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AN INVESTIGATION OF MOISTURE CONTENTS UNDER PAVED ROADS IN KUCHING, SARAWAK

by

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SUMMARY

As a first approach to forecasting the moisture contents in subgrades under bituminous surfaced roads in Sarawak, moisture content data was obtained for the subgrade below sealed pavements at five sites in Kuching. The soils were clays or sand silt clays alluvially deposited. The moisture contents found in the soils (which ranged from 14 to 48 per cent) gave a good correlation with the plastic limits. The results suggest that a relationship M = 1.1(P.L.) may be used to predict critical conditions for design for roads built over the plastic alluvial soils where the water table is 3-7 ft below the road suface.

The observed moisture contents also correlated well with moisture contents calculated from a knowledge of the depth of the water table and the plasticity characteristics using a method suggested by Black[1] for predicting moisture content and C.B.R. value. These results suggest that with subgrades of these types of soil compacted to a density equal to 100 per cent B.S. Normal compaction and with a shallow water table, design may generally be based on C.B.R. values of the order of 5-7 per cent.

AN INVESTIGATION OF MOISTURE CONTENTS UNDER PAVED ROADS IN KUCHING, SARAWAK

Introduction

The strength of a soil depends on density and moisture content. In order to design roads economically, engineers need to be able to predict the moisture conditions which will develop in the subgrade after the road is constructed, since they may be different from those at which the materials are placed.

As a first approach to forcasting the subgrade moisture contents which will be attained after construction of bituminous roads in Sarawak, moisture contents were measured at five locations in the Kuching area which had been surfaced for from three to ten years. These moisture contents are compared with the plastic limits of the soils. The field work of this investigation was carried out during a period when the writer was attached to the Sarawak Public Works Department on a Technical Assistence assignment.

Soils examined

The soils examined were grey/white and yellow/grey coloured clays and sand-silt-clay materials of medium to low plasticity and had no structure. At one location they were of alluvial terrace origin while at the others they were recently developed soils possibly derived from weathered shale. Details and laboratory data are shown in Table I and in Fig. 1 the liquid limits and plasticity indeces of the samples are shown on the Casagrande chart.

Method of examination

Since it was not possible to open up roads which were in good condition solely for testing purposes, the samples were obtained in the course of other work. Some were obtained in the course of trench excavations for water-mains in Kuching where these crossed road junctions. They were thus far enough from the verges to avoid edge effects. Prior notice was usually received from the Authority concerned so it was possible to take samples within a few minutes of the road being opened, most of them from depths between one and three inches below the pavement layers.

Other samples wer obtained during an investigation into surface crazing on Port road (2). In this case samples were taken under both sound and crazed areas and in situ C.B.R. measurements were made.

An estimate was made of depth of the water table below the road surface by measuring with hand-level and staff, the depth of the sample point below the road surface. Despite day to day fluctuations of waterflow in the ditches, indications of the mean level were usually present, and these were taken as an approximate indication of the position of the water table.

Climatic data

The mean monthly rainfall data of the area is given in Appendix 1.

Tests carried out

Samples from every site were tested for moisture content and Atterberg limits. In addition samples from the sites examined during the road-failure investigation were tested for grading and dry density while a few representative compaction and specific gravity determinations were carried out. At a few

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of the locations opened for pipe-laying, in situ density, grading, specific gravity and compaction tests were carried out. Tests were performed according to B.S. 1377: 1961, (3) Tests 1A, 2A, 3, 4, 5A, 6D, 10, 11 and 12D. Results are shown in Table I.

Analysis of results

(a) State of compaction

Reference to the data in Table I shows that at the points where compaction test samples were taken, states of compaction were as shown in Table II. The mean density was close to the maximum given by the British Standard Normal compaction test.

TABLE II

States of compaction

Soil No	Soils Type	Relative Compaction % (to B.S. Normal)
1	White clayey silt	92
3	White Sand-silt plus clay binder	100
4	White Sand-silt plus clay binder	104
5	White Sand-silt plus clay binder	101
16	Light grey silty clay	98
20	Black silty clay	95
21	Black silty clay	91
22	Black silty clay	92
23	White Sand-silt plus clay binder	99
24	White Sand-silt plus clay binder	104
25	White Sand-silt plus clay binder	108
26	White Sand-silt plus clay binder	109
Mean		99

(b) Comparison of the measured moisture contents with the plastic limits

The actual moisture were compared with the plastic limits of the soils. These comparisons are shown in Fig. 2. Using the method of least squares, the best straight line which fits the data is M = 1.1 x PL for samples taken where the surface was in good condition.

Where M = the measured moisture content of the subgrade
and PL = Plastic limit of the soil.

The method of calculation is shown in Appendix 2.

Discussion of results

In the area investigated of recently deposited or derived soils and with water tables varying from 3-7 ft, there is a good correlation of the measured moisture content of the subgrade under sealed roads and the plastic limit of the soil as suggested in Road Note No. 31 (5). The correlation coefficient in this case is 0.95 and the method of calculation is given in Appendix 3.

