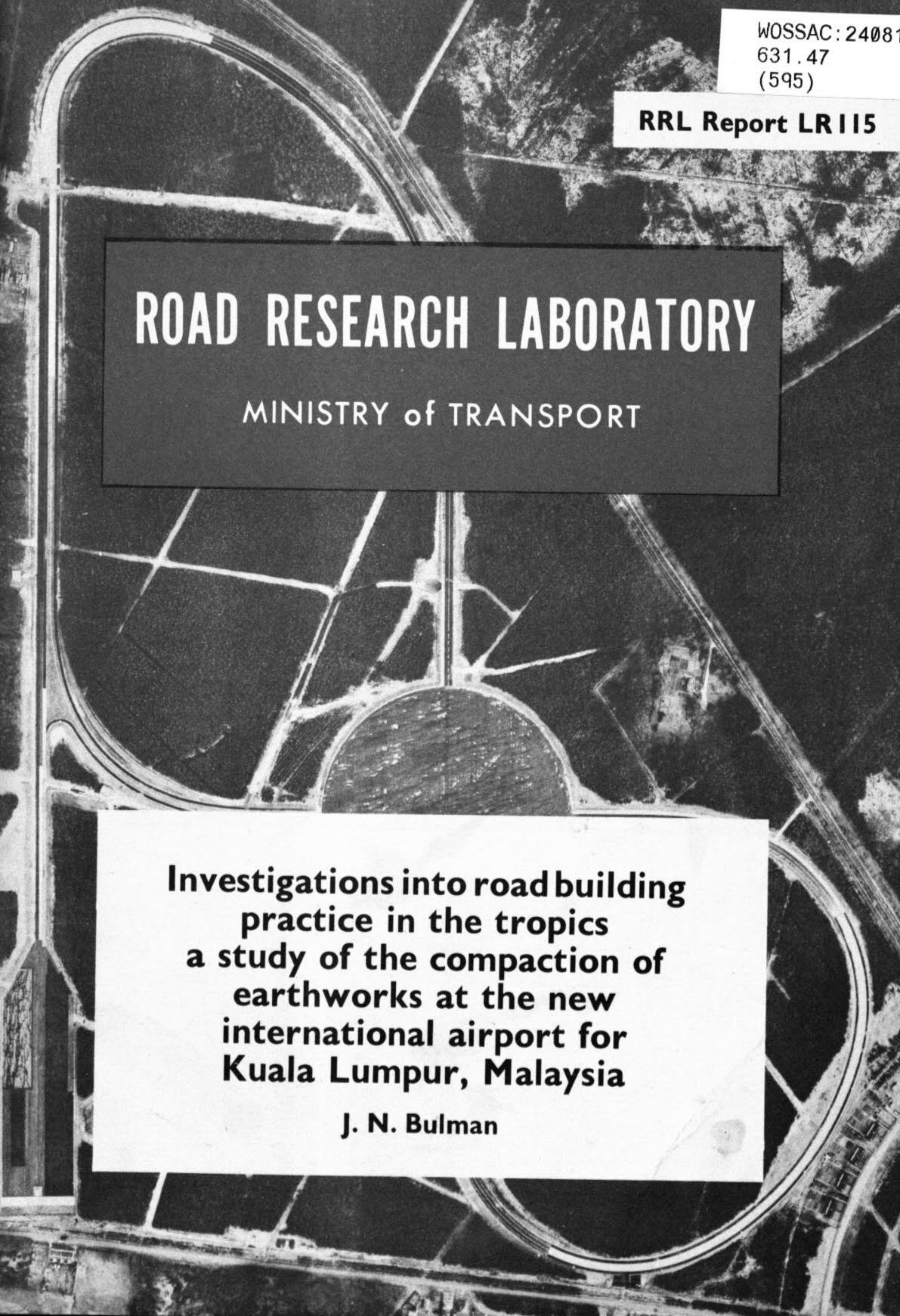

RRL Report LR 115

ROAD RESEARCH LABORATORY

MINISTRY of TRANSPORT

Investigations into road building practice in the tropics a study of the compaction of earthworks at the new international airport for Kuala Lumpur, Malaysia

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INVESTIGATIONS INTO ROAD BUILDING PRACTICE IN THE TROPICS A STUDY OF THE COMPACTION OF EARTHWORKS AT THE NEW INTERNATIONAL AIRPORT FOR KUALA LUMPUR, MALAYSIA

by

J. N. Bulman

CROWTHORNE

ROAD RESEARCH LABORATORY

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ABSTRACT

As part of a study of aspects of normal road-building practice in tropical countries the levels of compaction achieved on earthworks at the new international airport at Kuala Lumpur, Malaysia, were investigated.

The study shows that given efficient site-management, with particular emphasis on the minimising of the effects of adverse weather conditions, high states of compaction can be consistently obtained in a wet tropical climate on residual sandy clay soils.

1. INTRODUCTION

In most branches of civil engineering the materials employed can be specified within fine limits and the quality and dimensions of the finished product can be controlled within close tolerances. The road and airport engineer is among the least fortunate in these respects; his field of operation is spread over a ribbon or tract of country on soil foundations which may vary from yard to yard; the materials he uses, soils, gravels and crushed rocks, vary within themselves; and above all, his work is exposed to the whims of weather. Such problems are often acute in road and airfield construction in developing countries of the tropics where extensive use is made of natural rather than processed materials.

To produce a practical design and a realistic specification the design engineer should know the inherent variability of the materials and processes he intends using, the effect of weather conditions on them and the standards of construction that can be consistently attained. In addition, data on the effort and cost of working to given standards and tolerances should enable him to assess the benefits accruing from and the expense of achieving different standards. This greater understanding of construction processes should also enable construction engineers to use their resources more efficiently.

