17. PAVEMENT SURFACE TREATMENTS AT AIRPORTS IN GREAT BRITAIN*

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SUMMARY

This paper describes the civil engineering work of the past 12 years, at airfields in the United Kingdom, to deal with the skidding and aquaplaning problems which first arose there in 1955 when the Royal Air Force began to operate high-performance aircraft from relatively short and smoothly finished runways without arrester-gear installations.

Until 1962, the works were carried out by the Directorate General of Works of the Air Ministry who up to that time had dealt with all airfields, civil and military, in the United Kingdom. In 1962, a new Ministry of Public Building and Works was formed by merging the separate Works Organisations of the existing Ministry of Works, the Royal Navy, the Army, and the Royal Air Force; since 1962, the works have been continued by Civil Engineers of the new Ministry, many of whom have been associated with the problems since 1955.

The possible treatments of existing concrete and asphalt surfaces to improve their skidding resistance, as well as the materials and methods which can be used in new construction, are described and illustrated. Detailed specifications for runway surface treatments which have been used extensively are included as appendices.

Although the paper is largely oriented to pavement-construction engineers' viewpoint, it also includes reference to Airport Operators' opinions obtained from the Civil Aviation Division of the Board of Trade and military pilots' opinions obtained from the Ministry of Defence (Air).

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*This paper includes data already published by F. R. Martin and R. F. A. Judge, Civil Engineer of the British Ministry of Public Building and Works and data supplied by the Board of Trade (Civil Aviation Division) and by the Ministry of Defence. It also makes reference to joint activities of the British Ministry of Public Building and Works, The Road Research Laboratory, the Board of Trade, and the Ministry of Technology on airfield pavement surface problems.

INTRODUCTION

In 1955, the Royal Air Force began to operate supersonic aircraft from runways in the United Kingdom which had been lengthened from 6000 feet to 7500 feet. The runways had maximum cross gradients (or cambers) of 1 in 100, many less steep, and the surfacing was of lightly broomed concrete (fig. 1) or hot rolled asphalt (fig. 2). The riding quality of the runways had been the most important single requirement allowed for in the design and construction of the pavements, and the full significance of surface texture needed to combat skidding had not been fully appreciated. It soon became apparent that an increase in surface friction was needed to prevent aircraft from running off the runway ends in wet weather conditions, in some cases because of what was undoubtedly aquaplaning although it was not recognized as such at that time. No arrester cables were provided on these runways because the aircraft were not provided with hooks.

In 1955, the equivalent U.S. Air Force aircraft with hooks operated from runways, in the United Kingdom, 9000 feet long. The runways had all been reshaped to give cambers or crossfalls of 1 in 67, all surfaces except for concrete runway ends were of Marshall asphalt (fig. 3), and arrester cables were provided for hook engagement. Problems of skidding and aquaplaning did not arise.

The first lessons learned, therefore, were that length of runway, rapid surface drainage from relatively steep surfaces, and reasonably rugous texture of the runway surface materials were all important, from an operator's point of view, if skidding and aquaplaning problems were to be avoided on runways where arrester cables were not provided.

For the Royal Air Force, in 1955, there were three possible civil engineering solutions: firstly to lengthen the runways, secondly to reshape them to improve the surface-water drainage characteristics, and thirdly to attempt to increase the wet-surface friction either by texturing the existing surfaces or by adding a new surface to them. Any one, or all, of these possible solutions could have been adopted, but lack of available land in a small island, allied to a natural reluctance to spend more large sums of money on recently developed runways, led to the third (cheapest) alternative being investigated first. A start was therefore made to look into the possibility of "roughening" both concrete and asphalt surfaces by mechanical means. Concurrently, other surface treatments for both existing and new runways were investigated. A history of all this work to date is given herein.

SKID RESISTANCE – MEASUREMENTS

Some measure of the skid resistance of a surfacing was needed, and a method developed by the United Kingdom Road Research Laboratory for road surface measurements was adopted initially for runway surface measurements. By this method, measurements are made with a lightweight trailer mounted at the rear of a Jaguar car. The trailer carries a test wheel, with a tire manufactured to aircraft standards, but 16 inches in diameter and 4.0 inches wide with pressure of 20 lb/sq in. The trailer is towed at speeds up to 100 mph over typical pavement sections which are maintained thoroughly wet.

The test wheel is braked, whilst being towed, by a disc brake controlled from the Jaguar. The brake action also clamps the trailer about the towing point to prevent trailer swing and car oscillation. A sprung load of about 250 pounds is carried on a separate frame. The suspension is damped by a hydraulic shock absorber. Braking forces with the wheel locked are measured by means of a torque arm, and a continuous record of braking force for differing speeds is obtained on a chart.

It was appreciated that measurements made with such a trailer would not necessarily reflect the effect of surface conditions on aircraft travelling at higher speeds with very different loads and tire pressures, and the Ministry of Aviation (now the Ministry of Technology) put into operation aircraft flight trials with specially instrumented aircraft. These trials, and laboratory tests in the Ministry of Public Building and Works Civil Engineering Laboratories at Cardington with aircraft tires (appendix 1), although not showing the same range of values, gave results which were broadly comparable with those obtained on the same surfaces with the light trailer. The trailer method of measuring braking force coefficients was therefore accepted as a reliable and economic way of indicating a good surface from a bad one as far as surface friction properties were concerned. Such measurements allied to an experienced Civil Engineer's engineering study of pavement surfaces and their drainage systems have therefore been used since 1956 in the United Kingdom to indicate whether runways are likely to encourage skidding and/or aquaplaning in wet weather conditions. Further flight tests are however being arranged by the Ministry of Technology's Royal Aeronautical Establishment at Farnborough, in conjunction with the Civil Engineers of the Ministry of Public Building and Works, on many different types of surfacing to attempt to correlate the surface effects on the light trailer with those on aircraft. The development of a heavy test vehicle has also been proposed. In the meantime the trailer measurements continue to be used as an indication of the type of surfaces demanded by aircraft. The success of this approach, as far as the Civil Engineer is concerned, is measured by full-scale "experiments" which have led to pilot opinions of the kind given in appendix 2. Appendix 3 summarises all the relevant tests made by the light trailer since 1954. Figure 4 shows braking force coefficient values for speeds up to 100 mph on typical runway surfaces in the United Kingdom.

Mechanical Roughening

At first a number of methods of mechanical roughening were tried on both concrete and asphalt surfaces. These included the use of –

(1) High-speed percussion rotary hammers (fig. 5) to texture the surfaces;

(2) Disc flails (fig. 6) to groove the surfaces; and

(3) Thermal shock (fig. 7) to roughen the surfaces (of concrete only) by spalling.

These experiments showed that –

(1) All mechanical treatments were difficult to control, since they depended on the differing skills of operators and on the varying quality and uniformity of the pavement surfaces;

(2) The rate of progress of surface treatment was very slow and consequently the costs were high;

(3) Grooving in the same direction as the aircraft landing direction did not improve the surface frictional value; and

(4) Only the disc flails for both concrete and asphalt surfaces seemed likely to produce acceptable economic finishes.

Following these tests, transverse grooving of asphalt surfaces with flails was carried out between 1956 and 1963 at all Royal Air Force Fighter Command Stations at which high-performance aircraft operated. In 1961 and again in 1964, on the Ministry of Public Building and Works advice, both the original asphalt and the newly surfaced runway at Manchester Airport were grooved in this way. By this method, a number of hard steel discs indent the surface and create grooves 1 inch apart, 1/8 inch wide by 1/16 to 1/8 inch deep. A specification for this form of treatment is given in appendix 4.

The first concrete runway to be grooved with flails was treated in 1960.

One big advantage of the flail method of grooving is that the machines work dry and can therefore operate without too much interference with normal flying activities, an important consideration, particularly at busy Civil Airports.

In 1960, saws were developed (figs. 8 and 9) for grooving both concrete and asphalt surfaces with grooves similar to those obtained with flails, but since they needed a large supply of water during their operation, they were considered to be less satisfactory than flails. One other drawback to their use is the tendency for the saws to ride over low areas and thereby produce a rather patchy treatment. In 1961, the asphalt main runway surface at Farnborough was grooved with saws.

In 1963, the diamond drum method of roughening a concrete surface by scoring was introduced. In 1966, on the Ministry of Public Building and Works advice, this method was used on the runway at Leeds Airport. This method now appears to be the most effective for treatment of a concrete surface to produce uniform results, and several other military runways have now been roughened in this way. A specification for the treatment is given in appendix 5. See also figures 10 and 11.

Acid etching of concrete has also been tried but has been abandoned because of the very variable and temporary improvement only that it produces.

Other Surface Treatments

Asphalt.- Between 1956 and 1958, "surface dressing" of asphalt surfaces with tar and bitumen binders (and their emulsions), with and without rubber, using pre-coated and uncoated chippings of various gradings, both hot and cold, were tried. From a large number of such trials, it soon became clear that surface dressing was the simplest, cheapest, and most effective method of improving the skid resistance of an existing asphalt surface. At first, surface dressing was not welcomed on many airfield pavements by the operators of aircraft. The small propeller type aircraft sustained propeller damage from flying chippings, and for jet aircraft taking off closely behind each other – which was often the case at Fighter Command airfields – loose chippings were not an acceptable hazard. Improved specifications and application did, however, result in the acceptance by the Royal Air Force of surface dressing at the main Bomber Command airfields in 1957, and at some Fighter airfields in 1963 (fig. 12). Appendices 6 and 7 reproduce the Ministry of Public Building and Works Specification for surface dressings with bitumen and tar, respectively, in which 1/8-inch single size, pre-coated rock crushings were applied hot. On the Ministry of Public Building and Works advice, both Birmingham (in 1960 and again in 1964) and Belfast (in 1960 and again in 1962) civil airports have adopted this specification for the treatment of their runways. Victors, Vulcans, Valiants, and Hunters have all operated successfully from surfaces laid to this specification.

