Countrywide Survey of Maximum Highway Subgrade Saturations in India

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According to the standard method, the design of a road or runway pavement is carried out at saturated conditions of the subgrade. The thickness thus determined will be uneconomical if the subgrade is not likely to be saturated in actual practice. It is, therefore, necessary to know the degree of saturation to which the subgrade is wetted during the worst part of the year so that the design at that particular moisture (but not higher) is carried out. With this object in view a countrywide survey was carried out to find out the degree of saturation of the subgrade (mostly under flexible pavement, which forms bulk of the road mileage in the country) at the time of recession of the monsoon when subgrade moisture conditions are worst. The study indicates that the degree of saturation varies considerably and does not justify the design of pavement at 100 percent saturation of the subgrade at all places in India.

• ACCORDING TO standard practice, the thickness of a pavement is designed on the assumption that the subgrade will become completely saturated sometime during the year, even though it is known that such an assumption amounts to varying degrees of overdesigning, depending on the maximum degree of saturation that the subgrade in the area concerned is ever likely to undergo.

It is also known that in certain areas, complete saturation of the subgrade is never reached. In the U.K., for instance, it was established that in areas abounding in silty clays the maximum saturation that the subgrade can ordinarily attain is substantially below saturation, under a sealed surface. Consequently, for the area concerned, it has been laid down that the design of pavement is to be carried out at this particular moisture, called "equilibrium moisture content." This has resulted in reducing the designed thickness of pavements appreciably.

It is further known that the phenomenon of "equilibrium moisture" does not exist in tropical countries, due to wide variations in temperature conditions, etc. The prevailing practice in such areas is either to design as per standard practice by assuming complete saturation, or to combine standard design and experience, particularly in dry areas with low water tables, and to fix a thickness in between.

OBJECT OF THE STUDY

As the information on the subject of subgrade moisture in regard to India has an equally important bearing on the economic pavement design in that country, the present study was undertaken both with a view to make subgrade moisture data for India available to the various research organizations working on fundamental aspects of ground

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moisture movements, and also to obtain authentic data about the maximum subgrade moisture in different parts of the country, with a view to seeing if in certain areas not subject to complete saturation of subgrade the standard design can be justifiably modified with a view to rationalization, as well as economy, of design. The economics of the problem can be well realized from the fact that every inch reduction in the hard crust of the road pavement in India reduces the cost by about Rs. 2,000 to 3,000 ($420 to $630) per mile for 10-ft wide road.

FACTORS INFLUENCING MOVEMENT OF MOISTURE

As far as is known, the degree of saturation of a subgrade is dependent mainly on the rainfall and soil conditions of the area, and as such, for investigation, the country was divided into different zones on the basis of rainfall and soil type.

Rainfall

As a result of rainfall, the wetting of the subgrade under the sealed surface can take place in the following manner, to a large extent due to the proximity of the water table. The nearer the water table is to the subgrade, the lesser the negative pore water pressure, and consequently greater the moisture content, and vice versa. It is a common observation that the water table is lowest during the driest season and starts rising with the onset of the monsoon, and is highest just when the monsoon recedes. The subgrade under a sealed surface in an area with a low water table can still be wetted to a limited extent, due to the suction of moisture by the subgrade from the adjoining unsurfaced berms, wetted as a result of rainfall. The distance to which the moisture can travel in this way is limited to 2 to 3 ft (1) from the edge towards the center of the road. The actual moisture content will however depend on the intensity of the rainfall. It can, therefore, be assumed that, at a certain site abounding in a particular type of soil, the wetting of the subgrade is governed by the intensity of the rainfall, and therefore, one of the ways of dividing India into different zones for purposes of sampling would be on the basis of rainfall intensity. According to the Meteorological Department of India, the annual rainfall varies widely, but a general division into nine rainfall zones ranging from less than 10 in. to over 200 in. per year can be made. The various parts of India covered by each rainfall zone are shown in Figure 1.

Soil Type

Apart from the intensity of the rainfall another factor that greatly contributes to the variations in the moisture-holding capacity of the subgrade is the nature of the soil itself. It is well known that for the same water table, a clayey subgrade absorbs more moisture and will consequently have a lower bearing capacity than sandy soil. It will, therefore, be necessary to know the different soils of India. In the absence of a soil engineering map of India, use was made of the data collected as a result of soil survey carried out by the Agricultural Department. The nomenclature adopted in the agricultural map is such that most of the research workers in the soil mechanics laboratories are familiar with their corresponding engineering properties. According to this map there are 20 different types of soils in the country, 14 of which are shown in Figure 2:

1. Alluvial soils (undifferentiated).
2. Coastal alluvium (new).
3. Grey and brown soils of Indus, Jamuna, and Gangetic basin impregnated with salts.
4. Gangetic alluvium (calcareous).
5. Deep black or Regar soils of valleys.
6. Medium black soil of trap.
7. Shallow black soils.
8. Mixed red and black soils.
9. Red loam.
10. Red gravelly soils.

