

SYMPOSIUM ON AIRFIELD CONSTRUCTION ON OVERSEAS SOILS †

Paper No. 6243

Airfield construction on overseas soils

by

Kenneth Ernest Clare, B.Sc.

Paper No. 6239

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by

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Paper No. 6258

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by

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and

Bryan Openshaw Skipp, Ph.D., F.G.S.*Discussion*

Mr K. C. Mann (Director of Works, Air Ministry) thought that the most interesting soils overseas were those which were classified in Paper No. 6239, Section II, Part 3, as "calcareous silty clays" (Table 9). Those soils were broadly termed "cotton soils," and in the Levant zone of the Middle East were normally of a reddish tinge. They had an extraordinary capacity for absorbing moisture and, when in a soaked state, a very low bearing value, even below 3% C.B.R., although when dry the C.B.R. value might exceed 70% (see Fig. 22).

262. He had seen the hummocks referred to in § 66 as "gilgai", which formed through swelling; indeed, on one occasion he had been shown the end of a paved runway at Qastina in Israel, to which the Author had referred, which had risen by about 3 ft above its normal level from this cause.

263. The other extreme, when the soil was dried out, was illustrated in Fig. 35, although it showed dried-out silt. It was common for the crack at surface level to be 4 in. in width and to diminish in tapering wedge shape until, at a depth of about 5 or 6 ft, it disappeared.

264. The difficulty which faced engineers was the creation of a soil condition which would give adequate bearing capacity within economic limits of effort, without undue risk of reduction leading to failure of any superimposed surfacing for a runway or road.

265. From Mr Mann's knowledge of the airfields listed in Table 9, he would say that the soil at St Jean in Israel was the worst type of those listed, much more so than,

† Proc. Instn civ. Engrs, vol 8, p. 211 (Nov. 1957).

say, Nicosia in Cyprus; yet, comparing the two, the liquid limit differed by only 8%, the plastic limit by 3%, the plasticity index by 5%, and the shrinkage limit by 3%. Were there other factors which would account for St Jean being so bad? In each case the optimum moisture content was nearly equal at an average of 22%, over a range of 21 to 24%.

266. In § 82 the Author referred to a method adopted in 1944, when reconstructing Lydda Airport's pavements, to overcome the effect of cotton-soil shrinkage and expansion. A method planned later for the development of Aqir airfield in Israel, but not carried out because of the termination of the Mandate, had had as its main feature the intention to hold the moisture content of the subgrade at a constant which would ensure reasonable runway life at the desired load-bearing capacity, taking into account that moisture was always found beneath an impervious surface even in arid zones.

267. It had been planned to construct a moisture cut-off wall, about 2 m in depth, longitudinally along each edge of the runway, and to ensure that adequate apron protection and storm-water drains were laid so that no surface-water could penetrate the inside face of the bituminous-faced curtain walls. The prepared subgrade surface within those walls was to have been covered by a membrane upon which normal airfield pavement construction would have been placed—in that case a flexible pavement surfaced with dense hot-rolled asphalt.

268. Such a system of construction, but with a light cut-off wall, had been adopted when developing Khartoum airfield, which lay in the area of land at the junction of the Blue and White Nile rivers. The soil had some characteristics similar to those described by the Author as "calcareous silty clays," but might well be a mixture of alluvial deposits as well as clays carried down by the two rivers.

269. In Part 4 the Author had dealt with alluvial sands and silts and referred in § 99 to the reconstruction of Abu Sueir airfield in Egypt; this site was typical of those found bordering the Suez Canal and not unlike other desert regions such as Libya. One feature was the extraordinarily hard surface which usually existed, requiring a pick-axe to disturb it; often this surface was covered by fine wind-blown sand, but it always appeared undesirable to Mr Mann to disturb this naturally bonded surface, and that its potential load-bearing capacity should be developed by building upwards the necessary load-distributing surfacing, using cement-soil stabilization (the soil being obtained from borrow-pits) instead of in-situ stabilization. Areas containing soft spots were almost certain to be encountered, and these could be dealt with by in-situ treatment.

270. In designing and constructing airfield pavements care must be exercised not to use materials which when consolidated had inferior bearing capacity to the existing subgrade when consolidated.

271. Paper No. 6239 also showed that many classes of soil existed abroad which it should be possible to stabilize. This was encouraging, especially if bitumen, usually readily obtainable in the Middle East, could be used as the stabilizing medium. The introduction of aircraft with high tire pressures made the use of unpaved surfaces impracticable, and there were few aircraft in general use which could operate from natural saline sand-surfaced airfields on a long-term basis. It was a pity that aircraft designers had so greatly increased the undercarriage wheel loadings and tire pressures, for there were many zones along the Red Sea and Trucial and Oman Coasts where the soils provided an easily maintained natural runway surface without the need for expensive runways.

272. Referring to §§ 104 and 105, he considered that if modern concrete-mixing and paving equipment were to be used in areas subject to sand storms, the result would be satisfactory but would require the setting up of stone crushing and grading plant. It was mainly because in the past concrete work had been undertaken within limited local resources that poor results had been achieved. Recent overseas airfield construction jobs whose concrete ends to runways and hardstandings had been built were comparable to standards achieved in Great Britain.

Dr R. S. Millard (Head of Colonial Section, Road Research Laboratory, Harmondsworth) mentioned one particular group of soils—the residual soils. To engineers who were trained and experienced in Great Britain such soils were not at all familiar.

274. In Paper No. 6243, Mr Clare had described the physical and chemical processes of weathering. Dr Millard described one of the consequences of this weathering when the parent rock was acidic in character. Chemical weathering of granite produced clay minerals which were leached downwards by water producing a typical profile which graded from quartzitic sands near the surface through a gradual transition to a clay-enriched layer, and finally to the undecomposed rock below. Such material had been described by Grace and Henry in Hong Kong¹¹⁶ and was referred to twice in the Papers in the symposium. Under conditions of impeded drainage, however, the transition from the quartzitic sand to the clay-enriched layer, instead of being gradual, could be very sudden indeed, and a layer of fine impermeable clay might be encountered at a depth of several feet below the relatively permeable quartzitic sand. If this was undiscovered, it could lead to early and catastrophic failures. During the rainy season the water percolated rapidly from the quartzitic sand overlay and then flowed over the surface of the clay and, if construction cut through the outcrop of this clay, trouble might be expected there. If the ground survey was at all superficial—and sometimes overseas it was—constructional plans might be drawn up only on the indications of the good surface soil.

275. He then showed two slides, the first of which was of a road cutting in East Africa in which the quartzitic sand could be seen above the clay. The evidence of failure in the road could be seen at the point where the clay outcropped.

276. The second slide showed a watercourse in Central Africa, in which there was an outcrop of a clay layer. This particular formation was common in Central Africa. Salisbury airport, for instance, had this well-defined layer of clay at a depth of 12 ft, causing very little trouble, but there were other situations in both Central and East Africa where trouble had developed because the formation had not been recognized.

277. Turning from the residual soils to black cotton soil, one notable airport which had been built on such a soil was the new Embakasia airport at Nairobi. There the black cotton soil was quite thin—about 4 ft in thickness—and it has been possible to remove it. Elsewhere Dr Millard thought that, when the engineer was siting an airfield, he should usually be able to avoid siting it on such difficult soil. It was the road engineer who was more often confronted with the problem of construction on tropical black clays. Apart from the major difficulty of handling mechanical plant over the sticky soil during wet weather, there were the difficulties of the large change in volume of the soil between the wet and dry seasons and the differential movements which this could cause in embankments on black cotton soil.

278. When the road or airfield was of gravel standard, these differential movements did not matter a great deal, but as soon as a bituminous surfacing was applied, the shrinkage and swelling could cause damaging cracks in the surfacing.

279. Dr Millard then showed three slides of black cotton soils. The first showed the typical surface cracking pattern; in this case the cracks went down as deep as 9 ft, and there had been instances of even deeper cracks.

280. The next slide was of an embankment on black cotton soil with 12 in. of other soil in the upper layers. Cracks evident in the side slopes of the embankment were likely to penetrate underneath the surface of the road. The last slide showed a newly-constructed bituminous-surfaced road over black cotton soil in Central Africa. The embankment was of quartzitic gravel and was about 24 in. high. At the end of the dry season a longitudinal crack, about $\frac{1}{2}$ in. wide at its widest point, had developed about 12 in. from the edge of the road. As the black cotton soil underneath the edges of the embankment had dried out, so it had contracted vertically, thus causing the longitudinal crack. Transverse cracks had occurred, beginning at the edge and penetrating towards the centre of the road; these might possibly be associated with horizontal contraction. Two significant points were the very narrow width of shoulder and the green vegetation at the foot of the embankment. Away from the

embankment vegetation was dry and wilted and it was obvious that the thin line of green plants was a powerful agent in drying out the soil under the edges of the embankment.

281. When black cotton soil was covered by an embankment, and the loss of moisture by evaporation and transpiration was prevented, the moisture conditions in the soil, under the centre of the road at least, probably tended to equilibrium and there might be permanent volume changes after construction associated with the movement towards this equilibrium. To anticipate the permanent movement, more needed to be known about the equilibrium condition, and he hoped that more would be learnt about this from an examination which was planned of the moisture conditions under roads on different soils in Kenya.

282. Dr Millard suggested two ways to reduce the seasonal "flapping" of the edges of roads and runways. First, vegetation should be prevented from becoming established at the edge of the embankment; this would reduce the loss of moisture by transpiration. There was generally no need on black cotton soil to fear erosion when vegetation was removed. Secondly, a blanketing layer of non-cohesive material should be placed over the side slopes of the embankment. The black clay was itself relatively impermeable and during the dry season most of the moisture removed from it must be removed as water vapour by air circulating the fissures. It could be assumed that these fissures, which extended vertically in the natural soil, would also extend in a transverse direction underneath an embankment. If this fissuring could be stopped it was likely that the movement could be greatly reduced. The provision of even a thin layer of non-cohesive soil over the black cotton soil would inhibit evaporation considerably, and should reduce the severity of the fissuring of the clay. This suggested a rough guide—that the width of the shoulder from the edge of a bituminous surface should be made roughly equal to the depth to which fissures penetrated into the clay in the dry season.

Mr J. W. Burns (Assistant Civil Engineer, George Wimpey & Co. Ltd) recalled that when he had undertaken the construction of the Lydda civil aerodrome for the British Mandatory Government of Palestine in 1935, at a site situated about 12 miles south-east of Jaffa-Tel Aviv, their knowledge of the behaviour of the black clay (the so-called "black cotton soil" mentioned in Paper No. 6239, was very limited. That pioneer construction, being the first of its kind in the Middle East, was mentioned by the Author in § 82.