/Black

Black [1] has suggested a method by which moisture contents and bearing capacity can be estimated from a knowledge of the Atterberg limits of the soil and the depth of the water table, and these figures have been estimated. Table III gives the calculation of the suctions at the various sites. Since the soils at the sites were of recent geological origin and normally consolidated, it was decided to make the comparison with remoulded soils. Fig. 3 shows the relation between suction and effective moisture content for soils whose atterberg limits lie on a line whose equation is

$$(P1) = 0.838\ (LL) - 14.2.$$

The soils tested in Sarawak did not conform to this relation, and a correction is needed to the moisture content which is read off Fig. 3. The correction is made on the assumption that at any plasticity index, soils with the some consistency index will have the same suction. (The consistency index $CI = \frac{LL-m}{PI}$ where m is the moisture content). The method of making this correction is given in Appendix 4, and the results are shown in Table III and Fig. 4. The correlation is good with a straight line relationship, $M = 0.95\ Md + 4.6$

Where M = actual moisture content
and Md = deduced moisture content

with a correlation coefficient of 0.98 for the samples taken from under the pavements.

The C.B.R. results have been estimated by determining the consistency index corresponding to the calculated suction and plasticity values for undisturbed soils given by Black [1]. The estimated C.B.R. values are given in Table IV for comparison with the in situ measured values. In most cases the estimated values are marginally lower than the values measured.

<u>Conclusions</u> - see summary.

/TABLE I

TABLE I

Soil, pavement and water table data

Soil No.	Site	Soil description	Soil origin	Water table below road surface approx. ft	Depth below constr. in	Date	Atterberg limits L.L.	P.L.	P.I	Grading Gravel %	Sand %	Silt %	Clay %	S.G.	B.S. Normal compaction D.M.C. %	M.D.D. LB/ft^2	A.V. %	Conditions under road M.C. %	D.D. LB/ft^2	A.V. %	Remarks
1	Port Road	White sand-silt-clay	Alluvial	5	2	Feb 62	43	27	16	0	8	58	34	2.61	22	99	5	31	91	1	11" construction close together — Sample points
2	Port Road	White sand-silt-clay	Alluvial	5	2	Feb 60	37	25	12	0	20	38	42	2.66				27	96	1	
3	Port Road	White sand-silt-+ clay binder	Alluvial	5	2	Feb 62	29	18	11	0	40	43	17					19	103	5	11" consturction close together — Sample points
4	Port Road	White sand-silt + clay binder	Alluvial	5	2	Feb 62	26	20	6	0	59	32	9	2.62	17	103	9	17	107	5	
5	Port Road	White sand-silt + clay binder	Alluvial	5	2	Feb 61	27	20	7	13	43	27	17					19	104	5	
6	Mosque Road	Gravel-sand-clay	Alluvial	5	2	Jan 63	43	22	21	16	37	47						27			12" construction
7	Satok Road	Light grey sand-silt clay	"Bottom Lands" from weathered shales	6	2	Jan 63	48	21	27	1	40	59						28			6" construction
8	Batu Lintang Road	White silty clay	"Bottom Lands" from weathered shales	5	6	Apr.63	65	43	22									48			18" construction
9	Batu Lintang Road	Light grey clayey silt	"Bottom Lands" from weathered shales	5	2	May 63	28	18	10					2.65				19			12" construction — Sample points close together
10	Batu Lintang Road	White clayey silt	"Bottom Lands" from weathered shales	5	12	May 63	31	22	9									25			12" construction
11	Batu Lintang Road	White clayey silt	"Bottom Lands" from weathered shales	5	24	May 63	50	34	16									39			12" construction
12	Batu Lintang Road	White silty clay	"Bottom Lands" from weathered shales	5	36	May 63	50	34	16									40			12" construction
13	Batu Lintang Road	Grey clayey silt	"Bottom Lands" from weathered shales	4	2	May 63	27	17	10	0	8	92						18			21" construction
14	Batu Lintang Road	Grey clayey silt	"Bottom Lands" from weathered shales	4	2	May 63	24	15	9	0	10	74	16					18			24" construction
15	Batu Lintang Road	Grey silt-clay	"Bottom Lands" from weathered shales	3	2	May 63	35	20	15	0								24			21" construction
16	Batu Lintang Road	Light grey silty clay	"Bottom Lands" from weathered shales	5	2	Sept.63	46	25	21					2.60	26	92	5	30	90	2	18" construction
17	Bamfylde Road	White silty clay	"Bottom Lands" from weathered shales	6	2	Sept.63	45	25	20					2.62				27	94	2	18" construction
18	Bamfylde Road	Yellow/grey clay	"Bottom Lands" from weathered shales	7	3	Sept 63	49	32	17									31			21" construction
19	Bamfylde Road	Yellow/grey clay	"Bottom Lands" from weathered shales	7	15	Sept.63	51	33	18									34			21" construction
20	Port Road	Black silty clay	Alluvial	5	2	Feb 60												26	95		11" construction — Sample points close together
21	Port Road	Black silty clay	Alluvial	5	2	Feb 61	41	28	13	0	12	51	37	2.67	21	100		28	91		crazed
22	Port Road	Black silty clay	Alluvial	5	2	Feb 62												27	92		12" construction
23	Port Road	White sand-silt + clay binder	Alluvial	5	2	Feb 62	29	18	11	0	40	43	17				8	24	102		crazed
24	Port Road	White sand-silt + clay binder	Alluvial	5	2	Feb 60												14	107		Sample points close together
25	Port Road	White sand-silt + clay binder	Alluvial	5	2	Feb 61	28	19	9	2	58	30	10		17	103		21	111		11" construction crazed
26	Port Road	White sand-silt + clay binder	Alluvial	5	2	Feb 62												14	112		