As part of the Laboratory's programme of research overseas an investigation into road building practice was initiated in East Africa in 1960 with the examination of seventeen road-construction schemes [1]. Subsequent studies were made in Sierra Leone [2] and the British Virgin Islands [3]. The climate in these regions is often dry and even in the wetter parts rainfall is confined to well defined seasons.

The presence of a research team from the Road Research Laboratory in Malaysia enabled studies to be extended to work in a wet tropical environment where rainfall is well distributed throughout the year. This report gives details of the standard of compaction attained in the construction of the new international airport at Kuala Lumpur, which was constructed in 24 months during 1963-65. Although not a road-building project there are no basic differences in earthworks construction techniques. The more compact site on airfield construction does allow more intensive supervision and in the present instance it is considered that the amount of control was higher than on normal road construction. The levels of compaction attained under the paved areas at the airport represent the highest that can reasonably be expected on a normal contract using commonly available compaction equipment.

The research team from the Laboratory visited the site over a period of several weeks, observing the construction procedures and the control techniques of the supervisory staff; a typical area of fill was examined in detail to obtain more data on the variability within the completed works. Abstracts of site records were also made.

2. DETAILS OF THE SITE

2.1 Location

The new international airport is situated about 15 miles (24 km.) west of Kuala Lumpur on the west side of the Malayan peninsula. Physiographically the site is in a region of moderate relief lying between the main north-south mountain range, which is the 'backbone' of the peninsula, and the flat coastal plain. Characteristically this transitional region comprises numerous dome-shaped small hills of residual soil, ranging in height from about 50 feet to 250 feet (15 metres to 76 metres), and frequently cultivated as rubber plantations.

2.2 Climate

The mean annual rainfall in the Kuala Lumpur district is 96 inches (2, 440 mm), with the highest monthly falls occurring in March, April, September, and October. In each of these months, the total on average is between 10 and 11 inches (250 and 280 mm). The driest month of the year is normally June, with an average of 4 inches (100 mm) of rain, but even in this month significant rain can be expected on 12 days out of the 30.

During the 24-month period when earthmoving took place (April 1963 to March 1965) the rainfall measured by four gauges on the site gave an average of 200 inches (500 mm). This total was reached in spite of exceptional dryness in June, 1963, and rainfall well below the average in May, 1964 and January, 1965. The monthly rainfalls measured on site are shown in Fig. 1.

There is little variation in the daily temperature in Kuala Lumpur during the year, the mean maximum being 32°C, and the mean minimum 23°C.

The daily variation of relative humidity also shows very little change throughout the year, the mean maximum being 96 per cent and the mean minimum 63 per cent.

2.3 Details of the works

The design and construction of the new Kuala Lumpur airport has recently been described in detail by Skepper et al [4]. Briefly, the airport consists of a runway 11, 400 ft (3, 475 m) long and a parallel taxiway connected to the runway by four linkways. The width of the runway is 150 ft (45. 7 m) and the taxiway is 75 ft (22. 9 m) wide.

All the paved areas, which total about half a million square yards (about 420, 000 m^2) are of 'flexible' construction consisting of a sub-base of 4 inches (10 cm) of lime- or cement-stabilized soil, a bituminous-bound granular base 12 inches (30 cm) thick, and a 4 inch (10 cm) thick rolled-asphalt surfacing. The pavement was designed to have a Load Classification Number (L.C.N.)[5] of 100.

Earthmoving involved about $6\frac{3}{4}$ million cubic yards (5.2×10^6 m^3) in all, $5\frac{1}{2}$ million (4.2×10^6 m^3) of which were in the residual granitic soils. The remainder included roughly $\frac{1}{4}$ million cubic yards (0.2×10^6 m^3) of topsoil, $\frac{2}{3}$ million cubic yards (0.5×10^6 m^3) of sand and the balance of a mixture of peats and alluvial silts and clays. Rock was not encountered on the site.

The maximum depths of cut and fill, about 60 ft (18 m) and 30 ft (9 m) respectively, occurred at the southern end of the site where small hills of the residual soil were separated by steep-sided gullies.

2.4 Soil types

The low lying northern end of the airport site consists of heterogeneous recent alluvium overlying sedimentary rocks. Peaty swamps, sands, silts, and clays are all found in close proximity to each other.

The elevated southern half of the site consists of residual sandy, silty, clays developed over granite. The majority of the earthmoving at the site, apart from some swamp-clearing and removal of soft spots, involved the latter soil type, which provided virtually all the cut and 90 per cent of the fill on the contract. In the later stages of the job some sand fill, representing about 10 per cent of the total, was hauled from an off-site borrow-pit.

Residual granitic soil similar to that found at the site occurs widely in the Malay peninsula, chiefly in the mountainous areas. About one eighth of the federal road system is built over such soil. The investigation into the compaction achieved on earthworks was confined to this group of soils.

At the surface the granite has weathered into a sandy clay, which gradually merges into a sandy silt at greater depths. Three different types of the soil are distinguishable in the profile by both colour and texture, and they can be roughly classified by their silt content.

Table 1 shows the United States Public Roads classification [6] and the range of properties of the three soil types, based on the results of a large number of tests [7] made on site; also shown are the results of laboratory compaction tests on typical samples of each soil type. Fig. 2 shows the particle-size-distribution curves and specific gravities for these typical samples.