284. The work had been carried out by direct labour, the rough earth moving being executed by Jewish labour, using light mechanical scrapers. The remaining processes of fine grading, compaction of the subgrade, mixing of the sand-bitumen carpet, and compaction by rubber-tired rollers and 2-ton Green's Diesel rollers had been carried out by Arab labour, Pegson mixers being used for the sand-bitumen mix. Very great care had been taken with the cambering of the subgrade, and its compaction with 10-ton steam and Diesel rollers, during the dry months when the moisture content of the earth was between 8 and 10%. This had been controlled by a system of strained piano wires, laid over an intensive network of wood-capped steel level pegs. By this means the parabolic camber of the 100-m-wide runways had been meticulously maintained.

285. The final result had been at least as good as the best mechanical grading which could now be obtained by machines. In those days they had had no knowledge of the possible failure of the subgrade caused by the absorption of moisture from the lower strata, as mentioned in § 81 of Paper No. 6239; any failure by cracking in the sand-bitumen carpet had been immediately attended to by opening up the crack and adding and compacting some new mix.

286. To exclude the ingress of surface-water via the earth cracks at the edge, the carpet had been bordered by a 3-ft-deep vertical sand-bitumen cut-off, but despite this the edges of the runways had been moistened and swelled for about 14 ft inwards from the edge. In the following summer this band of disturbed surfacing had been scarified, collected, and re-gauged with an additional 25% of bitumen, and had been returned to its original position after the removal of the swelling in the earth subgrade. The resulting repairs had been very satisfactory.

287. The cost of construction at Lydda had been very low in comparison with similar work nowadays, and had worked out at 2s 2½d/sq. m for all processes and materials. The reconstruction mentioned in § 82 had cost at least five times that figure.

288. The Author, in Paper No. 6243, § 47, mentioned that Lees²⁹ had used a clinker produced by burning the black clay at Malakal, Sudan, with scrub timber as fuel, and with this a runway about 12 in. thick had been formed. Mr Burns had had to carry out the surfacing of this runway in 1937 with pre-coated macadam, and the runways had been extended by importing granite from a hill, the Gebel Zeraf, rising out of the White Nile marshes, about 300 miles distant. For that transport, a broad-gauge railway line, about 7 miles long, had had to be established in the swamps, and the remaining distance covered by barges drawn by Nile paddle-boats. The baked loam could only be looked upon as a substitute for more permanent materials, and was generally very costly to produce.

289. Referring to the end of § 83, he would like to add that in some districts moles were a great pest. They could puncture quite hard bitumen surfacings. They should be exterminated by gassing in their burrows. Also in the case of the black cotton soils, beetles punctured the surface. It seemed that they congregated in the cracks of the sun-baked loam and tried to escape as soon as the carpeting had been finished!

Major V. J. M. Smith (Technical Staff Officer, Ministry of Supply) said that in the construction of the air base on Christmas Island, the soils had been very typical of the calcareous soils referred to in Paper No. 6239. The Author had mentioned coral as being the best of them all, but it had been fortunate for those concerned that the coral on Christmas Island was of a reasonable quality. Major Smith thought it was worth giving a warning that the quality of coral varied. The Author had referred to reef coral, lagoon coral, and coral sand. Major Smith thought that the more normal third classification was "coral debris" rather than coral sand. The reef coral was that which grew under the surface of the water, and was obtained by blasting at low tide; sometimes it was geologically thrust upwards above the surface, where one could get at it. The lagoon coral was that which was deposited by sedimentation, and was different from the reef coral and the coral debris principally because of the silt content, that silt content being mainly lime in suspension. The coral debris was that which was washed off from the reef and deposited on the shore. It could range from gravels down to sands; and it could be transported by the wind and be very uniform in size.

291. The airfield on Christmas Island had been built by the American forces, in the 1939-45 war, on a very wide area of wind-blown coral sand. It did not, therefore, have a very high bearing capacity. It was not too easy to compact. It was generally a uniform sand somewhere between the No. 14 and the No. 52 sieve. The "lagoon mud" used as the surfacing for the coral pavement (generally on top of a coral gravel obtained from the debris) was in fact a well-graded sand with about 20 to 25% passing the No. 200 sieve. It might seem rather peculiar to put what would in Great Britain be far the better material, the gravel, on the bottom and the sand on the top, but in fact the lagoon mud was a self-cementing sand.

292. Fig. 45 showed, in the thick black curves, the sort of deposit which had been obtained at the borrow-pit. All the lagoon-mud borrow-pit materials had been dug below the water-table. The thick black line showed the best material, for which the C.B.R. was greater than 100%; the thick dotted line represented a C.B.R. of 80%. Anything worse than that had not been used. They had in fact recorded C.B.R. values of 150 and as high as 182%. These were laboratory C.B.R. values. The interesting thing was that the C.B.R.'s obtained on the dotted line had been 30 to 40%. It was not too good a sand, but ranged from about the No. 14 down to the No. 200. The wind-blown sand had tended to be from No. 14 to No. 52, and with that they had estimated the C.B.R. values to be between 15 and 20%.

293. The density tests carried out to check on the compaction of the soils had been recorded, together with the moisture contents, and Fig. 46 gave some idea of the results. The lower broken line gave the C.B.R. values in the laboratory, and the

middle line gave the densities obtained in the laboratory when obtaining those C.B.R. values. It had been found at Christmas Island that densities obtained in the field were higher than those obtained in the laboratory with the modified British Standard compaction test; and he believed, although they had not measured the in-situ C.B.R. values, that they had got considerably higher C.B.R.'s.

294. In regard to the remarks made by Mr Tomlinson in presenting Paper No. 6239, Major Smith would like to say that, with coral, cheap airfields could certainly be built, and it was also of considerable use in making bituminous asphalt or macadam. Because this material was mechanically stable, coral aggregate could be used to produce asphalts with quite high stabilities. Fig. 47 showed a grading curve of asphalt aggregates. There were three thick lines which represented the envelope of Air Ministry gradings. The Air Ministry normally specified nowadays about 1,500 lb. as the minimum Marshall stability. It would be noted that the top line in Fig. 47 (the West borrow-pit), was rather poor grading. It was fairly typical of some of the borrow-pit

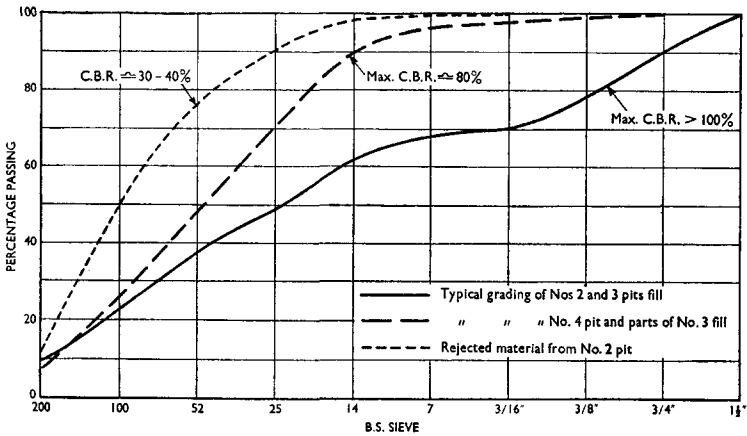


FIG. 45.—COMPARISON GRADINGS OF MATERIALS FOUND IN BORROW-PIT AREAS

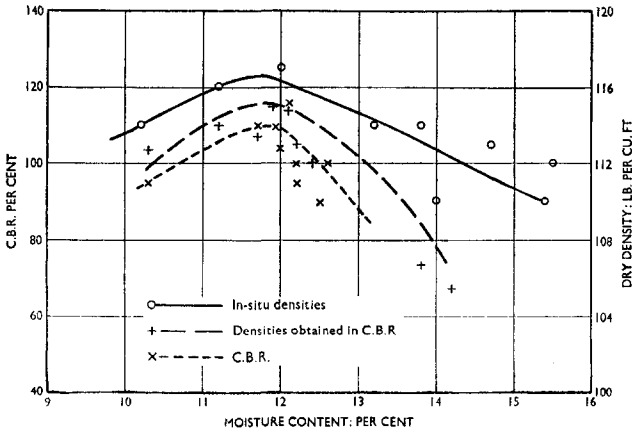


FIG. 46.—PAVEMENT CONTROL-TEST RESULTS

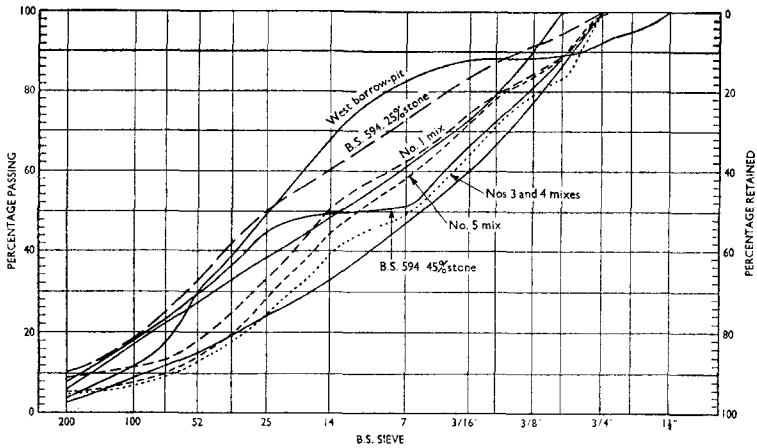


FIG. 47.—GRADING CURVE

sands that he had mentioned. It had given 1,500 lb. in the laboratory. The other curves fitted more or less within the Air Ministry standards and gave stabilities of 2,500, 3,000 and 3,500 lb.

295. To sum up, one could certainly use coral to build a good base, and to make a decent asphalt. It had been said that coral did not make good concrete. Major Smith thought that for cheap airfields that need not be a matter for concern.

296. The Authors had remarked on the need to beware of classifying soils by, say, the mechanical or the Casagrande method. Certainly on Christmas Island, by looking at the way in which the Island had been formed (the geology), it could be estimated precisely from an air photograph where good borrow-pit material, good aggregate for concrete, or good material for asphaltting might be found.

Mr C. B. Brown (Partner, C. B. Brown and Partners) observed that most of the recommendations in the Papers appeared to be based upon the assumption that they were concerned with airfields where the traffic was considerably lighter than elsewhere. This, while it was certainly true generally, was not the only consideration which should govern the design of an airfield in a tropical country. The other main consideration was the fact that labour in tropical countries was, on the average, comparatively cheap, and manufactured material was usually dear—sometimes extremely so. This meant that the best use should be made of natural material found locally, even if the quantity of labour required in construction and subsequent maintenance was substantially more than would be countenanced in a more highly developed region.