Note 1. Construction at sample points 1-7 and 20-26 was grouted crusher-run for total depthe shown. Construction depths for all other points include 6-8 in. grouted crusher-run with gravel sub-base.

Note 2. The surface at the points where samples 20-26 were taken was crazed.

/TABLE III

TABLE III

Plasticity, suction and deduced moisture content

I	II			III	IV	V	VI	VII	VIII	IX	X	XI
Soil No	Atterberg data			Water table below road surface ft	Depth of soil above sample to nearest foot	Depth of construction above sample to nearest foot	Height of sample above water table to nearest foot	Over burden pressures feet of water to nearest foot	Compressibility factor	Total suction = VI + (VII x VII)	Deduced moisture content %	Actual moisture content %
	L.L.	P.L.	P.I.									
1	43	27	16	5	0	1	4	2	0.3	5	27	31
2	37	25	12	5	0	1	4	2	0.2	4	24	27
3	29	18	11	5	0	1	4	2	0.2	4	16	19
4	26	20	6	5	0	1	4	2	0	4	16	17
5	27	20	7	5	0	1	4	2	0.7	4	17	19
6	43	22	21	5	0	1	4	2	0.4	5	23	27
7	48	21	27	6	0	1	5	1	0.6	6	23	28
8	65	43	22	5	0	2	3	4	0.5	5	44	48
9	28	18	10	5	0	1	4	2	0.1	4	16	19
10	31	22	9	5	1	1	3	3	0.1	3	20	25
11	50	34	16	5	2	1	2	5	0.3	4	34	39
12	50	34	16	5	3	1	1	6	0.3	3	35	40
13	27	17	10	4	0	2	2	4	0.1	2	16	18
14	24	15	9	4	0	2	2	4	0.1	2	14	18
15	35	20	15	3	0	2	1	4	0.3	2	21	24
16	46	25	21	5	0	2	3	4	0.4	5	26	30
17	45	25	20	6	0	2	4	4	0.4	6	25	27
18	49	32	17	7	0	2	5	4	0.3	6	31	31
19	51	33	18	7	1	2	4	5	0.4	6	32	34
20				5	0	1	4	2	0.2	4	27	26
21	41	28	13	5	0	1	4	2	0.2	4	27	28
22				5	0	1	4	2	0.2	4	27	27
23	29	18	11	5	0	1	4	2	0.2	4	16	24
24				5	0	1	4	2	0.1	4	15	14
25	28	19	9	5	0	1	4	2	0.1	4	15	21
26				5	0	1	4	2	0.1	4	15	14

/TABLE IV

TABLE IV

Estimated C.B.R. values from depth of water table and in situ C.B.R. values

Soil No.	Estimated C.B.R.%	Measured in situ C.B.R.
1	5	7
2	4	9
3	4	22
4	10	11
5	10	10
6	5	-
7	6	-
8	5	-
9	4	-
10	4	-
11	4	-
12	3	-
13	2	-
14	2	-
15	1.5	-
16	5	-
17	5	-
18	5	-
19	5	-
20	4	7
21	4	3
22	4	2
23	5	8
24	17	15
25	17	21
26	17	20

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(1) BLACK W.P.M., 1962. A method of estimating the California Bearing Ratio of cohesive soils from plasticity data. Geotechnique, London, 1962.

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(4) RUSSAM K. and D. CRONEY. Estimation of subgrade moisture distribution. Transport-Communications Review, 1961, (176), 151-9.

(5) A guide to the structural design of bituminous surfaced roads in tropical and sub-tropical countries. Road Research Laboratory, Road Note No. 31 Department of Scientific and Industrial Research, Road Research Laboratory, Harmondsworth 1962.

