

Discussion.

Mr. J. V. Cook, who introduced the Paper in the absence of the Authors, said that he had visited the site in September 1946, when the work was in its very early stages.

The Authors had explained, in the Paper, that the importance of the Jan Smuts airfield lay in the fact that it would serve as the main terminal for the trunk route services to the Union of South Africa. There were two main routes from Europe to South Africa, namely, the Eastern "all red," or rather "all-pink," route through Egypt, the Sudan, and Kenya, and the trans-Sahara West Coast route, which made use of staging posts in British, French, and Belgian territory. The routes followed by the various nations all terminated at Johannesburg, where South African Airways took over and ran the internal services to the south. He understood that the main internal airfields in the Union would be developed eventually to I.C.A.O., Class C.

It had been hoped that Palmietfontein, which was built as a temporary trunk route terminal, would take all the traffic through Johannesburg until the Jan Smuts airport was finished, but Mr. Cook understood that that traffic had increased at such a rate that it might be necessary to develop facilities at Palmietfontein to cope with the situation which would exist until the new airfield was operational.

In addition to the Jan Smuts airport, The South African Railways had been involved in the preliminary work on a formidable airfield job at Durban, in the delta of the Umlaas river, necessitating the diversion and canalization of the river, the flood discharge of which was about 50,000 cusecs, and the cutting of a new channel through a ridge of sandhills. The excavation involved was about 6 million cubic yards, and the post-war shortage of plant had raised the difficult problem of distributing the equipment available within the Union in such a way as to enable the Durban and Jan Smuts projects to be completed at approximately the same time. In one way, since the work was done departmentally, the initial shortage of plant had been an advantage, because the Authors had been able to build up their organization as the tempo of the work increased, which was always a good thing.

At the time of Mr. Cook's visit a specification for the sub-grade work had not been finalized, but his recollection was that it had been proposed to use selected graded stone from dumps of material excavated from the Rand mines, which would be an economical source of supply of very good quality stone, and to bind the top course of the base by penetration methods. The surface was to be an asphalt pre-mix.

In one important respect the Authors had been more fortunate than any airfield engineers in Great Britain. He had asked them whether it was proposed to operate on one runway or on a portion of the airfield before it was finally completed, and they had stated that only over their dead

bodies would an aircraft land on the airfield before it was 100 per cent. finished! He had felt at the time that that was presenting a landing risk which few pilots would be prepared to take, and he had been filled with envy and admiration. The matter was a very important one. The disruption of work caused by flying operations on a partially completed lay-out of runways was insufficiently appreciated by the layman. It invariably resulted in additional work and extra expense, however carefully the construction programme was planned. Therefore he hoped that the Authors would be able to adhere to their resolve and that circumstances would not prevent their doing so.

He had been impressed by the care taken, even at that early stage, with regard to the problem of grassed areas. The nurseries had been well started and were expanding rapidly with the help of the best agricultural advice in the Union. Although it was not made perfectly clear in the Paper, he believed that all the grass to be planted, both on the airfield and in the gardens, would have been developed in the nurseries at the site.

Although it was no part of his job to criticize the Paper, he thought that it might be to the Authors' advantage to carry out plate loading tests on a trial portion of the runway completed to specification, in view of the large number of assumptions made in that empirical method of design, and he invited comments on that point in the discussion.

As the Paper covered only the early stages of the work, the Authors had made no detailed reference to buildings. The South Africans appeared to be having the same difficulty as was experienced in Great Britain in finalizing the lay-out of the terminal buildings but the general principle of segregating functions into separate buildings had apparently been agreed. There were to be separate buildings to house technical services, operating companies, internal passenger facilities, and overseas trunk route passenger facilities, and a restaurant to serve both kinds of passengers, sited between and linked with the two passenger buildings. In addition, a great deal of work was proposed in connexion with amenities and recreational facilities for the large staff employed at the airfield.

It would be interesting to hear in due course the story of the final stages of the construction. Mr. Cook hoped that the discussion on the Paper would be critical, because he believed that criticism would be of the greatest value to the Authors in the work that still remained to be done in South Africa.

Mr. J. A. Dawson observed that the Paper was of particular interest because airfields in Great Britain were generally constructed with runways of the rigid type, whereas the Authors had described the construction of a flexible pavement. Members would look forward to a further Paper giving details of the later work on the airfield.