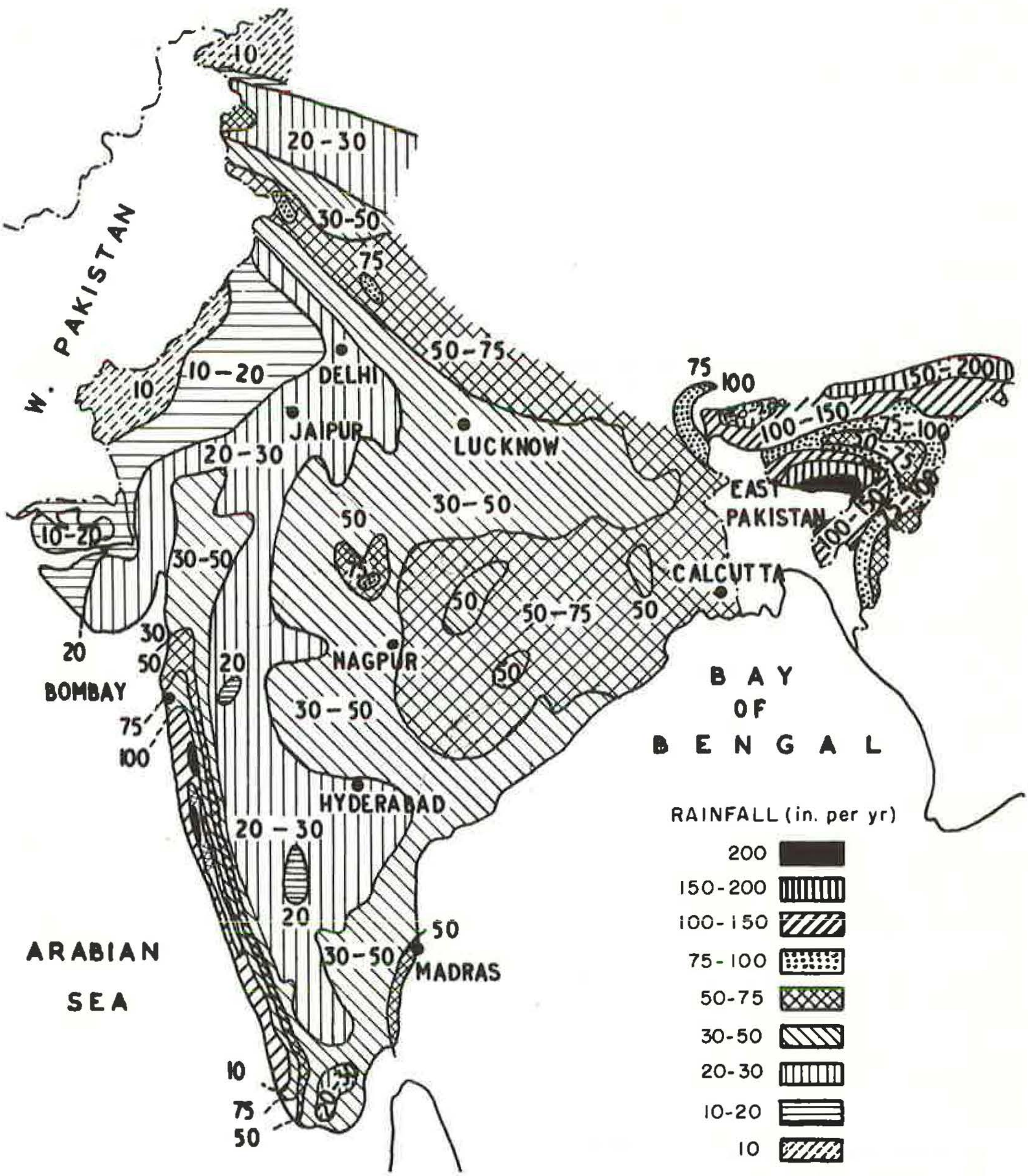

Figure 1. Rainfall map of India.

11. Red and yellow soils.
12. Laterites (high and low level).
13. Laterite soil (old alluvium).
14. Desert soils (grey and brown).
15. Saline and deltaic soils.
16. Skeletal soils.
17. Forest and hill soils (undifferentiated).
18. Sub-montane regional soils (undifferentiated).
19. Foot-hill swampy soils (undifferentiated).
20. Peat soils.

Climatic Conditions

The moisture content of an unsurfaced earth road is likely to be affected by the atmospheric temperature, relative humidity, etc., but the same factors are not likely to influence the moisture content of the subgrade under a sealed surface to any appreciable degree. This is particularly true at the time of recession of the monsoon, when the investigation was carried out. It was, therefore, thought unnecessary to consider this additional factor for subdivision of the country into different zones for purposes of this study.

It is admitted that there may be factors other than those mentioned (such as the situation of a particular area in a certain terrain or general drainage conditions) which would also affect wetting of the subgrade, but taking into consideration the size of the country (covering about 1.27 million square miles), the local conditions of a particular area that may be limited to a small patch had to be ignored in a study of this type.

Division of the Country

Figure 1 shows that, though there are nine rainfall zones in the country, the area covered by zone with rainfall more than 200 in. annually is very small; therefore, for purposes of the present study the remaining eight zones only have been considered. Similarly, there are 20 different types of soils as shown in Figure 2, but soils designated as (a) saline and deltaic soils, (b) skeletal soils, (c) forest and hill soils, (d) sub-montane regional soils, (e) foot-hill swampy soils, and (f) peat soils are minor in the sense that they cover only a small area; therefore, in the present study, only the remaining 14 soils have been considered.

If the rainfall map is superimposed over soil map, it will give approximately 35 zones which will cover all combinations of soil types and rainfall intensities. An idea of the various parts of the country covered by such zones can be gained from the appendix which indicates the name of important cities in each zone.

SAMPLING AND TEST PROCEDURES

Roads

The selection of an actual road for purposes of present investigation within the zone itself was left to the Chief Engineer of the State concerned. It was intended that the road proposed by the State should be such that it does not lie on a very high embankment, does not have poor side drainage, or is not subjected to flooding. This was done with the object of eliminating as many variables as possible, so that the study of movement of subgrade moisture could be restricted to the water table, as a result of rainfall and soil type only. The location of road sites selected for investigation is shown in Figure 3. Because the concrete road mileage in the country is very significant, the selection of roads was restricted to flexible pavement with a bituminous surface only. The thickness of the road crust generally varied from 10 to 12 in.

Airfields

Because the information about the bearing capacity of subgrade is equally important for the design of runways, the present study was extended to the civil runways also.