TABLE 1

Summary of Properties of Granitic Residual Soils

Soil Type	'Type I'		'Type II'		'Type III'	
Description	Yellow sandy silty clay		Yellow sandy silty clay with red mottling		Yellow/red mottled sandy clayey silt	
U.S. Public Roads Classification	A-6 and A-7		A-7		A-7	
Particle Size Distribution						
Gravel* per cent	0 - 30		0 - 25		0 - 5	
Sand per cent	30 - 64		30 - 64		30 - 64	
Silt per cent	5 - 30		5 - 55		35 - 60	
Clay per cent	25 - 60		10 - 50		5 - 20	
Plasticity Determinations						
Liquid Limit per cent	35 - 100		45 - 105		40 - 70	
Plastic Limit per cent	25 - 48		25 - 48		30 - 45	
Plasticity Index per cent	10 - 50		10 - 62		5 - 30	
Type of Laboratory Compaction Test	Heavy B.S. ≠	B.S. ≠	Heavy B.S. ≠	B.S. ≠	Heavy B.S. ≠	B.S. ≠
Range of site laboratory results						
Maximum dry density lb/ft^3	97 - 114	85 - 107	100 - 112	93 - 99	100 - 113	96**
g/cm^3	1.55 - 1.83	1.36 - 1.71	1.60 - 1.79	1.49 - 1.59	1.60 - 1.81	1.54**
Optimum moisture content per cent	14 - 26	18 - 31	14 - 24	20 - 24	13 - 19	20**
Typical samples						
Maximum dry density lb/ft^3	104	93	110	98	105	91
g/cm^3	1.67	1.49	1.76	1.57	1.68	1.46
Optimum moisture content per cent	21	27	16	22	15	26

* All the gravel fractions passed the ¼" sieve.

≠ The B.S. Heavy Compaction Test (Test No. 11 B.S. 1377: 1961) corresponds closely to the modified A.S.S.H.O. (A.S.S.H.O. Designation: T180-57) and modified Proctor Compaction tests. The B.S. Compaction Test (Test No. 10 B.S. 1377: 1961) corresponds closely to the A.A.S.H.O. (A.A.S.H.O. Designation: T99-57) and Proctor Compaction tests.

** Only one result obtained.

'Type I' soil always occurred overlying 'Type II' soil, which in turn overlay 'Type III', but the thickness of the two upper layers varied considerably from place to place.

The natural moisture content of the soils ranged from 20 per cent to 40 per cent and the in-situ densities from 70 per cent to 90 per cent of Heavy B. S. maximum dry density.

3. COMPACTION SPECIFICATION

The degree of compaction for the various types of fill was specified by the relative compaction method. The acceptance criterion for fill in areas under pavements was a minimum relative compaction value of 95 per cent Heavy B. S. maximum dry density. Fill away from the paved areas was required to be compacted to the original in-situ density of the cut material, or a minimum relative compaction of 85 per cent Heavy B. S. maximum dry density.

4. THE COMPACTION OPERATIONS

4.1 Site compaction trials

Compaction trials were carried out on the site at the commencement of the contract with various rollers and, as a result, 15 ton (approximately 15 tonne) sheepsfoot rollers and a 15 ton (approximately 15 tonne) steel-drum roller were selected for the compaction of all the fill. Table 2 gives details of the rollers used.

TABLE 2

Details of compaction plant

Towed smooth-wheel roller	Roll diameter	6ft. 11in. (211 cm)
	Roll width	10ft. 0in. (305 cm)
	Gross weight	15.3 tons (15.5 tonne)
	Load per inch width	285 lb.
	Load per cm width	51 Kg.
Towing track-laying tractor	Draw-bar H.P.	185 H.P.
	Width of each track	24in. (61 cm)
	Distance between centres of tracks	84in. (213 cm)
	Gross weight	Approx. 47,000 lb. (214 tonne)
	Average track pressure	8.5 lb./sq.in. (0.60 kg/cm^2)
Towed sheepsfoot roller	Roll diameter	5ft. 7in. (170 cm)
	Roll width	6ft. 0in. (183 cm)
	Length of feet	7in. (18 cm)
	Size of feet	4in. x 5½in. (10 cm x 14 cm)
	Foot pressure	258 lb/sq.in. (18 kg/cm^2)
	Gross weight	34,050 lb. (15.5 tonne)
	Number of feet	180
	Minimum number of passes to give complete coverage	4.6

Note: The sheepsfoot roller was towed by a special tractor fitted with rear wheels in the form of narrow sheepsfoot rollers, each of which was identical to half the drum of the roller detailed above. These tractor wheels track outside the towed drum behind, thus at any one pass do not contribute to the state of compaction beneath the towed drum.

It was found that a relative compaction of 95 per cent Heavy B.S. maximum dry density could be obtained on the 'Type I' soil with between 10 and 20 passes of the sheepsfoot roller, and on the 'Type III' soil with between 16 and 26 passes of either roller when the compacted layers were about 6 in (15 cm) thick, the equivalent loose-layer thickness being about 9 in (23 cm). The moisture content range over which this degree of compaction could be reached was about 5 per cent for 'Type I' soil but only about 2 per cent for 'Type III' soil, (see Figs. 3 and 4). 'Type II' soil had intermediate compaction characteristics.

In practice it was very difficult to maintain the silty 'Type III' soil at a suitable moisture content for good compaction; thus, as far as possible, this soil was reserved for the fill in areas that were not to be paved.

The maximum values of relative compaction obtained during these trials were of the same order as the highest values obtained with any of the compaction plant used in the full-scale compaction trials carried out at the Road Research Laboratory [8].

4.2 Compaction control procedure

Control of the compaction of fill was confined in the main to the areas underlying the pavements. It was found that the 85 per cent Heavy B.S. requirement for the areas remote from the airfield pavements could be achieved with very little compaction additional to that given by the earthmoving equipment itself; thus control testing in these areas was infrequent.

In the fill underlying the pavements the state of compaction of each nominal 6 in (15 cm) thick compacted layer, which in practice might well range up to 9 in (23 cm) thick on occasion, was checked by measuring the in-situ density using the sand-replacement method. Normally one measurement was made for every 750 to 1,000 sq. yd. (630-840 m^2) but in the top 2 feet (60 cm) this was increased to one determination for every 500 sq. yd. (420 m^2). Density holes were 6 in (15 cm) deep. These rates of testing are in the middle of the range recently recommended by the Laboratory [9].