With regard to the design of the flexible pavement, the chart given in *Fig. 7* did not define whether the gross load was carried on two single-wheel undercarriages or on dual-wheel undercarriages, and no reference was made

to tire-pressures and contact-areas, although those points were of considerable importance ; but as the lines on the chart were smooth curves and were, indeed, almost straight, it could be inferred that the same wheel system applied throughout. For the smaller loads covered by the chart the aircraft would undoubtedly be of the two-wheel type, and from the characteristics of the curves it could, therefore, be assumed that that was the loading basis used throughout the chart. Such an arrangement would be in line with the rules laid down by I.C.A.O. in its pre-1947 manual, that aircraft with a total load of less than 200,000 lb. should be assumed to be on two main wheels. As, however, the C.A.A. chart did not provide for the loading for which the Jan Smuts airport was to be designed, the base thickness for an 80,000-lb. wheel load had been increased to that for a 135,000-lb. wheel load by applying the factor $\frac{\sqrt{135,000}}{\sqrt{80,000}}$, on the assumption

that the strength varied as the square of the depth. An aircraft of 270,000 lb. would, however, be carried on at least four main wheels and the equivalent single-wheel load would be less than was assumed in the above calculation. By that method of reasoning the result of the calculation might be rather high and therefore the pavement was perhaps unnecessarily thick.

The seven tests mentioned under the heading " Soil Survey and Paving Design " (p. 9) were essential for the determination of the characteristics of the soil on which any airfield was to be established, and Mr. Dawson agreed that it was necessary to make a large number of tests and to take an average value. It was customary to use the results of those tests in conjunction with an appropriate chart, to enable a preliminary estimation of the depth of the base to be established ; but, as the Authors had recognized, the design method was essentially empirical, and that made it more essential that actual tests should be carried out, in order to confirm the capacity of the sub-grade and the pavement to carry the required loads. Those tests could be applied to trial areas before the work had advanced too far and valuable information could be obtained which might well influence the design and enable economies to be effected. That procedure was particularly necessary in connexion with the design of the rigid pavement for which the apron was to be constructed, because when the correct value of the modulus of subgrade reaction had been ascertained it would be possible to apply the normal formulae to calculate the thickness of the pavement more accurately and more realistically. Mr. Dawson was very interested to note that tests were contemplated by the Authors, and he believed that it would be of very great value if they were really to tackle that problem.

With regard to compaction, he wondered whether the very large number of passes, mentioned on p. 24, the necessity for using a heavy-duty harrow, and the unsatisfactory results obtained from the use of pneumatic-tired rollers did not arise from the deposition of a too thick a layer of loose

material. Were trials made with layers of different depths before the 8-inch layer was selected? The effect of rolling was greatly affected by the depth of the layer to be consolidated, and the fact that a harrow had had to be used to disturb part of the consolidation seemed to point to the possibility that, if the layer of loose material had been only 5-6 inches deep, the required results might have been obtained without disturbing any of the work carried out and with less total effort. In his experience, excellent results had been obtained by the use of sheepsfoot rollers and rubber-tired rollers in tandem, and the rubber-tired rollers might have acted as a very efficient auxiliary to the sheepsfoot rollers if the layer to be consolidated had not been so thick.

Mr. J. B. F. Hawkins observed that the design of the drainage appeared to be based fundamentally upon the methods evolved by Mr. Gail Hathaway in connexion with the rapid construction of airfields to meet the expansion of the United States Army Air Force during the war. In designing airfields for use in war some risk had to be taken, owing to the shortage of constructional plant, materials, and man-power, and because of the need for completing a project by a given date in order to synchronize with planned operations.

Mr. Hathaway's method allowed for the ponding of water on the verges immediately adjacent to the runways at peak periods of precipitation, and Mr. Hawkins understood that it went so far as to permit flooding on to the sides of the runways at times of abnormal rainfall, with the limitation that 100 feet in the middle of the runway should be left clear of standing water. He doubted whether it was sound practice to accept that condition at an important international civil airport, no matter how infrequently it might occur. In addition to that objection to ponding, there was the danger of flowing water scouring the turfed margins and of gullies being formed. Those effects of scour would have to be removed with the minimum of delay, resulting in high cost of maintenance. He considered that water should be taken clear of the paved areas and, better still, clear of the airfield, as quickly as possible under all estimated conditions of precipitation. That was being done at the new London airport, at present under construction, by the provision of balancing reservoirs and, in some cases, by increasing the sizes of the drains also. Owing to the elevation of the Jan Smuts airfield, it would appear that no difficulty would be experienced in disposing of surface water without recourse to the expense of providing balancing reservoirs or increasing the sizes of the drains.

In the past too little attention had been devoted to the sub-bases for paved areas, but, with the increased all-up weights of aircraft and the vastly increased concentration due to the undercarriages, the preparation of the sub-grade was now receiving much more attention than had been given to it in the past.

With regard to the consolidation of the sub-base, the difficulties experienced in the compaction of the laterite appeared from the Paper to be

general. Mr. Hawkins considered, however, that much of the difficulty arose from the varying grading of the laterite. He presumed that the material available resembled the murram encountered in East Africa and Ceylon rather than the hard block laterite which was to be found in Singapore. The clay-, silt-, and sand-contents of the murrams of which he had had experience varied as widely between loads from the same pits as in the case of the hoggin used for similar purposes in the United Kingdom.