Concrete.- A short length of a concrete runway surface was surface dressed in 1960 by using an epoxy-pitch binder and coarse grit. The results obtained were excellent (see appendix 3, Airfield Test No. 1) but the cost of such treatment in the United Kingdom is still too high to consider for large scale use. Other binders do not fix the dressing sufficiently well to concrete surfaces and are not therefore acceptable.

NEW SURFACINGS TO EXISTING AIRFIELD PAVEMENTS

In 1959, a number of trial areas of permeable bitumen macadam surfacings were laid over existing impervious asphalt surfaced pavements. The aims of these trials were –

(1) To find a surfacing material which was stable but which did not allow the buildup of a water film on it;

(2) To measure the skidding resistance of such surfacings; and

(3) To compare the weathering properties with those of normal asphalt surfacings.

Such a "friction course" surface is shown in figure 13, and Airfield Tests Nos. 15, 24, 29, 30, 32, 40, and 47 (appendix 3) give results of skidding tests carried out. These skidding tests showed the potential of such surfacings.

Because of the need to make observations of the effects of the weather on such open-textured surfacings, it was not until 1962, after three winters without any obvious deterioration in the surfacings, that a decision was taken to surface part of a military runway with the best of the surfacings tested.

Between 1962 and 1966, a minimum temperature of -8.2° C was recorded at this station and the number of days on which zero temperatures were recorded was 170 but the surfacing shows no sign of deterioration. Two other military runways have now been treated in the same way and an experimental, slightly coarser, material has been laid on the secondary runway at Farnborough for flight trials and for further weathering observations. A specification for this type of surfacing now known as a "friction course" is given in appendix 8. A surface to this specification has been laid by Liverpool Airport as the final surfacing of the new runway there.

Friction courses can only be recommended when they are to be laid over a new or an existing runway surface which is impervious to water and has good drainage. There must not only be free penetration of the surfacing by the water falling on it but the water must drain to an underlying impervious surface and flow quickly to the runway drainage channels. Any underlying surface on which water lies or which is pervious can only lead to a deterioration of the friction course itself.

NEW AIRFIELD PAVEMENTS

Concrete

Various methods of producing a skid resistant surface on new concrete pavements during their construction have been tried and include the transverse texturing with soft and bass brooms (Airfield Test Nos. 79 and 80) and wire combs (fig. 14, Airfield Test No. 56) as well as the mechanical application of carborundum grains and granite chippings (Airfield Test Nos. 95 and 96). The most satisfactory of these surfaces was that obtained with the wire comb, and the new concrete runway recently laid at Glasgow Airport had the following clause written into its specification: "The concrete surfacing of the runway (except for 300 feet at each end) is to be textured by drawing a purpose-made wire broom across the pavement at right angles to the side forms whilst the concrete is still soft enough to take an impression. The broom head is to be 24 inches in minimum width and wire filled with 32 gauge by 1/20 inch wire tapes."

Asphalt

The main specified requirements for a stable dense bituminous surfacing are –

(1) To resist deformation by aircraft at high loads with high tire pressures; and

(2) To be impermeable to protect the natural foundation on which the complete pavement is built.

These requirements are not normally conducive to a finished surface of high skid resistance. The large number of tests on many types of dense bituminous surfacings of all ages show the wide range of results and the difficulty of ensuring high skid resistance with the normal "blacktop" specifications (Airfield Test Nos. 18, 19, 27, 33, 38, 41, 43, 44, 46, 52, 53, 54, 55, 59, 64, 65, 75, 76, 78, 83, 84, 89, 93, 97, 101, 102, 103, 104, and 105).

The most carefully controlled dense asphalts have been found to have a range of braking force coefficients at 80 mph of 0.08 to 0.46.

Weather and wear continue to affect braking efficiency of all bituminous surfacings throughout their useful life. In general, it can be anticipated that their skid resistance improves with age.

Choice of binder is also known to influence the weathering quality of bituminous surfacings. For some roadwork in the United Kingdom, mixtures of tarpitch and bitumen have been used as binders to accelerate weathering and hence increase surface friction. Since, however, the weathering of road surfaces and airfield pavements proceeds at very different rates due to difference in trafficking patterns and intensity, the use of blended binders for airfield pavements is not considered to be a desirable proposition. Weathering of runways is normally fast enough with normal binders and the problem usually is in trying to extend the life of pavements so as to increase the period between resurfacings.

Methods of roughening new "blacktop" surfaces during construction have also been tried. Grooving hot asphalt with "banded" rollers failed because of the difficulty of controlling the finish. As a final operation, the creation of the grooves depended on the virtual reshaping of a fully compacted material and the process tended to create a surface of unacceptable riding quality. "Backblinding" of hot asphalt with the coarser fractions from the hopper of the asphalt spreading machine (Airfield Test No. 20) and the rolling in of pre-coated chippings of various sizes and at varying rates of spread were also tried (Airfield Test Nos. 13, 14, 16, 21, 22, 26, 31, and 35). Although the tests were promising, the chippings tended to become dislodged from the surface over large areas after only a few years and these methods of treatment are not now recommended. Similar methods used on roads in the United Kingdom where the passage of traffic is much more frequent have, of course, proved satisfactory.

From the results it is obviously not possible to ensure that dense asphalt or tarbound surfacings to any acceptable specification will have a specific resistance to skidding. The variables in the mixtures, even under the most carefully specified and controlled conditions, are too great. Variations in the shape of aggregate, both coarse and fine, affect surface friction values; but it is not considered economical, even if it were physically possible, to control friction by being too restrictive in the allowed aggregate type.

For new asphalt pavements, therefore, the solution would appear to be the laying of a "friction course" surfacing over the dense asphalt or to groove or to surface-dress the top surface.

EXTENT OF SURFACE TREATMENTS

For all special surface treatments, it has been the practice in the United Kingdom to exclude a length at each end of a runway up to the "start line" to –

(1) Reduce the effect of fuel and oil spillage in clogging a textured surface and making it difficult to clean;

(2) Avoid an increase of slipperiness when an aircraft moves from a taxiway to a runway where treatments depend on directional grooving;

(3) Avoid increased rate of destruction of surfaces by fuel spillage, heat, and jet blast; and

(4) Take advantage of the fact that at lower speeds the braking force coefficients of special treatments are no better than those for normal surfaces.

For runway ends, concrete remains the best surfacing material. It is not damaged by fuel spillage, heat, or jet blast and is easier to clean. Where concrete cannot be provided, then an asphalt surfacing with a normal finish sealed with tarpitch emulsion is an alternative. It resists damage by fuel and oil spillage and only the smallest aircraft with jet effluxes near the ground will destroy it by heat and blast. The surface can, however, become very slippery in wet weather.

Complaints about the slipperiness of markings, particularly in turning from taxiway to runway, have led to an enquiry into the real need for many of the markings at present called for at runway ends. Complaints about slipperiness generally arise because of the differences of texture of the surface of the markings with the surrounding pavement. It is not necessarily the lines themselves which are at fault. Calcined flints added to paint markings, or lines made with material incorporating calcined flints – such as hot applied thermoplastic material – give high friction values. On the other hand, glass beads which are frequently added to painted lines to improve visibility give low values.

THE FUTURE

Some aspects of the skidding problem still need to be examined. For example, it is not yet clear exactly how the longitudinal gradients of a runway allied with crossfalls or cambers affect skidding, but quite obviously the longer the path that surface water has to take to get to the drains the greater the problem will be.

The provision of a much more positive method of getting water away from runway surfaces, perhaps by providing a close pattern of slotted drains to take surface water immediately down below the surface rather than allowing it to flow over the surface at all, may be worthwhile.

Plastic or metallic grids of shallow depth might be fixed, perhaps in the centre width of the runway only, to provide a "dry landing lane" at all states of the weather, or an electrically heated strip might in some cases be an economical solution to create a dry landing area.

Whatever the long-term solution may be, the civil engineer has for the past 10 years, as this paper shows, tried and has had considerable success (see fig. 4) in keeping pace with the requirements of high-performance aircraft, particularly if the pilot opinions given in appendix 2 are accepted as the main measure of achievement rather than comprehensive scientific quantitative assessments with aircraft, which in many cases are yet to come. This is in keeping with the tradition that has persisted quite rightly from the start of aviation history that the aircraft designers have been able to design aircraft which have largely been the undisputed dictators of runway lengths, surface textures, etc. It could be argued, perhaps, that a time might come when the civil engineer should say just what he can provide economically and let the aircraft designers start from there. It may be it is just not an acceptable idea that the planned performance of an aircraft in the air should be restricted in any way by limiting the facilities for it on the ground, but aircraft safety – particularly for civil aircraft – might at some time dictate otherwise.