The in-situ densities were taken on a set grid pattern, examples of which are shown in Figs. 5 and 6. Moisture content was measured by "SPEEDY MOISTURE TESTERS" in the field and the in-situ densities calculated on the spot. Moisture-content samples for oven-drying were also taken to confirm each "Speedy" moisture content. Each "Speedy Moisture Tester" was calibrated for the three soil types and it was found that the "Speedy" and oven-dry moisture contents remained in satisfactory agreement throughout the contract.

Samples for laboratory compaction tests were taken the previous day in the area of cut from which the layer of fill under test was being won. Thus, using the "Speedy" moisture content an immediate decision was possible on the acceptability of the in-situ density results.

If two or three individual in-situ densities out of a group of twenty or so were below the acceptance level they would commonly be ignored and the whole area would be accepted.

Attempts were made to allow for the variability in the soil compaction properties that could occur in one layer of fill by the visual identification of two or three soil variants whose laboratory maximum dry densities had been previously determined.

In addition to the part-time supervision of an engineer, the earthworks compaction control was carried out by a full-time staff of 2 to 3 technicians and 5 or 6 labourers. This amount of control although within the recommended range for the United Kingdom [9] is much greater than would be found on most road-construction schemes in Malaya. It is considered that the levels of compaction attained under the paved areas at this airport represent the highest that could reasonably be expected with these soils and with commonly available compaction equipment.

4.3 The effect of rainfall on the earthworks compaction

The earthworks output and particularly the amount of fill compacted varied greatly from week to week, mainly on account of rainfall. This is illustrated in Fig. 7, in which the area of fill compacted per month is compared with the monthly rainfall over a period of two years.

Attempts were made to minimise the effect of rain on newly placed fill as far as possible, particularly in those areas where a high relative density was required. A steep crossfall was arranged on the fill and temporary drainage provided. When rain threatened, loose areas were 'sealed' with a 15 ton (approximately 15 tonne) smooth-wheel roller to reduce the penetration of the water.

In practically all instances the fill, when placed, was wetter than desirable for compaction and was allowed to dry out to a suitable moisture content before effective compaction could be achieved. The drying-out process was assisted on many occasions by breaking up the soil with disc ploughs. A more detailed description of the processes is given in reference 4.

4.4 Additional density measurements by research team

A typical area of about 5,000 sq. yd. (4,200 m^2) of the runway formation was selected by the research team from the Laboratory for a more intensive density checking than was possible in the routine control testing. Fifty in-situ density determinations were made in groups of five, distributed evenly over the area, as indicated in Fig. 8. The soil was 'Type II', and the Laboratory Heavy B.S. maximum dry density of five bulk samples taken at distances along the runway corresponding to each pair of in-situ density-hole groups, ranged from 108 lb/cu. ft. (1.73 g/cm^3) to 105 lb/cu. ft. (1.68 g/cm^3). The results obtained are set out in Table 3.

TABLE 3

Summary of data from intensively tested area

Chainage (see Fig. 8)	feet metres	475 144.8		525 160.0		575 175.2		625 190.4		675 205.6		
Heavy B.S. Compaction Test	Maximum dry density g/cm^3 lb/ft^3	1.82 114		1.84 115		1.79 112		1.79 112		1.73 108		
	Optimum moisture content per cent	14		14		15		14		16		
B.S. Compaction Test	Maximum dry density gm/cm^3 lb/ft^3	1.67 104		1.68 105		1.60 100		1.62 101		1.54 96		
	Optimum moisture content per cent	20		19		23		20		23		Average of all tests
Average of Test Group		West	East	West	East	West	East	West	East	West	East	
In-situ dry density	g/cm^3 lb/ft^3	1.64 102.2	1.80 112.6	1.64 102.2	1.80 112.4	1.65 102.7	1.75 109.2	1.67 104.1	1.73 108.0	1.74 108.5	1.66 103.7	1.71 106.6
In-situ moisture content per cent		21.2	14.0	22.4	17.0	21.3	18.9	20.3	17.2	18.4	20.8	19.1
Compaction relative to heavy B.S. compaction per cent		89.6	98.8	88.9	97.7	91.7	97.5	92.9	96.4	100.5	96.0	95.0
Compaction relative to B.S. compaction per cent		98.3	108.3	97.3	107.0	102.7	109.2	103.1	106.9	113.0	108.0	105.4
Average in-situ moisture content of group minus B.S. optimum moisture content per cent		1.2	-6.0	3.4	-2.0	-1.7	-4.1	0.3	-2.8	-4.6	-2.2	-1.9
Average air-voids of group per cent		4.1	7.4	2.2	2.1	3.5	1.6	3.7	5.6	3.1	3.5	3.6

The average relative densitites ranged from 88.9 per cent to 100.5 per cent of Heavy B.S. maximum dry density, which corresponds to 97.3 per cent to 113.0 per cent of the lighter B.S. maximum dry density. Six out of ten of the hole groups gave average relative dry densities greater than 95 per cent of Heavy B.S. maximum, and eight out of ten of the groups gave average relative densities greater than 100 per cent of B.S. maximum dry density.

The average in-situ moisture content of the samples from the density-hole groups tended to be close to or drier than the B.S. optimum moisture content, though one lone group was some 3 per cent wetter. Only samples from one group of density-holes had an average in-situ moisture content as dry as the corresponding Heavy B.S. optimum moisture content.

In the normal control testing this same area had been covered by eight in-situ density tests, each of which was recorded as being 95 per cent of Heavy B.S. or more.