When the Very Heavy Bomber airfields were being constructed in Great Britain during the war, similar difficulty had been experienced in compacting the hoggin fill, owing particularly to two causes, namely, the inconsistency of the grading of the hoggin and the impossibility of maintaining anything approaching a constant moisture-content in the English climate. In the case of the Very Heavy Bomber airfields, it had been found, after much experimenting with various depths of hoggin, that it was almost impossible to obtain the results required. Therefore it had been decided to introduce chalk into the fill, but, although the results then obtained were better, they were still not good enough, and it had been decided ultimately to lay a course of chalk, wet it thoroughly and cover it immediately with hoggin, roll with sheepsfoot rollers, and finish off with power rollers. Experiments had also been made with rubber-tired rollers, but the best results had been obtained with almost pure sand rather than with hoggin.

Were the sheepsfoot rollers used by the Authors of the Le Tourneau or the Allan type? From the photographs they appeared to be the former.

Plate tests, not only on the sub-grade but also on the formation and the slabs, as designed and constructed, yielded invaluable information and could prove or disprove the efficiency of the design and methods of construction. The preparation and testing of trial areas and slabs in the early stages of construction might well save the resident engineer from many headaches after the main construction had got into full swing.

Dr. L. J. Murdock said that his main interest in the Paper lay in the description of the soil surveys and the earthworks.

The choice of the method of design of pavings was always a matter of controversy, and he wondered whether it was wise to restrict the selection of the method to the C.A.A. method for all the airfields in South Africa, as suggested by the Authors, and whether it would not be better to consider each site on its merits. The results obtained by the various methods of design available could then be related to the local conditions, and any experience of the behaviour of roads, etc., in the neighbourhood could be used to arrive at the most suitable and economical construction. The question of the effect of moisture-content upon the strength and stability of the sub-grade, whilst probably of less importance in the design of the Jan Smuts airfield, often played an important role in the design of pavements resting on clay and silty sub-bases.

He was not quite clear whether the C.B.R. tests referred to in *Fig. 8*

had been made at the moisture-content at which the soil was compacted or in the usual manner, after saturation.

With reference to the Authors' statement (p.14) that "most of the soils encountered, including the laterite gravel, fell into the E.3B class," *Fig. 11* showed that all the samples had a plasticity index of more than 10 per cent. Therefore, according to Table I, they should be classified as E.4. Dr. Murdock assumed that some of the materials would be upgraded into E.3B because more than 45 per cent. material was retained on a No. 10 sieve. Whilst that did not affect the design, he would be interested to know why the plasticity index apparently had not been considered. Perhaps the Authors had not adhered very closely to the C.A.A. method?

Again, the factor $\frac{\sqrt{135,000}}{\sqrt{80,000}}$ gave a value of 1.3, and the design curves

in *Fig. 7* indicated a total thickness of $23\frac{1}{2}$ inches, instead of $20\frac{1}{2}$ inches, as given in the Paper. He wondered whether the Authors had made a reduction, as had been suggested by Mr. Dawson, believing that the runway was too thick.

Moreover, in the design of the apron, 10 inches of concrete on 12 inches of waterbound macadam, there was apparently no direct connexion with the C.A.A. method as illustrated in *Fig. 6*. How had those thicknesses been decided upon, and was there any evidence to show that the water-bound macadam would give any better results as a sub-base than the laterite gravel?

Dr. Murdock was rather puzzled by the excess of 20 per cent. found necessary in the cut over the fill (p.17). That would imply that the fill would be much denser than the original soil, and from the descriptions he would have thought that was rather unlikely.

With regard to the compaction of the laterite gravel, 100 passes of the sheepsfoot roller appeared to be excessive, and he wondered whether the benefit of that unusual effort in compaction made it worth while, especially as the material was likely to have a high frictional value in any case and should therefore be relatively stable and free from compression. Like Mr. Dawson, he considered that sufficient compaction would be obtained as soon as the sheepsfoot rollers walked out and that harrowing would be unnecessary. Opinion in Great Britain was tending towards the view that gravels were better compacted by heavy pneumatic-tired rollers alone, or perhaps preceded by sheepsfoot rolling for one or two passes to compact the bottom of each layer, and he would be interested to know the increase in compaction related to the number of passes of the sheepsfoot roller as used in South Africa. His own experience at Heathrow and elsewhere had shown that it was better to roll at a moisture-content rather below the optimum and to use heavier compacting equipment, than to roll at the optimum moisture-content and use lighter equipment. He could confirm the statement that it was impossible to obtain satisfactory compaction at a moisture-content above the optimum.