TABLE 1

DEGREE OF SATURATION AND CONSISTENCY LIMITS OF SUBGRADE SOILS FROM VARIOUS SITES

Type of Site	State	Site No.	Station	Location	Approx. Water Table (ft)	Degree of Saturation (%)					Consistency Limits of Soil		
						Surface 2 In.	First Foot	Second Foot	Third Foot	Bottom 2 In.	Liquid Limit (%)	Plas. Index (%)	Sand Content
Road	Jammu & Kashmir	1	Jammu	Jammu Miran Sahile Road, mile 5	18	25.65	27.98	31.78	33.05	33.97	23.4	8.7	29.0
		2	Srinagar	Srinagar Jammu Road, mile 11	10	77.22	82.43	84.09	88.58	84.93	46.3	22.6	2.3
	Punjab	3	Amritsar	G. T. Road, mile 275	6.5	79.90	80.52	87.05	92.35	92.35	26.6	10.7	16.6
		4	Bhatinda	Surnam Bhiki, Bhatinda Road, mile 99	80	15.93	20.60	26.83	37.42	38.83	24.1	7.2	35.4
		5	Hissar	Delhi Hissar Submanki Road, mile 99	-	19.34	19.03	20.61	20.01	21.51	28.1	12.0	17.1
		6	Jullundur	G. T. Road, mile 223	22	28.63	36.03	35.04	33.18	33.69	24.8	10.8	44.0
		7	Karnal	G. T. Road, mile 77	10	41.60	47.01	50.29	62.53	69.09	28.8	13.0	11.3
		8	Patiala	Patiala Nabha	12	21.55	23.70	24.57	25.43	25.86	22.9	7.2	70.5
	Rajasthan	9	Ajmer	Mangliwar-Pisan-Gunj Road mile 12	-	37.62	39.83	38.21	31.59	31.18	29.5	12.7	42.2
		10	Jaipur	Jaipur-Ajmer Road, mile 6th Jaipur	60	9.91	13.48	13.81	13.20	14.62	21.2	3.8	68.4
		11	Jaisalmer	Pokaran-Jaisalmer, Road mile 63	-	18.91	22.06	20.28	21.22	21.22	22.6	6.8	64.0
		12	Jodhpur	Jodhpur-Patti Road, mile 7th	15	5.26	6.48	6.68	8.77	8.77	23.1	8.2	71.0
	Madhya Pradesh	13	Betul	Betul-Nagpur Road, mile 56	-	79.45	81.93	84.42	81.87	83.80	57.9	30.1	5.7
		14	Bhopal	Bhopal-Sehore Road, mile 4th	8	95.48	93.44	94.46	95.90	98.81	57.5	22.4	20.0
		15	Bilaspur	Bilaspur-Mandla Road, mile 3rd	4	46.02	48.17	51.98	55.80	58.59	57.2	27.4	7.2
		16	Gwalior	Gwalior-Jhansi Road, mile 4th	30	72.42	74.20	73.61	80.47	89.69	31.3	14.2	12.0
		17	Raipur	Raipur-Dhamatari Road, mile 9th	3	51.88	57.12	63.78	63.87	62.29	43.4	21.3	48.0
		18	Satna	Rewa-Nowgong Road, mile 34	4	60.93	65.24	72.46	84.61	84.03	39.0	10.9	23.2
	Uttar Pradesh	19	Lucknow	Lucknow-Sultanpur Road, mile 4	45	21.65	25.11	22.74	24.77	25.58	31.5	11.5	32.0
	West Bengal	20	Burdwan	G. T. Road, mile 58	5	81.04	88.25	87.12	92.81	93.25	57.3	30.6	4.3
		21	Calcutta	Diamond Harbour Road, mile 9	1	97.15	101.90	102.0	100.7	95.67	55.2	27.9	3.8
	Assam	22	Gauhati	Gauhati Goalpara Road, mile 12	20	83.0	90.0	95.6	95.1	95.1	38.6	20.9	8.3
		23	Agartala	Agartala Assam Road, mile 2	5	--	78.49	80.75	83.82	--	39.7	19.2	30.0
	Bihar	24	Gaya	Gaya-Kawadah Road, mile 3	8	60.87	72.45	75.66	67.43	69.52	28.9	13.3	14.8
	Orissa	25	Cuttack	National Highway No. 5, mile 755	12	47.44	48.31	46.34	47.87	53.96	21.9	7.0	60.0
		26	Cuttack	National Highway No. 42, mile 13	4	83.95	85.10	83.76	77.76	81.38	29.9	10.9	34.9
	Madras	27	Madras	Mt. Paonamalli		60.15	64.45	75.56	76.88	83.87	29.4	13.8	46.5

		28	Vellore	Ranipet Krishna-giri Road, mile 4	15	25.86	34.65	36.49	33.76	36.01	--	--	--
	Andhra	29	Hyderabad	Hyderabad Bhongir Hanam Kunda Road, mile 2	8	50.55	61.16	61.50	70.48	77.71	34.4	18.2	46.8
	Mysore	30	Kolar	Cudappa Rly. Feeder, mile 1	15	39.38	41.94	58.42	51.02	51.52	30.6	14.2	51.0
	Gujarat and Maharashtra	31	Ahmedabad	National Highway No. 8, Karjan Makarpura sec. mile 8	30	16.18	18.26	19.94	22.58	22.58	23.6	9.4	52.0
		32	Baroda	Baroda Karjan Makarpura Road, mile 27	28	90.31	95.33	92.29	89.30	92.27	40.2	18.7	10.2
		33	Bhavnagar	New Jetty Road, mile 1	8	90.20	80.42	75.96	78.00	85.80	69.7	38.8	17.8
		34	Bhuj	Bhuj Anjar Road, mile 3	60	23.04	24.73	21.18	20.99	22.65	31.8	16.3	28.0
		35	Bombay	Bombay Agra Road, mile 20	5	66.50	67.50	80.64	82.42	83.47	46.9	19.3	36.5
		36	Jalagaon	Surat Dhulin Ealabad Nagpur Road, mile 195	20	--	79.12	86.15	88.09	--	73.9	36.3	9.0
		37	Junagarh	Junagarh Veravel Road, mile 2	30	67.03	70.61	73.01	84.32	87.54	50.1	25.2	22.2
		38	Junagarh	Junagarh Rajkot Road, mile 2	30	75.28	75.28	79.19	78.78	75.20	43.2	21.3	24.0
	Gujarat and Maharashtra	39	Nagpur	Nagpur-Raipur Road (N.H. 6), mile 5	--	91.33	82.85	82.25	87.20	92.51	66.3	32.8	6.2
		40	Rajkot	Rajkot Surendra Nagar Road, mile 5	10	84.44	88.05	86.80	84.48	88.77	69.7	30.0	10.5
		41	Surat	Surat-Dhulia Road, mile 8	28	85.31	91.08	92.85	93.75	97.30	53.0	24.6	17.0
		42	Bhandara	N. H. No. 6, mile 33	4	97.51	93.43	82.30	86.29	87.27	28.0	15.4	44.0
Airfield runway	Punjab	1		Amritshar[a]	3	92.7	92.7	91.3	98.0	98.9	26.6	10.3	6.0
	Rajasthan	2		Jaipur[a]	60	24.3	27.2	25.1	27.2	22.6	23.5	7.0	69.0
	Uttar Pradesh	3		Lucknow[b]	8	98.0	100.0	100.0	100.0	100.0	32.0	14.5	2.0
	West Bengal	4		Dum Dum (Calcutta)[b]	5	94.0	90.1	96.0	98.33	97.94	63.8	33.5	1.0
		5		Cooch-Behar[c]	10	71.0	74.0	73.7	71.0	68.7	47.5	23.5	10.0
	Assam	6		Agartala[b]	4	83.7	89.7	89.6	92.1	91.7	39.4	15.7	28.1
		7		Gauhati[b]	2	--	75.5	77.5	80.2	--	30.9	14.2	22.0
		8		North Lakhimpur[d]	--	--	--	--	--	--	23.2	6.2	43.2
	Orissa	9		Bhubneshwar[b] (Cuttack)		83.32	77.18	75.82	79.23	76.50	32.7	14.1	34.0
		10		Gaya[b]	1	83.6	91.0	90.5	97.0	94.3	46.3	27.4	5.7
	Madras	11		Madras[b]	6	72.4	75.2	72.3	83.5	83.0	23.5	7.4	63.0
		12		Tiruchirapalli[b]		80.5	84.7	88.4	90.2	87.4	43.2	23.9	44.8
	Andhra	13		Begumpet[b]	8	45.4	43.1	56.2	55.0	56.7	34.6	14.8	46.0
		14		Santacruz[b] (Bombay)	4	98.9	94.7	93.5	95.2	91.5	75.0	39.5	5.4
		15		Ahmedabad[b]	20	51.07	56.35	59.87	51.50	50.98	22.4	6.2	64.7
		16		Nagpur[b]	3.5	92.6	91.4	92.0	88.1	90.7	--	--	--
		17		Bhavnagar[b]	3	97.6	96.3	99.8	100.0	100.0	47.9	21.8	23.0
		18		Bhuj[b]	19	36.9	38.2	32.5	28.17	32.12	20.3	5.0	70.0
		19		Rajkot[a]	--	42.4	44.5	40.82	46.0	42.3	34.0	9.9	44.0
	Delhi	20		Safdarjung[a]	8		64.2	64.3	72.8		31.9	14.4	18.3