5. CONCLUSIONS

The concluding stages of the earthworks at the airport had been reached by the time the research team from the Laboratory arrived in Malaya in September 1964. This curtailed the amount of supplementary testing possible; further data would have been desirable, particularly on the amount of testing required and on the location of testing points.

However, it is quite clear from the data available that the degree of compaction achieved on the earthworks was high. Routine site-control testing showed that the average compaction relative to the maximum dry density in the Heavy B.S. compaction test obtained on the residual granitic soils under the paved areas was 96.1 per cent [4]; this is equivalent to about 108 per cent relative to the lighter B.S. compaction test. On the more intensively tested area the corresponding average values were 95.0 and 105.4 per cent respectively. These values exceed those normally obtained on roadworks in the United States of America, Great Britain and East Africa on subgrade layers and are often greater than those found in sub-base and base layers [10].

A similarly high state of compaction has recently been reported in the construction of the R. A. F. airfield at Tengah, Singapore [11]. Consideration of the air voids and the moisture range prevailing in the intensively tested area also shows that a high degree of compaction [12] was achieved.

There was good agreement between the behaviour of the residual granitic soils in the compaction trials and in the intensively tested area. The optimum moisture content for the plant operating in the field was about 6 per cent drier than the optimum moisture content in the B. S. compaction test (see Table I, Figs. 3 and 4). Theoretical calculations [13] for the sheepsfoot roller using the shear strength moisture content relations for the sandy and heavy clay soils [14] used in the full-scale compaction trials, give relative compaction and optimum moisture content values in good agreement with those measured in the field. This type of roller has a high loading; in addition, the large bearing area of each of the feet means that a low number of passes gives complete coverage. The results show that it can achieve states of compaction equal to the highest obtained by other forms of compaction equipment [8].

The interpretation of the specification on site was sensible, and the practice of allowing some 2-3 values out of every 20 results to fall below the specified level made reasonable allowance for the normal scatter in test results. Specifications are now tending to state that at least 9 out of every 10 consecutive samples taken of the compacted material shall have a relative compaction greater than a given value, or that the air-voids content shall be less than a given value [15]. There is often confusion, however, in that the average value found in the compaction trials becomes the limiting value in the above type of specification. Work in East Africa on a large number of road-building schemes indicates that the limiting value in these circumstances should be some 5 per cent relative compaction below the average value [9].

On the more intensively tested area there is some discrepancy between the site control data and that obtained in the more intensive testing. Without more data it is difficult to attribute this to a specific cause. The amount of site control testing carried out is well up to accepted levels [9].

The maximum values of relative compaction obtained in the full-scale compaction-plant trials [8] carried out at the Road Research Laboratory are given by the following expression:-

Maximum relative compaction (per cent) =
112 per cent B. S. maximum dry density $\leqslant$ 104 per cent Heavy B. S. maximum dry density with a maximum error of $\pm$ 3 per cent relative compaction.

The results of the site compaction trials (Figs. 3 and 4) are very close to this expression. The greater difficulty in compacting 'Type III' soil compared with 'Type I' soil to a given degree of compaction relative to the B. S. Heavy compaction test is explained by the relation of this level to the lighter B. S. compaction test for the two types of soil. The lighter B. S. compaction test provides a constant reference value over a wide range of soils, with the B. S. Heavy compaction test providing an overriding maximum value on the lighter soils and granular materials.

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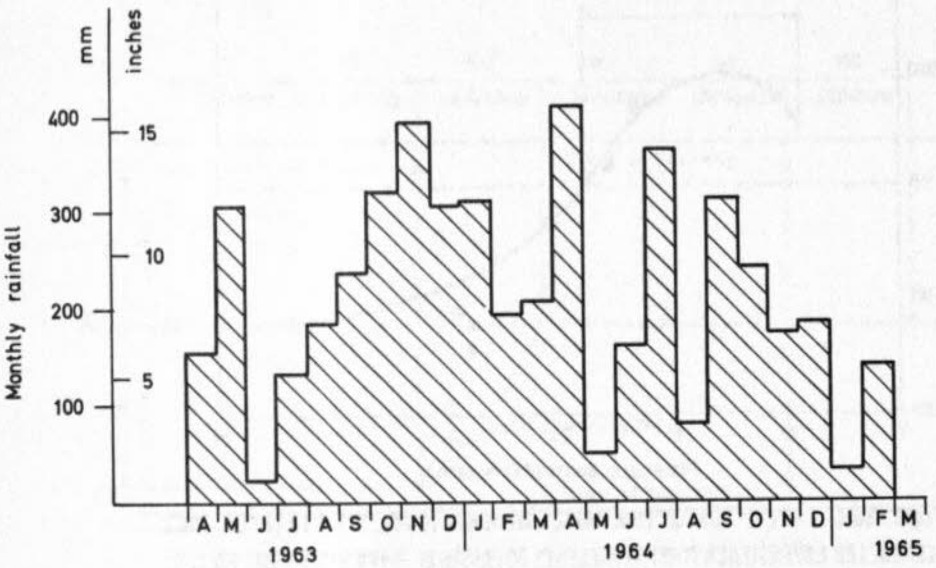