298. Laterite was without question one of the best of all soils for the construction of base courses, possessing as it did its own stabilizing agent. It could give results to those of stabilized gravel and without the necessity of any additive. Unfortunately, good laterite was not always available, and the best use must be made of some other poorer soils—latosols or alluvial soils or even clay. While the so-called latosols were found in many regions and were often entirely suitable in themselves, it was frequently necessary to improve them by the admixture of other soils or else by the addition of a stabilizing agent. Mr Brown felt that when stabilizers were mentioned there was too great a tendency to think immediately in terms of cement, bitumen, or other costly material. He considered that imported stabilizers should be resorted to only after a full investigation had proved that there was no suitable natural material to be found.

299. In this connexion, he had been very much interested in a statement in Paper

No. 6258 that oil of any type could be used. In many tropical countries oil was easily available, if not mineral oil, then vegetable oil, which in itself was a very useful stabilizing medium. It was interesting to note that many miles of road in such countries had been formed merely by clearing, draining, and levelling a strip through the bush. Such roads had proved themselves adequate, for light traffic, with very little maintenance. This apparent power of maintaining themselves was often derived from the stabilizing influence of vegetable debris containing natural oils. Had the Authors anything to say on this point?

300. On the question of paved airfields, Mr Tomlinson had stated that in arid regions these were not generally necessary, but that they were always necessary in humid regions. Mr Brown felt that that statement was somewhat too sweeping. The necessity or otherwise of paving would surely depend primarily on the stability of the soil as a wearing course. In arid regions, where the soil was sandy, stability might be very difficult to maintain without paving of some sort.

301. Referring to the use of laterite as a concrete aggregate, a matter which was mentioned in Paper No. 6258, Mr Brown said that he had used it and found it very satisfactory. He had only used it for mass concrete. He considered, however, that very great caution should be exercised in its use for any high-strength concrete. Laterite could vary very considerably in strength, soundness, and absorption properties. It should therefore always be subjected to careful tests before its use was decided upon.

Mr J. H. Brass (Administrative Head of Plant Department, John Mowlem & Co. Ltd) referred to § 233, which stated "Frost is seldom a problem in tropical countries." The snow-line in the tropics was at about 12,000 to 15,000 ft, and at that level both men and internal-combustion engines suffered loss of efficiency! One of the most difficult construction conditions was when there was alternate freezing and thawing. Were there any airfields constructed in the tropics at this level, and were there any known cases of frost trouble?

303. Mr Brass thought that the Papers made too little mention of mechanical plant. On any airfield job with which he had been connected, there had always been a hue and cry if any of the plant broke down. Nowadays, the construction of an airfield overseas would be done largely by mechanical means. It would be necessary to know the right plant for doing the job; if it was available, or if there had to be some alternative; and how much it was going to cost. This information was not always easy to obtain. One thing to be learnt from the Papers was that the properties of soils were of interest to the plant engineer, and it was important that he should have some knowledge of soils to enable him to provide the most suitable plant for the construction. It was equally important that those connected with soil mechanics should also have some knowledge of the plant available, not only for digging the material, but also for spreading and compacting it on the runway.

304. The Papers described black cotton soil, red clay, lateritic clay, laterite, and so on, but they did not tell how to dig and dispose of those soils.

305. In § 178 the Authors stated "generally a vertical cut of laterite stands well". Mr Brass confirmed this by quoting a case where a main railway was left open to traffic (with a speed restriction of 4 m.p.h.) although the track ran along the upper edge of a 14-ft deep vertical cutting in laterite.

306. Rapid development of modern stabilization and compaction plant in large units or trains was taking place, particularly in the United States. Some of these had a very high output, and the capital cost was large, and must be justified by the extent of the work.

307. Mr Brass then showed a number of lantern slides illustrating various kinds of mechanical plant in use on tropical soils. One of these was a Cedars Rapid vibrating pneumatic-tired compactor weighing 35 tons, drawn by a 60-h.p. tractor, compacting gravel formation, with which repeated passes were made. The machine developed a powerful compacting action through its pneumatic tires by means of a vibrator unit mounted on the axle. Tire pressures could be varied according to the soil-bearing

capacity. How did such compaction compare with the manual compaction mentioned in § 168 as yielding better results than standard machinery and procedure?

Dr H. Greene (Adviser on Tropical Soils, Rothamsted Experimental Station, Harpenden) observed that, as an expert on tropical soils, he had to state that no soil man would be satisfied with the classification proposed by Mr Clare in Table 3, Paper No. 6243. From the soil man's point of view, this classification was acceptable for materials that had been subjected to little chemical weathering but it was unacceptable for materials that had gone some way towards changing into soils. Soil experts needed a more elaborate discrimination of parent materials than the Author offered and a more explicit recognition of the influence of climate (especially rainfall) and of topography (especially drainage conditions). Unfortunately, soil men were not yet able to offer very much help to the engineers.

309. Airfields were often built in low-lying areas which had alluvial or ill-drained soils; in the past pedologists had rather neglected these soils and had preferred to study better-drained soils on gentle or moderate slopes. However, pedologists were becoming less biased in this matter and they might be able to give the engineers more help in the future.

310. Dr Greene had been pleased to see in § 81 of Paper No. 6239 a reference to the effect of temperature on upward movement of water vapour beneath a paved surface. He imagined that the Author was correct in this. The cooling of the paved surface was probably most marked in arid regions where there was a large outflow of radiation from the paved surface into the clear night sky; the cooling was probably less where clouds interfered with this nocturnal radiation. Because the lower subsoil remained at a relatively high temperature differences in vapour pressure were set up so that water vapour distilled from the lower subsoil into the material just below the paved surface and then failed to escape because the surface was sealed.

311. In Paper No. 6258, Fig. 38 showed an idealized laterite profile. Photographs of such profiles had been given by Hallsworth and Costin.¹³⁰ It was now widely recognized that the ironstone cap as represented in Fig. 38 was an exposed subsoil. What was now the protecting cap of a flat-topped hill had formerly been a low-lying area receiving inflow of water from high land.

312. What happened was roughly this. When rocks were decomposed by weathering the silica and bases were washed out of their silicate minerals, leaving a residue of iron and aluminium oxides plus resistant minerals such as quartz. If the area was well drained, water entering the soil was soon replaced by air, and therefore any iron set free by weathering of rock was quickly converted to the highly oxidized ferric form and remained in situ, being almost insoluble. Thus there were formed in well-drained situations the very deep permeable soils, usually red, that had been called "red earths", "latosols", or "ferralites". They did not swell and shrink much with change in moisture content, they contained few or no concretions, and they gave no trouble from waterlogging because they were permeable and well drained.

313. On the other hand, if the rock-weathering occurred in an area of very gentle slopes, water entering the layer of loose material was less readily replaced by air, so that iron liberated by decomposition of silicate minerals tended to be in the reduced ferrous condition and to be carried away with the drainage-water in some soluble form. Sooner or later this drainage-water, carrying ferrous iron, reached low-lying land and approached the soil surface, so that, at any rate during the dry season, air had access to it. Consequently the ferrous compounds were oxidized to ferric compounds and separated out as rusty stains and as soft concretions. If this process continued long enough the subsoil in a low topographical situation became strongly impregnated with iron compounds, which could harden on exposure. This was the material originally described as "laterite" by Buchanan⁵¹ in South India.

¹³⁰ References 130 *et seq.* are given on p. 124.

314. The earth's crust was subject to slow movements, as a result of which it sometimes happened that what was formerly a low-lying area was lifted up and became well drained. In this way there were formed flat-topped hills capped with ironstone. The uplift might be interrupted so that ironstone ledges and layers of iron concretions were found at different levels. Also the process of impregnation with iron was not equally advanced in all low-lying areas. Therefore in some cases uplift and erosion exposed a conspicuous hard layer of lateritic ironstone and in other cases uplift and erosion exposed merely a number of iron concretions (pea iron) which might occur at the soil surface or might be buried beneath a more recent cover of fine material owing to action of termites or to drift by wind or water. It was for these reasons that soils containing iron concretions were so notably heterogeneous, presenting problems to the pedologist as well as to the engineer. A valuable note¹³¹ on the formation and characteristics of laterite had been published in 1955.

Mr K. R. Early (Chief Geologist, Soil Mechanics Ltd, London) said that the Papers for the Symposium made an important step in the right direction, concerning overseas soils, by the definite introduction of pedology as a background for classification. In dealing with lateritic soils or black cotton soils the material was entirely of pedogenetic origin, and would most probably be encountered on tropical plateau, or tropical valley and lowland sites. In tropical river, coast, and delta landscapes soils were of alluvial origin. Therefore it was thought that a geomorphological classification of sites would be useful initially.

316. Perhaps it had not been sufficiently stressed that in the humid tropics local variations of drainage in parent material could give rise to totally different pedological development within short distances. In this way lateritic, podsollic, and marginalitic developments could exist side by side. Even on a site where lateritic development was generally expected, this should be borne in mind.

317. It appeared that lateritic clays could be expected:—

- (a) On truncated mature lateritic profiles.
- (b) On young lateritic profiles.
- (c) On mature lateritic profiles beneath the tropical rain-forest vegetation.

This latter instance was reported by Mohr and van Baren,¹³² and it was of interest to note that forest clearance resulted in surface hardening and the production of something physically similar to laterite.

318. The discussion of laboratory testing procedure in Paper No. 6258 fully pointed out the difficulties of adapting standard tests to tropical pedogenetic soils. To mention another variable, the cementation factor, secondary porcellaneous kaolinite had been encountered in British Guiana. This factor was additional to the commoner sesquioxide type.

319. It appeared that compaction tests should simulate local conditions and practice rather than conform rigidly to standard procedure. Field tests might be of greater value.

320. Relations between the engineering stability of tropical pedogenetic soils and their chemical, mineralogical, and physical properties did not yet seem to have been established, and this seemed to be one of the most important lines of research.

321. In § 173 of Paper No. 6258, the material was inferred to be laterite, whereas stabilization had been achieved by the addition of lime and base-exchange, which suggested that, in fact, the material contained an appreciable quantity of base-exchangeable clay, not consistent with a laterite.

322. Mr Nixon frequently used the term "laterite mortar", referring to the matrix of a laterite. This term had unfortunately been used referring to iron-pan cementation in gravels. A confusion was often made between true laterite and iron pan which had

resulted from podsol formation. These different modes of occurrence of secondary iron oxide raised rather different engineering problems.