[a]Flexible pavement with bituminous surface.
[b]Cement concrete rigid pavement uncovered, except airfield sites 4, 7, 11, and 16 which are covered with asphaltic concrete.
[c]Gravel surface.
[d]Natural landing ground.

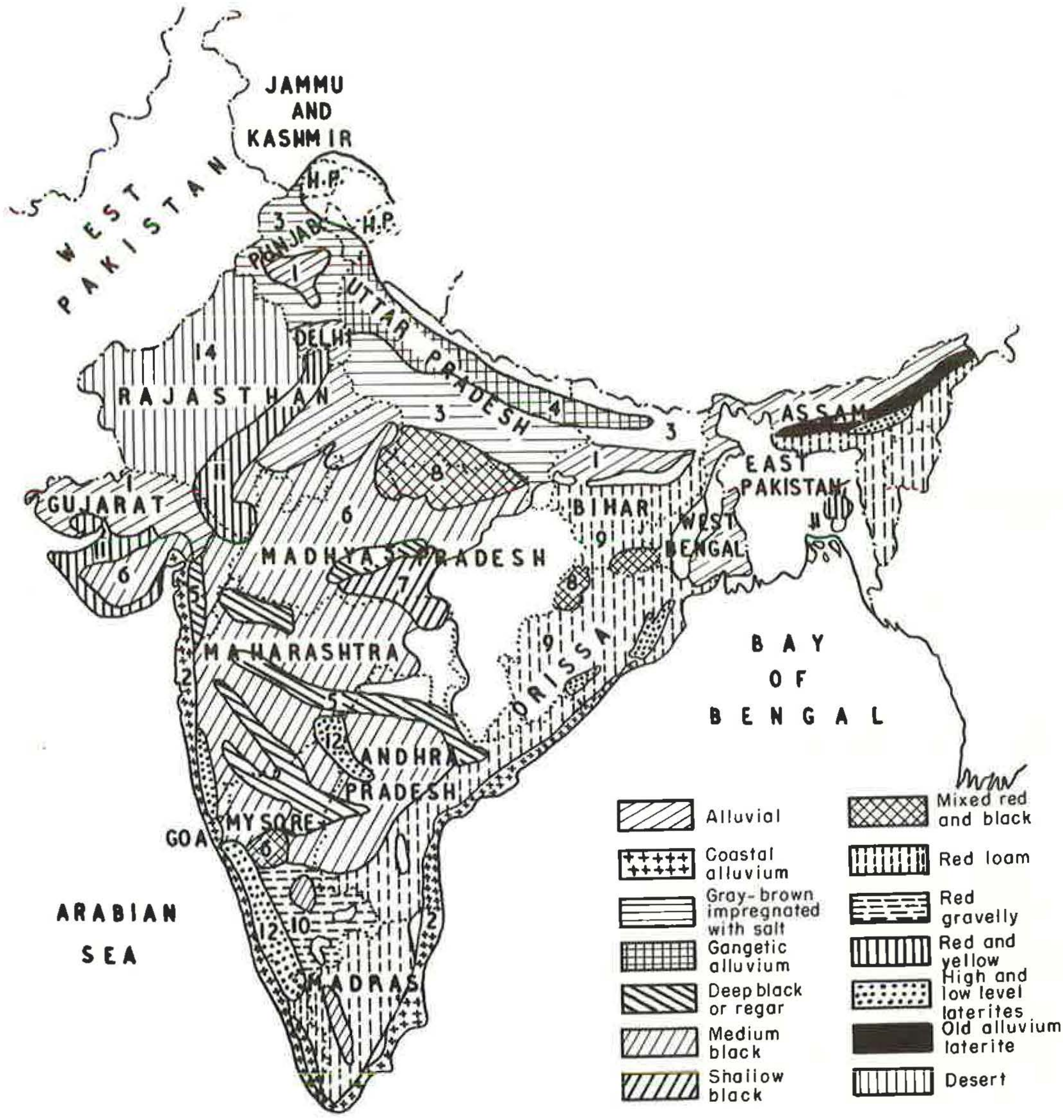

Figure 2. Soil map of India.

For want of facilities all the airfields could not be investigated and, therefore, only 20 runways, which are fairly well spread throughout the country, were selected for investigation. The location of these runways is shown in Figure 3, and also in the Appendix. Out of 20 airfields selected for the study, 13 had rigid cement concrete pavement, 5 flexible pavement, and the remaining 2 had a natural landing ground (Table 1).