/APPENDIX

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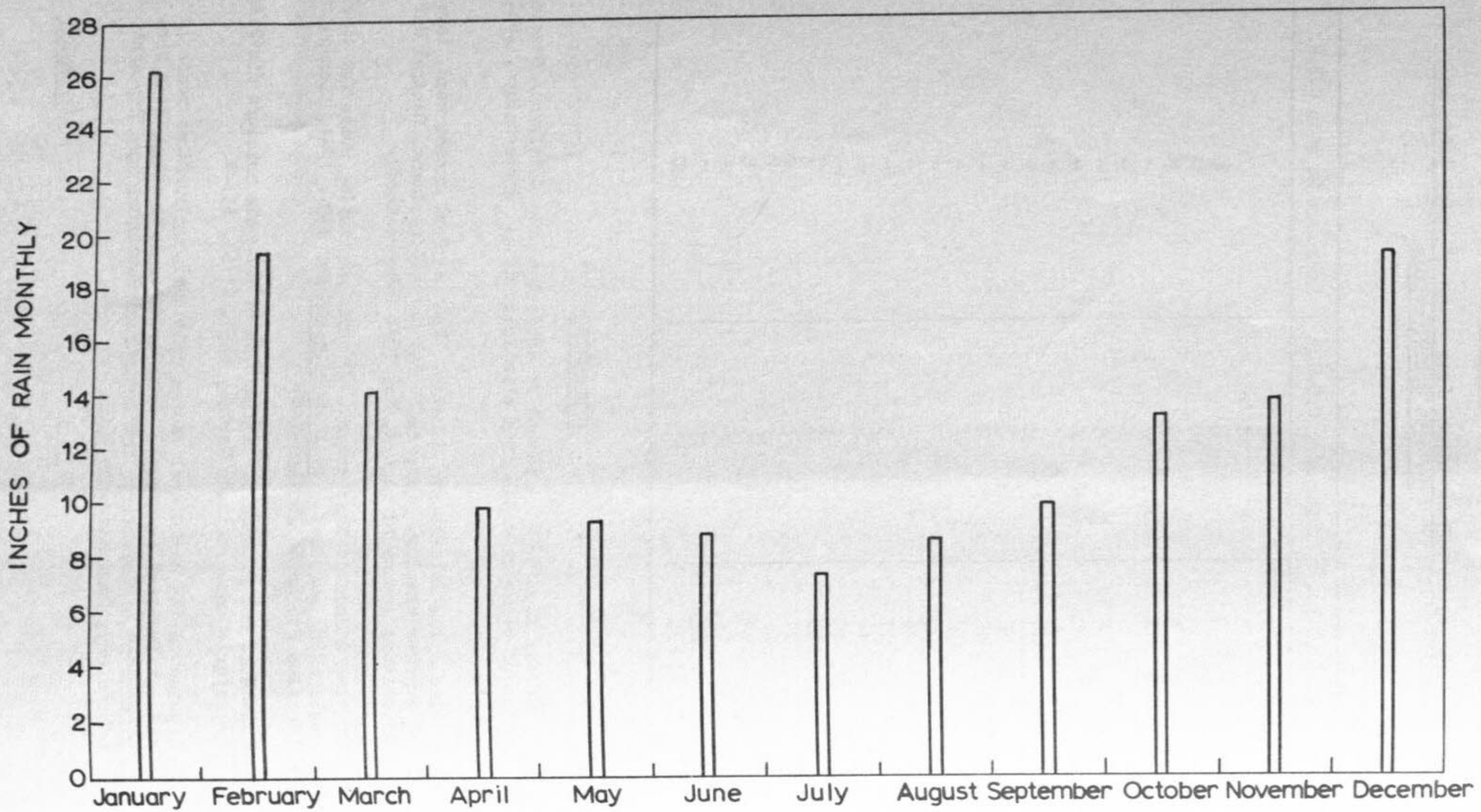
SW.



Appendix 1. MEAN MONTHLY RAINFALL FOR KUCHING

APPENDIX 2

Determination of parameters m and c in the expression y = mx + c relating plastic limit and actual moisture contents under sealed pavements in Kuching

Observation No	Plastic limit x	Actual moisture content % y	Equation (1) $y = mx + c$	Equation (1) x coefficoent of m $xy = mx^2 + cx$
1	27	31	31 = 27m + c	837 = 729m + 27c
2	25	27	27 = 25m + c	675 = 625m + 25c
3	18	19	19 = 18m + c	342 = 324m + 18c
4	20	17	17 = 20m + c	340 = 400m + 20c
5	20	19	19 = 20m + c	380 = 400m + 20c
6	22	27	27 = 22m + c	594 = 484m + 22c
7	21	28	28 = 21m + c	588 = 441m + 21c
8	43	48	48 = 43m + c	2064 = 1849m + 43c
9	18	19	19 = 18m + c	342 = 324m + 18c
10	22	25	25 = 22m + c	550 = 484m + 22c
11	34	39	39 = 34m + c	1326 = 1156m + 34c
12	34	40	40 = 34m + c	1360 = 1156m + 34c
13	17	18	18 = 17m + c	306 = 289m + 17c
14	15	18	18 = 15m + c	270 = 225m + 15c
15	20	24	24 = 20m + c	480 = 400m + 20c
16	25	30	30 = 25m + c	750 = 625m + 25c
17	25	27	27 = 25m + c	675 = 625m + 25c
18	32	31	31 = 32m + c	992 = 1024m + 32c
19	33	34	34 = 33m + c	1122 = 1089m + 33c
			521 = 471m + 19c	13993 = 12649m + 471c