323. In § 210, it was stated that latosols behaved as a clay and did not have strong concretions. Perhaps it would be better to reserve the term "latosol" for the broad pedological meaning.

324. Could the Author explain the discrepancy between the grading curves in Fig. 34, Paper No. 6239, and the description in the text of the Almaza Airport soil as silty sand? The grading curves showed 30% gravel and no silt.

325. In Part 4, the section dealing with alluvial sands and silts, only passing mention was made of alluvial soils in humid tropical climates. Mr Early thought this was an important factor, owing to the frequent presence of peat under such conditions, which was often hidden by later sand deposits. Numerous examples of airfields could be quoted in this instance, for example, Palisadoes, Montego Bay, and Colombo.

326. In § 12 of Paper No. 6243, the statement that alluvial and aeolian deposits had a limited particle-size range in common was opposed to the usual conception that a limited particle-size range was diagnostic of aeolian deposits only.

327. The statement was made in § 20 that calcium could accumulate in a manner similar to iron and aluminium. Perhaps this was rather misleading, since the formation of secondary calcium carbonate in soils nearly always involved a different pedogenetic environment in which transference in solution rather than chemical break-down was involved.

Mr Kandiah Arulanandan (Soils Engineer, Scott & Wilson, Kirkpatrick & Partners, London) expressed surprise that all those who had spoken in the discussion seemed to have agreed with the approach made to the classification of soils to be adopted for tropical soils. The most important thing was the design; what design thickness of construction would be needed on a soil and what type of soil should be used. Therefore, he felt that the best approach to classification of soils would be to use the standard tests that they had got, such as liquid limit, plastic limit, compaction, C.B.R., and so on, and not to use a classification which was more suitable for a chemist or a geologist, but which was often not of much interest to a practical engineer in the field.

329. When he had gone to West Africa about 5 years ago, he had been confronted with the problem of trying to adopt a classification of soils for lateritic soil in West Africa. He had been in some doubt when he went there, after having read all the literature on lateritic soils which was referred to in the Papers, whether he should use it or not. After a series of experiments, mainly on grading—which, of course, was meaningless for laterite because of the amount of material that dissolved—he had come to the conclusion that compaction tests and field-trial tests would be the most suitable tests.

330. In Table 12, Paper No. 6258, there were quoted some results of laboratory tests, and an attempt was made to correlate them and to see if laboratory tests results could be used in classifying materials. The test standard conditions were completely different; was there an error in the test which had led to the results on which Mr Nixon based his conclusion?

331. With regard to Dr Millard's point about the failure of roads constructed on black cotton soil, if on the black cotton soil a layer or blanket of sand was placed, and an adequate thickness of construction was provided, he rather doubted if a failure would occur. One of the main reasons for the failure that had occurred was the lack of adequate drainage on the site, as already mentioned by Dr Millard, and the other reason was probably lack of proper compaction of base, which would show up as failures towards the edges of tarred sections of road, owing to heavy concentration of traffic, as was the case in most of the roads designed to meet tropical standards.

332. He wished to stress the need for an engineering approach to the classification of soil for design rather than a geological or the chemical approach to the subject.

The following contributions were received in writing.

Mr P. W. Loveday (Senior Engineer, Richard Costain Ltd), recalled that during the period when he had been responsible, as Superintending Engineer A.M.D.G.W., for all airfields in Palestine, little knowledge was available on the subject of soil mechanics. The steps he had taken were therefore based on deductions drawn from his own observations.

334. It had been obvious that, when dry, the cotton soil of the coastal plain would carry, without superimposed paving, the heaviest aircraft then operating. His efforts, therefore, had been directed towards an effectively impervious pavement.

335. It was with the idea of maintaining the subgrade at its optimum moisture content that Lydda Airport had been originally designed, but the thin sand-mix pavement provided had been too subject to mechanical rupture to ensure prolonged serviceability under heavy loads. It had been obvious that a compromise had to be aimed at in which, while attempting to achieve an impervious surface, a sufficient construction depth would be provided to allow for any minor penetration of water resulting in partial local lowering of the bearing capacity of the underlying cotton soil.

336. During the summer of 1943 various new airfields had been constructed and some existing fields strengthened and extended. New construction, in all cases based on the specification successfully used by the P.W.D. for roads in that area, consisted of hand-packed soling laid on a coarse sand base and surfaced with a grouting macadam or bituminous carpet to a total construction depth of from 15 to 18 in. The existing fields had included Aqir, a pre-war airfield constructed to a specification similar to that of the original Lydda Airport. Where possible the strengthening of Aqir had been carried out on top of, and without disturbing, the existing sand-mix carpet, but where this carpet did not already exist, as in the case of the extensions, no such provision was made.

337. There had been, therefore, during the winter of 1943-44, a unique opportunity for studying the relative behaviour of the new and existing areas, both of which were identical in specification with the exception of the existing underlying sand-mix carpet of Aqir. This airfield had been heavily used during that winter by Halifaxes, among other aircraft, and though extensive failures had occurred in the new areas, no significant failures of any sort had been observed in the areas built on top of the original sand-mix base.

338. It was from this experience that Mr Loveday had successfully pressed for the specification finally adopted for the complete reconstruction and extension of Lydda Airport the following summer. Subsequent experience had completely justified the additional expense of the impervious undercarpet, and though it was true that there had been at that time no knowledge of the possibility of capillary and water-vapour rise from below, any increase in water content and consequent lowering in bearing capacity arising therefrom seemed to have been more than adequately catered for by the total construction depth, which had been arbitrarily rather than scientifically arrived at.

339. For as long as Mr Loveday had been able to obtain information as to the behaviour of Lydda Airport there were no pavement failures other than some slight longitudinal cracking adjacent to the side drains. Even that trouble could, he thought be overcome by a slight elaboration of the side-drain detail.

340. About the same time in Burma, quite unknown to him, similar thinking had resulted in Bit-hess, which must have contributed as much as any other single factor towards the successful outcome of the Burma campaign.

341. It was for these reasons that he felt that to design pavement thicknesses on such soils on the assumption that the subgrade would eventually become saturated was a counsel of despair which should not be adopted while there was evidence to show that reasonably inexpensive steps could be taken to hold the subgrade moisture content within safe limits.

Mr Tom Bassett (John Mowlem & Co. Ltd), noted that all the Authors had stressed the necessity of good drainage with the various types of sub-bases. Referring to the grass airfields that Mr Tomlinson had mentioned in § 59 of Paper No. 6239, Mr Bassett thought that that type of surface was, and would remain, a most important weapon in the armoury of the engineer who had to provide cheap airfields in underdeveloped areas striving to move with the times.

343. In British North Borneo all the airfields were grass strips except that at Labuan—those at Jesselton and Sandakan provided for DC-3's while the others were used by the Rapide aircraft of the "feeder" service. During the past year the low-lying airfield at Jesselton had been closed for 34 days, owing to deterioration of the strip in bad weather.

344. Such a condition was not always entirely one of drainage, for the use of the correct type of grass would have great bearing on the operation and maintenance of an airfield. This type of surface required as much thought and design as any of the other types more familiar to the civil engineer; the tests and trials took longer and required considerable experience to interpret, so that they should be undertaken at the earliest opportunity in the planning.

345. Since many governments, oil companies, and mining concerns had used grass surfaces for years, an effort should be made to collect the information and the results of the use of different grasses in different conditions. One failing of grass on sandy soils was evident at Anduki where during dry spells the sand was blown from beneath the blades of grass, leaving the stalks about $\frac{1}{2}$ in. clear of the surface. This small area held a tremendous quantity of water when sudden storms occurred, in spite of a very steep camber. The most damaging effect of this was that all the dead clippings from the regular mowing became mobile and were sprayed up into the retractable undercarriages of aircraft, necessitating continual maintenance and extra-skilled supervision from the ground staff.

346. The popular grasses had been Bermuda grass, Kentucky blue top, and marram grass, but these had not proved to be universally suitable and Mr Bassett felt that more could be found out about some or the slower-growing grasses, such as paspallum, which could be sown with the intention that in due course they would take over from those which formed the initial surface. The civil engineer ought to take great interest in this, since he would still be responsible for the maintenance and would continue to be subject to criticisms (that go with a grass field) from the flying personnel.

347. Perhaps the future engineers in tropical countries would be relieved of the problems of grass airfields by the development of the helicopter, and would only have to provide small heliports for small but prosperous communities. However, Mr Bassett anticipated that oil companies and mining concerns would require cheap airfields for many years to come and that grass would be the most usual surface.

Mr K. Russam (Colonial Section, Road Research Laboratory, Department of Scientific and Industrial Research), observed that Mr Tomlinson had pointed out in § 98 of Paper No. 6239 that although with well-compacted alluvial sands there was likely to be an increase in moisture content of the subgrade owing to alternating hot and cool seasons, it did not seem to be enough to reduce the stability of the sandy soils to an extent sufficient to cause failure.

349. The Road Research Laboratory was at present analysing the results of measurements of the moisture contents of soils at overseas airfields, obtained over a period of years by the Air Ministry. These data were being analysed together with the results of suction and plasticity tests made on samples of the soil tested in the laboratory to ascertain:

- (a) if theories relating to the moisture distribution under impervious pavements, developed for British conditions, could be applied to areas having very different climates; and

- (b) if in countries where large seasonal fluctuations in temperature occurred there was evidence of any accumulation of moisture under pavements which could be attributed to transfer of moisture vapour.

350. During the 2 years when measurements had been made at Abu Sueir airfield, Egypt (very deep water-table) the moisture contents in exposed soil and in soil under the pavements were similar and little seasonal variation in moisture content had occurred. At this site the moisture in the soil appeared to be in equilibrium with the humidity of the atmosphere. Again, at Khormaksar airfield, Aden, there had been little difference between the moisture contents in the sandy soil beneath paved and unpaved areas. In this case the moisture distribution with depth in the soil was controlled by the position of the water-table, which was approximately 3 ft deep.

351. At neither of these sites, which were both subject to large daily and seasonal variations in temperature, had evidence been found of any changes in moisture content that could be attributed to vapour movements. On the basis of available knowledge it was suggested that evidence of vapour movements should first be sought in clay-bound sand subgrades, since in those soils there seemed to be a possibility of resulting moisture changes sufficient to cause a significant loss of stability.

Mr L. W. Hatherly (Senior Engineer, Central Laboratory, George Wimpey & Co., Ltd) said that in many parts of the world, particularly in the Middle East and Central Africa, it was possible to operate medium-sized aircraft from unsurfaced fields for 11 months or more in any year. The cost involved in providing a paved runway, which would provide a serviceable airfield for 12 months in the year, was in many cases very high, for reasons which had been discussed in the various Papers, particularly that by Tomlinson. Before embarking on the construction of a major all-weather airfield it would seem desirable to enquire closely into the seasonal traffic pattern, since the wet season often coincided with a seasonable drop in air traffic, in which case an unpaved field might well be adequate. In other cases it was often sufficient to provide paved taxi-tracks and runway ends if the airfield users were content to restrict flying operations during the rainy part of the year.