Mr. H. W. W. Pollitt said that he agreed with the opinions of previous speakers in connexion with the pavement design. Why had the Authors adopted the C.A.A. method in preference to other well-known methods, such as that used by the United States Corps of Engineers, which were based on the California bearing ratio of the soil? The Authors had mentioned that work by Kleyn and others had shown that a soil could have different C.B.R. values at the same dry density, depending on the compacting conditions. That fact was well-known and should perhaps be taken as some indication of the variation in conditions which actually occurred in the field. Therefore there would seem to be no valid reason why the C.B.R. method of design should not have been used, if care had been taken in interpreting the test results in designing and in constructing. On the other hand, it could be said in favour of the C.A.A. method that it appeared to gloss over that particular difficulty of variability.

He also felt that much could be said, especially in the case of major jobs such as that under discussion, for applying as many methods of design as possible to the problem in hand, determining in that way the appropriate thickness of construction, and then constructing small test-areas of certain alternative constructions based on the data and carrying out plate bearing tests. He noted that the Authors proposed to adopt that method in connexion with the concrete apron.

With regard to the maximum wheel load, it was expressly stated in the C.A.A. manual setting forth that new method that, as long as airports were designed for a single wheel load of 80,000 lb., they should be capable of carrying aircraft of gross loads exceeding 160,000 lb., because development in aircraft was such that increases in gross load above 160,000 lb. would almost certainly be accompanied by the use of more than two wheels per aircraft. It was, in fact, stated that, if an airport were designed for a single wheel load of 80,000 lb., it should be satisfactory for aircraft of weights of from 200,000 lb. to 300,000 lb. Why had the Authors concluded that that consideration should be neglected?

Tests in progress at the Road Research Laboratory had shown that sheepfoot rollers gave their best performance on soils with a moisture-content approximately equal to the modified Proctor optimum, whereas pneumatic-tired rollers and smooth-wheeled rollers were most suitable for use on soil rather above the ordinary Proctor optimum, that was to say, in the region of the plastic limit. In relatively dry climates, such as that experienced in Johannesburg, sheepfoot rollers would, as the Authors had indicated, be preferable to other types of roller, because the soil would normally be found nearer the modified Proctor optimum than the ordinary Proctor optimum. It did not follow that the same treatment would be applicable in Great Britain. The most appropriate treatment in one country differed from that in another country, according to the conditions. In Great Britain the moisture-content of soils was usually in the region of the plastic limit, and in that condition the sheepfoot rollers gave a relatively

poor performance in comparison with the smooth-wheeled and pneumatic-tired rollers.

To illustrate that point, the most common soil type referred to by the Authors, which appeared to be a poorly graded sandy clay, containing some coarse material, could probably be compacted in Great Britain to the required density in 3-4-inch layers with from eight to ten passes of a smooth-wheeled roller, loaded to, say, 2-3 cwt. per inch of width. A similar treatment would also be suitable for the coarser soils encountered. For the finer soils it might be better to use from three to four passes of a pneumatic-tired roller with a tire-pressure of 50 lb. per square inch and a comparable thickness of layer.

In view of the difference between the optimum moisture-content obtained in the field and that obtained in laboratory compaction tests, it was desirable, on major jobs such as that described by the Authors, to supplement laboratory tests with field trials, in order to determine the moisture/density relationships of the available compacting plant, with a view to determining the most economical type of roller, number of passes, thickness of layer, and soil moisture-content to use.

The Authors should be congratulated on having explored some of the possibilities of varying the design and spacings of the feet of the sheepfoot rollers used, and further information relating to the performance of the other rollers tried would be welcomed. The importance of that aspect of the work was borne out by the Authors' description of compaction work as being in the nature of a bottleneck, and also by the fact that the extra compaction required for the paved areas had increased the earth-work cost from 1s. 6d. to 2s. 6d. per cubic yard.

Mr. E. A. Turner observed that the time spent in making a grid survey of the site appeared to be fully justified, since it enabled due consideration to be given to the most economical lay-out and design of the finished job, and a plan of operations to be drawn up for economy in construction. He considered that a grid survey paid over and over again financially, and that often the time spent was saved in the end.

The Authors had not explained why the conventional triangular lay-out had been adopted. They had used a good deal of ingenuity in designing the lay-out to reduce the length of the taxi-tracks, but that was still considerable and aircraft designers might look askance at the taxiing distances. He would have thought that in the wide open spaces of Africa it would be possible to develop a tangential plan, which had distinct advantages for operating aircraft, and he would be interested to learn of the arguments which had led to the decision to adopt the triangular lay-out.