521 = 471m + 19c (1)

13993 = 12649m + 471c (2)

Solving these simultaneously gives m = 1.1
c = 0

/APPENDIX 3

APPENDIX 3

Calcualtion of correlation coefficient for the relation between plastic limit and actual moisture contents under sealed pavements in Kuching

Observation	Plastic limit x	Actual moisture content % y	$x-\bar{x}$	$(x-\bar{x})^2$	$y-\bar{y}$	$(y-\bar{y})^2$	$(x-\bar{x})(y-\bar{y})$
1	27	31	+2.2	4.8	+3.6	13.0	+7.9
2	25	27	+0.2	0.04	-0.4	0.2	-0.1
3	18	19	-6.8	46.2	-8.4	70.6	+57.1
4	20	17	-4.8	23.0	-10.4	108.2	+49.9
5	20	19	-4.8	23.0	-8.4	70.6	+40.3
6	22	27	-2.8	7.8	-0.4	0.2	+1.1
7	21	28	-3.8	14.4	+0.6	0.4	-2.3
8	43	48	+18.2	331.2	+20.6	424.4	+374.9
9	18	19	-6.8	46.2	-8.4	70.6	+57.1
10	22	25	-2.8	7.8	-2.4	5.8	+6.7
11	34	39	+9.2	84.6	+11.6	134.6	+106.7
12	34	40	+9.2	84.6	+12.6	158.8	+115.9
13	17	18	-7.8	60.8	-9.4	88.4	+73.3
14	15	18	-9.8	96.0	-9.4	88.4	+92.1
15	20	24	-4.8	23.0	-3.4	11.6	+16.3
16	25	30	+0.2	0.04	+2.6	6.8	+0.5
17	25	27	+0.2	0.0	-0.4	0.2	-0.1
18	32	31	+7.2	51.8	+3.6	13.0	+25.9
19	33	34	+8.2	67.2	+6.6	43.6	+54.1
	471	521		972.4		1309.4	1077.3

Mean $\bar{x} = \frac{471}{19} = 24.8$ Mean $\bar{y} = \frac{521}{19} = 27.4$

Standard deviation of x, $\sigma x = \sqrt{\frac{\Sigma (x-\bar{x})^2}{n}} = \sqrt{\frac{972.4}{19}} = 7.16$

Standard deviation of y, $\sigma y = \sqrt{\frac{\Sigma (y-\bar{y})^2}{n}} = \sqrt{1309.4} = 8.30$

Correlation coefficient $= \frac{\frac{1}{n}\Sigma (x-\bar{x})(y-\bar{y})}{\sigma x \sigma y} = \frac{\frac{1}{19} \times 1077.3}{7.16 \times 8.30} = 0.95$

/APPENDIX 4

APPENDIX 4

Correction of calculated moisture contents for soils not conforming to the equation P.I. = 0.838 (L.L.) - 14.2

Example: Soil No 1.

From Table III total suction = 5 feet
plasticity index = 16

Interpolating in Fig. 1, indicated (uncorrected) moisture content = 20 per cent.

The liquid limit of soils satisfying the equation P.I. = 0.838 (L.L.)-14.2 and having a plasticity index of 16 per cent is

$$\frac{16 + 14.2}{0.838} = 36 \text{ per cent}$$

$$\text{The consistency index } \left(= \frac{\text{L.L.} - \text{M.C.}}{\text{P.I.}}\right) = \frac{36 - 20}{16} = 1$$

∴ Assuming that for a given plasticity index, soils with the same consistency index will have equal suctions, the corrected moisture content, Md, for soil No. 1 with liquid limit = 43, is given by:

