesses of the stabilized soil base course and WBM wearing coat of the successful specifications reveal that the performance of these sections is as expected by the C.B.R. Method of design for the traffic existed on the experimental stretches.

Hence from the above it is seen that for conditions covered in this experiment, that total road crust of 37 cm thickness comprising 25 cm thick stabilized soil bases, covered with 12 cm WBM with thin bituminous

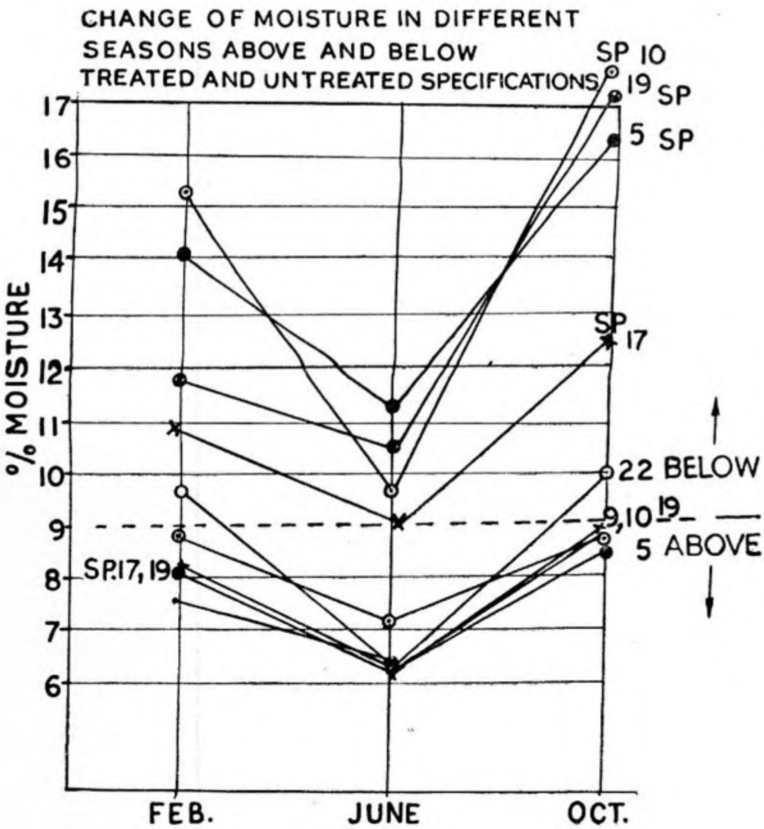

FIGURE 10.

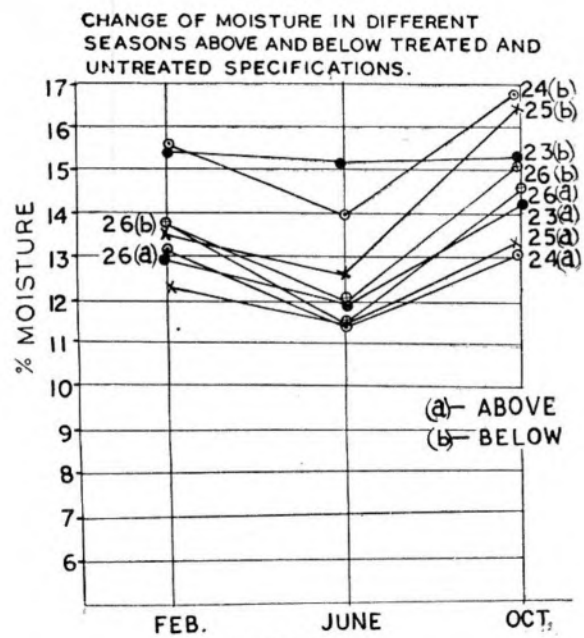

FIGURE 11.

surfacing on top is adequate for the then existing traffic of about 500 vehicles/day.

(*ii*) *To compare the Performance of Stabilized Base with that of the Conventional Type using Brick Soling*

With regard to the objective, i.e., to compare the performance of stabilized soil base with that of conventional brick soling the specification Nos. 1, 2, 3 and 12 to 18 are taken for study. For similar C.B.R. value of subgrade of about 6 under stabilized soil base and brick soling, using the data obtained on subgrade settlements and visual examination combined with the extent of patch work, no definite conclusion could be drawn.