353. Mr Hatherly noticed that none of the Authors had made more than a passing reference to the problems of surface-water drainage for paved airfields. It was in the past the practice of European designers to rely upon French drains to dispose of the surface-water run-off, but unfortunately the required filter material for this type of drain was often unavailable, or even if available, not used.

354. He suggested that a very high percentage of all the airfield French drains in existence were either completely or partially silted up and were not working efficiently. In the majority of cases this meant that surface-water entering the drainage system had free access to the construction layers of the runway itself when the drainage trench became filled with water. This could lead to progressive softening of the subgrade soil and also to structural damage resulting from a reduction in the strength of the base materials. In his opinion, surface-water should always be collected through a system of drop inlets and should be carried away in outfall conduits to natural drainage channels, particularly in tropical climates where rainfall was likely to be of high intensity.

355. With reference to §§ 81 and 233, it was necessary to consider the effects of temperature variations and other climatic conditions on the stability of the base materials as well as the subgrade.

356. As a result of observations made on sites in tropical conditions in many parts of the world, he was convinced that the stability of base construction materials should always be investigated in a saturated condition.

357. Did the Authors agree with these views, and had they experienced any similar effects?

Mr K. A. McKechnie (Resident Civil Engineer, Malacca Power Station, Malaya) stated that he was now supervising the construction of the new Malacca Power Station foundations on the soil described in Table 14 of Paper No. 6258 under the sub-heading "Malacca, Malaya".

359. He had just carried out a further set of four auger borings on the site and the results confirmed those quoted in the Table, with one important difference. The various clays and silts encountered were all firm to stiff, in some cases so stiff that the rate of drilling with six men on a 3½-in.-dia. auger had been reduced to 3 in. in 10 min.

The soil profile in all bores was as follows:—

The top layer was of coarse to medium sand of very uniform size. This deposit was comparatively recent and the site was right on the seashore. Under this sand, which was 12 to 18 ft thick, was a layer of ironstone pebbles and nodules, with occasional small boulders. These pebbles appeared to be water-worn and the layer, about 2 ft thick, had probably originally been a capping of ironstone, as shown on the typical section in Fig. 38 of the Paper. At some points on the site there was a layer of peaty mud between the sand and the ironstone. This had probably been deposited in a back-water isolated from the sea by a sandbar which had later drifted over it.

Below the ironstone layer were a series of multicoloured clays and silts with varying proportions of sand. Some were quite free of sand, others could be described as silty sands rather than sandy clays. The ground-water level was approximately 7 ft below ground level so that when taking augered samples there was always water in the borehole and the samples were considerably softened during the drilling process and also when withdrawing the auger through the water.

360. Some of the sandy clays or silts contained a high proportion of mica and Mr McKechnie was doubtful of the description of these soils in Table 14 as "alluvial". His own opinion was that they were residual soils formed by the weathering and leaching of igneous rocks or possibly gneiss, but since all outcrop rocks in the vicinity were of the granite family (apart from ironstone outcrops) the parent rock in this case was probably the same. The variation in colour of the clays was haphazard and very local rather than in regular layers, which would appear to favour a residual soil rather than an alluvial deposit. The description of these deposits as soft silts and clays, based on disturbed samples received in London, emphasized the importance of having an experienced engineer on the site during the preliminary investigation, and also of recording on the borehole log sheets the ease or difficulty experienced in drilling, since this was usually a guide to the stiffness of the various strata.

361. The ground encountered on the Malacca site was very similar to that under the Connaught Bridge Power Station in Selangor, 125 miles north from Malacca but still near the west coast of Malaya, and both stations were founded on reinforced concrete piles.

362. These tropical clays and sandy clays provided excellent foundation materials as long as they were kept undisturbed. Particular care was necessary in excavating the sandy clays to keep the excavated bottom well drained and to ensure that the labourers walked on planks and not on the clay itself, because it soon degenerated to a slurry under the combined influence of water and foot traffic.

363. The soft grey clay with red iron stains referred to in Table 14 was in fact a very stiff clay of the kaolin type, and when pile-driving on the site it was probably this layer in which the piles were founded.

364. Driving 30-ft-long reinforced concrete piles, 14 in. square, with a 3-ton drop hammer falling 3 ft, to a set of $\frac{3}{8}$ in. for ten blows, the average penetration had been 27 ft 6 in., and this was about the depth at which the grey clay occurred.

365. Test loading of these piles under a 95-ton load had given a total settlement of

0.23 in. after 3 hours. No further settlement had been recorded in 24 hours, and when the load was removed the pile recovered to its original level.

366. Mr McKechnie supported the comments made in Paper No. 6258, on the loose use of the term "laterite", which seemed to be applied to everything from solid rock to sandy silts and clays, and could be most misleading when making local enquiries. To define laterite by chemical composition was not of great use for site purposes and he preferred to confine the term to the gravel-clay mixture used for roads, etc., and to use the term "ironstone" for rock deposits and "clay" or "sandy clay" for those deposits without the laterite nodules.

Mr Elisha Shklarsky (Senior Lecturer, Highway and Soil Engineering Division, Israel Institute of Technology) and Mr Gdalyah Wiseman (Lecturer, Highway and Soil Engineering Division, Israel Institute of Technology), commented on the reference in Paper No. 6239 to the methods of construction and materials used at several airfields in Israel prior to 1948. Since 1948 it had been necessary to lengthen and strengthen existing runways. Agencies responsible for runway construction in Israel had instigated extensive programmes to study the behaviour of existing runways and to improve design methods, and the Israel Institute of Technology, through its Highway and Soil Engineering Division, had been active in this work.

368. At an airfield in Israel the pavement had been opened after more than 10 years' service and the in-situ condition of the highly plastic clay subgrade (CH) determined. Classification tests had given the following results:—

Liquid limit	60%
Plastic limit	21%
Shrinkage limit	10%
Finer than 0.002 mm	54%

In the laboratory after 4-day soaking, for specimens compacted at optimum moisture content, by modified AASHO compaction, the C.B.R. value was 4%. At one-third of the locations there was an "impervious undercarpet" overlying the clay subgrade. Table 16 showed that there was a very definite trend for the in-situ C.B.R. value to be higher and the natural water content lower when the impervious undercarpet had been used.

TABLE 16

	With undercarpet	Without undercarpet
No. of test pits	10	20
Average water content %	24.8	28.1
Range of water contents %	22-28	25-35
Average in-situ C.B.R. %	6.7	4.8
Range of in-situ C.B.R. %	4-10	2-6

369. In connexion with new construction at the airfield mentioned, a thorough laboratory investigation into the swelling characteristics of the subgrade clay had been carried out to determine optimum placement conditions to ensure minimum swelling and maximum strength upon reaching moisture equilibrium. Some of the test results were shown in Table 17.

After swelling all samples had reached a 90-95% degree of saturation. From a study of the test results it had been concluded that to minimize deformation of the runway surface and extreme loss of strength of the subgrade owing to swelling a surcharge was

TABLE 17

Compactive effort	Modified AASHO			Standard Proctor		
"Moulding" water content: %	15	20	25	15	20	25
Compacted dry density: ton/cu. m	1.67	1.73	1.57	1.36	1.47	1.52
Swelling pressure (required to prevent movement): kg/sq. cm	4.5	3.5	1.5	0.7	0.8	—
Volume swell (zero surcharge): %	31.5	24.5	6.8	17.3	14.0	8.5
Volume swell (surcharge=0.15 kg/sq. cm: %	13.6	6.8	2.0	3.0	2.8	2.0
Final water content (zero surcharge): %	39	34	31	45	36	29
Final water content (surcharge=0.15 kg/sq. cm): %	29	24	26	35	30	28

necessary of at least 70 cm (0.15 kg/sq. cm) of non-swelling material above the subgrade and that the clay should be compacted at a "moulding" water content of at least the plastic limit (21%).

370. In accordance with the practice established by British engineers during the construction of Lydda Airport, Israeli engineers had continued, until recently, the use of impervious undercarpet. The undercarpet had consisted of local sands or "kurkar" mixed with 80–100 kg of cut-back asphalt (MC-5 or S-125) per cubic metre of compacted mix. This mixture was spread and compacted to a 5- to 10-cm thickness. As might have been expected when this mix was tested for permeability, it had been found to be pervious and porous. With the realization that the key to a truly impervious undercarpet was to reduce the percentage of air voids, various mixes had been tried in the laboratory and their coefficients of permeability determined. To obtain impervious (coefficient of permeability: $k \leq 1 \times 10^{-7}$ cm/sec) mixes, it had been necessary to improve the gradation of the sand or kurkar by the addition of 50% crushed stone fines and the use of 10% bitumen by weight. Upon compaction this gave less than 4% air voids in the total mix. However, this percentage of bitumen was twice as much as had been used to date.

371. In an effort to reduce the cost of the impervious undercarpet and yet obtain an impervious cover for the clay subgrade, an asphalt membrane had been tried on recent construction in Israel. The method of construction of this asphalt membrane was as follows:—

- (a) The clay subgrade was brought to the required moisture and density and trimmed to shape.
- (b) On the subgrade, 3 to 5 cm of crushed stone fines were immediately spread (not allowing the surface of the clay to dry out), wetted, and rolled by 8-ton pneumatic rollers.
- (c) A prime coat of 1 kg/sq. m of cut-back asphalt MC-0 was sprayed on the crushed stone fines.
- (d) A membrane of 3 kg/sq. m of 50/60 penetration asphalt cement was sprayed in one pass.
- (e) A 5-cm blanket of clean dune sand was spread by hand to protect the membrane from puncturing during the spreading of the next lift.

The above construction procedure had been followed without any difficulty, and executed at considerable speed for about half the cost of the usual sand-asphalt undercarpet.

372. The asphalt membrane, upon being exposed for purposes of inspection on numerous occasions during construction, had always been found to be intact, although

it was subject to rather rough treatment, since the layer above the sand blanket was a calcareous sandstone (kurkar) spread by crawler-type bulldozers. A plastic-sheeting membrane protected by the same 5-cm sand blanket, which was experimented with, had been punctured in numerous places when subjected to the same treatment.