$$1 = \frac{43 - Md}{16}$$

$$\therefore \quad Md = 43 - 16 = 27 \text{ per cent}$$

ATTERBERG TEST RESULTS FOR KUCHING SOILS

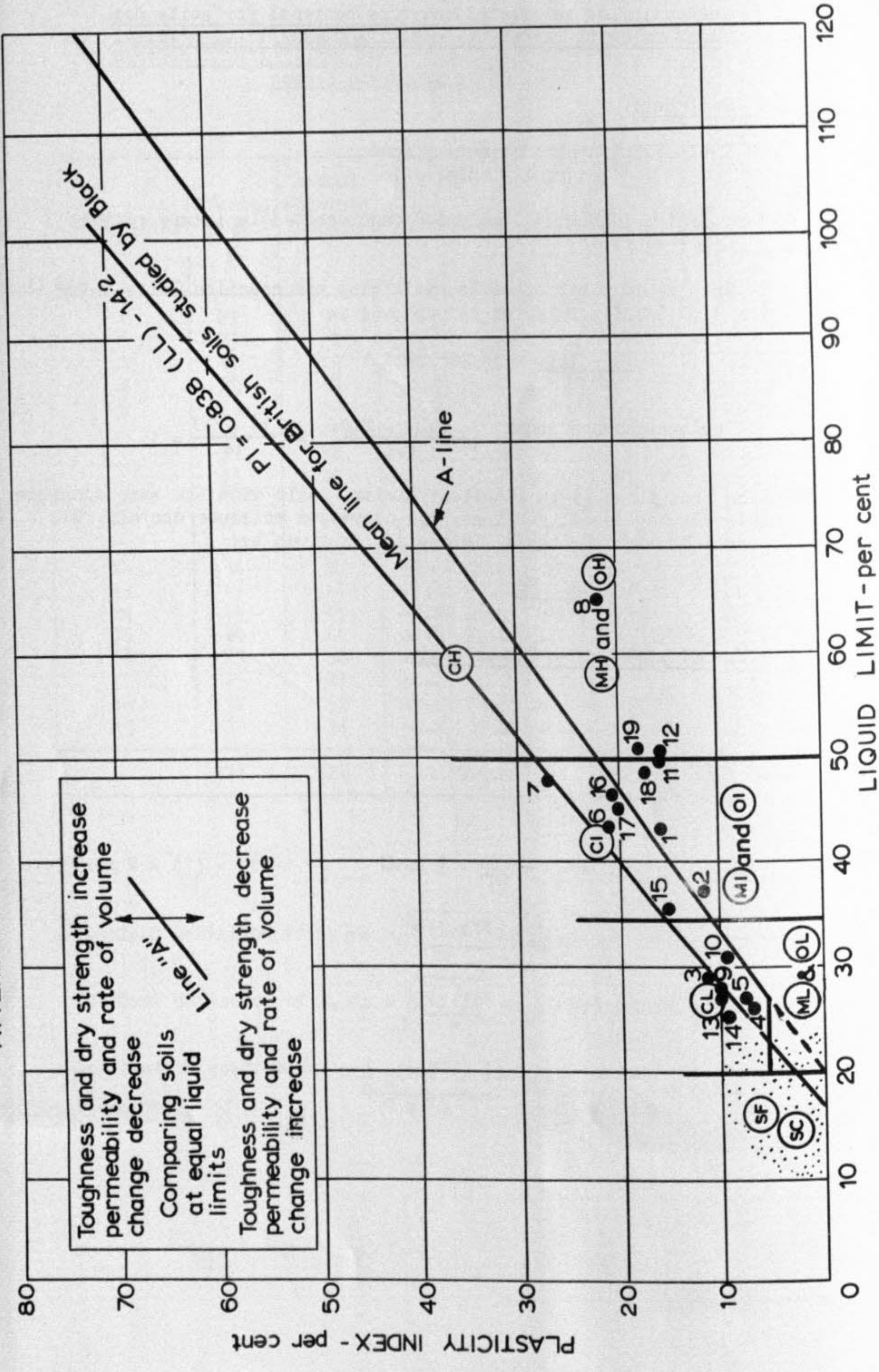