The Authors had been very fortunate to have a ground upon which they could employ a very economical flexible slab instead of rigid paving. The flexible slab had distinct advantages, in that it avoided joints, which bade fair to become a major maintenance problem for aerodrome engineers. The traffic on runways made that problem very difficult, and if maintenance

were not carried out very carefully indeed there was a risk of weakening of the sub-grade that struck at the very root of the design. The tendency during the past few years had been towards the rigid rather than the flexible slab, but that was probably because mathematicians had given engineers something fairly tangible in regard to the strength of the rigid slab, whereas for flexible surfaces the basis was more empirical. Nevertheless, the flexible slab gave an equally practical result. In the present early stage in designing pavements for the loads in question, the design should always be checked by test before it was adopted, on the score of economy. The authorities concerned could not afford to make the paving more than safe. Far too much capital was involved in the aircraft industry to permit of any extravagance.

Even with the flexible paving, maintenance of the surface was still difficult. The common surfaces were tarmac or asphalt, and it would be interesting to know what specification the Authors had in mind for their surface, having regard to the fact that it would not be continually rolled by rubber-tired traffic, as was a road surface. Incidentally, it seemed that the Authors intended to use a rigid paving on the aprons, and they would then have to face the jointing difficulty. Had they considered the possibility of using a lean-mix concrete, which would remove some of the difficulties with secondary stresses, and of depending upon tarmac isolating strips for expansion ?

They had stated that compaction had proved unexpectedly difficult and that without the experience gained in 12 months of departmental work the preparation of a contract document to cover that essential part of the work would have been impossible. Mr. Turner considered that experimental work before finally deciding upon the process to be adopted, was well worth while. His experience was that every soil and every aggregate required a technique of its own and that the most economical technique could be ascertained only by practice. If an attempt were made to draw up a contract for the compaction of an unknown material, or of a material that was known only in the laboratory, either allowance had to be made in the contract for unknown quantities or the engineer was faced with having to vary the specification, often at enormous cost.

Mr. W. G. Harris observed that he had been particularly interested in the field tests carried out by the Authors, but he wondered whether plate bearing tests would not have been easier to carry out during the course of the work than the apparently difficult field density tests.

During the war speed of construction had been of paramount importance and it was fair to say that full scientific control of sub-grade compaction during the work had very rarely been possible to the extent to which it had been practised by the Authors. The sum total of experience in the matter was small at the present time, and engineers learned most from the difficulties encountered in field work, so that it would be valuable if the Authors could enlarge on the practical difficulties experienced by them in organizing

their relatively fast-moving plant and deciding upon the intensity of their field tests.

Further information on the question of drawing up a specification for the class of work in question would also be of considerable interest, since there again very little experience was available on which to draw.

Rainfall was one of the major problems confronting airfield engineers in Great Britain, but the Paper had shown that it was not a very serious factor on the Jan Smuts airfield. Mr. Harris believed, however, that in Johannesburg very heavy storms occurred occasionally between January and November, and he would be interested to know to what extent rainfall had interfered with the Authors' work, and the length of the interval before it was possible for the machines to resume work on the compaction.

With regard to interruption of work on an airfield by the early introduction of flying, the Authors had stated that, so far as could be foreseen, it was improbable that duplication of the runways would be necessary, but that, if so, heavy earthworks and drainage would be required. That was a serious consideration, because, when an airfield was in commission and extensive flying was taking place, further heavy constructional work was bound to involve serious and expensive interruption either to the flying programme or to the constructional programme. He hoped that duplication of the runways on the Jan Smuts airfield would not be necessary, at all events for some considerable time.

Dr. T. P. O'Sullivan observed that, with regard to the design tentatively adopted for the apron (p. 16, *ante*), the results obtained in the case of a somewhat similar construction which had been applied to the floor and apron of the assembly hall of the Brabazon aircraft works at Bristol might be of interest. The method adopted there had been to determine the depth of hardcore by carrying out unconfined compression tests and applying the information obtained by means of the Glossop and Golder method. It had been considered that in all cases a modulus of sub-grade reaction of 500 lb. per square inch should have been obtained, but in fact it was possible to find points where the permissible modulus of sub-grade reaction was not met for a specific design thickness. It was thought, therefore, that the Authors might find it necessary to increase the thickness of their slab or to reinforce it in some way over small areas. If the hardcore filling or other material used was available at the right time, in the right grading, and in sufficient quantities, and if the laying and consolidation were fully in accordance with the specification, no difficulty should ensue. However, to meet any difficulties found to arise, the Authors might wish to consider whether at certain spots the prepared sub-grade should be removed and the slab thickness increased. In the Brabazon aircraft works, the number of spots where the difficulty arose was small, but the slab thickness was found to be deficient in some instances, and one of two alternative methods had been adopted, according to which was found to be the more convenient. One of those methods was to grout up the hardcore and then to carry out

the plate bearing tests again for the purpose of measuring the modulus of subgrade reaction. Subsequently, as a result of the application of the concrete grout, the design slab thickness was found to be quite satisfactory for the purpose. The other method was to use a special arrangement of reinforcement consisting of a girder at the top and a mat at the bottom, which did not project to the edges of the slab, that arrangement being considered the most economic to resist anticipated tensile stresses in the appropriate panel.

