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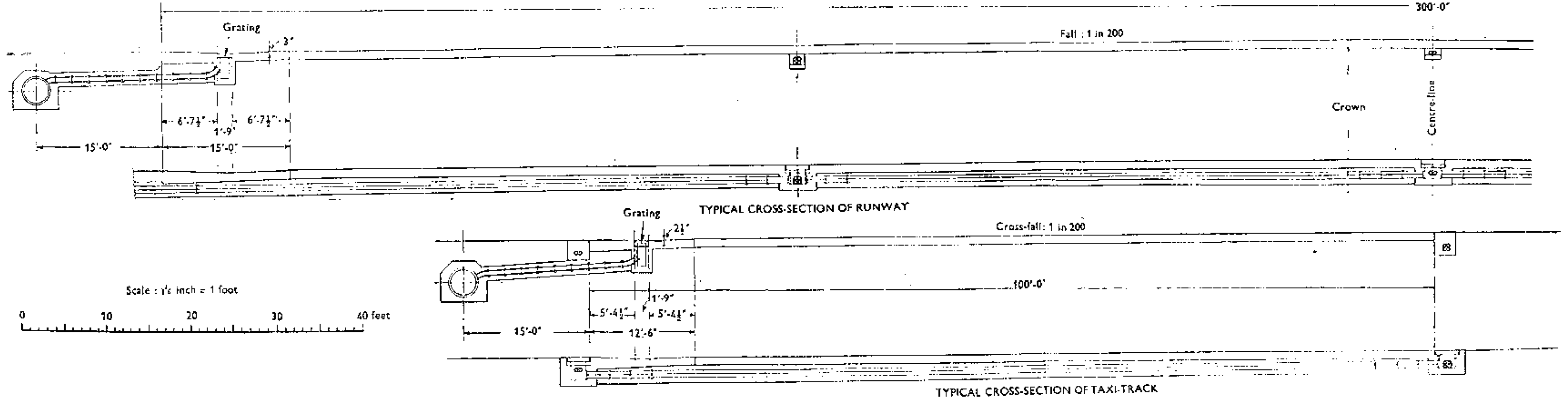
Discussion.

Mr. Goode, in introducing the Paper, said it had been prepared in the hope that it would prove to be of practical assistance to engineers engaged in airport engineering. Certain sections of the subject had been dealt with rather briefly, and it might be advantageous to elaborate them.

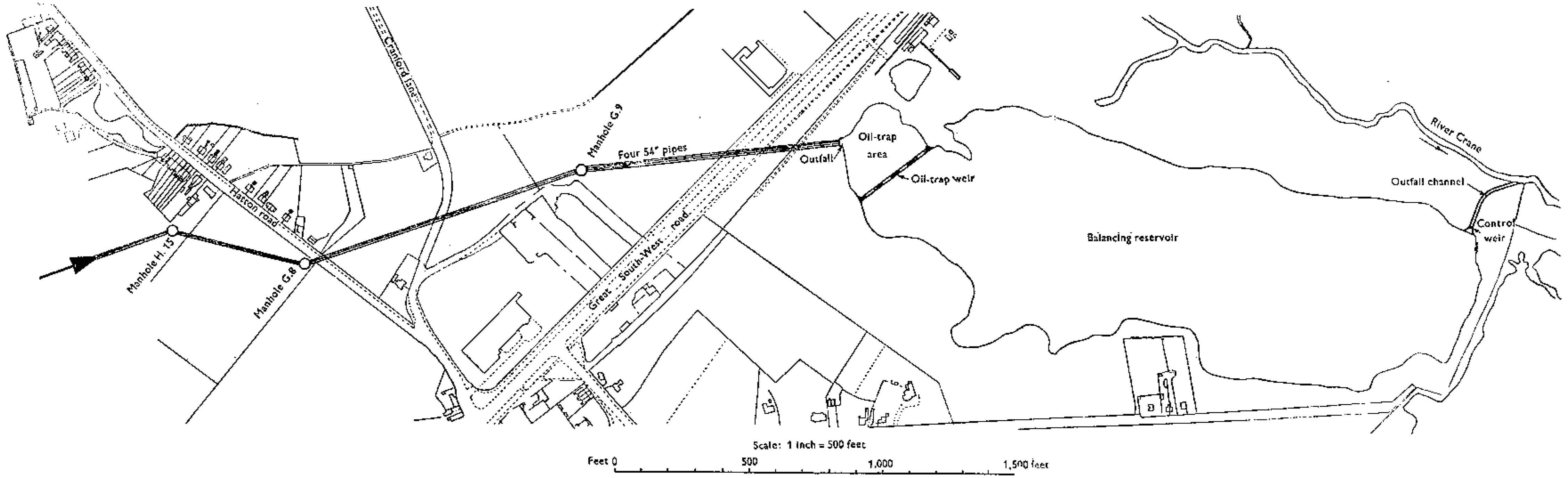
The Authors had mentioned that they were not clear whether a twin wheel with individual wheels at 4-foot centres acted as a single wheel, but in *Fig. 1* they had plotted graphs for the " Super-Fortress " and the " Brabazon ", both of which were twin-wheel aircraft, and it would seem that a Class D airport would just take a " Super-Fortress ", whilst a Class C airport might take a " Brabazon ". On that, the Authors were doubtful, and it would be wise to assume that a twin wheel was equivalent to a single wheel of a loading equal to the sum of the individual wheel-loads. The wheel-loads which had been plotted in *Fig. 1* referred to the main wheels of an aircraft, but it was possible that in the future tail wheels or nose wheels would have to be taken into account, because the tire-pressures now in use in the nose and tail wheels of aircraft were much higher than the tire-pressures in the main wheels of aircraft. For instance, the " Spitfire " had in some models been fitted with tires with a pressure of 150 lb. per square inch. If tail or nose wheels of that pressure were fitted to large aircraft, such as the " Brabazon ", whose nose-wheel loading was probably

Figs 15



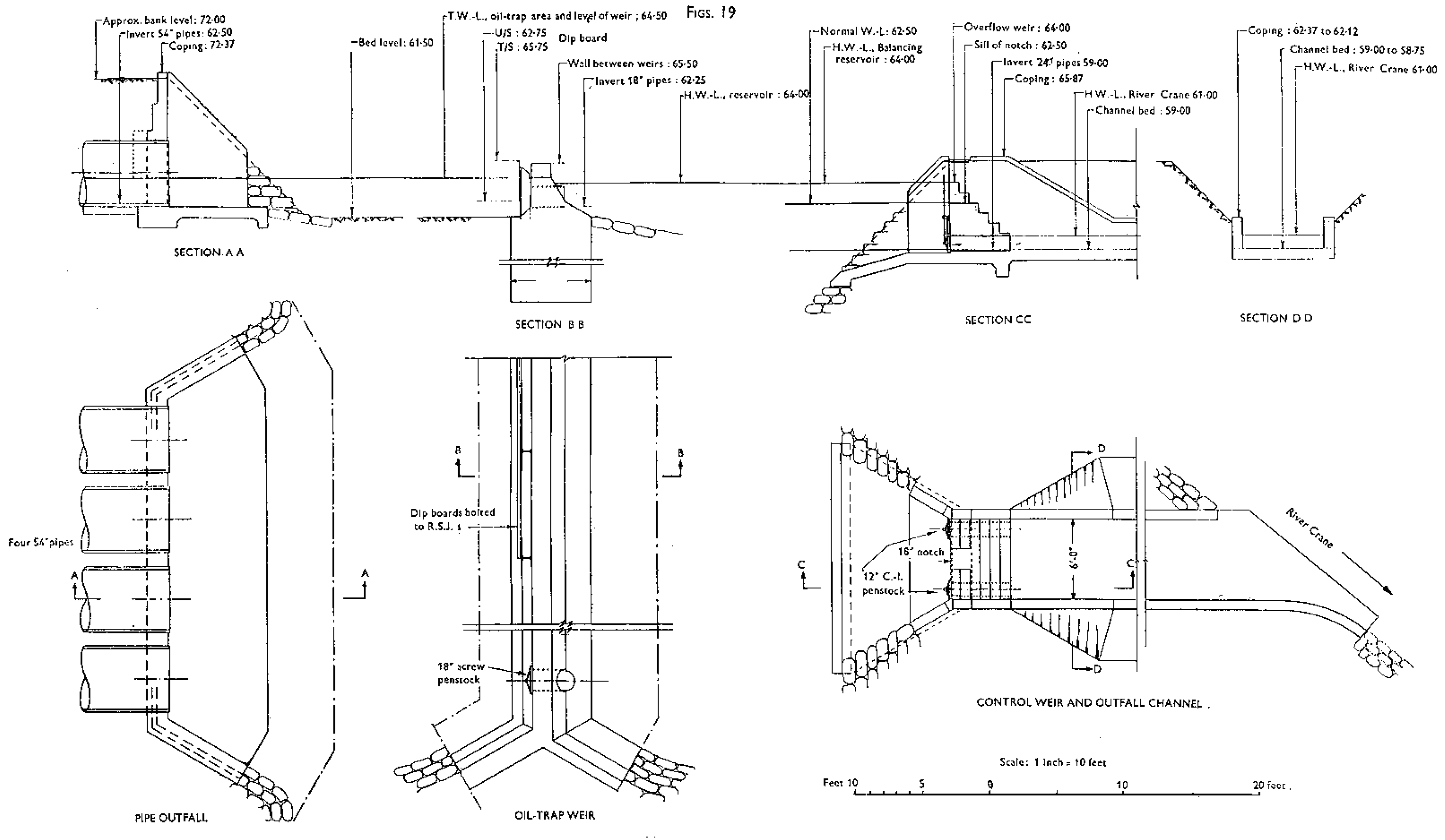
TYPICAL CROSS-SECTIONS OF RUNWAYS AND TAXI-TRACKS

Fig. 18.