Sampling Period

It has been discussed previously that wetting of the subgrade at a particular site having proper side drainage, depends on the intensity of rainfall. With the onset of the monsoon, the water table starts moving up, thereby increasing the moisture content of the subgrade. The worst condition of subgrade moisture will, therefore, be reached at the time of the withdrawal of monsoon, when the site has had maximum rainfall and consequently the highest water table. This fact was confirmed by taking

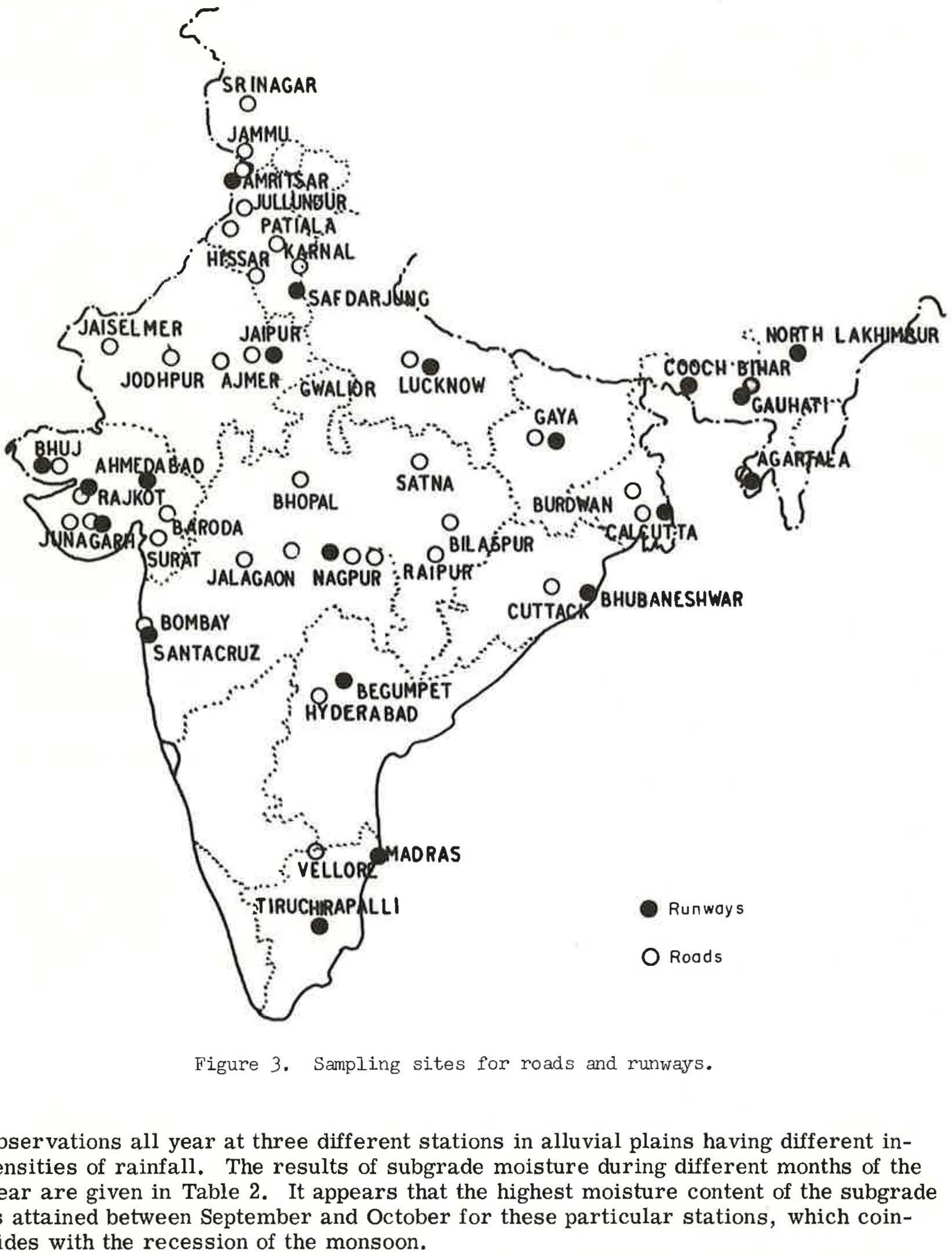

Figure 3. Sampling sites for roads and runways.

observations all year at three different stations in alluvial plains having different intensities of rainfall. The results of subgrade moisture during different months of the year are given in Table 2. It appears that the highest moisture content of the subgrade is attained between September and October for these particular stations, which coincides with the recession of the monsoon.

It was, therefore, decided to take samples of the subgrade in different parts of the country at the time of withdrawal of the monsoon. Because the dates of withdrawal of the monsoon in different areas are likely to change by a few days from year to year, arrangements were made with the Meteorological Department for telegraphic intimation about the probably date of withdrawal of the monsoon for that year, so that the samples of the subgrade could be taken at the most appropriate time. Information gathered from the Irrigation Department showed that the water table does not start

TABLE 2

SEASONAL SUBGRADE MOISTURE VARIATION UNDER ROAD PAVEMENT

Month	Subgrade Moisture (%)		
	Lucknow	Delhi	Mathura
Jan.	2.9	14.1	19.3
Feb.	4.8	15.2	--
March	4.5	16.3	18.6
April	--	6.8	--
May	--	8.0	19.1
June	3.1	6.5	15.9
July	2.1	17.7	--
Aug.	--	20.4	19.1
Sept.	--	22.3	26.0
Oct.	7.6	17.1	--
Nov.	--	18.6	18.8
Dec.	3.5	17.1	--

receding immediately with the withdrawal of the monsoon, but that it takes a few days to recede. This gave some flexibility to the duration of sampling at different sites without seriously affecting the highest moisture content of the subgrade.

Location and Frequency of Sampling

It has been stated earlier that wetting of the subgrade can take place either from the water table when it is high enough, or from the wet berms to a width of about 3 ft, towards the center of the road, when the water table is low. In any case, if the sampling point is fixed at 3 ft from the edge towards the center of the road, it will take care of both processes of wetting the subgrade. Based on these assumptions, the sampling points were fixed at a distance of 3 ft from the edges towards the center of the road. It was also advantageous because, incidentally, this place is normally subjected to the maximum traffic effect, being under the wheel track in most of the roads.