CONCLUDING REMARKS ON BEST PRACTICES FOR AIRFIELD PAVEMENT SURFACINGS

The best techniques* that have so far been evolved by civil engineers in practice in the United Kingdom for improving the surface finish of runways so that the twin hazards

*Now all included in the British Ministry of Public Building and Works (M.P.B.W.) Airfield Specifications.

of skidding and aquaplaning may be reduced are summarised in this section. The methods can be recommended with the confidence born of pilot opinion rather than from measurements of fully correlated ground vehicle/aircraft performance, provided that a full engineering appreciation of existing pavements is made at each site before any particular method is adopted and that the selected method is suitable for the types of aircraft operating.

1. Existing Asphalt (figs. 2 and 3)

   (a) Surface dressing (fig. 12)

      (i) Operational considerations

      Surface dressing is not recommended where the frequency of air movements is heavy, where propellers or jet engines are close to the ground, or where aircraft take off side by side or follow closely behind each other either in landing or take-off. There is no limit to the size of aircraft, providing these restrictions do not apply. Aircraft with twin-tandem undercarriages at tire pressure 280 lb/sq in. and all-up weights exceeding 200,000 pounds have been operating regularly for a number of years from runways which have been deliberately surface dressed to improve friction. There is no evidence of an increase in tire wear.

      (ii) Consideration of existing pavement

      The overall shape and profile of the existing runway is not as important as it is with other treatments and, where a number of transverse and longitudinal slope changes occur in the runway length, surface dressing is probably the only suitable method other than expensive reshaping. Nevertheless, in spite of the fact that the overall shape need not be ideal, for a successful application of this treatment, the compacting equipment must be capable of following the minor surface irregularities to ensure a uniform adhesion of the chippings. Where this condition cannot be assured, a new asphalt wearing course may be necessary before applying the surface dressing.

      (iii) Effectiveness of treatment

      A satisfactory surface dressing will initially raise the braking force coefficient of the surface to a high value which thereafter, depending on the intensity of trafficking, will slowly decrease. Normally, an effective life of up to 5 years can be expected.

      (iv) Runway ends

      Runway ends used for take-off should not be treated. Aircraft scuff in turning, and both fuel spillage and heat will soften the binder, and blast will lead to loose chippings.

(v) Specification

See appendix 6 or 7.

(vi) Cost in United Kingdom

1s. 3d. per sq yd.

(b) Grooving (fig. 15)

(i) Operational considerations

There do not appear to be any operational objections to the grooving of existing asphalt surfaces. In the United Kingdom, high-performance aircraft with single main wheels at tire pressure 300 lb/sq in. and all-up weight 40,000 pounds have been successfully operating from grooved asphalt surfaces for over 10 years. Undoubtedly there is no limit within the foreseeable future to the aircraft size, loading, or type for which such surfaces will be satisfactory. There is no evidence of a greater rate of tire wear.

(ii) Consideration of existing pavement

The engineer will have to be satisfied that the existing asphalt wearing course is a dense well compacted layer. If the surface exhibits fretting or where large particle fractions of coarse aggregate are exposed on the surface itself, then other methods will need to be considered, or resurfacing will have to be undertaken before grooving. Apart from the condition of the surface itself, the ratio between crossfalls and longitudinal slopes becomes important. More work on this aspect of the problem is required, though it is clear that if the longitudinal slopes are such that the water runoff is directed along the runway instead of flowing quickly to the runway side drains, then a condition could arise when the grooves would fill with free water, fail to drain quickly, and possibly encourage aquaplaning.

(iii) Effectiveness of treatment

Transverse grooving will always result in a measurable increase of the braking force coefficient though the extent of the improvement will be related to the quality of the existing surface. This improvement will be maintained throughout the life of the asphalt wearing course. Observations since 1956 confirm that grooving has not resulted in an increase in the rate of deterioration of the asphalt. In the United Kingdom there have been no reports of grooves becoming clogged with dirt, industrial waste, or other contaminants.

(iv) Runway ends

In the United Kingdom, a length at each end of the runway has been left ungrooved to make it easier to wash down and clean off fuel and oil droppings. Moreover, it would seem that engine blast could be more damaging on a grooved than on an untextured surface. It is also considered that the control of an aircraft moving from the taxiway onto the runway end could become tricky, as test measurements indicate that the improvement in the braking force coefficient is dependent on trafficking across the grooves and that there is a loss of friction in tests carried out along the grooves.

(v) Specification

See appendix 4.

(vi) Cost in United Kingdom

3s. 6d. per sq yd.

2. Existing Concrete (fig. 1)

Scoring (fig. 11)

(i) Operational considerations

There do not appear to be any operational objections to the scoring of existing concrete surfaces, and this method of treatment seems to be suitable for all types of aircraft.

(ii) Consideration of existing pavement

It will be understood that it would be difficult uniformly to score concrete surfaces which are "rough." Pavements with damaged or poorly formed joints, or on which laitance has led to extensive spalling of the surface, would be equally difficult to score. If the existing surface is reasonably free of these defects, there are no other engineering limitations to scoring.

(iii) Effectiveness of treatment

Transverse scoring of concrete has been adopted in preference to the earlier grooving of existing concrete surfaces, which was similar to the method specified previously for asphalt surfaces. The tests show this treatment to give more uniform results than the grooved concrete surfaces. In all cases, there is a considerable improvement in the braking efficiency of pavements initially textured at the time of construction, with belts, burlap, or soft brooms. The useful life of the treatment will depend on the frequency of trafficking but it is expected that at the majority of airfields the scoring will remain effective for the life of the concrete, which it in no way affects.

(iv) Runway ends

As when grooving asphalt so also when scoring concrete, the United Kingdom does not carry this treatment over the runway ends. Similar reasons apply. In addition, it is thought that in the case of scoring, a possibility of an increase in tire wear in turning cannot be totally discounted.

(v) Specification

See appendix 5.

(vi) Cost in United Kingdom

5s. 0d. per sq yd.

3. New Pavements

All new runways should be designed to a uniform transverse profile with the maximum crossfall permitted by the International Civil Aviation Organization (ICAO), and the longitudinal profiles should be as nearly level as possible. A cambered transverse section from a centre crown is preferable but if for any reason this cannot be provided then the single runway crossfall should be carefully related to prevailing wet winds to ensure that surface water drainage is not impeded by the wind blowing up the transverse gradient. (In the case of single crossfalls, it may be necessary at certain sites to provide cut-off drainage along the higher edge to prevent water from the shoulder strip spilling over the runway surface.) If these ideal shape criteria are met, aquaplaning incidents should be reduced; but departures from these ideals will result in an increase of aquaplaning probability no matter how good the braking force coefficient of the surface itself may be. Aside from other operational needs affecting this aspect, it is highly desirable that maximum crossfalls permitted by ICAO should be increased. Similarly, there is a need to establish a practical ratio between crossfall and longitudinal gradients. Meanwhile, it is suggested as a guide for new runways that the longitudinal slope at any point along the runway should not exceed 1/3 the crossfall at that point; thus, a 1-66 crossfall should not have a longitudinal slope sharper than 1-200. These comments hold true for major reconstruction projects; in addition, when old runways become due for resurfacing, the opportunity should be taken wherever possible to improve the levels to assist surface drainage. Every improvement in shape, no matter how small, helps.

It is also known that changes of surfacing materials and of surface textures at intervals along the runway length cause disconcertingly different responses in the aircraft during its ground run, particularly during braking, and it is therefore important to maintain a uniform surface material and texture between runway ends. This should be taken into account when new extensions are planned. If different materials are proposed for the extensions, it may be necessary to consider resurfacing the existing runway at the same time with a similar material, though obviously the opportunity to provide a texture to an improved standard on the new extension should not be missed. Changes of surfacing at runway intersections should be avoided.

(a) New concrete (fig. 14)

(i) Operational considerations

There appear to be no operational objections to the current United Kingdom method of texturing new concrete runways during construction with wire brooms.

(ii) Effectiveness of treatment

A comparison of measurement on a new concrete runway constructed in 1966, which was the first to be textured to the current specification, with measurements on previous runways textured to earlier specifications shows the marked improvement achieved. The life of the treatment will depend on the intensity of trafficking, but it is anticipated that at most airfields it will remain effective throughout the life of the concrete surface.

(iii) Runway ends

The current specification excludes the coarse texturing of runway ends. It is considered that the coarse texture which this specification provides if applied in the take-off areas could aggravate the difficulties of removing fuel and oil deposits; and if these deposits could not be removed, slippery areas could develope at these points.

(iv) Specification

Runways textured with soft brooms and with bass brooms have been laid and tested over the years, but the current specification calls for a wire brooming. The contractor is required to texture trial areas for approval of the finished surface, and is thereafter "to reproduce a uniform texture throughout the runway length." In order to assist the engineer in his choice of the trial areas, a sand-patch test which measures the area of spread of a carefully defined quantity and grading of fine sand over the surface as a guide to texture depth has been devised.

(v) Specification

See appendix 9.

(vi) Cost in United Kingdom

6d. per sq yd.

(b) New asphalt – grooving, surface dressing, or "friction course"

(i) Operational considerations

Where aircraft with high tire pressures operate, it is essential that the asphalt surfacing on the pavements should be of high stability. This can only be achieved with an asphalt design mixture of high density, compacted in the field virtually to refusal, so that thereafter air trafficking will not deform the surfacing and cause irregularities in the surface which might result in a bumpy ride and ponding water. These requirements are not conducive to a finished surface of high skid resistance, and after a large number of tests on asphalt surfacing it became apparent that it is not possible to ensure surfacing to any acceptable stability which will at the same time have a specific resistance to skidding. Trials were carried out in an attempt to improve the braking force coefficient of the asphalt during laying, including the rolling in of chippings, and grooving with banded rollers, but so far these methods have not been successful.