Fig.1. SITE MONTHLY RAINFALL — AVERAGE OF FOUR GAUGES

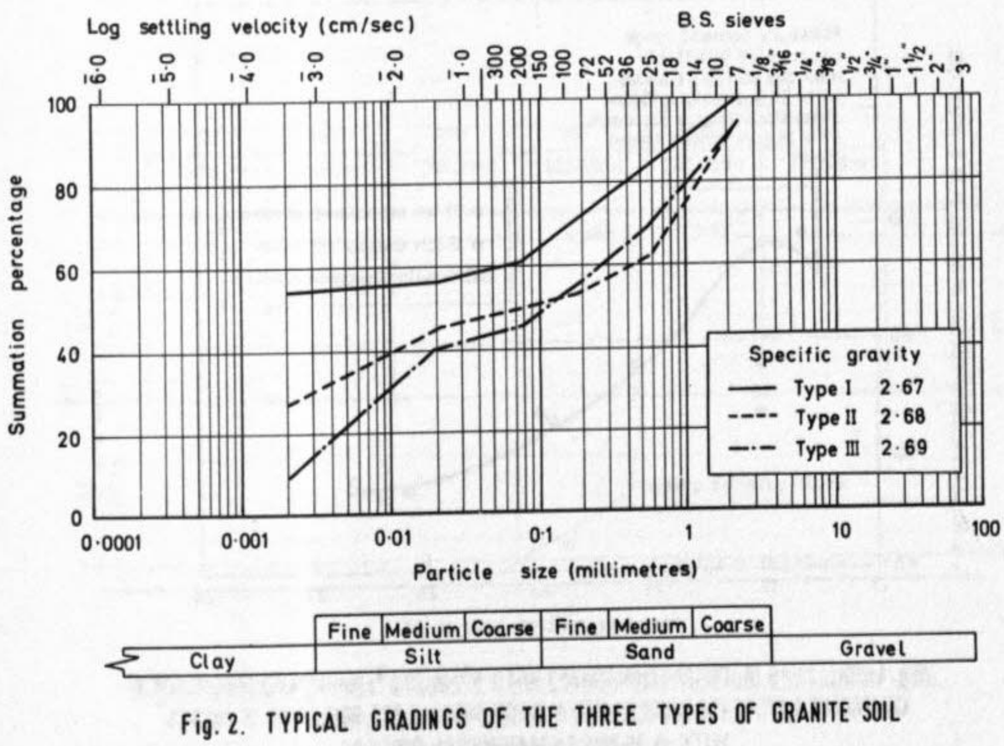

Fig. 2. TYPICAL GRADINGS OF THE THREE TYPES OF GRANITE SOIL

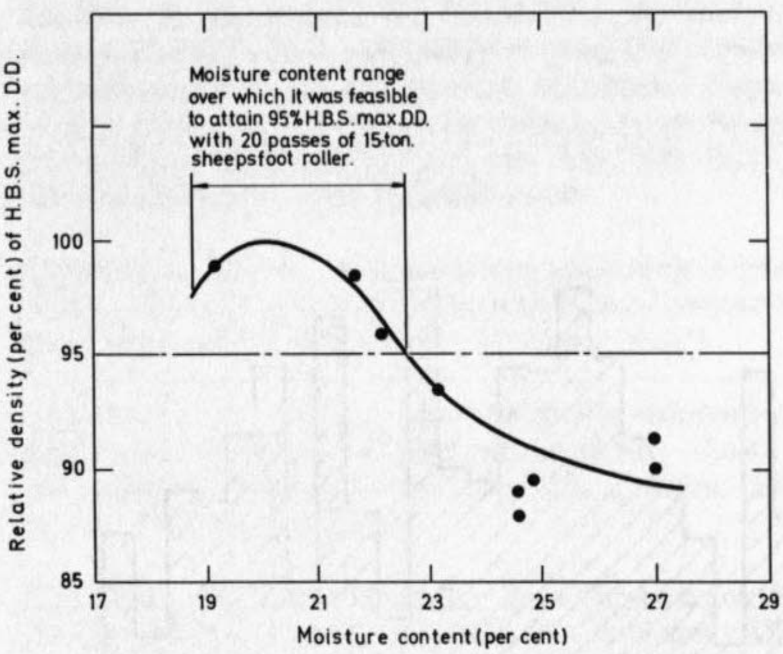

Fig. 3. SOIL 'TYPE I' COMPACTION TRIALS WITH 6-IN. TO 7-IN. (15 CM. TO 17·5 CM.) THICK COMPACTED LAYERS (EACH POINT REPRESENTS 20 PASSES OF 15-TON SHEEPSFOOT ROLLER)

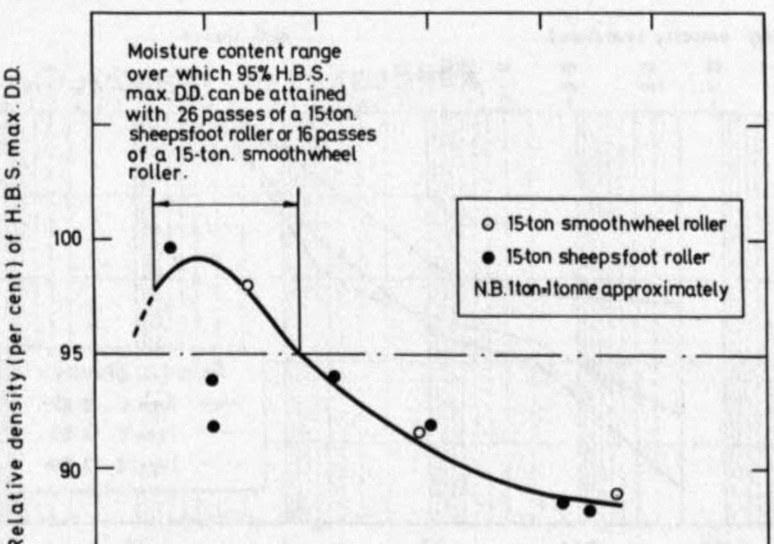

Fig. 4 SOIL 'TYPE III' COMPACTION TRIALS WITH 5½-IN. TO 6½-IN. (14 CM. TO 16·5 CM.) THICK COMPACTED LAYERS (26 PASSES WITH A 15-TON SHEEPSFOOT ROLLER OR 16 PASSES WITH A 15-TON SMOOTHWHEEL ROLLER)