PLAN OF OUTFALL AND BALANCING RESERVOIR.

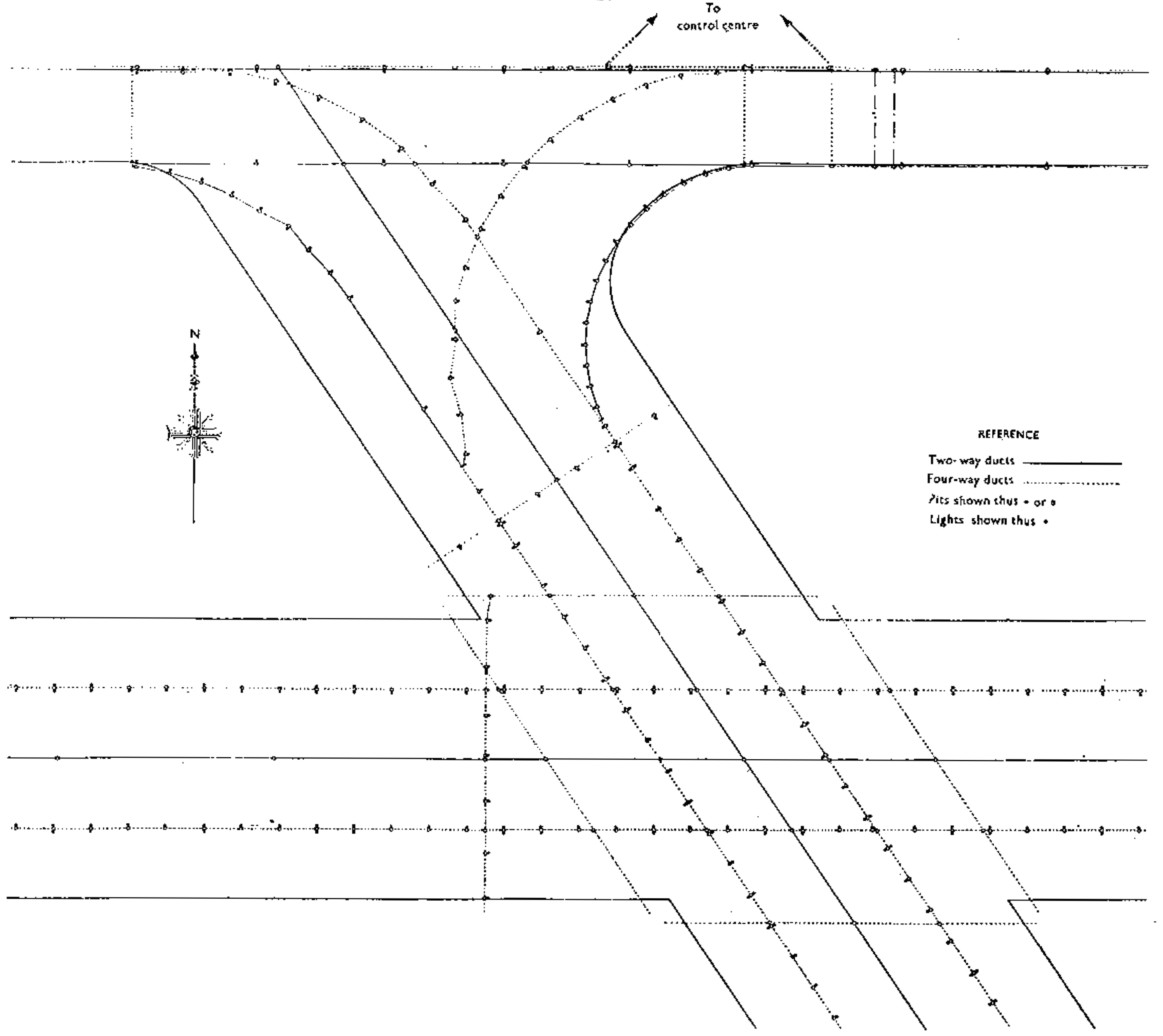
Figs. 19



DETAILS OF OUTFALL AND BALANCING RESERVOIR.

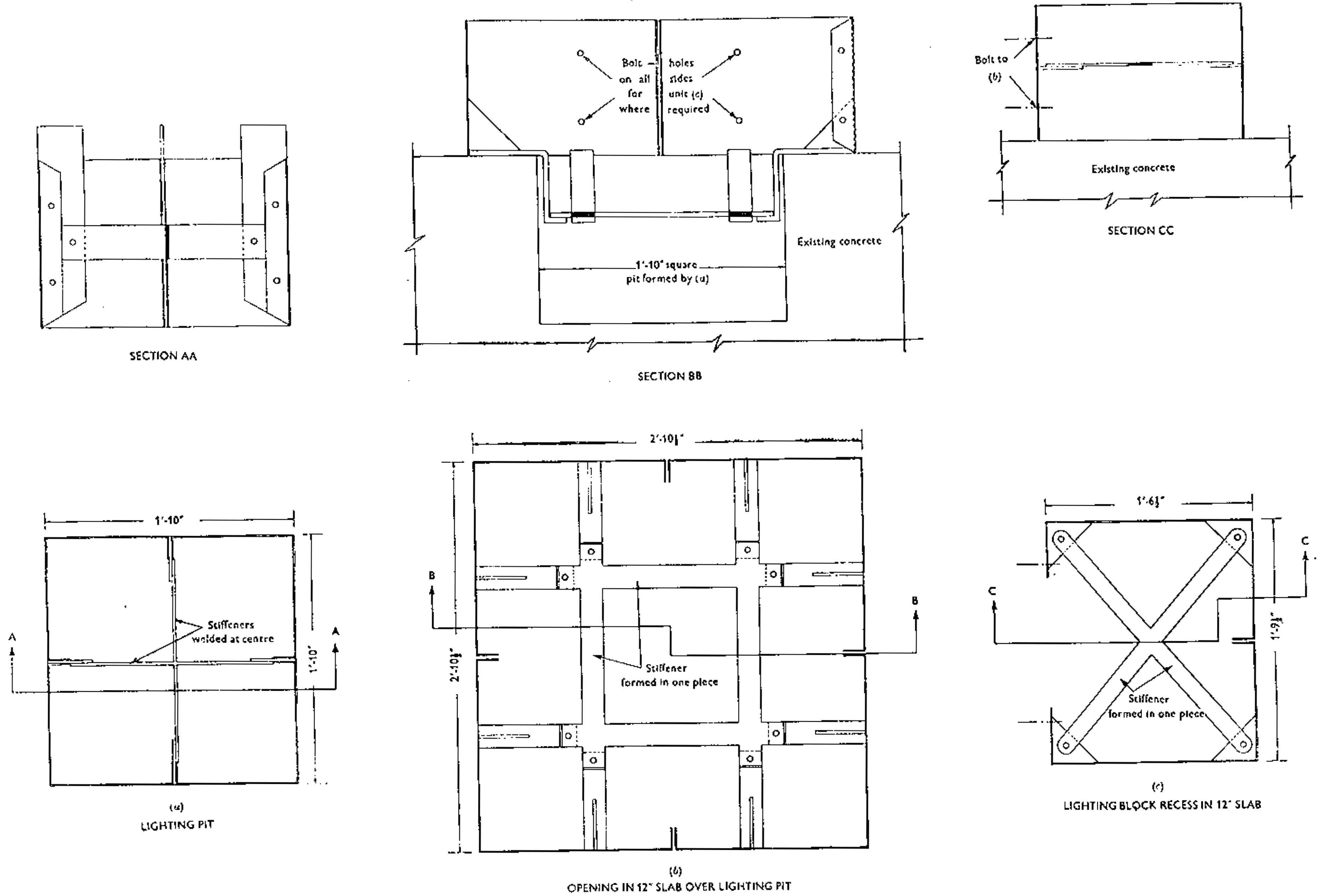
SOME PROBLEMS IN THE DESIGN AND CONSTRUCTION OF LARGE AIRFIELDS.

Fig. 21



DIAGRAMMATIC PLAN OF LIGHTING AT INTERSECTION OF TWO RUNWAYS.

Figs. 24.



SECTIONAL FORM WORK

J. K. FISHER, A. GOODE, and C. E. DOCKER.

William Clowes & Sons, Limited : London.

about 20,000 lb., it was quite possible that the effect on the pavement would be the same as the effect of the main wheels of the aircraft with the larger loading.

With regard to *Fig. 2*, which showed the area of land surrounding an airfield over which there were building restrictions, in the various funnels the trees and buildings were demolished to give a gradient of 1 in 30, 1 in 50, or 1 in 75 from the strip end, depending upon the type of aircraft using the airfield. In Area C, which was the circuit-area, on which restrictions were imposed for aircraft circling the ground, it was customary to try to keep all obstructions down to a level not exceeding 150 feet above airfield-level. That was not always possible, and a great deal depended upon a commonsense application of the rule. For instance, if Area C was heavily wooded and on rising ground, so that the tops of the trees were perhaps 200–250 feet above airfield-level, there would not be much point in prohibiting the erection of a building to be erected alongside, the level of which did not exceed the level of the trees on top of the knoll in Area C. The same applied to Area B. If hangars were erected in the space between the perimeter track and the airfield boundary, there would not be much point in prohibiting buildings 50 feet, 60 feet, or 70 feet high immediately behind them. Certain regulations had to be made to limit buildings around airfields, but those regulations should be interpreted in a commonsense manner, depending upon the local conditions.