(ii) Surface treatments

It has been the normal practice in the United Kingdom to specify a high-stability asphalt and to provide a high skid resistance after completing the usual laying and compacting techniques by treating the new asphalt surfacing with a surface dressing to the specification already given, or by grooving it as previously described.

(c) Friction courses (new asphalt) (fig. 13)

(i) Introduction

As an alternative to the surface dressing or grooving of new asphalt wearing courses, a new venture was undertaken in 1962, when following a series of trials laid some years earlier, a permeable bitumen-macadam surfacing was laid as a special additional course over a normal high-stability asphalt wearing course, after reshaping of the runway. This so-called "friction course" was deliberately designed not only to improve the skid resistance but to reduce aquaplaning incidence by providing a highly porous material to ensure a quick getaway of water from the pavement surface directly to the underlying impervious asphalt.

(ii) Limitations of friction course

Friction courses of this kind should only be laid on new runways of good shape, or on reshaped runways approaching the criteria outlined above for new runways. They must always be over densely graded impervious asphalt wearing courses of high stability. Both of these requirements are necessary to ensure a quick flow of the water through the friction course over the impervious asphalt to the runway drainage channels.

(iii) Effectiveness of treatment

It is still too soon to give an accurate assessment of the effective life of the friction course. The course laid in 1962 shows no sign of deterioration so far.

(iv) Runway ends

The friction course is not recommended at the runway ends. Oil and fuel droppings would clogg the interstices and soften the bitumen binder, and jet engine heat would soften the material which blast would then erode.

Erosion would tend to be deeper than on a normal dense asphalt. Scuffing might occur in turning movements during the first few weeks after laying.

(v) Specification

See appendix 8.

(vi) Cost in United Kingdom

4s. 6d. per sq yd.

APPENDIX 1

M.P.B.W. CIVIL ENGINEERING LABORATORY TESTING RIG FOR PAVEMENT ROUGHNESS TESTS

The Cardington static friction test rig consists of a "Lightning" aircraft wheel mounted in a frame which is loaded to give a known total weight upon the tire, inflated to 300 lb/sq in. A sample of pavement is fixed below the wheel in a trolley which is carried on rollers and is free to move horizontally against a proving ring. A shower of water plays upon the sample throughout the test. The wheel frame is suspended so that the tire is just clear of the pavement, and the wheel is rotated by an electric motor. The current is cut off, and when the wheel has slowed to a predetermined speed it is dropped upon the pavement sample. The horizontal thrust upon the sample caused by friction between it and the tire is measured by the distortion of the proving ring.

APPENDIX 2

PILOT OPINION

Civil Airports

The Aerodromes Operations Policy and Flight Safety Branches of the Board of Trade (Civil Aviation Division) maintain that high-friction well-drained runways provide the primary method of preventing wet-skidding accidents and that there is already sufficient known for this approach to be implemented on a wide scale. They have compiled brief consolidated reports from a number of United Kingdom civil airports of their experience with the various types of texture and these reports are given below: All these airports are operated by Municipalities but are regulated by a national system of licensing and advice by the Board of Trade on matters considered at the Conference. For example, licensed airports have been advised that –

(a) Plans for new runways or resurfacing should ensure that good drainage and friction qualities are provided; and

(b) Known poor existing surfaces should be rectified urgently, or, in borderline cases, improved when the runway is due for major maintenance.

In order to take a first step in implementing this policy, the Board of Trade and Ministry of Public Building and Works have in hand a programme of runway surveys designed to identify the poor or below average surfaces, to indicate where remedial action is required to the authorities concerned, and to classify runways vis-à-vis each other in terms of their wet friction characteristics.

Table 1 summarises relevant statements from the following airports on the various types of runway surface that exists:

<u>Birmingham</u> – Asphalt; grooved $\frac{1}{8}''$ wide $\frac{1}{8}''$ deep at 1" centres; extension only, 1967

<u>Glasgow</u> – New reinforced concrete runway; crowned to 1 in 67; wire combed; 1966

<u>Leeds/Bradford</u> – Concrete; some scored and some wire broomed; 1965 and 1966

<u>Liverpool</u> – New runway; crowned 1 in 67 plus "friction course" surfacing; 1965

<u>Manchester</u> – Asphalt; grooved $\frac{1}{8}''$ wide $\frac{1}{8}''$ deep at 1" centres; 1961 and 1965

<u>Southend</u> – Reshaping to 1 in 67 plus macadam "friction course"; 1967

APPENDIX 2

TABLE I

Airport	Reason for treatment	Effects on – Drainage	Effects on – Maintenance	Operators' views – Wet braking	Operators' views – Tire wear
Birmingham	Original surface of old asphalt extension when tested by light trailer gave low braking force coefficients: At 100 mph: Existing runway . . . 0.41 Extension: Before . . . . 0.12 After. 0.61		With regard to mud accumulation and deposits, no change More difficult to clear ice No evidence of more rapid deterioration of asphalt	No adverse comment	No adverse comment
Glasgow	Complete resurfacing and extension for strengthening on change of role Braking force coefficient: At 80 mph assessed at 0.6	Dries quickly after rain	No visible deterioration	Satisfactory Glasgow operators are completely "sold" on this type of treatment	No adverse comment
Leeds/Bradford	Original lightly broomed concrete surface giving rise to pilot complaints of skidding etc. Braking force coefficient: At 80 mph: Original concrete . . . 0.16 Wire brushed concrete . . . . . . 0.41 Scored concrete. . . . 0.54	Improved Water stays in scored surface and leaves top surface dry	No evidence of any abnormal wear or deterioration	Original complaints from operators stopped after treatment Appears far superior to lightly broomed runways Crosswind limits have not changed but wet handling has improved	Tire wear has not increased
Liverpool	New runway Braking force coefficient: At 80 mph 0.51		Virtually no loosening of aggregate In $2\frac{1}{2}$ years, vacuum cleaned only once. No frost damage	Runway gives a very smooth ride Crosswind operations are not difficult Runway has been described as "the best in Europe" A.D.C. 8 Pilot landing in wet, gusty weather said that he could have turned off the runway after 4600 feet	Seems to be no abnormal effect on tire wear
Manchester	Original Marshall asphalt produced an extremely slippery surface when wet Braking force coefficient: At 80 mph: Original surface . . . 0.22 Grooved surface assessed 0.5	Improved, probably because of the grooves forming minor drainage channels	Not sufficient evidence yet to say what effect grooving has on the life of the asphalt Generally speaking, the runway keeps very clean	Before grooving, some operators reduced crosswind limitations by about 5 knots for the wet runway whilst others inserted warning notes in their manuals; these limitations were removed after grooving had been successfully proved; any doubts about crosswind operation were removed A slight increase in tire noise has been mentioned	No real evidence on which to base comment
Southend	Resurfacing due Braking force coefficient: At 80 mph: Original surface. . . 0.1(?) New surface . . . . . 0.41 At 105 mph: New surface 0.51	Improved due to increase in surface gradients	No visible deterioration to date No sweeping difficulties but brush wear slightly more	No complaints even during heavy rain	No adverse comments

APPENDIX 2

Military Airfields

Pilot opinions on three runway surfaces are quoted below:

1. Original surfaces – soft broomed smooth concrete.

   New surfaces – wire broomed new concrete in reshaped areas; scored texturing of old concrete.

"A very great improvement. A by-product is the new "white" surface caused by the scoring process, making the airfield much more easily seen from the air in low visibility."

"Tire wear. Some evidence of increased wear but some may be attributed to higher crosswinds experienced." (See below.)

"Drainage characteristics of runway, much better."

"The braking characteristics improved on runway when dry, and very much improved on runway when wet. Many of the flying restrictions which were imposed during the use of the original runway have been lifted. Aircraft are now allowed to land with a crosswind of 25 knots. (Previously, a limit was imposed of 20 knots for a dry runway decreasing with the extent of the surface wetness. Stream landings were not permitted when the crosswind component exceeded 10 knots on the dry runway and never when the runway was wet). Unless the runway is now "flooded" by a very recent downpour, it seems to make little difference to normal braking distances whether the runway is wet or dry. The restriction on stream landings have been lifted altogether."

"The new surfaces are extremely "confidence building," especially in crosswind conditions. The tendency to feel that one has to land in the first few feet of the runway (when it is wet for example), and therefore risk undershooting, appears to have been eliminated."

2. Orginal surfaces – smooth asphalt.

   New surfaces – reshaped with asphalt plus "friction course."

"It has a far more effective braking surface than the other runways."

"Water drains off the surface quickly and it needs prolonged heavy rain before any surface water is seen."

"Dry crosswind limits can be safely used even when the surface is wet."

"Frost and ice do not form as quickly on the surface as they do on the other asphalt and concrete surfaces at the [Air Force Fighter Command] Station."

"Tire wear has not significantly increased with the introduction of a 'friction course.' In fact, if anything, tire consumption has fallen slightly due, in part, to the reduced braking required."

"Because of the excellent braking surface presented by the 'friction course,' it has been possible to treat this runway as a 'dry surface' in all weathers."