In the case of runways, fixing the sampling point at a distance of 3 ft from the edges was of no practical use, as this part of the runway is never under traffic. The sampling points were, therefore, fixed at a distance of 10 to 15 ft from the edges towards the center of the runway to get as close to the subgrade condition of the track as possible without interfering with the air traffic.

To get a good average, five samples in a mile every 1,000 ft apart were taken for both the roads and the runways.

Depth of Sampling

The depth to which stresses due to traffic will travel down to the subgrade will depend on the area of contact and the type of pavement. For the same intensity of traffic, the stresses will travel to a greater depth in the case of a flexible pavement as compared to a rigid pavement, but even in the case of a flexible pavement, the stresses are not likely to travel even under heavy traffic beyond a 3-ft depth of the subgrade. Undisturbed samples of the subgrade were, therefore, taken to a depth of only 3 ft, by driving thin steel tubes with an area ratio of about 20 percent.

Vegetation in the Vicinity

The type of vegetation growing close to the road was also recorded to see if this had any marked effect on the subgrade moisture. It was, however, observed that there was no difference in the moisture content of the subgrade due to the difference in the nature of vegetation growing at that time of the year. This can probably be attributed to the fact that vegetation had plenty of water from rain itself and, therefore, the moisture content of the subgrade was not affected. It is more likely that vegetation will have an influence on the subgrade moisture during the dry season.

Testing and Samples

The undisturbed soil samples collected to a depth of 3 ft from the various stations were subjected to the following tests in the laboratory:

1. Moisture content.
2. Dry bulk density.

3. Specific gravity.
4. Liquid limit.
5. Plastic limit.
6. Sand content (fraction coarser than 200, U.S. std. sieve in soil mortar).

Laboratory Testing Procedure

It has been stated earlier that undisturbed samples of the subgrade for a depth of 3 ft were collected in a sampling tube. For laboratory tests, samples from various depths of the profile were obtained by pushing out the samples by means of a plunger. In the case of very clayey soils, this procedure did not work well and undisturbed samples from the tube were taken by inserting another tube of a smaller diameter, with a sharp cutting end. The type of tests and their frequency of determination in the 3-ft profile is discussed next.

Moisture Determination.—The moisture content of the subgrade profile was determined in the top 2 in. in the middle of first, second, and third foot; and also in the last 2 in. of the third foot. The moisture in the top 2-in. sample was determined to find out if there was any accumulation of moisture at the top immediately under the payment.

Dry Bulk Density.—The dry bulk density for each foot of the sample was determined. Because a large number of samples were to be dealt with, the method of determining dry bulk density was expedited by pushing a thin-walled cylindrical mould with a 2-in. diameter and a height of about 0.5 in., into the undisturbed soil sample. Because the mould had a known weight and volume, the test resolved itself to the determination of weight of the mould with the sample, before and after drying in the oven. The dry bulk density generally varied from 1.6 to 1.7 g per cc, but no results are recorded in this paper.

Specific Gravity.—The specific gravity of each foot of soil profile was determined by means of a specific gravity bottle according to the standard method, and the values generally ranged between 2.65 and 2.75 g per cc.

Consistency Limits.—An average sample of 1-ft soil profile was tested for liquid limit, plastic limit, and fraction coarser than 200 U.S. standard sieve in the soil mortar. The results are given in Table 1.

Degree of Saturation.—The moisture present in the soil is expressed as the percentage moisture in the dry weight of soil. This is not very informative as the stability of a soil is dependent not only on the moisture but also on the final moisture-holding capacity under a saturated condition for a particular dry bulk density in the field. The moisture content is, therefore, expressed in this paper as the degree of saturation, which also takes into consideration the dry bulk density and specific gravity of soil. The degree of saturation was calculated according to the following formula:

$$\text{Moisture content to fill voids completely} = \frac{\text{Specific gravity} - \text{Dry bulk density}}{\text{Specific gravity} \times \text{Dry bulk density}} \times 100$$

$$\text{Degree of saturation} = \frac{\text{Moisture content}}{\text{Moisture content to fill voids completely}} \times 100$$

ANALYSIS

From the data of moisture content, dry bulk density, and specific gravity of the subgrade soil samples, the degree of saturation of the subgrade for the top and bottom 2-in. samples as well as the average of the first, second, and third foot depths of the subgrade was calculated. The results for the degree of saturation which is an average of five samples at a particular site are given in Table 1.

The results show that by and large there is a regular moisture gradient in the subgrade—the moisture content increasing with the depth. This is true both for roads and runways irrespective of the soil type and rainfall conditions. There are, however, some exceptions. In the case of heavy clays (such as black cotton soils, which are montmorillonitic in nature), the moisture content in the top 2 in. of the subgrade immediately under the pavement is the highest. This is shown in Table 1 by road sites 33 and 39 and airfield runway site 14 with the liquid limit between 66 and 75 percent and the plasticity index between 33 and 40. This observation is, however, not fully supported by road site 40 soil, which is almost as clayey as the other soils.

It is quite likely that due to a poor sealing surface, some moisture might have traveled down to increase the moisture content in the top 2 in. of the subgrade. More data are, however, required to establish this phenomenon. Also, in the case of road sites 6, 9, 30, 32, and 34 which vary in texture from loamy to silty clay loam and lie in dry areas with a low water table, the moisture content in the first foot of the subgrade is generally higher as compared to moisture in the top 2 in. or a foot or two below it. In the absence of sufficient data, it may not be possible to offer a proper explanation, but it has been observed in certain dry areas in India that there is a tendency for the moisture to travel in the vapor phase on account of the thermal gradient in the subgrade which causes the accumulation of moisture at a certain depth towards the surface.

The observations made earlier during the discussion of the data on moisture gradient are equally true for airfields except that, inasmuch as there is no embankment, the surface is nearer the water table as compared to roads in the same zone, thereby resulting in a comparatively higher degree of saturation.

Because there are not many cement concrete road pavements, it is not possible to compare the degree of saturation under a cement concrete and water-bound macadam with sealed surface. It is, however, possible to some extent in one of the cases where a bituminous-sealed water-bound macadam and an airfield with an almost identical thickness of crust having a water-bound macadam base and having six in. of cement concrete (1:2:4) as the wearing course lie in a particular zone with the same water table. This refers to road site 29 and airfield site 13 in Table 1. It appears from the results that the degree of saturation under a bituminous-sealed surface is higher than under a cement concrete pavement. This is only an isolated case and requires a separate study to establish it fully.