The Authors had pointed out that, in the determination of the design of a rigid runway, it was necessary to adopt a value for the modulus of subgrade reaction for the site under consideration. When the work proceeded it was customary to check the k-value of the formation, using a constant size of plate to apply the load. The k-value for a particular formation, however, varied with the size of plate used in its determination. For instance, if the k-value on sand was determined with an 18-inch diameter plate, probably a k-value of 800 would be obtained, but that value would be reduced by using plates of larger diameter, until for plates of 26 inches diameter and upwards a constant value of approximately 600 lb. per square inch per inch would be obtained. [For all soils with plates exceeding a certain size, the k-value remained constant, irrespective of the size of plate used, and that was the k-value that should be used in the design.] Similarly, with a clay, as the plate-size was increased the k-value decreased. For example, a 15-inch plate might give 400; a 20-inch plate 270; a 25-inch plate 190; a 30-inch plate 140; a 36-inch plate 145; and plates of 40 inches and upwards 140. It was necessary for any particular site to determine beforehand the relationship between the k-value and the size of plate, so that if a constant size of plate —say, 20 inches—was used in checking during the course of construction, it would be known that the value obtained with that plate would have to be reduced by a certain proportion in order to obtain the true k-value which had been utilized in the design.

Despite the difficulties encountered in making large-scale tests on concrete runway slabs, and in the interpretation of the results, such tests had been carried out by the Air Ministry during the past 18 months. From the results obtained certain broad conclusions could be drawn. It had not been possible up to the present to check back on Westergaard's formulae, as the actual characteristics of the concrete in the slabs tested had not been known. Apparatus had now been obtained, however, for cutting out concrete beams from the runway slabs, which had been tested or were to be tested. Those beams would be tested in the laboratory, and it was anticipated that in a few months' time a considerable amount of valuable information would be obtained on the accuracy of Westergaard's theory. If other properties of the concrete were utilized in arriving at estimates for the values of the elastic constants, E and μ, and the modulus of rupture, it would appear that the design of runways based on Westergaard's formulae was conservative.

The Authors wished to make it clear that the stresses due to temperature warping and the difference of 50° F. mentioned on p. 34 were intended to apply only in the case of a country such as Iraq. In Great Britain, in field tests on runway slabs, the temperature at the top and bottom of the slabs had been measured and some hundreds of results obtained, and the maximum temperature-variation between the top and bottom of a concrete runway slab had been found to be about 15° F. It should be borne in mind that an airfield was a large open space and that even on the hottest summer day a cool breeze could be felt. That had its effect on the runway surface, and the temperature of the concrete seldom reached such a height as was obtained in laboratory experiments, where a concrete slab might be screened from all draughts and be exposed to the direct rays of the sun. Therefore it was customary, in Great Britain, to adopt a factor of safety of 1 when designing concrete runway slabs, to resist the combined stresses due to load and temperature warping.

Generally an increase in the moisture-content of the formation reduced the value of k, or of the California Bearing Ratio, although if a formation was properly consolidated to maximum density and shape, so that no ponding occurred on the surface in periods of wet weather, the moisture-content did not increase materially except in a very thin superficial layer. If, however, a formation had not been thoroughly consolidated the moisture-content might increase rapidly, with a corresponding decrease in the load-bearing value. Therefore it was of great importance that the drainage of the site should be the best possible. If the drainage of the site was adequate, so that the water table was stabilized, the only means of increasing the water-content of the formation was by admission from above. That was prevented by the swift removal of water from the paved surface, but trouble usually occurred at expansion joints, dummy joints, or at cracks which might appear in the slab. Unless the sealing compound used in the expansion and dummy joints was elastic and adhered to the concrete under all conditions of temperature, cracks would open and water would seep through to the formation. Therefore it was of the utmost importance that the maintenance of runways should be adequate and that all cracks, whether due to failure or whether occurring at the expansion and dummy joints, should be immediately sealed with bitumen or other suitable material. In cases where serious cracking occurred, a tar-macadam or asphalt carpet over the whole of the slab had been found very efficacious, not only from the point of view of waterproofing the slab but also because the carpet had been shown by loading tests to spread the load considerably —in fact, far more than the commonly-accepted 45-degree spread. The provision of an asphalt or tar-macadam layer over concrete had been useful during the war in helping to camouflage the airfield, but in peace time the opposite effect was desired and the airfield should stand out as much as possible from the surrounding countryside. For that purpose, plain concrete was much better than tarmacadam or asphalt, and it behoved the engineer, therefore, to make his concrete sufficiently strong to support the aircraft loads without cracking.

The Chairman observed that the Authors had rightly stressed the necessity of investigating the ground conditions of any airfield. During the war it had not always been possible to carry out such investigations with the detail which was desirable, and he thought one or two accidents had happened on that account.

The Institution, at the behest of the Ministry of Works, had appointed a Committee to prepare a Code of investigation on sites for civil engineering works. The draft Report of that Committee would probably be circulated in the near future, and the Code, in combination with the Paper, should be of the utmost value to engineers in designing airfields.

The Authors had not referred to icing conditions in Great Britain. Information on that subject would enhance the value of the Paper.

Mr. A. Shaw Maclaren observed that buildings were mentioned in only one section of the Paper (" Location of Site "), where reference was made to " ancillary buildings." The dictionary definition of " ancillary " was " subservient " or " auxiliary ", but buildings were very important features of both civil and military airports. The terminal buildings were the core of a civil airport, as all the traffic had to be handled there, and he considered that at least the reservation of enough space for them in the right place in the airport deserved some mention in the Paper. Further, an air line was successful largely by virtue of good maintenance of its aircraft, so that hangars and the sites for them were also an important feature of lay-out.

Not long ago, after considerable discussion, it had been finally decided, in both Great Britain and the United States, that the requirement that an aeroplane should be able to come to a stop on the runway if an engine failure occurred at take-off led, in the case of large modern aircraft, to excessive demands for land and in cost of runway construction. It appeared to be generally accepted, however, that an aircraft ought to be able to climb out of the airport if one engine cut out after it had attained its flying-speed. Runway length was now determined as the minimum length required for operating under ideal conditions with a first-class test pilot and the aircraft in new condition, multiplied by a factor to allow for everyday operating conditions.

The statement in Mr. Maclaren's Paper,[1] that the product of the wing loading and power loading was indicative of the performance of an aircraft in landing and taking off appeared still to be true for products of wing loading and power loading up to about 600; but modern aircraft, which might have higher products than that, incorporated aerodynamic improvements which had arrived within the last year or two and which offset the increase of runway-length which would be obtained according to the rule quoted.

More standardization of method was needed in the technique of airports. With regard to the Authors' remarks on altitude, a second method was used to a considerable extent for determining the increase of runway-length required for altitude and temperature. In that method, a factor was applied to the runway-length which was based on corrections for barometric pressure and temperature separately. The result obtained was more accurate than that given by the method based on density-altitudes, and he could not understand why it had not come into general use.

With regard to the number of strips, in preparing the latest figures which had been used for one of the largest airports, it had been estimated that, with present technique and clear weather by day, landings might be made at 1½-minute intervals and that take-offs might be made at twice that speed, namely, ¾-minute intervals. With balanced traffic, that was, equal numbers of arrivals and departures, that gave fifty-four aircraft movements per hour per runway. In bad weather a lower movement rate was used, giving sixteen movements per hour per runway, which was more conservative than the Authors' figure and, therefore, probably much safer; but that was expected to improve.

An arrangement of three parallel runways had been evolved which avoided crossing traffic, and he believed that it was likely to be used at both the London Airport and the Orly aerodrome, Paris.

Mr. Maclaren considered that the flightway floor slopes mentioned in the Paper were rather steep, in view of the abandonment of the landing requirement on the runway to which he had referred. He believed that for large aerodromes, 1 in 50 was being adopted as the slope for the flightway of a main runway, and 1 in 40 for the subsidiary runways, where wind assisted the aircraft taking off and landing. Those slopes, although they might not be absolutely essential, appeared to be desirable in order to

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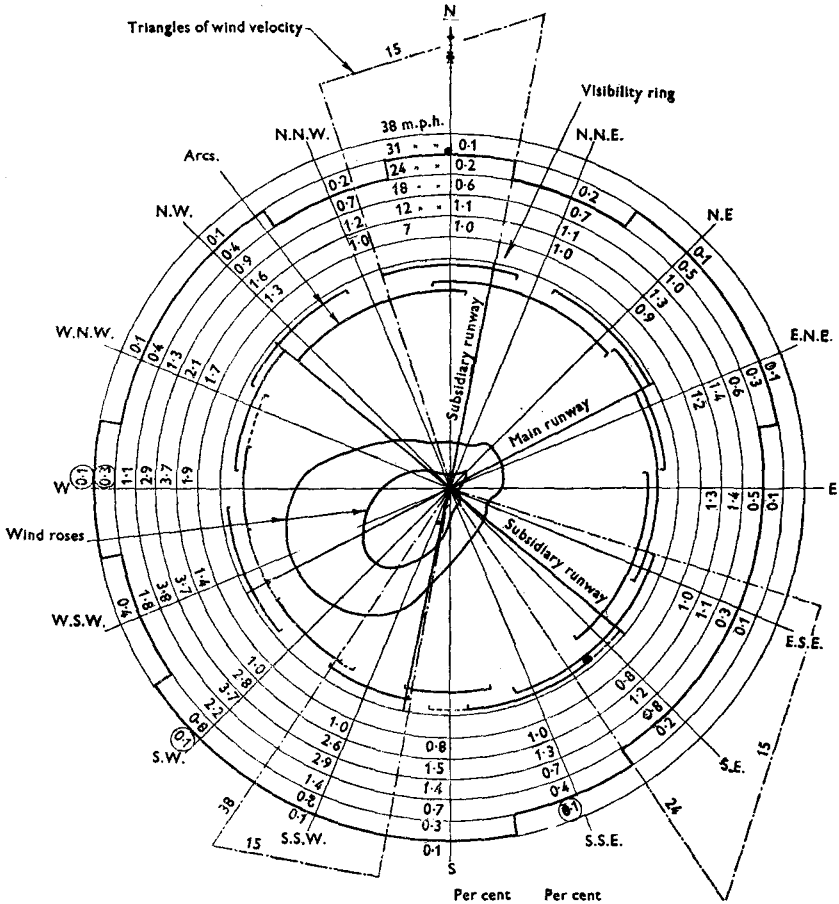
[1] *Loc. cit.*, p. 57, *ante.*

enable an aircraft which had an engine failure after take-off to climb out of the airport.