3. Original surfaces – smooth asphalt.

New surfaces – grooved asphalt.

"Fighter Command have gained active experience on the effect of grooving on wet runways and are very satisfied with the results."

APPENDIX 3

SUMMARY OF SKIDDING TESTS ON AIRFIELD PAVEMENTS

Airfield Test Number	Date of surface treatment (or laying)	Date of skidding tests	TEXTURE OF TEST AREA AT TIME OF TESTING (with Test Nos. before and after treatment)	VALUE OF BRAKING FORCE COEFFICIENT (Light trailer 320lb/20lb.sq.in.) taken from smooth curves drawn through plotted points at the following speeds (miles per hour) (Figures in brackets indicate results before special surface treatment)			M.P.B.W./C.E. Laboratory Friction Test Rig, (16,000 lb./ 300 lb. sq. in.) Mean co-ef. at 75/150 m.p.h.	"Swift" Aircraft Flight Tests, (16,000 - 18,000 lb./ 300/320 lb. sq. in.) Mean co-ef. at 120 Knots
				20	50	80		
1	1960	1960	Concrete treated with epoxy-pitch and $\frac{1}{8}$ in. porphyry chippings (Test 68).	.84 (.74)	.68 (.38)	.63 (.25)		
2	1958	1958	Asphalt treated with tar and $\frac{1}{8}$ in. pre-coated basalt chippings (Test 105).	.62 (.34)	.61 (.11)	.61 (.06)		
3	1959	1959	Acid etching of concrete finished with purpose-made wire comb (Test 56).	(.63)	(.46)	.58 (.28)		
4	1960	1960	Asphalt grooved by flails; $\frac{1}{8}$ in. grooves one inch apart (Test 93).	.73 (.73)	.60 (.28)	.57 (.15)		
5	1963	1963	Eighteen year old concrete scored transversely (Test 73).	.65 (.57)	.57 (.33)	.56 (.23)		
6	1958	1958	Asphalt treated with outback bitumen and $\frac{1}{8}$ in. uncoated chippings.	.60	.55	.55		
7	1960	1960	Marshall asphalt grooved by flails; $\frac{1}{8}$ in. grooves one inch apart (Test 89).	.66 (.58)	.56 (.37)	.54 (.16)	0.130	
8	1960	1960	Marshall asphalt grooved by saws; $\frac{1}{8}$ in. grooves one inch apart (Test 89).	.65 (.58)	.53 (.37)	.53 (.16)	0.124	
9	1956	1956	Asphalt grooved by flails; $\frac{1}{8}$ in grooves one inch apart (Test 64).	.72 (.65)	.58 (.44)	.52 (.26)		
10	1959	1959	Open-graded macadam friction course; $\frac{3}{4}$ in. quartzite aggregate (Test 53).	.63 (.57)	.54 (.42)	.52 (.31)	0.136	
11	1960	1960	Marshall asphalt grooved by saws; $\frac{1}{8}$ in. grooves one inch apart (Test 103).	.61 (.70)	.53 (.23)	.51 (.08)		
12	1959	1959	Open-graded macadam friction course; $\frac{3}{8}$ in. hornfels aggregate (Test 53).	.59 (.57)	.51 (.42)	.50 (.31)	0.140	
13	1958	1958	Asphalt roughened with $\frac{3}{8}$ in. coated chippings at 200 sq. yd./ ton (Test 102).	.64 (.57)	.54 (.28)	.50 (.10)		
14	1958	1958	Asphalt roughened with $\frac{3}{4}$ in. coated chippings at 150 sq. yd./ ton (Test 102).	.62 (.57)	.53 (.28)	.50 (.10)		
15	1962	1963	Open-graded macadam friction course; $\frac{3}{8}$ in. hornfels aggregate	.55	.52	.50		
16	1958	1958	Asphalt roughened with $\frac{3}{8}$ in. coated chippings at 225 sq. yd./ ton (Test 102).	.66 (.57)	.54 (.28)	.49 (.10)		
17	1961	1961	Asphalt grooved by saws; $\frac{1}{8}$ in. grooves one inch apart (Test 93).	.75 (.73)	.51 (.28)	.49 (.15)		
18	1957	1958	Asphalt with 50% limestone aggregate	.53	.53	.48		
19	1952	1956	Four year old limestone asphalt	.68	.56	.48		
20	1958	1958	Marshall asphalt with backblinding	.82	.53	.48		

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				20	50	80		
21	1958	1958	Asphalt roughened with 3/8 in. coated chippings at 250 sq. yd./ ton (Test 102).	.64 (.57)	.53 (.28)	.48 (.10)		
22	1958	1958	Asphalt roughened with 1/2 in. coated chippings at 175 sq. yd./ ton (Test 102).	.61 (.57)	.51 (.28)	.48 (.10)		
23	1958	1958	Asphalt roughened with 1/2 in. coated chippings at 150 sq. yd./ ton (Test 102).	.59 (.57)	.52 (.28)	.48 (.10)		
24	1959	1959	Open-graded macadam friction course; 3/8 in. quartzite aggregate (Test 53).	.65 (.57)	.52 (.42)	.48 (.31)	0.136	
25	1950	1956	Six year old limestone asphalt.	.66	.53	.47		
26	1958	1958	Asphalt roughened with 3/4 in. coated chippings at 120 sq. yd./ ton (Test 102).	.60 (.57)	.51 (.28)	.47 (.10)		
27	1959	1959	Marshall asphalt with basalt aggregate.	.77	.61	.46		
28	1959	1959	Acid etching of concrete finished with bass broom.	.69 (.62)	.53 (.28)	.46 (.19)		
29	1959	1959	Open-graded macadam friction course; 3/8 in. quartzite aggregate (Test 53).	.52 (.57)	.47 (.42)	.46 (.31)	0.139	
30	1959	1959	Open-graded macadam friction course; 3/8 in. hornfels aggregate (Test 53).	.53 (.57)	.47 (.42)	.46 (.31)	0.140	
31	1958	1958	Asphalt roughened with 1/2 in. coated chippings at 200 sq. yd./ ton (Test 102).	.60 (.57)	.50 (.28)	.46 (.10)		
32	1959	1959	Open-graded macadam friction course; 3/8 in. quartzite aggregate (Test 53).	.51 (.57)	.47 (.42)	.45 (.31)	0.139	
33	1957	1958	Asphalt with 50% limestone aggregate.	.65	.53	.44		
34	1956	1958	Asphalt with 1 in. coated chippings rolled in.	.60	.47	.44		
35	1958	1958	Asphalt roughened with 3/4 in. coated chippings at 180 sq. yd./ ton (Test 102).	.64 (.57)	.49 (.28)	.44 (.10)		
36	1959	1959	Acid etching of concrete finished with soft broom (Test 80).	(.62)	(.28)	.44 (.19)		
37	1959	1959	Acid etching of concrete finished with granite chippings (Test 96).	(.63)	(.28)	.44 (.14)		
38	1950	1954	Four year asphalt with granite aggregate.	.74	.59	.43		
39	1957	1957	Asphalt grooved by flails; 1/8 in. grooves one inch apart (Test 76).	.70 (.59)	.49 (.33)	.43 (.21)	0.148	0.165
40	1959	1959	Open-graded macadam friction course; 3/4 in. hornfels aggregate (Test 53).	.57 (.57)	.43 (.42)	.42 (.31)	0.139	
41	1955	1957	Asphalt with 55% limestone aggregate.	.80	.57	.40		
42	1959	1959	Dense tar surfacing.	.83	.55	.40		

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				20	50	80		
43	1958	1958	Marshall asphalt with limestone aggregate.	.69	.52	.39		0.115
44	1963	1963	Marshall asphalt.	.76	.52	.38		
45	1956	1958	Asphalt with ½ in. coated chippings rolled in.	.65	.44	.38		0.112
46	1955	1961	Five year old asphalt with 55% limestone aggregate.	.85	.55	.37		
47	1959	1959	Open-graded macadam friction course; ¾ in. hornfels aggregate (Test 53).	.61 (.57)	.42 (.42)	.35 (.31)	0.139	
48	1958	1958	Asphalt treated with tar and ⅛ in. pre-coated chippings.	.68	.43	.34		
49		1959	Asphalt with 1 in. chippings rolled in.	.70	.41	.34		
50	1959	1959	Acid etching of concrete finished with carborundum grains (Test 95).	(.61)	(.31)	.34 (.15)		
51	1958	1958	Asphalt treated with cutback bitumen and ⅛ in. pre-coated chippings (Test 101).	.69 (.63)	.45 (.30)	.33 (.12)		
52	1956	1959	Asphalt with granite aggregate (Tests 74 and 92).	.75	.49	.33		
53	1959	1959	Marshall asphalt with basalt aggregate (Tests 10, 12, 24, 30, 32, 40 and 47).	.57	.42	.31		
54	1957	1958	Marshall asphalt.	.62	.42	.30		
55	1961	1963	Marshall asphalt with gritstone aggregate.	.69	.45	.29	0.096	
56	1958	1958	Concrete finished with purpose-made wire comb (Test 3).	.63	.46	.28		
57	1956	1957	Reinforced concrete finished with broom (Test 98).	.74	.45	.28		0.09
58		1959	Concrete finished with broom.	.62	.37	.28		
59	1957	1958	Marshall asphalt with granite aggregate.	.63	.42	.27		
60	1946	1954	Eight year old belted concrete.	.56	.37	.27		
61	1957	1958	Concrete finished with broom.	.57	.36	.27		
62	1958	1958	Asphalt roughened by heating and brushing (Test 104).	.73 (.63)	.44 (.18)	.27 (.08)		
63		1959	Reinforced concrete finished with broom.	.73	.44	.26		
64	1955	1956	Asphalt (Test 9).	.65	.44	.26		
65	1956	1960	Four year old asphalt with 45% basalt aggregate.	.80	.44	.25		
66	1963	1963	Concrete finished with broom.	.81	.42	.25		
67	1957	1958	Marshall asphalt	.56	.33	.25		
68		1960	Concrete finished with broom (Test 1).	.74	.38	.25		