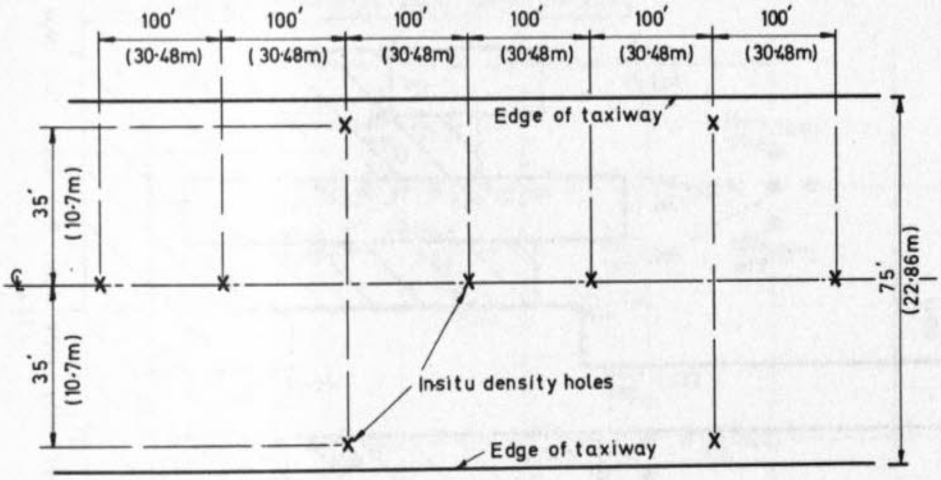

Fig. 5. LAYOUT OF IN-SITU DENSITY HOLES FOR COMPACTION CONTROL OF THE TAXIWAY, TOP TWO FEET (60 CM) OF FILL

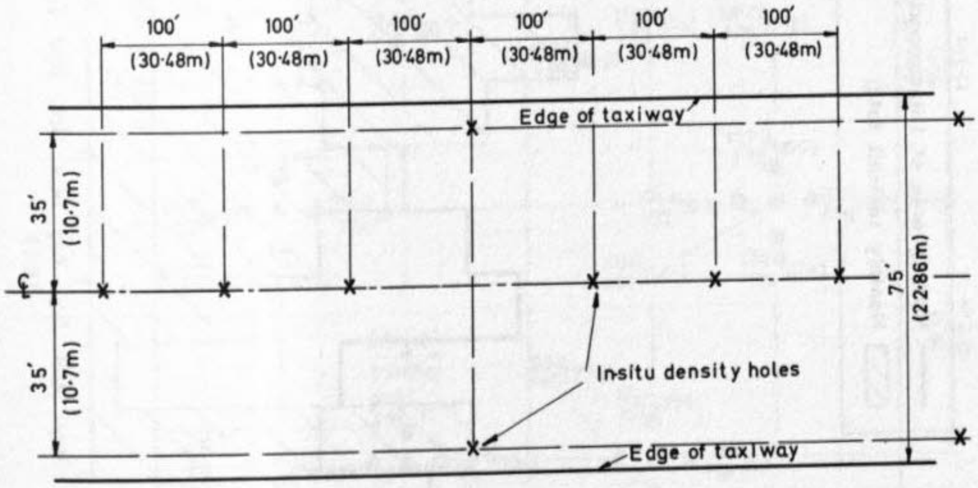

Fig. 6 LAYOUT OF IN-SITU DENSITY HOLES FOR COMPACTION CONTROL OF THE TAXIWAY TWO FEET (60 CM.) TO FIVE FEET (150 CM.) BELOW FORMATION LEVEL