Fig. 37.



	Per cent	Per cent
	100	100
Observations missed	5·3	
	94·7	
Observations not covered	0·6	0·6
Certain usability	94·1	
Possible usability		99·4

With regard to the orientation of runways, the requirement that a runway should not be used with more than a certain crosswind component had seemed to him for some time to be rather difficult to work out. *Fig. 37* and Table XI illustrated a method which he used in his own office.

TABLE XI.

Mean Wind Speed: Statute M.P.H.	Percentage Number of Hours Recorded.																
	N.N.E.	N.E.	E.N.E.	E.	E.S.E.	S.E.	S.S.E.	S.	S.S.W.	S.W.	W.S.W	W.	W.N.W	N.W.	N.N.W.	N.	All Directions.
0 1– 3																	} 10·9
4– 7	1·0	0·9	1·2	1·3	1·0	0·8	1·0	0·8	1·0	1·0	1·4	1·9	1·7	1·3	1·0	1·0	18·3
8–12	1·1	1·3	1·4	1·4	1·1	1·2	1·3	1·5	2·6	2·8	3·7	3·7	2·1	1·6	1·2	1·1	29·1
13–18	0·7	1·0	0·6	0·5	0·3	0·8	0·7	1·4	2·9	3·7	3·8	2·9	1·3	0·9	0·7	0·6	22·8
19–24	0·2	0·5	0·3	0·1	0·1	0·2	0·4	0·7	1·4	2·2	1·8	1·1	0·4	0·4	0·2	0·2	10·2
25–31		0·1	0·1				0·1	0·3	0·6	0·8	0·4	0·3	0·1	0·1		0·1	3·0
32–38								0·1	0·1	0·1		0·1					0·4
39–46																	
Total 4 m.p.h. or more	3·0	3·8	3·6	3·3	2·5	3·0	3·5	4·8	8·6	10·6	11·1	10·0	5·6	4·3	3·1	3·0	83·8
Total 13 m.p.h. or more	0·9	1·6	1·0	0·6	0·4	1·0	1·2	1·5	5·0	6·8	6·0	4·4	1·8	1·4	0·9	0·9	

Percentage under 4 m.p.h.	10·9
Percentage number of hours missed	5·3
Total	100

Table XI—a simplified diagram of the usual Air Ministry record of wind direction and velocity—showed the percentages of wind of different velocities which occurred from the sixteen points of the compass over a period of years. It included only steady winds and allowance had to be made separately for gusts.

In *Fig. 37* the percentages were plotted round the outer circles representing velocities. The figures for each compass-point covered winds which might have occurred anywhere within an arc of 22½ degrees, with transitions midway between compass-points, and the greatest velocities recorded were shown by the heavy indented circle. By means of the triangles of wind velocities, sixteen arcs were drawn, one for each compass-direction, each arc denoting the sector within which a runway should lie in order that the component of wind at right angles to it might not exceed the permissible value, in that case 15 miles per hour, when the wind blew from the associated compass-direction with maximum velocity. The least number of runway directions which fitted the site and intersected the greatest number of arcs, thus covering the greatest proportion of winds with the least loss, was then determined by inspection and trial. The observations of wind which were not covered were shown ringed with circles and it was sometimes necessary, when an observation was not covered, to extend the corresponding arc to the length which it would have for the wind of next lower velocity from the same direction, in order to determine whether that observation was covered. Such extensions of the arcs were shown dotted.

In the centre of the diagram were two wind-roses, or vector diagrams of the frequency of occurrence of wind from the sixteen compass-points. Those assisted in the choice of directions. The outer wind-rose was plotted for all winds : the inner only for winds which exceeded in velocity the permissible value of cross-wind component. The latter were the critical winds.

The annular space referred to as the visibility-ring allowed conditions of poor visibility which occurred with wind at the site, for example dust storms, to be entered on the diagram in the directions from which they commonly occurred. That also assisted in the choice of directions.

Mr. J. A. Dawson observed that the description of the work involved in the drainage of the London Airport at Heathrow was of considerable interest and brought out the point, which might not always have been fully appreciated, that the substitution of vast impervious areas for what was previously largely natural ground in agricultural use created entirely new drainage problems which required the closest investigation. It was particularly necessary to make a thorough examination, as had been done at Heathrow, of the ability of the watercourses, into which the main drains were to discharge, to take the concentrated additional flow under flood conditions, and, if they were unable to do so, to decide what works were necessary to reduce the rate of discharge from the airfield system to that which the streams were capable of taking.

The Authors had made it clear, in explaining the basis on which airfield pavements were now designed, that they were fully conscious of the need for additional knowledge if design was to be undertaken in the most efficient manner. There could be no doubt that, with present knowledge, it was possible to provide, with reasonable economy, pavements which would safely carry the loads for which they were designed ; but he agreed that finality in the matter had not been reached and that, with greater knowledge of certain of the factors affecting design, it would be possible to deal with the problems involved with greater assurance and, he hoped, with even greater economy.

He could confirm the statement that the Air Ministry had not forgotten the need for furthering knowledge and that heavier testing-machines for concrete pavements had been designed and were in use for tests, not only to ascertain the breaking load of the concrete slabs and their deflexions under load, together with the moduli of subgrade reaction, but also to ascertain the values of Young's modulus and Poisson's ratio and the flexural strength of the concrete, all of which came into the Westergaard analysis and on which it was essential to have more accurate knowledge if design was to be advanced and carried out more efficiently than in the past.

With advancing knowledge in the matter of design it was necessary to have the greatest possible reliability in construction. Messrs. Graham and Martin, in their recent Paper [1] had shown that by the imposition of adequate controls it was possible to obtain high-grade concrete of consistent quality. In unreinforced slab construction it was particularly necessary that consistency should be obtained. It was essential that the base of the test-cube pyramids should be as narrow as possible and that the variations should be small, so that it was possible to be sure of getting the concrete required. But below the concrete, as the Chairman and Mr. Goode had remarked, lay mother earth, which carried the load, and, therefore, it was necessary to be quite sure that the surface strata were in a completely stable condition before the concrete was laid. If that condition had not been attained, many troubles might occur. If clay, or a material with a low plasticity index, formed the base the effect of water penetrating the concrete might be serious. Even if all the works described by Mr. Goode to keep the joints sealed had been carried out, there was always the possibility of water getting through, and, if there was an unstable material underneath, the bearing quality of the subgrade was lowered, " pumping " might occur under the traffic, and the inevitable result at a later stage would be fracture of the concrete.

In dealing with the practical difficulties in compaction, the Authors

[1] G. Graham and F. R. Martin, "Heathrow: The Construction of High-Grade Quality Concrete Paving for Modern Transport Aircraft" (Airport Paper No. 1), J. Instn Civ. Engrs, vol. 26 (1945–46), p. 117 (Apr. 1946).

had referred to the conditions in which a layer of lean-mix concrete might be required, and had suggested that, as that base might be fractured through various causes, it was unwise to reduce the thickness of the main slab in consequence of its introduction. He felt that was a far too conservative view of the contribution which a lean-mix base might make to the strength of a runway. Such a base, when provided, should be of sufficient thickness to ensure that it would remain intact under load, and constructional traffic should not be allowed to damage it. If that was ensured, the lean-mix base need not be ignored in determining the thickness of the main slab. If joints were staggered and the upper and lower slabs were kept entirely separate, the under-slab might contribute very materially to the strength of the whole. In fact, it appeared quite possible that it might be an alternative to dowels as a means of producing uniform strength where weak edge and corner conditions would otherwise exist. The strength of the main slab was evened up, and better results were obtained.

In dealing with the effect of varying subgrade conditions, the Authors had expressed the view that it was a matter for decision by the engineer whether a particular problem of design should be solved by thickening the slab or by improving the subgrade. That was normally true within fairly narrow limits. It would seldom be practicable to improve the k-value of a subgrade from 370 to 900, as in the example given in the Paper, assuming that the figure of 370 represented the load-carrying capacity of the consolidated soil. The increase mentioned was large and could be achieved only by superimposing material of better quality to a very considerable thickness ; and, whilst that was necessary where a flexible pavement was intended, it would hardly ever be justified where a rigid pavement was required and an adequate supply of materials for concrete was available. It was generally preferable to concentrate on obtaining a thoroughly compact and stable base than to attempt to effect a large increase of the k-value by the use of compacted material. The equivalent added strength was preferably obtained by thickening the main slab or providing an under-slab.