373. Calcareous sandstone (kurkar) had found considerable use in Israel as sub-base material for flexible pavement construction. The kurkar was extremely variable in composition and gradation, so that when compacted its C.B.R. values might range from 15 to 50%. Poorer quality kurkar, however, had been successfully stabilized by the addition of limestone fines. In one case the strength of a kurkar had been raised from an average C.B.R. of 15% to values between 50–75% by mixing the kurkar on the fill with 20% limestone fines.

374. Proper compaction of kurkar required large quantities of water. On one occasion where kurkar had been used, as a sub-base material directly overlying highly plastic clay, the large quantities of water necessary for compaction had seeped through the permeable kurkar and caused the clay subgrade to be softened to such an extent that subgrade failure had been caused when rolling a 15-cm lift of kurkar with an 8-ton pneumatic roller. The difficulty had subsequently been overcome by using an asphalt membrane on the clay subgrade as described above.

375. In airfield construction on swelling-type clays considerable attention should be paid to details of drainage and shoulder design. On these clay types, even without the effect of traffic, the edges of the runways deteriorated and longitudinal cracking developed, which progressed towards the centre with time. Though there were no doubt other reasons for this phenomenon, its main cause was seasonal variations in moisture content and subsequent volume change of the subgrade near the edges of the runway. To minimize this destructive phenomenon, surface run-off from the runway was prevented from entering the subsurface drains and shoulders by extending a buried membrane for several metres from the pavement edge. In connexion with subsurface drains, it should be noted that a rubble-filled type with vertical stand-pipe connexion to gutters collecting surface run-off had been installed during the period of the Mandatory Government of Palestine. Over a period of years they had been clogged by clay and had been responsible for subsurface erosion even under paved areas. When strengthening existing runways these drains had been removed, the trenches backfilled with properly graded filters, and the surface protected by an impervious asphaltic cover to guard against infiltration of surface-water to the subsurface drainage system.

Mr B. R. Goodsir (Civil Engineer, Air Ministry), referred to Mr Tomlinson's remarks in Paper No. 6239 on the construction of Abu Sueir Airfield in Egypt. The specification required that the soil should be completed to 95% of the modified AAHSO density to a depth of 18 in.; it was hoped to achieve this by rolling for eight passes with the Porter 200-ton roller fully loaded. In practice it had been found that using the roller fully loaded to 200 tons in the first instance the specification could not be achieved; the heavy roller on virgin ground had the effect of a "kneading" action rather than compaction. It had also been found that the moisture content had to be within limits of the optimum moisture content for the specification to be achieved.

377. Plate-bearing tests had then been carried out on areas at the right moisture content and the percentage recovery noted as the loading was repeated and then increased. As a result of this test the following main facts had emerged:—

- (a) At moisture contents within certain limits of the optimum the first and second application of load gave a low percentage recovery, i.e. good compaction; for any further repetition of the same load, very little further compaction had been obtained.
- (b) When the load was further increased the degree of compaction increased for the first two applications of load and thereafter the increases had been correspondingly small.

(c) The densities called for by the specification corresponded to 95% recovery and could be obtained with a loading equivalent to the roller loaded to 160 tons.

378. As a result of these tests an economic rolling programme had then been specified which was:—

One pass at 80 tons
 One pass at 100 tons
 Two passes at 120 tons
 Four passes at 160 tons.

It had been very important to work this programme out carefully, because the rolling operation governed the progress of the work. Owing to the vast area involved, it had been in the interests of economy and progress that the rolling should be limited to the absolute minimum required.

379. The soil conditions over the site being variable, there were many areas where the lack of fines in the soil had made compaction impossible with the plant available; in such areas the poor material had had to be removed or filled over with 18 in. of good material. For economical earthworks therefore the rule had been, where possible, to arrange the levels so as to have filling over poor areas and cutting in good areas, the excavation from the good areas being used to fill over the poor soil areas. This had avoided the unnecessary handling of large quantities of soil.

380. A further point of interest was the method finally adopted to get the moisture content within certain limits of the optimum moisture content, i.e. 4 to 6.5%. The method had been based on the way that the local farmers watered their fields. The formation after being levelled had then been divided into areas about 20-ft square by means of 3-in.-high soil ridges; water had then been run into these enclosed areas, the quantity required having been calculated after soil tests were done. These areas had then been left for 2 days during which time the water percolated through to a depth of 2 ft, and the moisture content had always been found to be very close to the optimum moisture content; this was checked by field tests. At this stage the formation had been rolled with a rubber-tired roller to seal the surface and then the heavy rolling commenced. It was interesting to note that even during the summer months the moisture content at depths of 6 to 18 in. below the surface had remained reasonably constant for many days; indeed, if by error too much water had been added the time it took to dry out to the right moisture content was tantalizingly long; the rule on the site had always been, "better a little too little than a little too much".

Mr A. E. S. Alcock (United Nations Housing and Physical Planning Expert in Panama, formerly Town Planning Adviser, Ghana) observed that block-making for building construction using Portland cement as a stabilizer had spread throughout the tropics, and in fact the method seemed to follow the distribution of latosols and laterites shown in Fig. 39.

382. He had developed a simple field shrinkage test for determining the proportion of cement to soil for building blocks based on field experience and laboratory tests in Ghana over the past 10 years. This test consisted briefly in putting a sample of the soil, with moisture content at the sticky point, into a box, 1½ in. square by 24 in. long internally and open on a long side, and keeping it in the sun for 3 days or in the shade for 7 days. The proportion of cement to soil, as measured loose before mixing, was determined as followed:

Shrinkage	Cement : soil
less than ½ in.	1 : 18
½ to 1 in.	1 : 16
1 to 1½ in.	1 : 14
1½ to 2 in.	1 : 12
more than 2 in.	soil unsuitable for stabilization

383. The moisture content before testing was found by pushing a dry shiny metal surface into the sample. The correct moisture content occurred when a smear first remained on the metal surface as the moisture content was increased from the dry state. The inside of the box was greased before the sample was inserted and care was taken to see that all the corners were filled with wet soil. The test should be valid for tropical climates where the sample would reach an air-dry state after the periods given.

384. Mr Alcock's experience in Ghana had shown that linear shrinkage was the principal factor in determining whether or not a soil was suitable for stabilization with cement for building blocks. The optimum moisture content was another significant factor. Soils which required smaller quantities of moisture to bring them to maximum density made better building blocks than those which required greater quantities of moisture. The optimum moisture content, which was related to compaction, did not seem to receive as much attention as the liquid limit, which was related to friction and vibration. Mr Alcock considered that the optimum moisture content, because of its direct relation to the physical factor of maximum density, was often of greater engineering significance than the liquid limit. The quantity of moisture which entered into a soil to produce maximum density had some relation to its nature and might provide a simple, if crude, guide to its behaviour under wetting and drying in walls of buildings not subject to the impact pressure and attrition experienced by soil in airfield foundations, which required C.B.R. tests also for closer determination of their suitability. However, it was also found that the higher the liquid limit the worse the soil for building purposes, but the differences were much less marked than in the case of the optimum moisture content.

Mr Clare, in reply, said that the discussion had undoubtedly added considerably to the value of the symposium by placing on record a great deal of valuable information derived from the field experience of engineers who had worked abroad. This information had materially increased the value of the symposium as a record of present knowledge on tropical soils.

386. Mr Mann's remarks in § 265 regarding the soil at St Jean illustrated the underlying motive for the development of the ideas in Part 1 of the symposium. The difficulty of interpreting the results of the physical tests on the soil encountered at this site pointed to the desirability of considering alternative approaches in soil evaluation. It was precisely for such reasons that thought at the Road Research Laboratory had turned to methods which took into account factors governing the formation of soils. Mr Clare suggested that a pedological examination of the soils in Israel and in Cyprus might indicate the reasons for the differences in performance which Mr Mann had in mind.

387. An essential part of the morphological system of soil examination was the stress laid on the examination of the soil profile rather than on the properties of individual samples, and the value of this approach was illustrated in Dr Millard's observations in §§ 273-276 regarding the influence of an underlying layer of clay on the engineering characteristics of a site. In such cases the establishment of the character of the whole soil profile along the length of a runway was clearly of great value to the engineer.

388. With regard to the work at Malakal in the Sudan, Mr Clare agreed with Mr Burns (§ 288) that vitrified clay was costly to produce. However, it was clear from his description of the difficulties in obtaining imported granite that that must also have been quite costly and it would be interesting to have further information about the relative economics of the two materials.

389. It was interesting to hear from Major Smith that he had found coral sand to possess cementing characteristics. These had been observed elsewhere and clearly constituted a useful property of this group of soils. In the same vein, Mr Brown had referred to the stabilizing power of different types of organic matter. The use of ground-nut husks, lalang grass, and coconut husks had been reported in this connexion.

Experiments at the Road Research Laboratory had suggested that the effects of vegetable material of this type would not be of long duration, since the materials themselves would ultimately be consumed by bacteria. However, it was possible that the use of such materials would be justified where they were locally available and if the stabilizing effect was not required to be of long duration, that was, perhaps for a year or so.

390. Mr Brass had rightly drawn attention in § 303 to the problems arising in the operation of mechanical plant with tropical soils. It was known that maintenance problems could be particularly acute with some abrasive soils and it would be expected that these would be more acute in arid tropical conditions than in temperate climates.

391. Mr Clare agreed with Dr Greene that an elaboration of Table 3 must necessarily take into account the important effects of rainfall and drainage, and that parent material also had considerable influence on the properties of the soils derived from it. However, a start had to be made and the classification in Table 3 was suggested as a first step in the application of pedological methods to problems of road and airfield engineering. It was hoped that as more knowledge accumulated it would be possible to elaborate Table 3, perhaps along the lines that Dr Greene had in mind, and in this connexion the information that had emerged during the discussion would be of particular value. Mr Early, for example, confirmed in § 316 the value of considering the drainage factor. The observation that alluvial and aeolian deposits had a limited particle-size range was based on the examination of lagoon sands from Nigeria. It was possible that Mr Early's disagreement with this view arose from a stricter view of what constituted a limited particle-size range than Mr Clare had had in mind. Mr Early's remarks in § 327 regarding the formation of secondary calcium carbonate in soils were somewhat difficult to understand, since it was difficult to see how a transference in solution could take place until the parent rock had been broken down chemically.

392. With regard to the remarks by Mr Arulanandan, Mr Clare felt that he must have misunderstood the objects of Part 1 of his Paper. The morphological approach was essentially a practical one, since it involved the visual examination of the soil in the field, a method with which most engineers were already familiar and which they already used to a very large extent. The object of the Paper was to draw attention to those aspects of the method which had validity in connexion with engineering problems. It was a means to an end and not an end in itself.