Fig. 1. THE CASAGRANDE SOIL CLASSIFICATION CHART

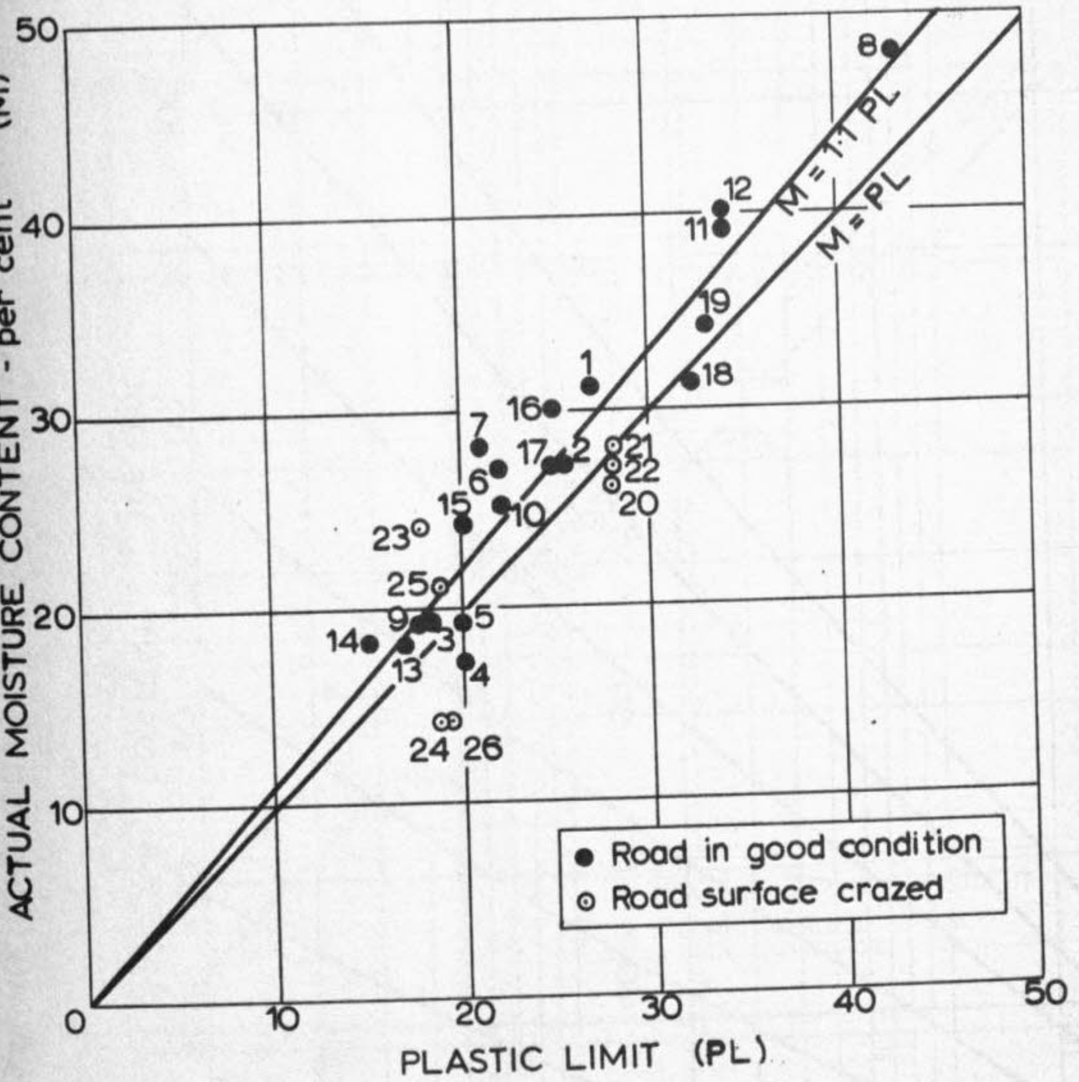


Fig. 2. COMPARISON OF ACTUAL MOISTURE CONTENT WITH PLASTIC LIMIT.