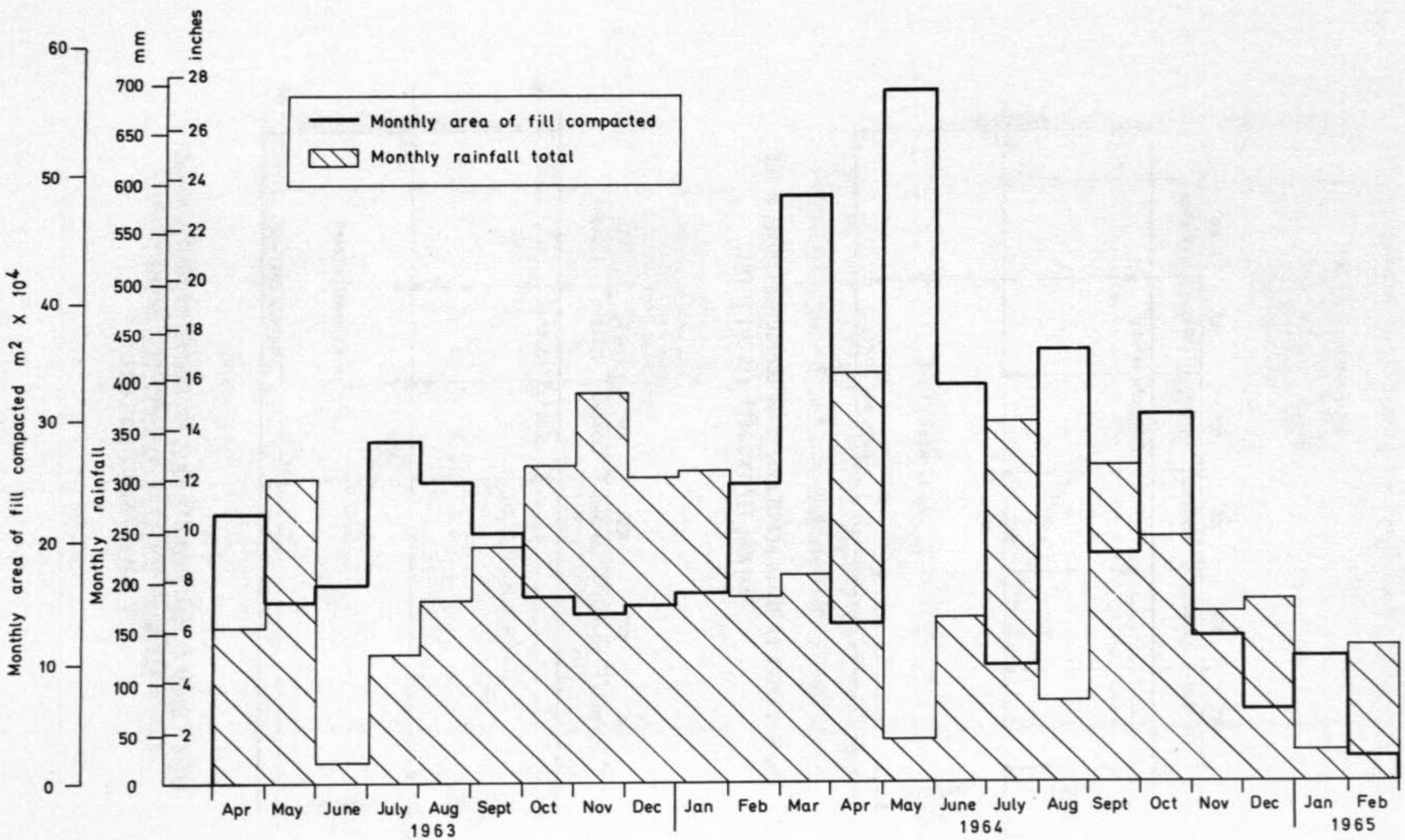

Fig. 7. MONTHLY AREA OF COMPACTED FILL COMPARED WITH MONTHLY RAINFALL

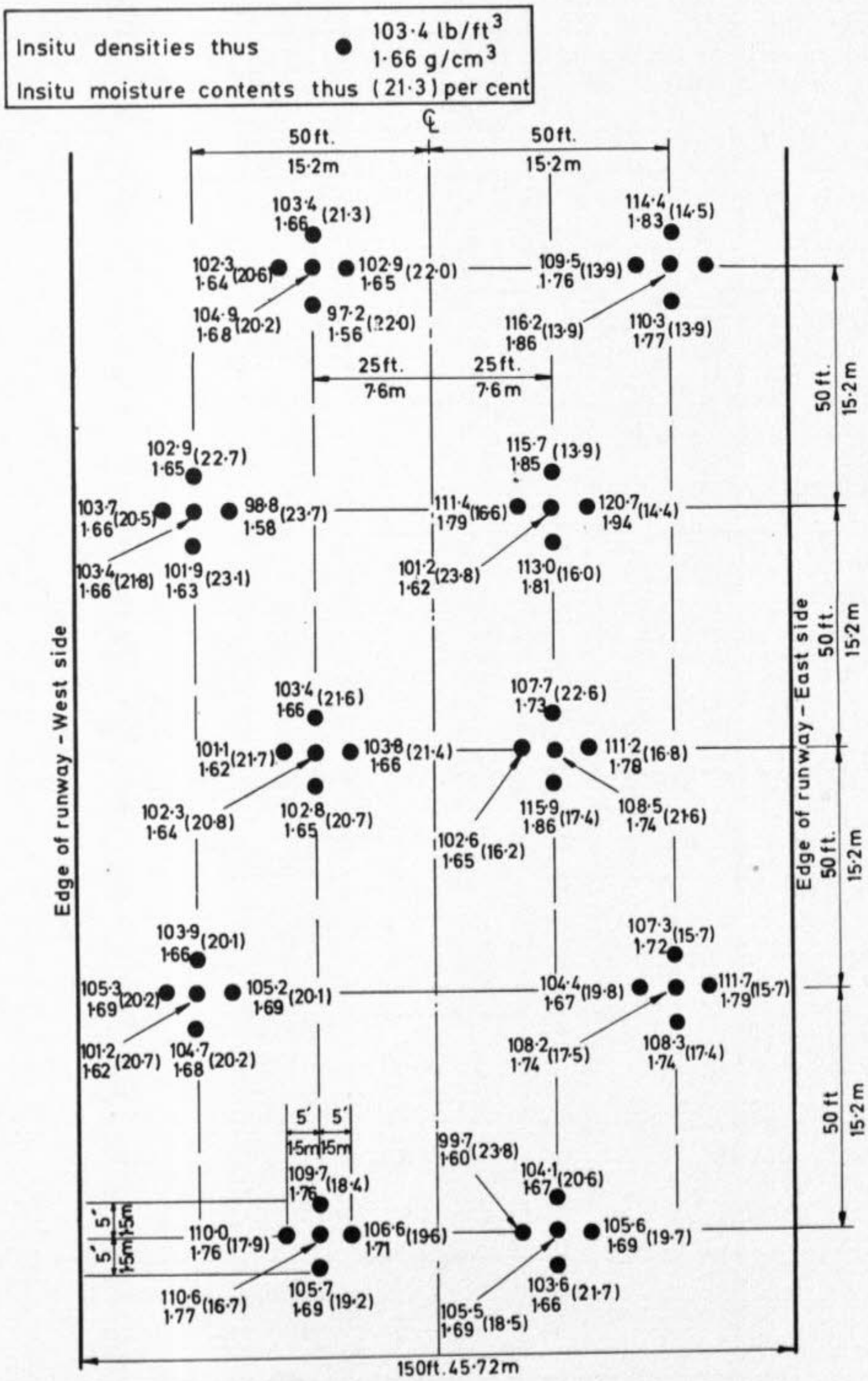

Fig. 8. IN-SITU DENSITIES AND MOISTURE CONTENTS IN THE INTENSIVELY TESTED AREA OF THE RUNWAY FORMATION