In dealing with the design of flexible pavements, the Authors had stated : "Various formulae and theories have been suggested for the determination of the thickness of imported material required above the formation." The inference was that no single method had been accepted as entirely satisfactory, and there could be no doubt that knowledge of flexible pavement design was unfortunately less complete than knowledge of rigid pavement design. It would be of considerable advantage if a scientific method could be developed which would make it possible to determine, without any doubt, the materials available and the characteristics of the subgrade being known, what construction was required to produce a permanent pavement capable of bearing certain specified loads. Hitherto the decision whether a flexible or a rigid pavement should be constructed had depended largely upon the availability of materials, but cases might occur in which it would be necessary to decide, quite irrespective of the question of supplies, whether a rigid or a flexible pavement would meet the requirements better, and much more information on the theory of flexible pavement design and the methods of construction was needed before such a decision could be reached with complete assurance. There were various trends of thought in the matter and opinions on the conditions in which a pavement should be made flexible, but a great deal more information would have to be obtained before a definite conclusion could be reached.

Mr. C. E. Loveridge observed that the Authors had pointed out that the demand that the gross weight of the aircraft should be carried on two main wheels only was an extremely severe requirement, and also that in the case of the Brabazon aircraft the load was, in fact, taken on two pairs of wheels. The difference between those two cases was very considerable. In the case of the Brabazon, which might be taken as a typical example, each wheel had a load of about 70,000 lb., but the wheels were about 4 feet 7 inches apart, and they were approximately equivalent to one wheel with a load of 80,000 lb. In other words, the Brabazon loading on the pavement of an airfield, although it might be 300,000 lb. when the aircraft was fully loaded, was equivalent to that of an aircraft weighing 175,000 lb. That was true so far as the surface of the pavement itself was concerned, the pavement being made of concrete slabs, but it was very far from true with regard to the sub-base. The Air Ministry's runways were built downwards instead of upwards, and he could not agree with Mr. Dawson's suggestion that the sub-base might be somewhat neglected and attention concentrated on better pavements. He considered that the strength of the pavement should be reduced progressively downwards until the natural soil strength was reached.

With regard to impact loading, the inertia of an actual wheel on striking a runway was comparatively small and the impact stress which was created was primarily that of the main frame and load of the aircraft itself as the spring of the undercarriage compressed. He believed that there was a reasonable possibility of incorporating a recording balance in the undercarriage of large aircraft in order to ascertain whether that impact force was a serious one or whether it was negligible in comparison with the ordinary static load of the aircraft.

A point of interest in connexion with impact was the surface finish of runways. Some time ago he had obtained a few figures on the horizontal shearing force or slicing effort, as it might be called, when a wheel which was not revolving struck a pavement. He had measured the centrifugal inertia of a wheel of a large aircraft and the striking distance of the skid on the surface of various runways, and, by taking the speed of the aircraft and the time into account, he had obtained a horizontal force, which he had been surprised to find was about 5 tons. For a concrete runway that was not a serious matter, but it could not be ignored in connexion with flexible pavements. In one particular case, which was the primary cause of his investigation, the complete surface of the runway had been sliced off at the touch-on points.

With regard to the Authors' statements on the design of concrete slab runways, he agreed that the theories still lacked proof, but they appeared to give a reasonable result. They might be slightly on the conservative side, but the development of heavy civil aircraft was still in its early stages, and he considered that they gave a reasonable answer to the problems involved and, as presented by the Authors, met all practical cases at the present time.

The Authors had suggested a method of correcting for altitude, and another method had been proposed in the discussion, but he believed that the problem was incapable of solution. He knew of more than one aerodrome at an altitude of 8,000 feet, and in the past many aeroplanes had been incapable of climbing to that height. The increase in length of a runway at an altitude depended upon the individual type of aircraft and bore no relation to the requirements of that particular aircraft at sea-level; thus in an absurd case it might be necessary to have a runway of infinite length in order to get the aircraft off the ground at all.

With regard to flexible runways, there was one primary difficulty. Tarmac runways needed working to retain their life, whilst bitumen runways were liable to damage by oil or petrol, especially in the standing areas; and, although an economical design in a flexible pavement might be achieved, the problem of maintenance on an airport which had to be kept open at all costs might become extremely serious.

Mr. J. N. McFeeters observed that the problem of impact had, in fact, been studied. The Royal Aircraft Establishment, at Farnborough, had installed in the undercarriages of aircraft a balance such as had been mentioned, and it had been found that impact values of up to three times the impact of gravity were obtained with an exceptionally bad landing over a very short period of time. That sounded extremely formidable, but a static loading test taken on a runway showed that at the instant when the load was applied much less deflexion took place than occurred several seconds later. It was some time before the effect of loading showed itself on deflexion-gauges and on stress-gauges. The high impact took place during an exceptionally short space of time, and the machine might be hundreds of yards away before a static load of the same value would take effect. Therefore there was justification for the idea that the static load might prove to be the worst load which could occur. The same tests showed that whilst, in a perfect landing, the machine, on touching down, had virtually a zero vertical pressure, the pressure increased in a straight line until the full weight of the wheel was developed as the machine came to rest.

He believed that designers of runways were more interested in the question of the change of gradients than in the gradients themselves. The lengths of tangent, the lengths of vertical curve, and the lengths of radius of curvature were the deciding factors in many difficult cases, especially where a downward gradient faced an upward gradient. It was very important that those two gradients should be married in a reasonable manner. In some cases that had not been done and a multitude of complaints from practical pilots had resulted.

A cross camber of 1 in 200 was too small on almost every airfield. It had been used at Heathrow, but there the subgrade was exceptionally good, with a bearing modulus of about 2,400. Possibly water percolating through the joints was not likely to cause serious trouble at Heathrow, and in the climate of London the risk of frost on films of standing water was not serious, but in other parts of the country, especially where there was a clay sub-base, those matters were of primary importance. Therefore, a cross camber of 1 in 80 or 1 in 100 would be appropriate to the run-off conditions on a concrete runway in most parts of the country. A concrete runway was a large complex of slabs laid side by side, possibly without any aligning medium, such as dowel or base course, to hold them regular, and it was natural to assume that after a time differences of level of $\frac{1}{10}$ inch, or even more, would develop at the joints. That would tend to trap water on low cambers and, indeed, on any camber. Mr. McFeeters considered that some agreement should be reached between the aeronautical and the drainage requirements.

The first revision of the original Westergaard formula had been made before the days of aircraft tires and had been due to the fact that at Arlington the highway loads had shown that the formula was extremely conservative. The second formula was likely to prove more accurate than the original formula. Mr. McFeeters' experience had been that the difference between edge and corner stresses and centre stresses was more marked than the Authors had indicated. He had nearly always found that the edges and corners were much more highly stressed than the centres.

Could the Authors give some indication of what had happened on the improvement of the subgrade? Like Mr. Dawson, he considered that it was difficult to improve the original subgrade without considerable work and that it was better to make the top slab do most of the work, but there was a medium and the question of economics entered into the matter very largely. An interesting experiment had been carried out, in which, when a subgrade was improved, a larger value of k had been obtained by means of a 30-inch plate, but when a 56-inch plate had been used on the same subgrade no marked improvement had resulted. The question then arose as to which gave the more accurate value of k in the Westergaard formula. He was glad to hear that further tests were being carried out, as they were much overdue, and he hoped that the results would be communicated to the Division in due course.

Mr. A. G. Gullan observed that the drainage of a large airport was a major engineering problem, and it was therefore necessary to have as much information as possible about rainfall and run-off.

He assumed that the design of the drainage had been based on a storm of 0·35 inch per hour, lasting for 93 minutes. Could the Authors state whether that was the greatest storm experienced over any particular number of years. He also assumed that a run-off coefficient of unity had been adopted. How much time had been allowed for the removal of rainfall from the hard surfaces—the total run off after the end of the storm? That figure would be important for those who had to deal with the outfall channels. According to the meteorological records taken at Croydon, in 1935 and 1936 the highest fall in one hour had reached an intensity of 0·567 inch, which was considerably in excess of the design figure of 0·35 inch given in the Paper. If the design were based upon the maximum storm, an allowance of ½ inch per hour would have been better. He would suggest that a recording flow-meter and recording rain-gauge could with advantage be installed at the outfall. The information collected over several years would be of great value in future designs. The variation in rainfall could be illustrated by records taken at Aldergrove, Northern Ireland, over a period of 9 years: during that period the maximum storm had an intensity of 0·23 inch and lasted for 7·1 hours, and only five storms had exceeded 0·1 inch per hour.

The cost of drainage might have been reduced by the installation of a pumping system, with which smaller pipes could have been used and deep excavation, concrete covering, and haunching to the pipes could have been largely avoided. Several pumping-chambers might have been arranged throughout the area, with delivery to the main reservoir. Had the Authors considered a box culvert for the main outfall in lieu of large-diameter pipes? For example, in order to obtain the same discharge as four 54-inch diameter pipes, requiring a trench about 25 feet wide, a box culvert 11 feet 9 inches by 4 feet 6 inches deep would have been sufficient, and consequently on excavation alone a reduction of approximately 50 per cent. would have resulted. The extra concrete required for the thicker walls would have been offset by the concrete required for surrounding the pipes. A culvert of that size would have increased the velocity by about 20 per cent., which would have been advantageous.

The removal of oil from the surface water was an essential item in airfield construction, as if the oil was not removed contamination of the water in the outfall rivers might involve the airport authorities in heavy compensation: but as the oil-trap had been located at the outfall of the four 54-inch pipes, Mr. Gullan doubted whether in periods of heavy rainfall the particles of oil would be satisfactorily removed.

At certain airports the storm-water might be harnessed and a small hydro-electric plant installed. That idea might have possibilities in tropical countries, where the design would have to include provision for much greater rainfalls, particularly if the outfall could be led to a site where a suitable head was available.