APPENDIX 3

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				20	50	80		
69	1955	1957	Concrete.	.61	.34	.25		
70	1959	1960	Concrete finished with broom.	.68	.37	.25		
71	1955	1956	Concrete finished with broom.	.60	.36	.24		
72	1960	1960	Four year old concrete grooved by flails; $\frac{1}{8}$ in. grooves one inch apart (Test 87).			.24 (.17)	0.096	0.10
73	1945	1963	Eighteen year old concrete (Tests 5 and 81).	.57	.33	.23		
74	1959	1960	Emulsion slurry sealing of asphalt six months after sealing (Tests 52 and 92).	.64	.31	.22		
75	1958	1960	Asphalt (Test 107).	.80	.41	.21		
76	1955	1956	Asphalt (Test 39).	.59	.33	.21	0.096	
77		1959	Concrete	.71	.38	.21		
78	1956	1958	Marshall asphalt	.71	.31	.19		
79	1958	1958	Concrete finished with bass broom (Test 28).	.61	.34	.19		
80	1958	1958	Concrete finished with soft broom (Test 36).	.62	.26	.19		
81	1963	1963	Eighteen year old concrete scored longitudinally (Test 73).	.66 (.57)	.35 (.33)	.18 (.23)		
82		1954	Concrete.	.48	.26	.18		
83	1955	1957	Asphalt.	.62	.35	.18		
84	1956	1958	Asphalt with 45% basalt aggregate.	.67	.42	.17		
85	1950	1954	Four year old belted concrete.	.52	.26	.17		
86	1959	1960	Asphalt with gravel aggregate.	.47	.25	.17		
87	1956	1960	Four year old concrete.			.17	0.088	0.10
88	1956	1958	Concrete finished with broom.	.65	.33	.16		
89	1960	1960	Marshall asphalt with granite aggregate (Tests 7, 8 and 11).	.58	.37	.16	0.089	
90	1948	1954	Six year old belted concrete.	.51	.30	.15		
91	1948	1962	Fourteen year old belted concrete.	.61	.29	.15		0.10
92	1959	1959	Emulsion slurry sealing of asphalt (Tests 52 and 74).	.72 (.75)	.28 (.49)	.15 (.33)		
93	1956	1960	Asphalt (Tests 4 and 17).	.73	.28	.15		
94	1956	1960	Concrete.	.73	.33	.15		
95	1958	1958	Concrete finished with carborundum grains (Test 50).	.61	.31	.15		

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				20	50	80		
96	1958		Concrete finished with granite chippings (Test 37).	.63	.28	.14		
97		1956	Asphalt.	.54	.27	.14		
98	1956	1957	Concrete treated with concealment stain (Test 57).	.40 (.74)	.18 (.45)	.14 (.28)		
99	1960	1960	Concrete roughened by thermal shock (Test 87).			.12 (.17)		0.10
100	1960	1960	Acid etching of four year old concrete (Test 87).			.12 (.17)		0.10
101	1957	1958	Asphalt with 35% gravel aggregate and density control (Test 51).	.63	.30	.12		
102	1958	1958	Asphalt with 45% gabbro aggregate (Tests 13, 14, 16, 21, 22, 23, 26, 31 and 35).	.57	.28	.10		
103	1960	1961	Marshall asphalt (Test 11).	.70	.23	.08		
104	1957	1958	Asphalt with 35% gravel aggregate and density control (Test 62).	.63	.18	.08		
105	1957	1957	Asphalt with 30% gravel (Test 2).	.34	.11	.06		
106	1959	1959	Asphalt with 45% basalt and density control.	.52	.17	.04		
107	1960	1960	Bituminous surfacing with epoxy-bitumen binder (Test 75).	.28 (.80)	.04 (.41)	.01 (.21)	0.075	

APPENDIX 4

M.P.B.W. SPECIFICATION FOR GROOVING ROLLED ASPHALT WEARING COURSES

The surface of the asphalt wearing course is to be grooved across the runway at right angles to the runway edges with grooves which follow across the runway in a continuous line without break. The machine for grooving is to be equal to the Traffic Mobile machine incorporating disc flails (Universal Highways Ltd.), the EDCO machine incorporating flail cutters (Errut Products Ltd.), or a sawing machine incorporating a minimum of twelve blades equal to Clipper Consawmatic (Clipper Manufacturing Co. Ltd.), or Concut (Concrete Sawing Equipment Ltd.). Sawing machines are to include supporting equipment such as water tankers and pressure sprays.

The machines are to be provided with flails or saw blades set to form grooves in the surface 1/8 inch wide by 1/8 inch deep at approximately 1 inch centres. After cutting, the surface is to be swept thoroughly and all loose material is to be removed.

APPENDIX 5

M.P.B.W. SPECIFICATION FOR SCORING EXISTING CONCRETE SURFACING

The runway is to be scored transversely by a single pass of a cutting drum incorporating not less than 50 circular segmented diamond saw blades per 12-inch width of drum. The drum is to be set at 1/8-inch setting on a multiwheel articulated frame with outrigger wheels, fixed to give a uniform depth of scoring over the entire surface of the runway, to ensure the removal of all laitance and the exposure of the aggregate, all as shown at the trial area and as shown on the plastic cast available in the Engineer's office. The machines to be used are to be equal to The Concut Bumpcutter (Concrete Sawing Equipment Ltd.) or the Christensen Concrete Planer (Christensen Longyear U.K.).

APPENDIX 6

M.P.B.W. SPECIFICATION FOR SURFACE DRESSING OF EXISTING BITUMINOUS SURFACING USING BITUMEN BINDER

[This specification is based on weather conditions in the United Kingdom. For use at overseas airfields, some amendments may be necessary, particularly in binder requirements]

Materials

Binder: The binder for spraying the surface to be dressed is to be cutback bitumen conforming with British standard BS 3690, Grade 50 secs. It is to have the following properties when tested in accordance with BS 3235:

Viscosity at 40° C (104° F), 50±10 secs
Solubility in carbon disulphide, 99.5 per cent by weight
Ash content, 0.5 max. per cent by weight

Distillation is to be determined in accordance with the appendix to BS 3690 and is to show –

Distillate to 225° C (437° F), 1 max.
360° C (680° F), 8-14 per cent by volume
Penetration of residue at 25° C, 100-300

Immediately prior to the application of the hot binder, a wetting agent at the rate of $1\frac{1}{2}$ per cent by weight is to be added and thoroughly mixed in accordance with the manufacturer's written instructions.

Bitumen for coating chippings: The binder for coating the chippings is to be petroleum bitumen conforming with BS 3690, Grade 200 pen.

Wetting agent: The wetting agent is to be stearine amine or other equal and approved substance.

Chippings: The chippings are to be 1/8 inch nominal single-sized from one of the following groups: Basalt, gabbro, granite, gritstone, hornfels, porphyry, or quartzite. They are to be of the grading and particle shape given in table I of BS 63.

Aggregate crushing value: A sample of chippings similar to those proposed for use, but of a size passing a 1/2-inch but retained on a 3/8-inch BS sieve, is to be tested in accordance with BS 812 to determine the aggregate crushing value. To be acceptable, this value is to be less than 16.

Coated chippings: The chippings to be coated are to be dried in an approved rock dryer and heated to a temperature of 240° to 280° F (116° to 138° C). They are then to be coated in an approved mixer with bitumen at a rate of $\frac{3}{4}$ to $1\frac{1}{2}$ per cent by weight at a temperature of 300° to 350° F (149° to 177° C).

Stripping test: The stripping test is to be carried out on the selected chippings in the following manner. After heating, a test sample is to be taken from the dryer, coated with bitumen at a temperature of 320° F (160° C) at the rate specified above, and thoroughly mixed. The sample is to be transferred to a screwcap glass jar of 1-quart capacity. The jar should not be more than one-half full; then, it is to be completely covered with distilled water. The screwcap is to be fitted tightly to the jar, which is then allowed to stand for 24 hours. The sample is then to be examined for stripping of the bitumen from the chippings. If stripping has occurred, the chippings are not to be used.

Plant

Heater and distributor for surface binder: The heated binder is to be applied by a mobile combined heater and distributor with pressure feed, all complying with BS 1707. When the test set out in appendix A to BS 1707 is carried out, the deviation of binder delivered on each 2-inch strip is not to be greater than 15 per cent from the mean for all the 2-inch units over the effective width. Furthermore, the mean of the amount of binder collected in any three adjacent trays within the effective width is not to differ from the average by more than 10 per cent. A certificate to this effect, not more than 1 month old from an independent laboratory, is to be submitted to the Specification Officer (S.O.) for each heater and distributor prior to its use.