Mr. J. V. Cook said that he did not feel qualified to reply to the more technical points which had been raised, but he could say that, although the grading of the laterite varied slightly over the site of the Jan Smuts airfield, it was much more consistent over a large area than was the murram which was common in East Africa.

He was sure that the discussion would be of great help and interest to the Authors.

The Authors, in reply, expressed their regret that they were unable to be present in London to present the Paper themselves, and their thanks to Mr. Cook for his kindness in acting for them. They were also grateful for the constructive and helpful criticism provided by the discussion.

They agreed that much valuable information would be obtained from plate bearing tests and they felt also that plate tests carried out with a large plate (say 30 inches diameter) were probably the only safe way of determining the effect of bad conditions existing at any depth below the surface. Unfortunately plate bearing tests had never been used in South Africa (probably because most roads were surfaced with flexible pavements) and the somewhat cumbersome and expensive equipment required had not been available when the work was put in hand.

The work had now reached a stage where the Administration could not afford the time to acquire the equipment and carry out those tests. As a possibly very inadequate substitute for the tests, however, a survey of the finished subgrade was being made with "cone-bearing test equipment." The testing was being done at levels 6 inches, 12 inches, 18 inches, and 24 inches below the surface, in exactly the manner advocated by Mr. Norman W. McLeod in his brochure on "Airport Runway Evaluation in Canada," a record of work carried out by him for the Canadian Ministry of Transport during 1945 and 1946. Mr. McLeod correlated his plate bearing tests with cone bearing and C.B.R. tests, and the Authors were making use of his figures. A check of the relation between cone-bearing and C.B.R. tests for the materials of the airport showed reasonable agreement with Mr. McLeod's figures.

The tests carried out so far had shown appreciable, though not very serious, variations in the strength of the runways and apron surface, and had served to emphasize the importance of a point made by Dr. L. J. Murdock, namely, the moisture-content of the subgrade. Attempts were made to carry out the tests after rain when conditions might be expected

to be at their worst and, whilst the laterite was found to have great strength when the moisture-content was less than 14 per cent., an increase over that content led to a rapid falling off in strength.

Two series of tests were being made, one as found and the other after soaking for 48 hours.

With regard to the views of various speakers, that the number of passes was excessive and the cost of compaction unjustifiably high, a variation in layer thickness was tried out, but without any appreciable improvement. The amount of rolling required was found to be directly proportional to the thickness of the layer. It was, therefore, decided to compact on 8-inch loose layers, because that was about the minimum thickness practical for spreading with the earthmoving equipment available, and also to avoid excessive motor grader work, since those machines were in very short supply.

The sheepsfoot rollers were all designed on the site and were locally manufactured. No particular overseas design was followed.

The Authors tried out various routines in an attempt to obtain easier compaction, without any satisfactory results. One method tried was to grade in material in 1-inch layers from a windrow while the rollers were in use, stopping the bringing in of material after 5 or 6 inches had been brought in; but the passage of the grader wheels had the effect of bringing the sheepsfoot rollers out too soon and a maximum of 90 per cent. Modified Proctor was obtained in that way.

The contractors had also tried out different routines, and had obtained the advice of two experts from overseas, but with little success.

Mr. Hawkins was correct in assuming that the grading of the laterite varied considerably. Of the materials shown in *Fig. 10*, groups Nos. 4-6 were mostly laterites and groups Nos. 7, 8, and 9 were all laterites. The curves shown in *Fig. 10* were the averages of the number of samples shown in *Fig. 9*, and a wide scatter of individual samples from the averages was noticeable in every case.

The laterite, as suggested by Mr. Hawkins, resembled the East African murram and in appearance was identical. It was quite likely that the difficulties experienced were due to the variation in grading.

As shown in *Fig. 11*, the optimum moisture for the materials varied greatly—for the laterite between 8 per cent. and 15 per cent.

The total cost of compaction per square yard of paved surface (assuming that compaction cost as much as 1s. 6d. per cubic yard) should work out at about 2s. 6d. per square yard of pavement. (Estimated 2,000,000 cubic yards of earthworks to be compacted in paved areas and 1,180,196 square yards of pavement.) The Authors considered that the added strength due to greater density probably justified the expenditure, which could, in any case, not be wholly eliminated.

With regard to the wheel loading worked to, possibly the Authors had not sufficiently emphasized the fact that the Jan Smuts airport would

probably be for many years the only really large airport in South Africa, and that it might have to be used for defence purposes and therefore have to stand up to the largest military aircraft, the wheel loadings of which might be higher than civil aircraft loadings. The loading of 135,000 lb. per wheel group was, in any case, fixed by the British and South African Governments at the South African Air Conference held in Cape Town in 1945. The first Author had never felt justified in recommending a reduction in the design loading then agreed to.