In the selection of an airport site it was advisable to be quite sure that storm-water could be easily cleared from the land, without an excessive alteration in the *status quo* of existing rivers, which again might involve the authorities in large compensation works. A discharge of 200–300 cusecs into the existing rivers could very easily cause serious flooding on lower-lying ground, which would probably be of an agricultural nature.

Mr. T. P. O'Sullivan observed that an outstanding feature of the Paper was the lucid exposition of the application of Westergaard's theory. The worked examples inspired considerable confidence in the application of the theory in determining the thickness of a slab.

With regard to compaction he suggested that when the surface soil had been removed some natural moisture was maintained in the subsoil and that the soil had the optimum content of moisture at that time. The excavation of a soil having high cohesive properties, such as a clay soil, might be carried out by a tractor and scraper. The surface would be left bare and, if any considerable delay occurred before the sealing, either the surface would dry out and cause fissures, the effect of the rain would damage the surface, so that a layer of silt would have to be removed, or alternatively, as had happened in the past, considerable quantities of hard-core or some artificial imported filling might have to be deposited before the final surface could be laid. It had been suggested, in that connexion, that a temporary concrete surface should be put down to overcome the difficulty, and he believed that it had also been suggested in certain quarters that a bitumastic spray of some kind could be applied; but, if the problem were considered from an operational point of view and the surface was laid very soon after the compaction had taken place, those measures should not be necessary. In the case of a non-cohesive soil, such as a gravel soil, the problem was perhaps not quite so serious, although of somewhat similar nature. If the subsoil had a natural optimum moisture-content, or a moisture-content approaching the optimum, consolidation might be effected without any difficulty, but, if the weather was hot and the effect of the sun was considerable over a period, drying out would result and any traffic—men, plant, or machinery—would break up the surface which had been previously consolidated, necessitating further work or the adoption of protective measures, such as the laying of a preliminary carpet.

A cross-fall would appear to be the best method of approach in most cases, as normally there would be a natural cross-fall to the landing ground and, if that were utilized as far as possible, the necessity for making up at the centre would be obviated. Moreover the drainage system might be slightly more economical, since a main drain would need to be laid only on the low side of the runway.

Drainage problems often had indirect consequences which might be rather embarrassing. For instance, in the construction of a maintenance depot, a large number of storage sheds and a concrete apron had tended to reduce the catchment-area of the agricultural ground in the vicinity of certain farms. The same problem would occur in the neighbourhood of a runway. On one occasion he had had to deal with the complaint of a farmer that, owing to the water being led away by a drainage system and the catchment-area being reduced, his well, which had never failed before, had dried up. Whether or not there was any substance in that complaint remained to be seen, but the matter was one of some interest.

*** **Mr. F. R. Martin** observed that one of the most important features of the Paper was that it brought forward again problems that had been discussed in the past, and presented them at a time when thoughts of the provision of airports for much more general civilian use than ever before were being correlated in regard to theory and practice. It was always important to bear in mind the many problems that remained unsolved, and which probably never would have a final solution. The controlling gradients, runway-widths, and lengths had been, and still were, to a large extent theoretical, and could vary within wide limits and yet still give satisfactory airfields or airports. It was preferable that an international standard should be laid down for major airports at all events, but " hard and fast " rules were difficult to make at the present transitional stage in the development of transport aircraft. The more general use in the future of gas-turbine engines might change the present-day outlook on what was needed for an airfield. The civil engineer might also be much more definite than in the past about what could economically be provided in the way of airfields, and place a greater onus on aircraft designers to provide aircraft to take off and land within certain provisions.

The importance of large-scale investigations into the ultimate strength and other physical properties of concrete paving could not be too strongly stressed. Until full-scale experiments had been carried out, and the results analysed, the use of the Westergaard formulae for wheel-loads exceeding about 20,000 lb. could not be made with any certainty that the resulting pavement would really be that required. The effect of the value of the constants E and μ on the calculated stresses had been clearly shown by the Authors, and the need for research was obvious.

The provision of load-transfer devices was desirable, and it would be interesting to know what methods the Authors would recommend for their incorporation in concrete slabs. Perhaps the practical difficulties in thickening the corners and edges were not so great as those involved in providing load-transfer devices. Mr. Martin suggested that for bars across transverse joints, particularly " dummy " joints, the concrete slab might be laid in two layers, the dowel bars being inserted before the second layer was deposited. That would be possible, when using machines, by setting the spreading and finishing beams of a leading machine lower than the running rails.

*** This and the following communications were submitted in writing:—SEC. I.C.E.

The construction of small panels to reduce warping stresses in a concrete slab was important. The trend towards the provision of "dummy" joints at close centres in the United States, and also to some extent in Great Britain, might lead to the entire omission of expansion joints, as had been suggested in the Discussion on Airport Paper No. 1.[1]

The subgrade preparation had been rightly emphasized by the Authors. It was fatal to lay any type of paving on an insufficiently compacted sub-base, and each type of strata encountered required investigating for the best methods of compaction. Each should be investigated and compacted fully before the paving work was commenced. Mr. Martin considered that the use of the word "weak" to describe the sub-base concrete, laid as dry lean-mix concrete, was misleading. Generally the water-content was restricted to the minimum and the resulting water/cement ratio was of the order of 0·6 (for a 12 : 1 by volume mix using a river aggregate); and the average strength obtained at 28 days would be of the order of 3,500 lb. per square inch, depending upon the degree of compaction achieved.

If the k-value was to be used as a measure of the compaction of a subgrade it was essential that it should be determined rapidly, and the development of the small apparatus described by the Authors for the determination of k-values was important. It was, perhaps, not widely realized that for values of moisture-content above quite low percentages it was impossible to attain full compaction, and even after so much excellent literature by the late Mr. Markwick[2,3] it was often still possible on civil engineering sites to see rollers, etc., making scores of "passes" in an attempt to obtain an impossible value of density! The use of dry lean-mix concrete, power-rolled in layers, was, therefore, an important development in the provision of efficient subgrades for most weather conditions.

The values of k quoted in Table X were perhaps misleading. Surely it would have been better to give in all cases a range of values for the different types of soils, and not merely single values—probably the maximum values?

The details of the drainage problems at Heathrow were interesting, but Mr. Martin considered that a separate Paper on that subject dealing with the problem in greater detail, would have been of even greater interest.

Flight-Lieutenant R. Lanman Mitchell had been rather surprised at the Author's statement that the Provisional International Civil Aviation Organization had recommended that the gross weight of aircraft with dual-wheel undercarriages should be regarded as distributed equally

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[1] G. Graham and F. R. Martin. "Heathrow. The Construction of High-Grade Quality Concrete Paving for Modern Transport Aircraft." J. Instn Civ. Engrs, vol. 26 (1945–46), p. 117 (Apr. 1946).

[2] A. H. D. Markwick, "The Basic Principles of Soil Compaction and their Application." Instn Civ. Eng. Road Paper No. 16 (1945).

[3] A. H. D. Markwick and H. S. Keep. "The Use of Low-Grade Aggregates and Soils in the Construction of Bases for Roads and Aerodromes." Instn Civ. Engrs, Road Paper No. 9 (1943).

between two main wheels. The Authors had expressed the view that that all-important requirement was conservative, but he considered that the matter deserved more serious consideration. If the dual wheels of the Brabazon were to be regarded as one wheel, should not also those on the Spitfire which had about the same track ? If not, where was the limit ? Also, how was an aircraft with four evenly-spaced wheels to be considered ? The answer, surely, was to develop a theory estimating the effect of dual wheels and meanwhile to proceed with full-scale research. The resultant saving in pavement thickness might well amount to half a million pounds on a Class " A " airfield.

That could be illustrated by considering a Brabazon aircraft on flexible pavements on a cohesive soil, where Boussinesq's formulae might be applied.

Assuming that the all-up weight of the Brabazon was 300,000 lb.; that the wheel track was 4 feet 8 inches; the tire pressure 90 lb. per square inch; that the contact-area was circular and uniformly stressed; and that tire rigidity accounted for an extra 13 lb. per square inch; then the radius of contact would be $\sqrt{\dfrac{75{,}000}{\pi(90+13)}} = 15$ inches.

Fig. 38 showed the vertical stress-distribution, after Boussinesq. The heavy lines were lines of equal vertical stress beneath the individual wheels of 75,000 lb. The dotted lines were the modified isobars of equal vertical stress of the combined undercarriage.

From that *Fig. 39* had been deduced. Line C represented the stress produced by a single wheel of the same tire-pressure and 150,000 lb. load, according to the P.I.C.A.O. recommendation.

It was clearly evident that the Brabazon would exert only approximately the same vertical stress as an aircraft of half its weight on single wheels.