(*iii*) *To conpare the 15 cm thick Cement Soil Base using $2\frac{1}{2}$ percent Cement with Stabilized Base of varying Thicknesses*

It has been observed that wherever less than designed thickness has been provided the subgrade has settled. In case of soil-cement it has been noticed that even though soil-cement layer has attained very high C.B.R. value the total thickness of the pavement being less, settlement has occurred. After the initial settlement its performance seems to be satisfactory and better than equal thickness of mechanically stabilized soil base course. From the C.B.R. value attained in soil-cement layer it appears if designed thickness is provided the stabilized soil specification with coment appears to be better than without cement.

SERIES II

To study the Performance of Stabilised Soil Base of varying Thickness in Waterlogged Conditions without using any Primer at the Bottom

As already discussed in Series I, Section 7·1, it has been observed from the moisture data that there is no appreciable difference in the primed and unprimed specifications. If a thickness of base required according to design is provided it can give good performance provided the thickness of crust over stabilised soil base also satisfied design criteria thickness. A study of Table II wherein the extent of patch repair carried out both in primed and unprimed subgrade specifications, it may be seen that the patch work carried out in case of unprimed specification is of the order of about 40 percent by 1964, whereas the degree of patch work in case of primed specification is of the order of about 5 percent further it cannot be seen from Table III, whereas the subgrade C.B.R. pavement of the unprimed section is of the order of 2·4, the subgrade C.B.R. of the primed section is about 6. Hence the total thickness of the crust adopted in case of unprimed section is much less than the design thickness as compared to primed sections. It appears that this structural inadequacy has led to more patches in case of unprimed sections than primed sections.

SERIES III

To compare the Stabilized Soil Base Coat with and without Graft Stone and Primer with Water Bound Macadam

The data from Table II indicates that performance of base coat with grafting is much better than the base coat without grafting. There is a patch work 20 to 29 percent in case of base coat with graft and 64 percent without graft. As far as the efficacy of the primer both for grafted and ungrafted section is concerned, the data does not reveal any significant difference in case of with and without primer.

The subgrade C.B.R. of the four specifications 4, 5, 6, 7 is 2·6 wherein stabilized soil wearing course was laid, requiring a crust thickness of 55 cm but total thickness provided in these sections is 46 cm which seems to be on low side than the requirement. Probably above reason, contributed to heavy patch repairs of the order of 60 percent in two sections, whereas in the grafted section the patch repair amounted to 20 to 30 percent during the same period. A study of the performance of similar stabilised soil wearing cost specifications, i.e., 20 and 21 with grafting accommodated in stretch II reveals that even though the patch work carried out, up to 1962, i.e., prior to laying the seal coat was of the order of 15 percent, the patch work carried out between 1962 and 1964 appears to be negligible. This indicates that in general if the other design requirements are fulfilled, it appears that the performance of the stabilised soil wearing coats with grafting is encouraging.

SERIES IV

(i) To study the Effectiveness of Various Alternative Design Methods for arresting the Detrimental Effects of Capillary Forces on Highway Pavements, in Waterlogged Areas, with a view to arrive at a Suitable and Economical Type of Design

POLYETHYLENE AND TAR-FELT

From the field observations it is quite clear that polyethylene film and tar-felt do not allow capillary rise through them and there is only 1.5 to 2·5 percent moisture difference between the soil layer over and below the films. Polyethylene film after the period of six years has not lost much strength while it has been observed that tar-felt apart from losing strength, the bituminous material has dispersed into the subgrade and there is slight moisture absorption by this layer. The performance of these two specifications has not been good due to the seepage of water from the pervious bituminous surfacing and instead of these layers being helpful in maintaining the strength of sub-base and course by not allowing rise of moisture from subgrade, have prevented the internal drainage from these layers and resulted in the settlement. It is, therefore, not advisable to provide such layers in case of pervious bituminous surfacing or where repair of surfacing can not be attended to immediately. Moreover, such treatments work out uneconomical.