So far as the design method was concerned, the Authors gave only certain charts taken from the C.A.A. "Design Manual."

In reply to Mr. Dawson's query whether the gross load was carried on two single-wheel undercarriages or on dual-wheel undercarriages, and his reference to the pressures and contact-areas, the C.A.A. "Paving Design Manual" stated: "Since the major portion of the planes which will use the airport have not yet been designed, specific figures on tire pressure, spacing, and number of tires will not be assumed for a particular design. However, the charts are based on the gross load carried on two tires; since the present trend towards spreading the load on more tires may be expected to continue, pavement designed for 160,000 lb. gross load will probably be adequate to carry future aircraft weighing 200,000 lb. to 300,000 lb."

The reason for the apparent discrepancy in the total thickness pointed out by Dr. Murdock, was that, in the C.A.A. text covering the use of the charts, provision was made for a 20-per cent. reduction in the thickness of a base where the base contained more than a certain proportion of fractured particles or where the material had cementitious properties. As the base course of waterbound macadam would contain at least 70 per cent. of crushed rock and the binder would be of high quality, that correction had been made in that instance.

In the design of the concrete apron, 2 inches of waterbound macadam had been taken as equivalent to 1 inch of concrete, and the design was assumed to be equal, therefore, to 16 inches of concrete. For runways with an R.1A subgrade (see *Fig. 6*) 14.3 inches of concrete would be required (assuming that the strength varied with the depth) and adding 1 inch, the addition specified by the C.A.A. for taxiways and hard standings, the thickness required was 15.3 inches (say 16 inches).

In reply to Mr. Pollitt, the Authors preferred the C.A.A. method because

(a) In the text importance was laid on those factors which experience had shown to be of importance, including—

- (i) survey to be carried out only by experienced paving engineers, with full information, and taking into account character and cost of available materials;
- (ii) Paving design was not an exact science;

- (iii) Service records of existing paving were taken into account ;
 - (iv) Climate was taken into consideration ; the base thickness might be reduced up to 35 per cent. in arid climates and 20 per cent. in semi-arid climates.
- (b) Design was based upon a flexible and realistic classification into groups. The C.A.A. text stated that : " It is realized that most materials will not fall exactly in one class on basis of all characteristics. Interpolation will be necessary to arrive at the proper *F* and *R* classification. . . . Judgement should be used in such interpolation, but the placing of undue importance on any one characteristic should be avoided."

In the Authors' opinion, that quotation justified the rating of the material generally as E.3 instead of E.4. Plasticity was a very important characteristic, but unfortunately the plasticity test was not very reliable. Liquid limits, determined by a much more reliable test, were well below the limit of 35 specified, for all but the worst materials.

So far as working on the basis of soil groups rather than on the result of one test (the C.B.R.) was concerned, the Authors believed that the following variable factors all affected the strength of a soil :—

- (1) The grading of the material and the nature of the clay-content ;
- (2) The moisture-content ;
- (3) The degree of consolidation ;

and that unless it was reasonable to suppose that the variation from point to point would be slight, a test assuming those factors to be constant and not variable was not satisfactory. A more general enveloping method based purely on experience was more rational.

At the site in question, as visualized by Mr. Hawkins and as partly shown in *Figs 9, 10, and 11*, the gradings varied greatly. Individual tests (including C.B.R.) showed considerable variation in samples taken close together and, as part of the runways were in cut and part in fill, variation in the moisture-content of the subgrade was to be expected. Further, in spite of all efforts, the field density results showed considerable variation from the average.

Variation in the strength of the subgrade should therefore be expected, but, in the Authors' opinion, only between the limits covered by the design factors. The moisture-content of the subgrade was of fundamental importance, and the Authors found it very difficult to estimate what that was likely to be when the subgrade was covered by paving, for, whilst wetting from the top would be cut off, so also would evaporation, and the capillary rise would be governed by the water table. The level of the water table would, in turn, be unpredictably affected by the drainage system.

A point in connexion with the survey which might interest Dr. Murdock was that, in testing samples from trial holes on runways 2 and 3, an attempt to estimate soil constants and characteristics by visual inspection was made, one sample in ten being fully tested in the laboratory as a check. The results obtained were excellent so far as percentage of silt and clay, plastic limit, and liquid limit were concerned, but were poor for Proctor densities.

The allowance of 20 per cent. cut over fill allowed also for the supply of about 250,000 cubic yards of soil binder for the waterbound macadam. Whilst some of the laterite was found existing at a high density, most of it and all the soil had a dry density of about 95 lb. per cubic foot, whilst after compaction the average dry density was 120.0 lb. (the average of 965 field density tests) per cubic foot.

The earthworks were now 67 per cent. complete and, as far as could be judged, the allowance made was reasonable.