Mechanical gritter: The heated and coated chippings are to be distributed by a mechanical gritter of approved type incorporating a mechanical feed for the chippings capable of ensuring that the selected rate of spread is rigidly maintained throughout the work.

Rollers: Not less than three multiwheeled smooth tread rubber-tire rollers, each loaded to at least 6 tons, are to be used in conjunction with each distributor. They may be either self-propelled or towed by smooth treaded rubber-tire tractors.

Workmanship

Restrictions during bad weather: Work is not to be carried out during periods of rain, snow, or sleet or on frozen surfaces or on those on which water is lying. When, in the opinion of the S.O., weather conditions make it necessary, suitable protection is to be afforded to the heated and coated chippings during delivery.

Existing pit covers, gully gratings, and airfield markings: Such items as existing pit covers, gully gratings, and airfield markings are to be protected by masking, and the surface dressing is to be finished neatly around them. When masking of the airfield markings is not indicated, they may be obliterated. Reinstatement by the contractor will not be required.

Preparation of the existing surfacing: Immediately before spraying the binder, the existing surfaces are to be cleaned thoroughly by mechanical brooms, supplemented by hand brooming if necessary. All vegetation, loose materials, dust, all debris, etc. are to be removed as indicated.

Trial areas: Trial areas are to be laid prior to the commencement of the works in order to determine the precise rates of spread required for the binder and chippings. The range from which the rate of spread of binder is to be selected is from 10 to 12 sq yd/gal. The first area is to be spread at the rate of 12 sq yd/gal working towards 10 sq yd/gal if the former rate does not cover the entire surface. The coated chippings are to be applied at a rate that ensures complete coverage of the binder after final sweeping.

Application of surface binder: The surface binder during application is to be maintained at a temperature between 300° and 320° F (149° and 160° C). At junctions with surfaces not to be dressed, clean lines are to be defined by masking with waterproof building paper, or other means. The binder is to be applied at the selected rate without variation in such a manner that a film of uniform thickness results. Particular care is to be taken to avoid dripping, spilling, and areas of excessive thickness. The rate is likely to be about 250 sq yd/ton of chippings.

Application of coated chippings: The temperature of the heated and coated chippings when applied to the sprayed surface binder is to be not less than 180° F (83° C). Before and during the rolling operation, any bald patches are to be repaired with fresh chippings.

Rolling: The coated chippings are to be rolled immediately after spreading and before loss of heat. Rolling is to consist of at least one complete coverage by each of the three rollers, following closely one behind the other.

Final sweeping and rolling: Within 3 days of the gritting operation, all loose chippings are to be swept from the surface with hand brooms, loaded into lorries, and removed as directed. The surface is then to be further rolled with at least three complete coverages of the area. The finished surface is to have all chippings firmly adhering thereto, is to be of uniform surface texture and colour throughout the work (entirely free from surface irregularities due to scabbing, scraping, dragging, droppings, excessive overlapping, or faulty lane or transverse junctions, or other defects), and is to be left clean and tidy to the satisfaction of the S.O. Under no circumstances are sweptup chippings to be reused.

Test certificates: Prior to the commencement of work, the contractor is to produce to the S.O. for approval the following test certificates:

(a) Manufacturer's certificate showing details of the surface binder;
(b) Manufacturer's certificate showing details of the wetting agent;
(c) Grading analysis of chippings and aggregate crushing strength;
(d) Details and results of stripping tests;
(e) Certificate for each combined heater and distributor to be used; and
(f) Details of trial areas, giving precise rates and spread agreed for both binder and chippings.

Records to be maintained: The contractor is to maintain the following records throughout the work:

(a) Temperatures, at half-hourly intervals, of binder and coated chippings; and
(b) Air temperatures, at hourly intervals.

APPENDIX 7

M.P.B.W. SPECIFICATION FOR SURFACE DRESSING OF EXISTING BITUMINOUS SURFACING USING TAR BINDER

[Clauses applicable to both bitumen and tar binders are not repeated]

Materials

Surface binder: The binder for spraying the surface to be dressed is to be road tar having properties which conform with table I of BS 76 when tested in accordance with the appendices in that standard. During the months of June, July, and August, the tar is to be Grade A50; for the remaining months, it is to be Grade A42. Immediately prior to the application of the hot binder, a wetting agent, at the rate of $1\frac{1}{2}$ per cent by weight, is to be added and thoroughly mixed in accordance with the manufacturer's written instructions.

Tar for coating chippings: The tar for coating the chippings is to be road tar Grade A34/B34.

Coated chippings: The chippings to be coated are to be dried in an approved rock dryer and heated to a temperature of 200° to 240° F (94° to 116° C). They are then to be coated in an approved mixer with road tar at a rate of 1 to 2 per cent by weight at a temperature of 200° to 240° F (94° to 116° C).

Stripping test: The stripping test is to be carried out on the selected chippings in the following manner. After heating, a test sample is to be taken from the dryer, coated with tar at a temperature of 220° F (105° C) at the rate specified above, and thoroughly mixed. The rest of the procedures is the same as that for bitumen-coated chippings.

Workmanship

Trial areas: The trial areas are to be laid prior to the commencement of the works in order to determine the precise rates of spread required for the binder and chippings. The range from which the rate of spread of binder is to be selected is from 12 to 14 sq yd/gal. The first area is to be spread at the rate of 14 sq yd/gal working towards 12 sq yd/gal if the former rate does not cover the entire surface. The coated chippings are to be applied at the rate of approximately 250 sq yd/ton, the rate finally selected being that which ensures complete coverage of the binder after final sweeping.

Application of surface binder: The surface binder during application is to be maintained at a temperature between 220° and 275° F (105° and 135° C). The application for the tar binder is then the same as for the bitumen binder.

APPENDIX 7

Application of coated chippings: The temperature of the heated and coated chippings when applied to the sprayed surface binder is to be not less than 160^{o} F (72^{o} C). Before and during the rolling operation, any bald patches are to be repaired with fresh chippings.

APPENDIX 8

M.P.B.W. SPECIFICATION FOR OPEN-GRADED MACADAM FRICTION COURSE

[This mixture is for runways only (excluding runway ends). It allows the free penetration of surface water to the underlying layer, which must be a densely graded impervious wearing course of high stability. It should be of uniform compacted thickness throughout and is not suitable over deformed or poorly shaped surfaces]

Aggregate: Crushed rock from one of the following groups: Basalt, gabbro, granite, hornfels, or porphyry.

Crushing value: Less than 16 per cent (BS 812).
Flakiness index: Less than 25 per cent (BS 812).
Stripping: Immersion test.

Binder: Petroleum bitumen, Grade 200 pen.

Filler: Portland cement or limestone but at least $1\frac{1}{2}$ per cent by weight of total mixed material is to be hydrated lime.

Aggregate grading: The aggregate grading (including filler) are –

BS sieve	Percentage by weight passing
1/2 in.	100
3/8 in.	90-100
1/4 in.	40-55
1/8 in.	22-28
No. 200	3-5

Binder content: Percentage by weight of total mixed material, 4.75 to 5.25.

Mixing temperatures:

Aggregate:	175° to 250° F (80° to 122° C)
Binder:	200° to 275° F (94° to 135° C)

Rolling temperature: Not less than 160° F (72° C).

Roller: As necessary to compact to refusal.

Compacted thickness: 3/4 inch.

Tack coat: Bitumen emulsion at 15 to 20 sq yd/gal.

Surface accuracy: 1/8 inch in 10 feet (in any direction).

APPENDIX 9

M.P.B.W. SPECIFICATION FOR TEXTURING NEW CONCRETE

The concrete surfacing of the runway, except for 300 feet at each end, is to be textured by drawing a purpose-made wire broom across the pavement at right angles to the side forms whilst the concrete is soft enough to take an impression. The broom head is to be 24 inches minimum width, wire filled with 32 gauge by 1/20 inch wire tape.

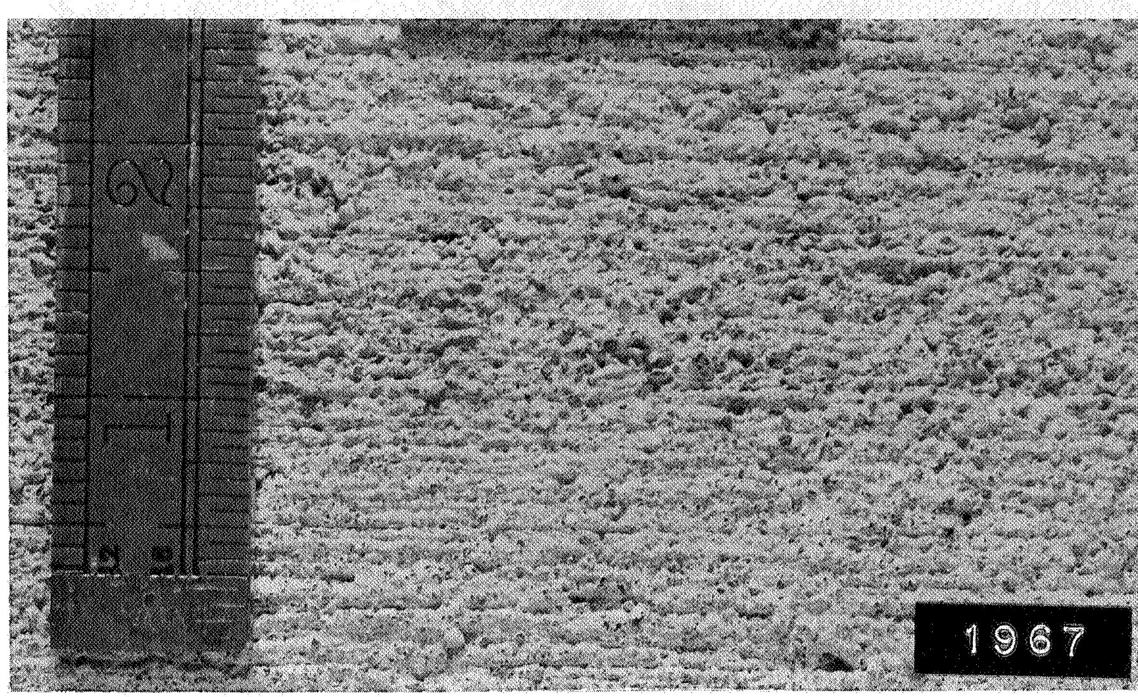

Figure 1.- Lightly broomed concrete.