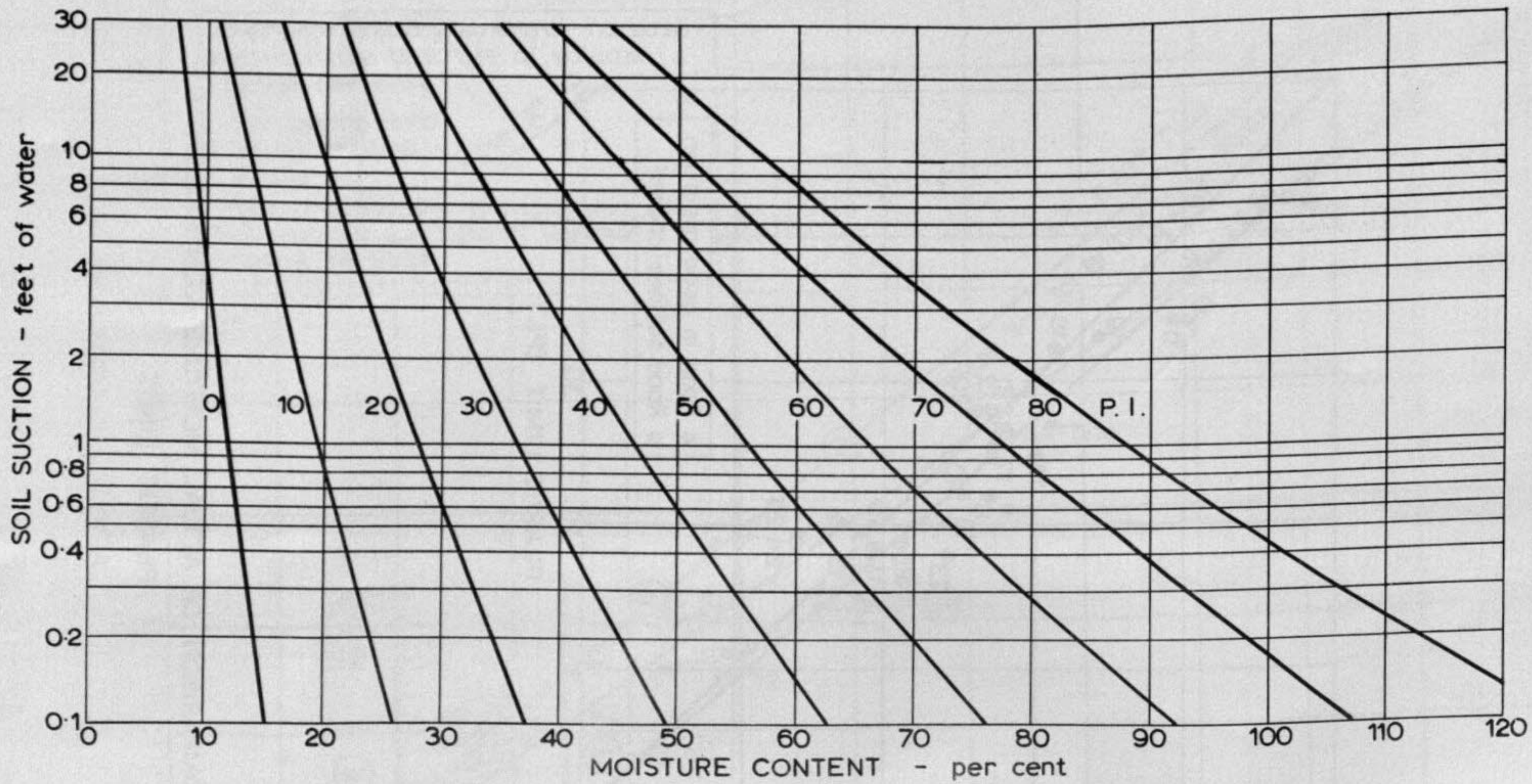


Fig. 3. THE RELATION BETWEEN SUCTION AND EFFECTIVE MOISTURE CONTENT AT VARIOUS PLASTICITY INDECES.

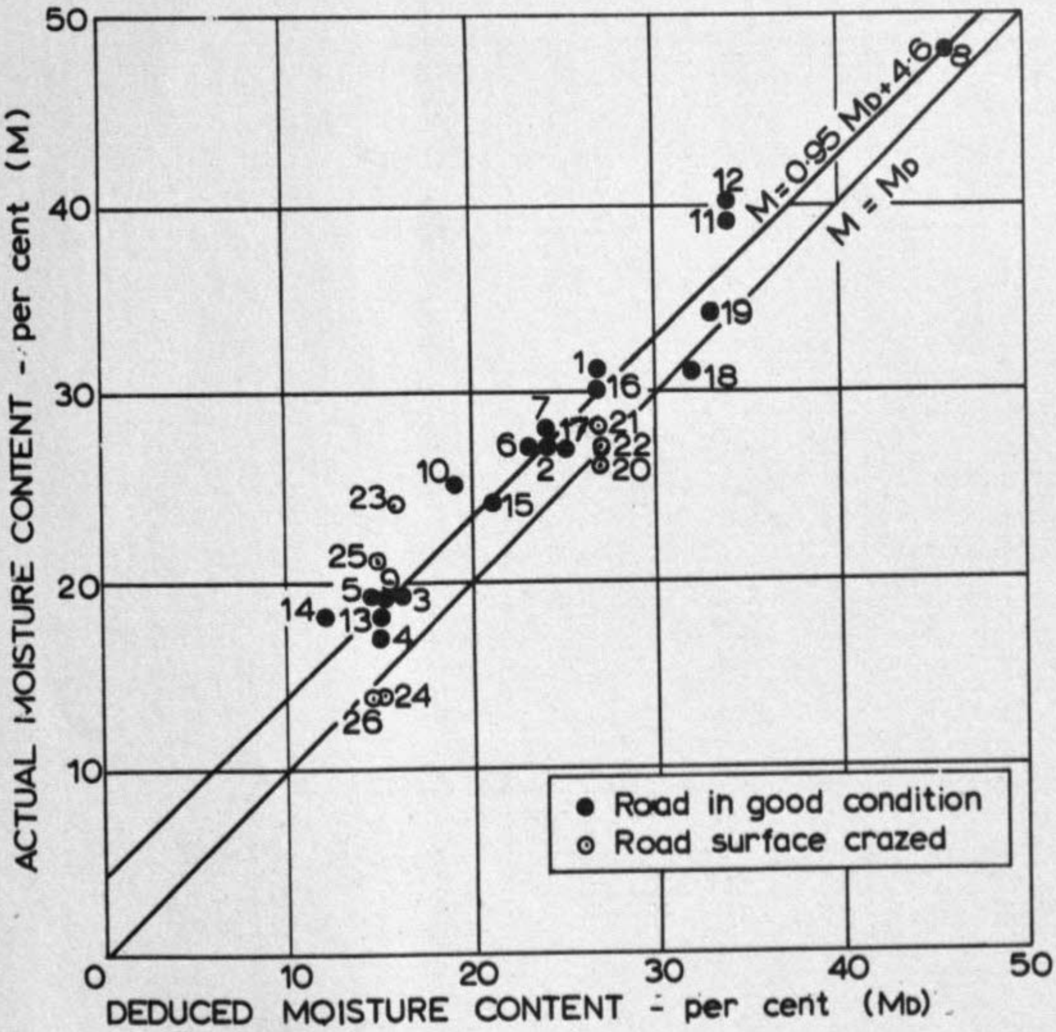


Fig. 4. COMPARISON OF ACTUAL MOISTURE CONTENT WITH THOSE DEDUCED FROM THE DEPTH OF WATER TABLE (1)