SAND ASPHALT

Due to the pervious nature of the surface course from the moisture data alone even though there was 14.9 percent moisture above sand asphalt layer and 15.5 percent below the behaviour of sand asphalt could not be judged, but there was 4.5 percent moisture absorbed by the sand asphalt which was equal to the percentage of moisture retained by the sand layer. It is, therefore, clear that the sand asphalt layer unless viodless may not be effective. As this layer could allow drainage of water, it behaved better than film specifications in the beginning.

PRIMER LAYER

The behaviour of primer at the subgrade for checking capillary rise has already been discussed under Series I.

SAND BLANKET

A proper thickness of sand on the subgrade reduces the capillary rise of moisture and at the same time allows the internal drainage of water and thereby stabilised soil base course can maintain the strength. There was a maximum 5 percent moisture in the sand layer. Though this specification due to the seepage of water from top showed sign of distress but after sealing, it was behaving satisfactory. It was also interesting to note that C.B.R. value of sand at this moisture and confined stage is quite high, i.e., 30 percent and 26 cm of total thickness of pavement over this is quite adequate and also the C.B.R. value of base course is 41.8 percent over which 12 cm of WBM is adequate. In case coarse sand is available, it appears that sand blanket is the economical treatment for waterlogged conditions.

SOIL-CEMENT LAYER

The soil-cement layer does not check the capillary rise of moisture but it provides a firm base and checks the settlement of the pavement in waterlogged subgrade. Even though the percentage moisture in soil-cement layer is 10.6 while it is 17.3 percent in the subgrade just below, but this difference may be due to difference in type of soil and in densities and not because it checks moisture. The C.B.R. value of soil-cement layer is very high, i.e., 100 percent and also C.B.R. value of stabilised soil base course is 33.5 percent. After the initial set-back the specification is behaving quite satisfactory.

(*ii*) *To see whether 8-10 P.I. Soil in the Base Coat be replaced by 5-7 P.I. Soil and to see the Performance of the Two and compare with Water Bound Macadam*

The performance of base coat with 8-10 P.I. soil is better than with 5-7 P.I. soil as there is 15 and 52.5 percent patch work respectively. The general performance of these specifications is encouraging if there is good surface drainage and impervious surfacing. There was no settlement of subgrade in case of these specifications.

8. Trend of Results

Under the conditions covered by the experiments at Palwal, the results of the various tests and observations made indicate the following trends :

SERIES I

(1) Even though the moisture data of the base course of primed and unprimed specifications did not show any difference between them yet the performance of primed is a bit better but that may be due to slightly more C.B.R. of subgrade of primed specifications.

(2) A total road crust of 37 cm comprising 25 cm thick stabilized soil base of the type used in the experiments at Palwal, covered with 12 cm WBM together with thin premix surfacing with seal coat on top—appears to be adequate for traffic up to 450 heavy vehicles per day.

(3) For equal performance based on patch work, it appears that 15 cm brick soling may be compared with 20 cm of stabilized soil as used in this experiment.

(4) The performance of cement-soil appears to be definitely better than similar thickness of stabilized soil without cement as sub-base in waterlogged areas.

SERIES II

Same as 1 of Series I.

SERIES III

(1) The stabilized soil base coat with grafting is better than without grafting.

(2) There is no significant difference between primed and unprimed base coats.

SERIES IV

(1) As long as the bituminous surfacing is impermeable, the behaviour of 8-10 P.I. soil in the base coat is better than that of 5-7 P.I.

(2) From the condition of polyethylene film after the expiry of six years indications are that capillary rise have not taken place through it, whereas tar-felt started deteriorating. Again their use in case of pervious surfacing is limited because of checking of internal drainage.

(3) Sand blanket with coarse sand having adequate thickness followed by stabilized soil base, is quite suitable for waterlogged conditions provided the sand is well compacted.

(4) Sand asphalt unless viodless may not be effective for checking the capillary rise.

(5) Even though the soil-cement layer did not check the capillary rise of moisture yet it provided a firm base (C.B.R. 100 percent) and therefore was suitable for waterlogged conditions.

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