393. Mr Bassett had made the interesting suggestion that the types of grass used on airfield surfacings should be examined to determine which were the best varieties to use. Pedology might have a part to play in work of this type, too, since it was known that the type of vegetation which developed best was influenced by the type of soil at the site. One of the principal objects of pedological research in the agricultural field was to indicate which crops were most suitable for which soils. It was therefore not too hard to imagine that the type of grass most suitable for an unpaved airfield would bear some relation to the pedological classification of the soil at the site.

394. Mr Alcock's contribution to the discussion was particularly welcome in view of his pioneering work in the use of soil-cement stabilization and it was interesting to hear that he found that the linear shrinkage was the principal factor determining whether or not a soil was suitable for stabilization. It was interesting to speculate as to whether or not shrinkage limit of a soil sample was materially affected by the type of profile and by the depth from which the sample had been taken.

Mr Tomlinson, in reply, referring to Mr Mann's remarks, said that it was rather doubtful if the calcareous clays of the Levant Zone of the Middle East could be truly described as "cotton soils". Admittedly they showed the same marked swelling and shrinkage characteristics, but they were not heavy clays and the liquid limits and plasticity indexes of the Levant soils were generally lower, and the carbonate contents higher, than the cotton soils listed in Table 5 of Paper No. 6243, Part 2. There was a considerable difference between the behaviour of the calcareous soils at Nicosia and St Jean as

mentioned in § 265. This difference was more marked than was indicated by classification tests. The climatic conditions were roughly the same, but there was a difference in the origin of the soils and the environment of the sites. The St Jean soil was an alluvial deposit in a low-lying coastal plain and the parent rock was probably Cretaceous; whereas the Nicosia soil was a thin covering over a Miocene limestone plateau and might well have contained a high proportion of residual soil.

396. Mr Mann had pointed out in §§ 267 and 268 the need to provide some form of impervious cut-off along the edges of paved areas. However, a cut-off required careful design, and it appeared from Mr Burns' remarks (§ 286) that the 3-ft-deep sand-bitumen cut-off wall to the original Lydda runways had been rather ineffective. Even the subsequent and more elaborate construction of flattened oil drums bonded into the paving had not been fully effective as shown by longitudinal cracking near the edges of runways and tracks.

397. Referring to Mr Mann's remarks in § 271, it was true that there was a swing towards aircraft with higher tire pressures, but not all modern aircraft had them. Mr Tomlinson pointed out that when introducing Paper No. 6239 he had shown slides of the Blackburn "Universal" freighter (143,000 lb. all-up weight and 50–82 lb/sq. in. tire pressures) operating from a sand-surfaced runway at Umm Said and a gypsum-surfaced runway at Fahud in Oman.

398. Dr Millard had advocated removing vegetation from the shoulders and slopes of embankments to roads on black cotton soil. This might lead to difficulties in controlling erosion. The bare soil in the Levant coastal strip suffered severe erosion during winter rains, and a blanket of non-cohesive soil over cotton soil would be expected to suffer even more erosion by wind and rain. Mr Tomlinson suggested that it might be possible to grow shallow-rooted vegetation in the non-cohesive soil layer.

399. Mr Burns had given an interesting account of the early construction of Lydda Airport. In spite of the careful workmanship and equally careful maintenance the runways had broken up in the winter of 1943–44. This was probably because of swelling and softening of the subgrade resulting from accumulation of moisture draw-up from below.

400. It was useful to have Major Smith's account of the physical characteristics of the coral used on the Christmas Island airfield. The C.B.R. values that could be obtained with compacted coral were astonishingly high, and what was more they could be maintained, because of the natural cementitious and impervious nature of the compacted material. It was also useful to know that coral was a satisfactory aggregate for bituminous and concrete pavings.

401. Mr Brown had suggested in § 299 that natural oils present in vegetable debris had a stabilizing influence on unpaved roads. Mr Tomlinson had had no experience of this, but crude-oil spraying was used to maintain the surface of many airfields on calcareous silty clays in Iraq and Jordan. Frequent re-spraying and rolling was necessary to maintain the surfaces, which were disrupted by aircraft turning with a locked wheel and by "salt boils".

402. Referring to Mr Brown's comments (§ 300) on unpaved airfields, Mr Tomlinson took the view that the climate had a more important influence than the soil type. In the arid regions of the Middle East unpaved airfields on a wide variety of soil types, including sandy soils, had given satisfactory service, but there were very few soils which could make unpaved airfields in humid climates. It so happened that all the unpaved airfields on sands known to him were near a source of salt water, which was used to build up a stable crust by repeated spraying and rolling. He did agree that constant maintenance was necessary, but this was often cheaper than building and maintaining paved runways.

403. Mr Brass had remarked (§ 303) on the lack of information on mechanical plant in the three Papers. In Mr Tomlinson's experience the choice of plant was governed not so much by the soil type as by what was available in the locality at a particular time. For normal sands, silts, and clays the corresponding types of plant used in the United

Kingdom could also be used on overseas soils. In arid climates the tendency was to favour plant which was suitable for dry working conditions, i.e. scrapers drawn by wheeled tractors, and smooth-wheel rollers. Sheepsfoot rollers were useful in breaking down hard clods of dry calcareous clays. The more peculiar overseas soils required special consideration. For example, the "gatch" of Kuwait could only be excavated by scraper or grader with difficulty and scarifying was often necessary to break up the material. Gatch fill for bases and sub-bases was excavated from borrow-pits by face-shovel without the need for explosives. Repeated trafficking by crawler tractors on a gatch subgrade resulted in a thick layer of fine white dust which was a nuisance in dry windy weather. Sheepsfoot rollers had been used for compacting gatch fill but since watering was necessary to aid compaction the sticky gatch clogged around the feet of the rollers. Pneumatic-tired rollers had been shown to be quite satisfactory. A vibrating roller had been tried for maintenance of an unpaved airfield on shelly sand where a stable saline crust had been formed by spraying with sea-water. However, the vibrations caused consolidation of the deeper unstabilized sand, with the result that the crust had broken up. Light smooth-wheel rollers were the best for this type of maintenance rolling.

404. Mr Tomlinson was pleased to see that Dr Greene (§ 310) agreed with his contention that the wetting of a subgrade soil could be caused by vapour movements from below rather than by percolation from the surface. He had had great difficulty in convincing engineers that this did in fact take place.

405. Referring to Mr Early's remarks in § 324, the Author did not describe the Al-maza soil as a "silty sand", but as a sand "with little silt" in the sense that there was hardly any silt. Most surface soils in the Near and Middle East contained some wind-blown dust and he imagined that Al-maza was no exception. He agreed that "gravelly sand" would have been a better description, and it was referred to as such in the caption below Fig. 34.

406. Mr Arulanandan was wrong in assuming that tropical soils could be described with adequacy solely in terms of an engineering classification. Such a classification would, for example, describe the Kuwait and Persian gatch as "a non-plastic sandy silt". Such a description could never convey to the engineer the peculiar characteristics of this material for airfield and road construction, neither could a material such as coral be defined in terms of an engineering classification. Mr Tomlinson would agree that esoteric geological or pedological classifications with involved and inconclusive theories on the origins and formation of tropical soils could be tedious and meaningless to the engineer. However, he doubted if any standard classification could be established which could describe in concise terms all the engineering characteristics of these materials. Unfortunately there was no substitute for first-hand knowledge and experience of the peculiarities of soil types in particular countries and climates. That was why he had used local names as far as possible so that engineers could recognize the types, and take the appropriate measures in design and construction.

407. Mr Loveday's deductions on the behaviour of runways, at Aqir and elsewhere, were based on the premise that softening of the subgrade resulted from percolation from above and not from accumulation of water drawn up in vapour form from below. Mr Tomlinson felt that the sequence of events was; first, swelling and softening of the subgrade owing to moisture drawn up from below, followed by pavement failure and then direct ingress of water through the resulting cracks in the surface. The final stage was rapid and extensive failure of the runway. The impervious undercarpet could do nothing to prevent softening by water drawn up from below, but it was a valuable safeguard against rapid spread of failure from local minor cracking in the surfacing and no doubt contributed in this way to the serviceability of the reconstructed runways at Aqir and Lydda. Until more was known about the long-term movements of subgrade soil moisture he was of the opinion that there was no alternative to the counsel of despair in designing runways on clays on the assumption of a saturated subgrade. The

greater part of the large pavement thickness required need not be in a high quality construction, and the provision of a "wrapped-up" soil sub-base was suggested in § 84. It had since been pointed out to him that there might be undesirable upward moisture movements within such a sub-base. It would be necessary to compact the soil in a dry state, and without the long-term research suggested in § 84 into these aspects, the soil sub-base could not be used with full confidence.

408. Mr Bassett had rightly pointed out that grass was in many ways an ideal surfacing for cheap airfields and had given some useful information on the difficulties experienced in growing and maintaining a satisfactory grass cover. Mr Tomlinson had the impression that grass in tropical climates grew so erratically and luxuriantly that it would be difficult to produce a level turf, and he was surprised at the extent of grass airfields in British North Borneo.

409. It appeared from the investigations of the Road Research Laboratory described by Mr Russam, that there were no appreciable seasonal moisture movements in sand subgrades at Abu Sueir and Khormaksar. This was reassuring and it was to be hoped that the Road Research Laboratory would publish full details of their investigations at an early date.

410. He agreed with Mr Hatherly that drainage was an important factor in overseas airfield construction, both for disposal of high rates of run-off and for controlling the position of the water-table. Mistakes had been made in the past by trying to combine the two functions, with the results described by Mr Hatherly. French drains were only useful in a free-draining soil where there was a risk of the water-table rising to near sub-grade level. They were ineffective and even dangerous in calcareous silty clays, as had been noted by Messrs Shklarsky and Wiseman (§ 375). Mr Tomlinson could not agree with Mr Hatherly's view that base construction materials should in all cases be investigated in a saturated condition. It was true that a so-called impervious surfacing could not be relied upon to remain impervious, with the result that water could accumulate in bases if escape was prevented by lack of drainage. It could also accumulate in bases by vapour movements from the subgrade soil under certain climatic conditions, but if the bases were of highly permeable materials with provision for drainage they could not reach saturation conditions. However, the risks were present and should be taken into account in design.

411. From the data given by Messrs Shklarsky and Wiseman in Table 16 it appeared that the impervious undercarpet had been at least partially effective in preventing full softening of the subgrade, although it seemed that the bitumen-sand carpets put down 10 years previously might not have been anything like impervious (§ 370). (This favoured Mr Loveday's contention (§ 341) that runways need not be designed for saturated sub-grade conditions.) The conception that the runway thickness was governed by the desirable surcharge to minimize swelling and softening was new to Mr Tomlinson. It was noted that the thickness of 70 cm required on this basis was not much more than the 60-65 cm provided in the 1944 reconstruction of the Lydda runways, which might explain why full softening had not taken place. They had made a useful contribution on the subject of impervious membranes, and had put forward another good point in that they enabled adequate watering to be given to aid compaction of sand sub-bases. The comments on drainage details in § 375 confirmed Mr Hatherly's views in § 354. The buried impervious membrane extending beneath the margins had been suggested by Mr Tomlinson in 1948,¹³³ and it was interesting to learn that this form of construction had been adopted.