Table 1 also shows that in a large majority of cases the variation in the degree of saturation within a 3-ft depth of the subgrade ranges generally between 5 and 10 percent. The degree of saturation for different parts of India as given in this paper is shown in Figure 4 to be about 10 percent.

The degree of saturation of the subgrade in dry areas abounding in predominantly sandy soils such as those met in the southwest of Punjab and Rajasthan is of the order of 20 to 40 percent. The western parts of Rajasthan being drier than the eastern parts, the different being due to the difference in the intensities of rainfall.

The alluvial soils with a rainfall of about 30 in. (such as those met with north of Gujarat State and south of Delhi) have degree of saturation ranging between 60 and 70 percent. As the rainfall increases in the same zone to about 50 in. per annum as in case of the Indo-Gangetic plains, the degree of saturation also increases to between 80 and 90 percent. With the further increase in rainfall to about 75 in. per annum and above, the degree of saturation further rises to between 90 and 100 percent. These conditions of high rainfall are encountered in the eastern part of West Bengal and north of Assam.

The red and yellow soils (such as those encountered in Central India) with rainfall ranging between 50 and 75 in., have a degree of saturation of about 70 percent. For the same rainfall intensities, the red loam soils have a slightly higher degree of saturation (80 percent). This is due to the fact that red soils contain a higher percentage of clay as compared with yellow soils.

The black cotton soils which cover almost the whole of Central India have a rainfall of 20 to 75 in. per year. The degree of saturation irrespective of rainfall intensity is 90 to 100 percent.

The coastal alluvium with rainfall above 100 in. has a degree of saturation of about 100 percent.

CONCLUSIONS

The study indicates that the degree of saturation of the subgrade consisting of a particular type of soil follows more or less the same pattern as the rainfall contours. There are, however, some small deviations due to abrupt changes in the texture of the soil. The only exception to this being the area abounding in black cotton soil, where the degree of saturation ranges between 90 and 100 percent irrespective of the intensity of the rainfall. This is due to the fact that black cotton soils have high colloidal content which exerts great suction to pull up moisture from the water table at various depths.

The study also shows that the phenomenon of "equilibrium moisture content," as found in some parts of England under sealed surface, is not observed in India.

It can be inferred that for the prevailing rainfall intensities (or water table conditions) in India, the design of the road pavement need not be carried out at complete saturation for all the places in India, as practiced now according to standard procedure.

Because the degree of saturation in different parts of the country for a particular depth of the water table is known from this study, subsequent small changes in the degree of saturation from year to year can roughly judged from the corresponding rise or fall of the water table, or more precisely, from laboratory study. This is, however, true only when the water table is within a certain range of the capillary fringe. When the water table is beyond a certain depth (as in the case of dry areas), then the present information regarding the degree of saturation can hold good for all practical purposes for some time to come, as there is not much likelihood of abrupt increase in rainfall intensity, the nature of the soil remaining the same.

It is admitted that a study of this type cannot be very precise to start with, but it does make out a case for future work, for more exact demarcation of boundaries for each zone, and also for taking up laboratory studies of a fundamental nature on subgrade moisture movement.

PRACTICAL ASPECTS

The present study has shown that the degree of saturation of the subgrade in different parts of the country during the worst part of the year varies from 20 to 100 percent. It is, therefore, logical that the design of a flexible road or runway pavement should be carried out at the moisture content equivalent to the highest degree of saturation actually attained in the field, and not at saturation, as is done at present according to the standard CBR test procedure.

This will, therefore, require a modification in the existing procedure of determining CBR, so that the test, instead of being carried out under a saturated condition, can be conducted at a moisture content corresponding to the degree of saturation prevailing in the field. One of the practical methods to achieve this would be to compact the soil to a desired density at a moisture content corresponding to a particular degree of saturation. This will require varying intensities of compacting effort, which will increase with the decrease in moisture content. The samples thus compacted could immediately be subjected to the CBR test. A study carried out at the Road Research Laboratory, London (2), with a number of soils statically compacted according to the procedure previously mentioned, shows that the CBR determined at varying degrees of saturation bears a straightline relationship when drawn on a semilog basis. It should, therefore, be possible to calculate the CBR at various degrees of saturation from a single test value determined experimentally.

It is known however, that strength of soil is governed not only by the moisture content and dry bulk density but also by the manner in which the particles are arranged. The preceding technique has, therefore, a drawback inasmuch as the method of compaction (especially at low moisture) is very drastic and does not simulate the field condition. The results thus obtained in the laboratory are, therefore, not likely to be of much practical value.

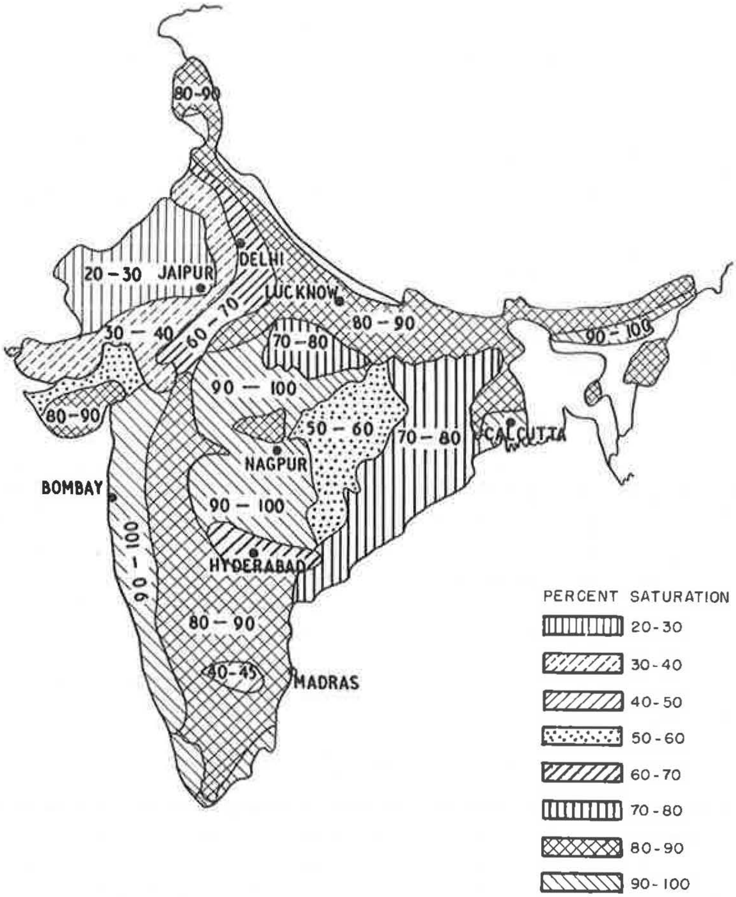

Figure 4. Map of degree of saturation of subgrade in India.