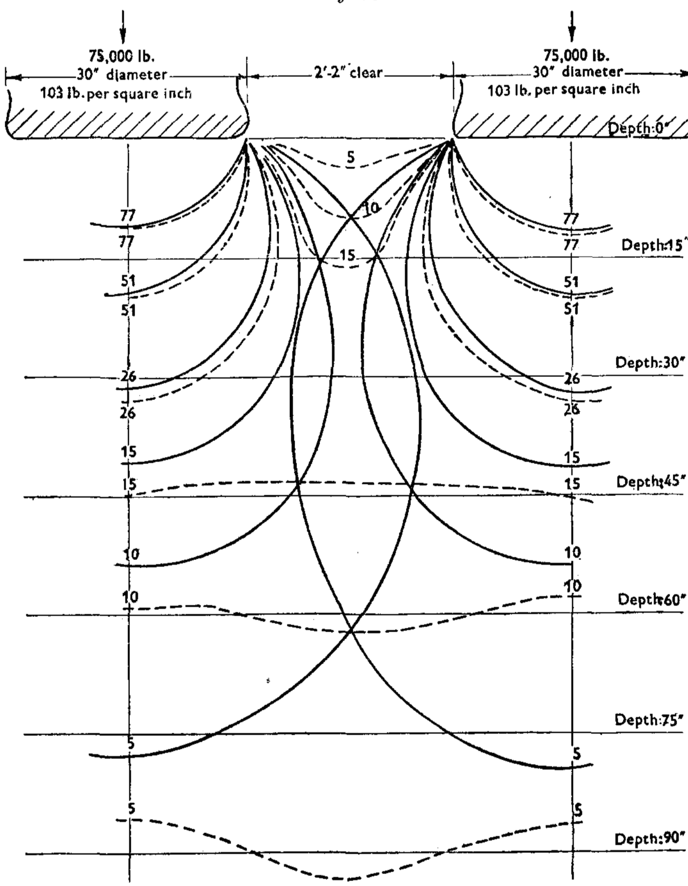
From *Fig. 39* it was possible to deduce a C.B.R. curve. That would hold true only over the clay range, unless it were assumed that Boussinesq's formulae would apply to more granular soils. Flight-Lieutenant Mitchell believed that recent American field research had confirmed the validity of that, when the stress was multiplied by a constant factor. Thus a corrected C.B.R. curve could be produced to cover all soil ranges. Therefore it should be possible to effect an economy in flexible pavement design, which would probably rule out the use of tensile (rigid) pavements unless Westergaard's formula, or some other formula, could be modified to cover dual-wheel undercarriages, and thereby justify reduction in thickness of tensile pavements.

If it were assumed that the failure of the corners of concrete slabs could be calculated as cantilever failures, then it should easily be possible to calculate the effect of the dual wheel. Did the Authors consider that to be reasonable ?

Mr. J. Maxwell Watson observed that he had been interested to hear the views of two speakers on the problem of the allowance to be made for impact at the moment of "touch-down" of aircraft on a rigid runway.

The technique of the "three-point" landing, for tail-wheel or tail-skid aircraft, consisted in placing the machine a few inches above the runway at a speed slightly above stalling speed and then reducing speed until the main plane stalled, when the aircraft dropped a small distance on to the ground. The angle of incidence at this time was high and the effective

Fig. 38.

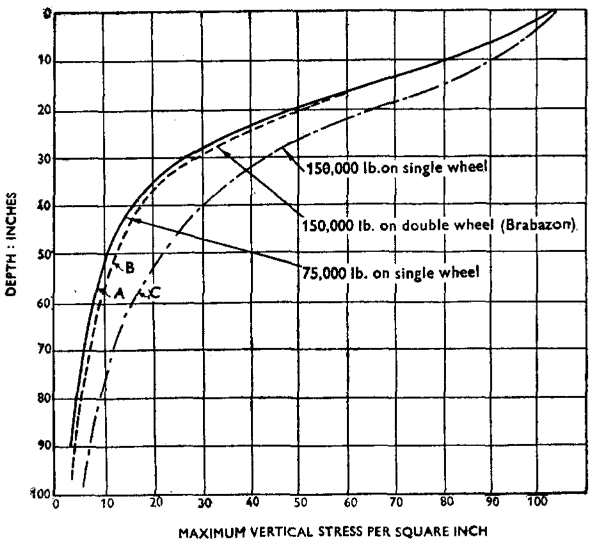


weight of the machine was considerably lightened by its forward speed. The shock of the drop was taken, so far as the aircraft fuselage was concerned, by compression of the undercarriage legs against a spring, to state the process in its simplest terms.

Mr. Watson had no knowledge of the measured magnitude of the reaction on the runway, but a normally good landing would probably impose an effective load of less than the stationary weight. A bad landing, in the worst case, could presumably impose a load sufficient to collapse the undercarriage or its attachment to the fuselage. Such an occasion was extremely unlikely and need not be taken into account in design, as the machine would be likely to " bounce " before collapse occurred. The three-point landing was now, however, usual only for light aircraft.

The normal type of landing for heavy machines was to " fly " them on to the runway, touching the main wheels gently to cause rotation before they took any weight, and then to slow the machine down so that the weight on the wheels increased very gradually. The machine " stalled "

Fig. 39.



with the main undercarriage wheels already on the runway, and the full stationary weight developed gradually as the machine came to a rolling speed, the tail wheel having been lowered gently on to the runway in the meantime. Thereafter the machine became a normal rolling load on pneumatic tires.

There was, in that type of landing, no chance of impact effect, as the machine at the moment of " touch-down " had practically no effective weight—it was airborne, but sinking at a controlled speed. Thus there was no need to consider impact effect for normal use by commercial aircraft. A heavy landing would, in fact, cause the machine to " bounce " because of the lightness of its effective weight.

With nose-wheel machines, the machine was " flown " on to the runway, and a very gradual and controlled application of load to the main wheels resulted. The only essential difference in that case was that, the centre of gravity being forward of the main undercarriage wheels, when the machine stalled the nose wheel took its small share of the load, but again in a gradual manner.

From the above consideration it appeared that design for a normal rolling load, without allowance for impact effect when landing, was the correct procedure for runways.

On taxi-tracks, allowance should be made for the additional load thrown on one leg of the undercarriage while taxy-ing round corners, and for impact caused by any step or pot-hole that might exist. For that reason discontinuties of taxi-track surface were a source of failure and every means should be taken to maintain as " smooth " a surface as possible.

The Authors, in reply, expressed their thanks for the reception accorded to the Paper. They were well aware how much it had left unsaid, but they had hoped that the discussion would throw additional light on some of the more difficult aspects of the subject.

The Chairman had referred to icing conditions and, in regard to frost effects, they could assure him that the effect upon concrete of the quality now specified and obtained by Air Ministry was negligible. They knew of no cases of frost heave of the formation in Great Britain and considered that, by proper compaction and the judicious grading of material forming the base courses, the possibility was very remote.

They agreed with Mr Shaw Maclaren's comment that the buildings at an airfield were important. Extreme care was necessary in the lay-out of the building area ; space was not available in the Paper to deal with that in detail. The building area as a whole, however, should be sited in a position where it would not affect the safety of aircraft operating from the airfield and, in their opinion, the flying requirements should take precedence. Mr. Maclaren's remarks concerning flight-way floor slopes were noted, but the Authors could not agree that the standards adopted by the Air Ministry and set out below Table III were too steep even for instrument landing conditions, and in practice they had proved adequate. They agreed with Mr. Maclaren that it was sometimes difficult to meet the requirement or, rather, to work out the requirement, that the runway should not be used with more than a certain cross-wind component, but they did not consider that the question of wind needed to be studied in very great detail, as the direction of a runway was primarily laid down from an economic consideration of site topography and, provided that it was within 1 or 2 degrees of the prevailing wind, they did not think that a very detailed investigation was necessary.

They agreed with Mr. Dawson's remarks generally, but could not agree that it was impracticable to improve the k-value of the sub-grade. For instance, at Heathrow, large portions of the runways overlay brick earth with a k-value of approximately 100 lb. per square inch per inch. It was a matter for decision whether to place a very thick concrete slab on that subgrade or to improve the sub-grade and use a thinner slab. It was agreed that the k-value of the brick earth in itself could not be materially increased, but, by excavating the layer of brick earth, about 4 feet thick, and replacing with selected natural gravel compacted at optimum moisture, the k-value of the formation was raised to 1,200 lb. per square inch per inch, and that proved to be a more economical solution than the provision of a very thick slab.

With regard to the points raised by Mr. Dawson on the provision of lean-mix concrete, and also referred to by Mr. Martin, the Authors pointed out that they were only referring to a thin layer of lean-mix concrete, provided on the formation when weather conditions were such that the final compaction of the top layer of formation was not possible. In that case, one of the objects of its provision was to carry construction traffic, and it was not possible to prevent damage by that cause and, from the load-bearing point of view, the concrete might be termed " weak ". If not cracked under construction traffic, it might well fail under the stresses imposed on it by a thinner main slab provided, due to assuming that it had a high k-value. For that reason, the Authors recommended that a higher k-value than that of the normal compacted formation should not be taken. They agreed that, where a layer of lean-mix concrete of requisite strength and thickness was provided as an under-slab, the engineer was fully justified in reducing the thickness of the main slab, provided that provision were made to prevent the adherence of the under-slab to the top slab.

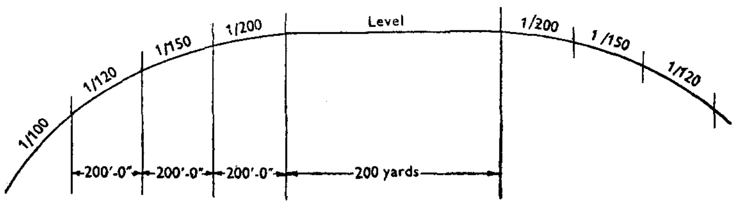
Mr. Loveridge had referred to runways being designed downwards. The Authors could not agree that runways should be designed downwards or upwards. They had stressed their opinion that sub-grade, base courses, and top course should be treated as one load-carrying structure, and that a good design was one which produced a structure of the necessary strength at low cost. Site conditions would determine the proportion of expenditure to be allocated to each course.

They agreed with Mr. Maclaren that it was not practicable to provide airfields at high altitude with runways of sufficient length for types of aircraft with low ceilings. It had to be assumed that only aircraft with the necessary characteristics would be licensed to fly on a route including such a high-altitude airfield. The P.I.C.A.O. had, presumably, considered that point and their recommended increase of 5 per cent. per 1,000 feet should be assumed to be a reasonable compromise. Any adjustment for increase in length of runway due to height, such as that of the P.I.C.A.O. or that adopted by the U.S. Corps of Engineers of one-fourteenth, or 7 per cent. per thousand feet, would, at the best, be approximate and the Authors could see little point in going into further detail, as suggested by Mr. Maclaren.