412. Mr Goodsir had given further information on the construction of Abu Sueir airfield, which had been briefly described in § 102. The method which had been adopted for obtaining optimum moisture content in the soil appeared, at first sight, to be somewhat primitive, but it was effective in achieving uniform moisture conditions for the full depth of the 18-in. layer which was compacted by the Porter roller.

413. Generally, the discussion had been valuable in amplifying the examples of soil

types and experiences in overseas airfield construction given in the three Papers. It had shown the need for a wider form of soil classification, than the purely soil mechanics approach, to describe the engineering characteristics of overseas soils. Mr Tomlinson thought that there was general agreement that climatic conditions, which played an important part in the formation of overseas soils, was also the all-important factor in the behaviour of both paved and unpaved airfields. However, there was still much to be learnt about moisture movements in different types of subgrade soils and also in sub-bases and base materials, and he would strongly recommend more intensive research into these problems.

Mr Nixon, in reply, thought that the most interesting thing that emerged from the symposium was the general agreement on the inadequacy of present-day soil mechanics classification tests. This was apparent when Dr Skipp and he had been preparing Parts 5 and 6 of their Paper, and they had been looking forward to learning the general opinion of other members on this important point. He agreed that, on occasion, the tests were of some value. For example, it had been shown that a tropical red clay with a high liquid limit was often a troublesome material, and many of these clays had been identified as of volcanic origin. This had first been noticed by Grace. However, Mr Nixon could not agree with Mr Brown that they were satisfied—far from it. Mr Arulanandan had remarked upon the poor correlation between the results of standard tests on two apparently similar materials, and had arbitrarily suggested that it was an error—rather than some other factor—which had caused the odd result. At the same time he had said that we should not resort to other methods of testing. Mr Nixon could not accept this approach, which left inconsistencies in test results, without an explanation. He believed that at present an open mind should be kept, and every available approach should be utilized in a search for a more favourable series of tests so as to arrive at a reliable engineering classification.

415. Mr Brown had drawn attention to the importance of making use, where possible, of inexpensive local materials for stabilization, rather than imported materials. Too often, one tended to consider only those materials with which one was familiar and to forget that they might be difficult and expensive to obtain in certain places. It was essential that, before any stabilization tests were carried out on tropical soil, a thorough survey was made of local resources for suitable additives, and that a comparison was made of the relative costs of all the agents which might be tried.

416. Mr Nixon was pleased that the final point in Paper No. 6258 on laterite, concerning the use of this material for concreting, had drawn at least one contribution (from Mr Brown), because it was again a question of using local materials.

417. Mr Brass had asked in § 302 if frost was ever a problem on airfields in the tropics. It appeared from inquiries that frost generally occurred in the tropics at 14,000 to 16,000 ft, and very occasionally as low as 9,000 ft. Airfields at this height were exceptional. In Ethiopia there were, however, airfields at 7,500 to 9,000 ft above sea level, but it was understood that there were no problems connected with frost, which occurred only at night. The only weather problem there was the mist. Frost did, however, occur in the tropics below 9,000 ft, in valleys, etc., but its duration was generally very short and, therefore, its effect was insignificant.

418. Referring to the comment, made by Mr Brass in § 303, on the fact that little mention had been made of plant, the reason for this was that there were few comparative studies where the soil conditions had been adequately described. One interesting exception was the paper by Henry and Grace.¹¹⁹ Mr Brass had also asked how the results from a very elaborate and heavy compaction machine might compare with hand compaction, in view of the quotation from Winterkorn and Chandrasekharan⁸⁶ which was given in § 168 of Paper No. 6258. One explanation for this possibly surprising statement was that sometimes it was better to leave the laterite free-draining where the natural structure was sufficiently strong not to break down under the applied loads.

Over-compaction, in such cases, might reduce the naturally weak granular material to a clay—with all the attendant disadvantages.

419. Mr Early had stressed the value of geomorphology. Mr Nixon admitted that to him, as an engineer, this was something quite new. Mr Early and Dr Skipp had, however, convinced him of its value in this problem. He realized that there was much to learn from experts studying soil from other viewpoints, and whose experience had been overlooked by engineers—particularly in regard to tropical soils. For example, the geologist could be very helpful when variations in the soil were being assessed horizontally as well as vertically. Topsoil, generally a very thin layer in temperate climates, had little engineering value and, therefore, there was no need for any detailed knowledge of it. In the tropics, however, this weathered soil could extend to a considerable depth and soils engineers had, for too long, overlooked what the pedologist had to offer.

420. The reference made by Mr Early in § 322 to iron-pan cementation and the different problems it raised as compared with laterite, had reminded Mr Nixon of the difficulty he had experienced in reporting upon the usefulness of a hard form of iron-pan at a certain site. Its thickness was invariably in doubt, so that its use could not be relied upon. Moreover, being very hard, it had been a difficult material to penetrate in test boreholes.

421. Mr Bassett's contribution about grass for airfields in tropical countries had added some useful knowledge to the Author's small store of information on biology and civil engineering.

422. Mr McKechnie's description of the actual conditions at the Malacca Power Station site, Malaya, was a valuable contribution. He had remarked about the important difference in consistency between the soil descriptions for samples from this site given in Table 14 of Paper No. 6258, and the actual conditions. That was easily explained and had, to some extent, been anticipated when the results were originally analysed at the laboratory in London. It was known that the samples mentioned in the Paper had been taken from holes made by percussion methods. This method was extremely fast through soils and thereby could cause considerable disturbance and softening even to naturally firm or stiff clay soils, so that samples taken—even after driving a tube—might not be representative. On the other hand, Mr McKechnie's description had been based upon auger borings which, although they were admittedly slower than other methods, generally provided good core samples of firm or stiff cohesive soils. The pile tests had confirmed the presence of stiff material. Mr McKechnie had rightly pointed out the importance of an experienced soils engineer being present on the site during the preliminary investigation. The rate of boring was but one factor in estimating the hardness, or otherwise, of the ground. It was essential, also, to know the boring technique: how it was being applied as well as the tool actually being used.

423. There seemed to be little doubt that some of the lateritic soils at this site were residual rather than alluvial, and Dr Skipp had treated this point in more detail in his reply.

Dr Skipp, in his reply, said that he had heard with interest the point made by Dr Millard regarding the decomposed granite, particularly with respect to Hong Kong airport. He had found it very difficult to classify this material, but would point out that this contrast between a well-drained zone and an impervious zone was likely to arise over a fairly wide range of tropical soils in which some degree of leaching had taken place.

425. Mr Brown had mentioned the clearing of the forest and the hardening of the top material. Mr Early had also commented upon this, noting that it had been referred to by Mohr and van Baren.¹³² Dr Skipp thought that it should be regarded as due to the local changes in climate and, possibly, the subsequent chemical changes taking place in the upper horizons of such materials after the clearing of the vegetation. He

did not think that, at the moment, one could speculate on the possibility of stabilization by residual oils or humus material.

426. Dr Skipp was very pleased that Dr Green had so lucidly explained the development of so-called "ground-water laterite" and had discussed the transportation of iron on slopes. He thought this was an example of how the pedologist could help the engineer in understanding the extent of local variations to be expected in this type of soil.

427. Mr Early had justly pointed out certain contradictions within the Paper on the use of the word "latosol". Dr Skipp entirely agreed with him. The word should be used in a very broad sense; and he thought that they should confine the word "laterite" to something very limited and, preferably, it should not be used unless absolutely necessary. Mr Early had also raised a point concerning the possibility of base-exchange going on in one of the materials, and raised doubts concerning the true lateritic nature of that material.

428. Dr Skipp noted with interest the results of four auger borings obtained by Mr McKechnie, at Malacca, and agreed that the description of the material as "alluvial" was open to question. Some of the results, quoted in Table 14, appeared to relate to this material, but he agreed that it would be better to consider all material below the ironstone as residual. Occasionally the peaty material was absent and a lateritic material was underlying a coarse beach sand. There was some evidence of laterite pebbles above a residual lateritic clay. Altogether it would appear that an original laterite profile had been truncated and, in places, some detrital lateritic material now overlaid the original profile. It was agreed that one could not define laterite by a chemical composition. Mr Nixon and he concurred with Mr McKechnie that the term "ironstone" should be reserved for rock-like materials, and the word "laterite" should be limited in usage.

429. Mr Alcock's contribution was of interest because it dealt with another aspect of the usage of lateritic materials. Mr Alcock's experience in Ghana had led him to the conclusion that the optimum moisture content, to achieve maximum compaction, was the principal factor in determining whether or not a particular soil was suitable for stabilization into blocks. This factor alone would not suffice for cement stabilization of roads and pavements. Even when dealing with well-graded soils of a similar type, the strength of compacted soil specimens when mixed with cement would be the primary factor.

430. Mr Arulanandan had made what was almost a wholesale attack upon the pedological approach and, indeed, there were dangers in this. Dr Skipp agreed with him regarding the unsatisfactory nature of the mechanical analysis, which often meant very little. He concurred that field-trial tests were most valuable, but that such tests were not considered simply "engineering classification" tests. However, the position regarding tropical soils was in some ways similar to that regarding general soil materials which obtained at the beginning of this century. Terzaghi had already mentioned how unsatisfactory was a simple geological classification. Indeed, at the Fourth International Conference in 1957 of the International Society of Soil Mechanics and Foundation Engineering, he had described his early steps in trying to correlate simple geological descriptions with engineering behaviour.¹³⁴ It was undoubtedly the recognition of the engineering classification tests and the measurement of strength parameters that had speeded the opening up of the whole field of soil mechanics. But engineers still needed the geologist and therefore the importance of the pedologist must be recognized when dealing with materials of almost entirely pedological origin. This was certainly the case in many of the tropical and sub-tropical zones, where there might be a layer of pedological material up to 30 or 40 ft thick, with a background and history distinct from normal geological material.

431. Dr Skipp thought that there was a case for a revision of the approach to tropical soils, and engineers should think of pedology and geology going hand-in-hand with a

somewhat more flexible approach to classification tests. This meant, not that engineering classification must be replaced entirely by complex descriptions, but that they must recognize the need for making a fresh approach to these materials.

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