There was every reason to think that the waterbound macadam would be much stronger than the laterite. Apart from the fact that the service records of roads in the vicinity with macadam foundations were outstandingly good, the highest C.B.R. value for any laterite on the site was 80 per cent., whilst some of the laterite had a C.B.R. value of only 15 per cent.; 35 per cent. was about the average. The C.B.R. test was based on the penetration of crushed stone being 100 per cent. Waterbound macadam consisting of crushed stone bound by the suitable earth binder existing on the site should be even stronger. The C.B.R. values shown in *Fig. 8* were obtained on "saturated" samples.

In reply to Mr. E. A. Turner, the Authors had not considered the use of lean mix concrete, but they proposed to use a 10-inch slab instead of a thicker slab because they considered that that would reduce secondary stresses due to temperature. It was proposed to adhere to the types of joints shown in the C.A.A. manual, namely "dummy longitudinal joints every 20 feet dowelled," "dowelled warping joints," and the conventional expansion joint, using hardwood and a jointing compound. At Palmietfontein a compound consisting of 75 per cent. high-viscosity tar and 25 per cent. cement was used successfully for jointing. One of the new patent rubberized compounds might, however, be used if tests proved it to be superior.

The surfacing proposed for the taxiways and main runway would consist of a base of $2\frac{1}{2}$ inches of penetration macadam, using 2-inch stone and $1\frac{1}{2}$ gallon of medium-viscosity tar per square yard.

The wearing course would consist of $1\frac{1}{2}$ inch of asphaltic concrete, using a 200-penetration bitumen and stone with a maximum size of $\frac{1}{2}$ inch. The grading and percentage of binder would be determined from the behaviour of twenty-five experimental strips laid at Palmietfontein airport, all laid crossways in the main taxiway.

In the estimate allowance was made for the finishing of the surfacing

with a seal coat of 0.15 gallon per square yard of natural asphalt cement blinded with crusher dust. As an alternative to the last, it was possible that cement brushed into the pre-mix might be used.

On the secondary runways, where less traffic was anticipated, the surfacing was being reduced to a total thickness of $2\frac{1}{2}$ inches.

No wide open spaces suitable for airport construction were available close to Johannesburg, and the acquisition of the site had cost about £100 per acre. A tangential lay-out would have required nearly twice the area and would necessitate the construction of six runways to start with, instead of three. Moreover, the terminal buildings and apron would have had to be moved farther from the road and railway, thereby increasing the travel time.

The rainfall at the site was about 32 inches per annum and the rainy season extended from September to May as a rule, although heavy rain was not usually expected before November. January was normally the wettest month. Both short high-intensity storms and "five-day rains" were experienced.

The Hathaway method did not necessitate the use of ponding areas, although their use would effect very great economies.

At the Jan Smuts airport no ponding was allowed for the hard standings and in the building area, but ponding, which presumably took the place of balancing reservoirs, had been allowed for on the flying field.

The ponding depth allowed in calculation ranged from 1 foot to 2 feet for a 15-year storm, with duration of ponding from 40 to 140 minutes. With ordinary storms no ponding would occur. Under the worst possible conditions water would not come within 90 yards of the edge of the runways. The Authors anticipated that intensities of up to 6 inches per hour for a period of 10 minutes should be expected.

They did not anticipate any trouble from scour once turf had been established on the shoulders of the runways, as the soil was not at all friable and velocities would not be high.

The system of storm sewers provided for the removal of water from the site at the rate of 1,900 cubic feet per second, which was considered reasonably high. It would be appreciated that without ponding the quantity to be removed would be much greater and the cost of sewers much higher.

They regretted that space limitations did not make it possible to give sufficient information in the Paper about the drainage design to make it intelligible.

The field density tests were carried out with a density cone and standard sand, and the cost was approximately 8s. 6d. per test; the cost of carrying out full laboratory tests on a sample, including C.B.R. value and Proctor density, was about £11.

For the period from November 1947, to May 1948, inclusive, the percentage of working time lost on compaction through delays due to

rainfall amounted to 34.75 per cent. For the remaining period of a year, June to October, it was never anticipated that any delays would occur, and therefore the percentage hold-up of compaction machinery due to rain for a year was about 20 per cent.

A large portion of that 20 per cent. was usefully employed in overhauling machines and therefore rain did not cause an appreciable loss of working time taken over the year. The time lost with earthmoving equipment was about half the above.

In reply to Dr. O'Sullivan, the Authors had seen an excellent film illustrating the construction of the Filton runway for the Bristol Brabazon, which showed, among other things, the infinitely greater difficulties with which British engineers had to contend.

As most of the apron subgrade would be in fill and construction difficulties were small, it was hoped that no weak spots requiring special treatment would occur. If they did occur, they would be difficult to locate.