With regard to Mr. Loveridge's remarks on flexible pavements, the Authors would point out that a further factor arose when jet-propelled aircraft were operated. Owing to the incidence of the jets towards the ground and the high temperatures of the exhaust gases, a detrimental effect occured on marshalling-areas, warming-up aprons, etc., when the jet impinged on the surface for some time, and on areas such as those it seemed that concrete would have, of necessity, to be provided rather than a tar or bitumen mixture for the surface.

They could assure Mr. McFeeters that Air Ministry practice was to make the change from one gradient to another as gradual as possible. Even in wartime, when it was essential to reduce cut and fill to the minimum to ensure maximum speed of construction, it was the practice, in a change, for example, from 1 in 100 up to 1 in 100 down, to proceed by gradual stages, namely, from 1 in 100 to 1 in 120 ; then 1 in 150 ; then 1 in 200 ; then level ; and so on down, 1 in 200; 1 in 150 ; 1 in 120; and 1 in

Fig. 40.



P.I.C.A.O. regulations 0·3 per cent per 100 feet

100 (*Fig. 40*). A minimum length at each gradient of 200 feet, or more if possible, was provided and whenever practicable the level portion was made not less than 200 yards. The P.I.C.A.O. regulations now stipulated that the change of gradient should not exceed 0·3 per cent., per 100 feet, which was greater than the Air Ministry's practice allowed.

Mr. McFeeters had also asked for additional information in regard to the possibility of improving the sub-grade to increase its load-carrying qualities. A few figures concerning two particular sites might be of interest. The first site was at Sculthorpe, where, as shown in *Fig. 13*, a k-value of 270 lb. per square inch per inch had been obtained on loam. On that site the effects of various thicknesses of hoggin and chalk laid and compacted on the sub-grade had been examined. The hoggin available contained some quite large stones and, therefore, it was not easy to lay and compact a very thin layer of uniform thickness or to measure accurately the thickness of a very thin layer. The thinnest possible layer was nominally 2 inches after compaction. That gave an average k-value of 317 lb. per square inch per inch, but it was difficult to state whether that was a true value, owing to the presence of large stones, and so on, under the plate of the testing machine. When the compacted thickness of hogging was increased to 4 inches, the k-value increased to 420, whilst 12 inches gave a value of 650. At that site, when depths of fill exceeding 12 inches were required the sub-grade was at first sealed with a layer of hogging, which was compacted, and then a layer of chalk was laid. The latter consisted of large lumps, spread as evenly as possible over the site, but it left a very rough surface. Hogging was then brought in and spread by means of bulldozers on top of the chalk, filling in the unevenness of the top surface of the chalk. The hogging and chalk were then watered and rolled with sheepsfoot rollers to give a very compact mass, 8–9 inches thick. That type of foundation, built up in successive layers, gave k-values of 1,000 for a thickness of 24 inches, and 1,200 for a thickness of 48 inches. In another case, at Leuchars, the k-value on the sand subsoil was 360, and that was increased to 650 by laying and compacting 6 inches of quarry overburden.

Those were just two isolated cases, but they showed that a considerable increase in the k-value could be obtained; and, in considering that, it was important to realize that, if filling materials could be used which would increase the k-value, it would be advantageous in reducing the thickness of concrete required on the top.

Mr. McFeeters had raised the question of comparison between stresses in the various parts of a runway. From calculation, as the Authors had shown, the difference was not very marked, but they agreed that the original formulae were strictly applicable only to loads on small contact-areas. They had, however, observed that failures occurred much more frequently at corners and edges than at the centre, and they suggested that that was primarily due to weakening of the subgrade by percolation of water through the joints. Maintenance of the joints and adequate sealing were of vital importance, as had been pointed out in the Authors' opening remarks. Both Mr. McFeeters and Mr. Maxwell Watson had agreed that the effect of impact, due to aircraft landing, might be ignored.

The Authors were interested in Mr. Mitchell's remarks concerning the effect of twin-wheels. American tests on flexible pavements had shown that near the surface the effect of the wheels was the same as that of an individual wheel, whilst at depths of 75 inches or more the effect was the same as that of a single wheel carrying a load equal to the sum of the two wheel-loadings. Those tests had been carried out with a B.29 "Superfortress". The Authors agreed with Mr. Mitchell and had, in fact, pointed out that further research was necessary.

With regard to the effect of twin wheels on rigid pavements, they were not aware of any tests that had been carried out, but the Air Ministry had under construction a testing-rig which would be capable of making such tests, and they hoped that in the not too distant future useful knowledge would be obtained to enable the design of rigid pavements to be carried out on a scientific basis. The recommendation of the P.I.C.A.O. to treat a pair of wheels as a single wheel with the same total load was thus felt to be conservative, to say the least.

The Authors could not agree that the corner of a concrete slab acted as a pure cantilever. That had been borne out in tests, and therefore it was not possible to make a simple calculation for the effect of dual wheels.

Several contributors had commented on the question of crossfall or camber, and the Authors had stated that the solution to that problem was governed by both aeronautical and drainage considerations. Where runways intersected, it was essential that the slope should be as small as was compatible with satisfactory drainage; as stated in the Paper, 1 in 200 was considered to be the flattest gradient that would give adequate drainage, and that that functioned satisfactorily, where the surface was plain concrete, had been amply proved by the experience at the London Airport during the considerable rains of 1946. It had been pointed out in the Paper that camber was preferable to a crossfall over the width of the runway from an aeronautical point of view, especially at runway intersections. In addition, there was a very definite drainage advantage, for it was one of the aims of drainage to remove water off the runway into the side collecting channels as quickly as possible, and the greatest distance that water had to travel to the side channel was doubled on a runway with a crossfall in comparison with one which was cambered. Mr. O'Sullivan had suggested that a runway laid with a crossfall might take advantage of any natural fall on the landing ground. The Authors considered that, in actual practice, the crossfall on the landing ground would hardly ever be found to fit in with the crossfall on the runway, so that it would still be necessary to excavate on the low side, or to make up the high side. So far as drainage was concerned, the total quantity of water to be dealt with was the same whether the runway had a crossfall or a camber, so that the saving of one large drain over two smaller drains would not be great and, as previously stated, would double the maximum distance travelled by water over the runway into the side channel.

They agreed that drainage of land might have far-reaching consequences, and they considered that all aspects should be thoroughly studied before a scheme wasp repared. At the same time drainage work was very often blamed for effects due to seasonal, exceptional climatic, or other causes.

The question raised by Mr. Gullan, of what "design storm" to adopt, was largely an economic one and practice varied in different countries; for example, in Canada design allowed for storms liable to occur once in 3 years, whilst in England allowance was made only for storms liable to occur once a year. The Air Ministry had followed standard English practice and, as stated in the Paper, had designed on the Lloyd-Davies "Time-of-Concentration" method and for duration and intensity of storms on the Ministry of Health formula, which was based, from statistics, upon storms liable to occur once a year. Having regard to "time of concentration", a storm of 0·35 inch per hour was the storm which gave the maximum discharge at the outfall, for from the Ministry of Health formula it would be found that storms (liable to occur once a year) having a greater intensity had a shorter duration and that water from paved areas nearer the outfall would have been cleared before water from more distant areas had reached there.

The disadvantages of pumping—cost of running, maintenance, attendance, depreciation and possibility of breakdown, etc.—were so well known to drainage engineers that it had become a fundamental principle to discharge by gravity whenever possible.

Mr. Gullan was correct in assuming that a run-off coefficient of unity was adopted. As stated in the Paper, the maximum allowance for removal of rainfall from the runway to the side channel was 5 minutes.

With reference to his suggestion of a box culvert instead of four 54-inch pipes, the outfall was constructed soon after "D-day", when timber for shuttering and reinforcing steel were difficult to obtain and, as the drain had to cross an arterial road, simplicity of construction and speed were important factors.

The outfall pipes discharged into an area of about 2 acres and the point of discharge was about 100 yards from the oil-trap weir. At maximum discharge, the velocity over the oil-trap weir would be less than 3 feet per second, and generally would be very much less. It was considered that oil would be easily retained, since there was no great velocity over the weirs, as Mr. Gullan appeared to anticipate.

The Authors had emphasized in the Paper that, in preparing a drainage scheme for an airport, the capacity of streams or rivers to take the concentrated discharge from paved areas should be thoroughly investigated and, where necessary, the discharge controlled, as it was at the London Airport (Heathrow).

In conclusion, they were glad to observe the interest taken in the design and layout of airfields, which, after all, was a comparatively new branch of civil engineering, that had come to the fore only during the past decade.

The rules governing the layout of airfields were now fairly well defined, although more definite information was required as to the building requirements in areas around the airfield other than funnels.

It was generally accepted that Westergaard's theory gave a reasonable method of design for rigid pavements, although modifications to his formulae might be necessary when more experiments had been carried out on full-sized runway slabs. The Authors had mentioned that such experiments were in train, but they doubted whether conclusive results would be obtained quickly.

Much more research was also necessary before a final, accurate solution could be obtained to the problem of the design of flexible runways, and that fact might well tend to discourage their use.

The drainage of large airfields was a very considerable problem, and drainage works formed a large portion of the total cost. Therefore it was quite uneconomical to design for the greatest possible storm that might be expected to occur once in, say, 10 years. The present practice of designing for the maximum storm in 1 year appeared reasonable and should not cause the airfield to be out of action except very rarely for short periods.

The Authors hoped that all questions raised in the discussion had been answered satisfactorily.

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