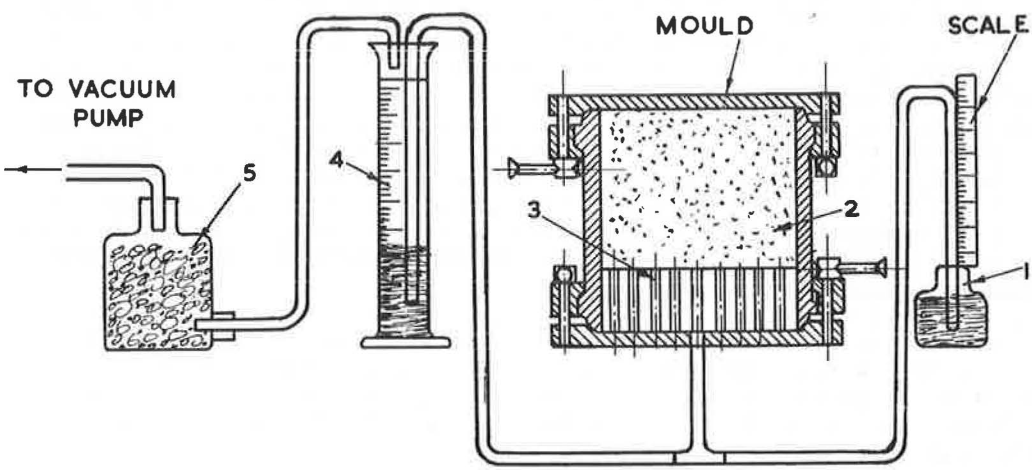

Figure 5. Laboratory set-up for bringing compacted soil to varying degrees of saturation: (1) manometer, (2) soil sample, (3) perforated wooden block, (4) graduated cylinder, (5) calcium chloride.

PROPOSED METHOD FOR ADJUSTING DEGREE OF SATURATION THROUGH SUCTION

The variation in the moisture content of the subgrade in actual practice is brought about by the movement of the water table. As the water table falls, it exerts negative pressure resulting in the decrease of moisture content in the subgrade and vice versa. In this technique, the degree of saturation existing in the field is simulated in the laboratory without disturbing the structure of the soils.

The soil is compacted dynamically at optimum moisture to a desired density. It is then allowed to saturate for four days according to standard procedure. The mould is then taken out and the 2-in. thick metallic spacer is replaced by a wooden perforated spacer of exactly the same size, to permit easy flow of water. A metallic base with a central hole is then screwed to the mould and carefully waxed to make it airtight. A plate is fixed, at the other end of the mould where the compacted soil crust is up to the top, and properly waxed. The base of the mould is then connected to the vacuum pump through a measuring cylinder. The set-up is shown in Figure 5. The vacuum is then applied; from the water removed from the specimen and collected in the cylinder, an approximate idea of the degree of saturation of the soil sample in the mould is obtained. A number of tests can be run with different moulds and brought to varying degrees of saturation for determining the CBR. Some preliminary trials with sandy soils have shown that a vacuum has to be created for about 12 hours to bring the degree of saturation down from 100 to 50 percent. The time for other degrees of saturation is given in Table 3.

TABLE 3

TIME FOR SOME DEGREES OF SATURATION

Deg. of Sat.	Period of Evac. (hr)
90	0.25
80	0.75
70	3.0
60	6.0
50	12

There will, however, be some moisture gradient in the compacted crust, which will increase as the degree of saturation falls. In such cases it will be better to base the CBR on the degree of saturation corresponding to the moisture content determined from the center of the mould.

Some initial trials have shown that the relationship is linear between the CBR and the degree of saturation ranging between 90 and 50 percent. There is, however, a tendency for the CBR at 100 percent saturation to shift from the line.

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DIVISION OF INDIA INTO DIFFERENT ZONES ON BASES OF RAINFALL AND SOIL TYPE

Annual Rainfall (in.)	Alluvial Soil	Coastal Alluvium	Alluvial Soil with Salt	Gangetic Alluvium Calcareous	Black Cotton Soil			Mixed Red & Black Soils	Red Loam	Red Gravelly Soil	Red & Yellow Soils	Laterite & Low & High Soils	Laterite Old Alluvium	Desert Soils
					Deep Black	Medium Black	Shallow Black							
<10														Jaisalmer
10-20	Bhatinda	Vellore	Hissar	Jodhpur							Bhuj[1]			
20-30	Shrinagar, Delhi[1]	Bhavnagar[1]	Karnal		Jalgaon	Kurnool, Ahmedabad[1], Junagadh, Hyderabad[1]			Trichinopoly[1]	Mandya, Bangalore, Kolar	Rajkot Jaipur[1]			Ajmer
30-50	Jammu, Gwalior, Patiala, Gaya[1]	Surat	Amritsar[1] Jullundur, Lucknow[1]		Baroda	Nagpur[1]	Betrul	Satna	Purlia		Bilaspur			
50-75	Calcutta[1]		Bombay[1], Madras[1]			Saugor	Bhandara			Ranchi	Raipur	Cuttack[1]	Burdwan	
75-100	North Lakhimpur[1]								Manipur Rd					
100-150	Agartala[1], Gauhati[1], Cooch[1], Bihar[1]													
150-200													Shillong	

[1]Runways.

Another paper, sponsored by the Committee on Surveying, Mapping and Classification of Soils, was presented at the 42nd Annual Meeting by A. H. Stallard and Glenn Anschutz. This paper, "Use of the Kelsh Plotter in Geo-Engineering and Allied Investigations in Kansas," includes discussion of the use of airphotos in geological, slide area, hydraulic and hydrographic investigations and in bridge deck and road condition surveys. Consequently the paper will be published in another issue of the Research Record devoted to Photogrammetry and Aerial Surveys.