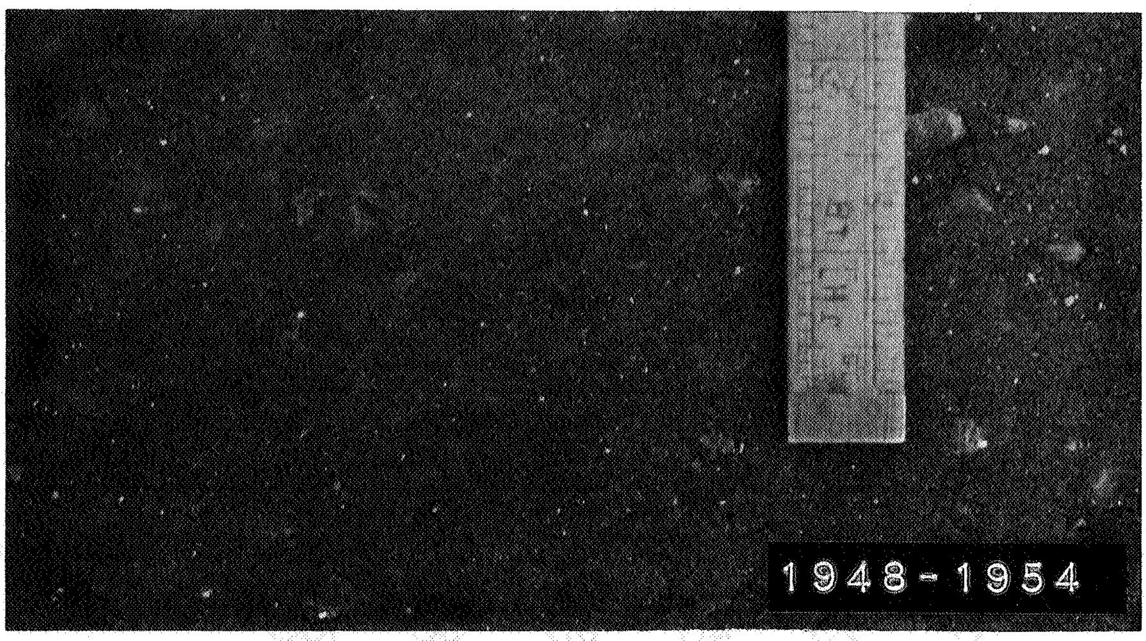

Figure 2.- Hot rolled asphalt.

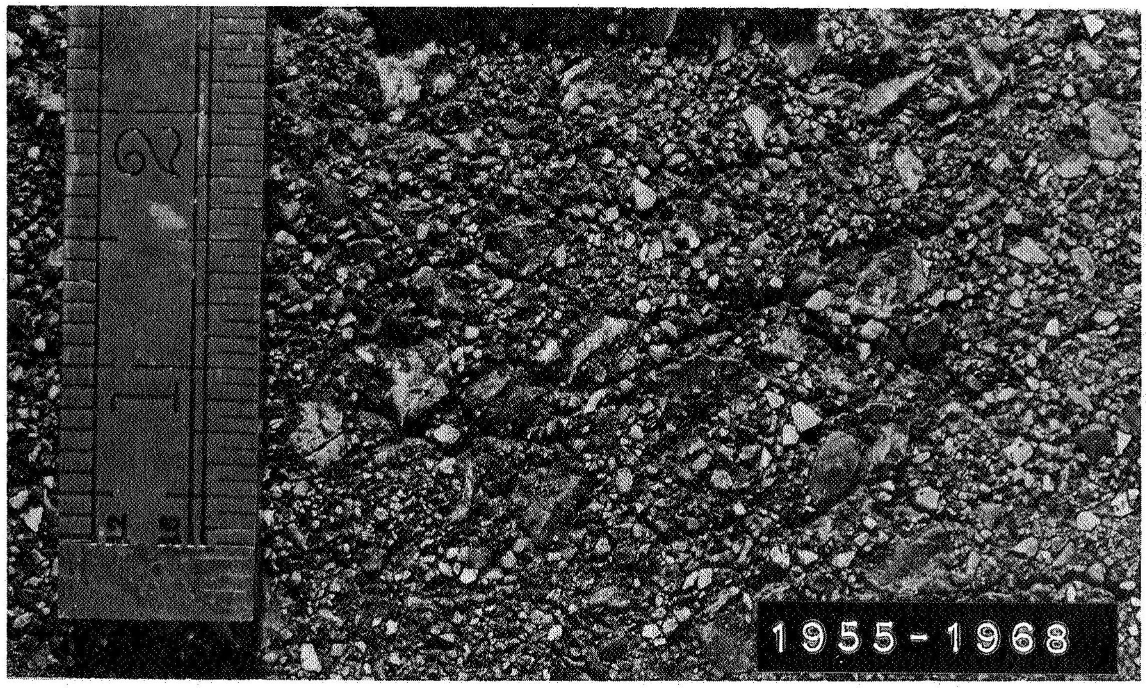

Figure 3.- Marshall asphalt.

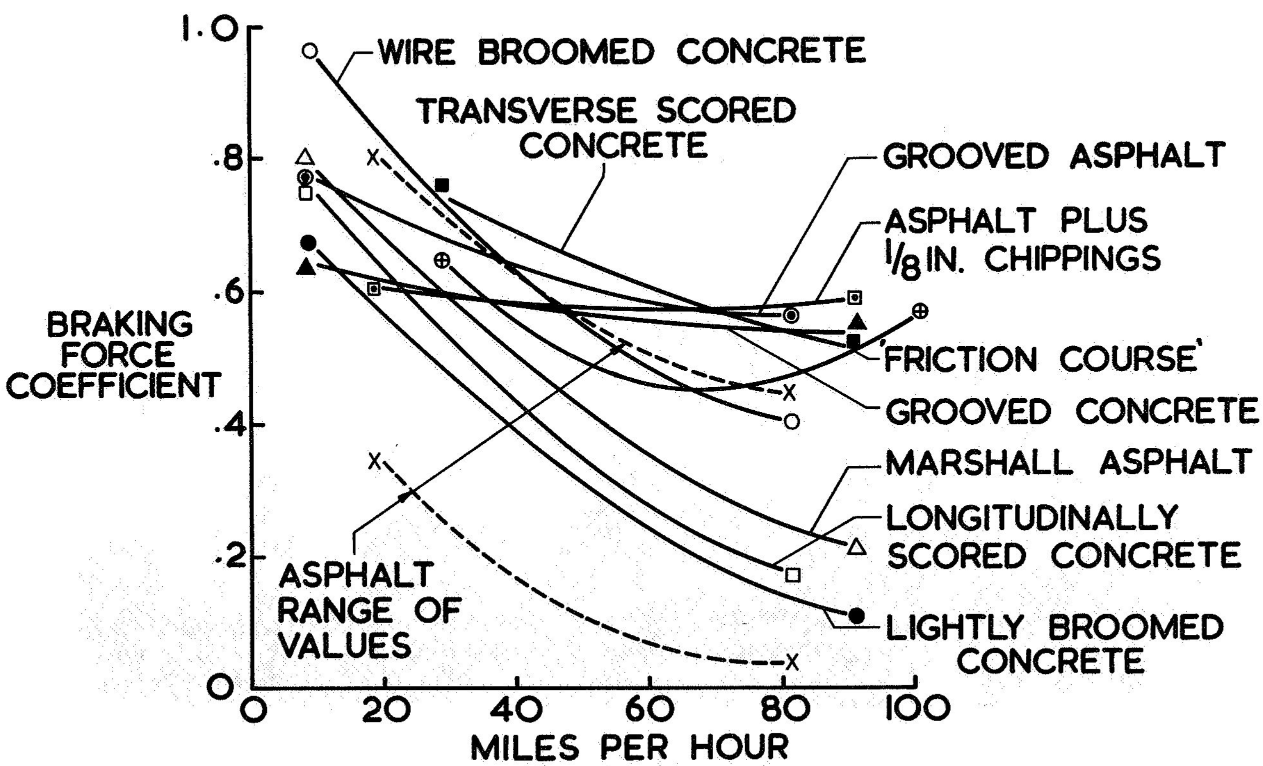

Figure 4.- Braking force coefficients as measured by the British Road Research Laboratory light trailer on wet surfaces.

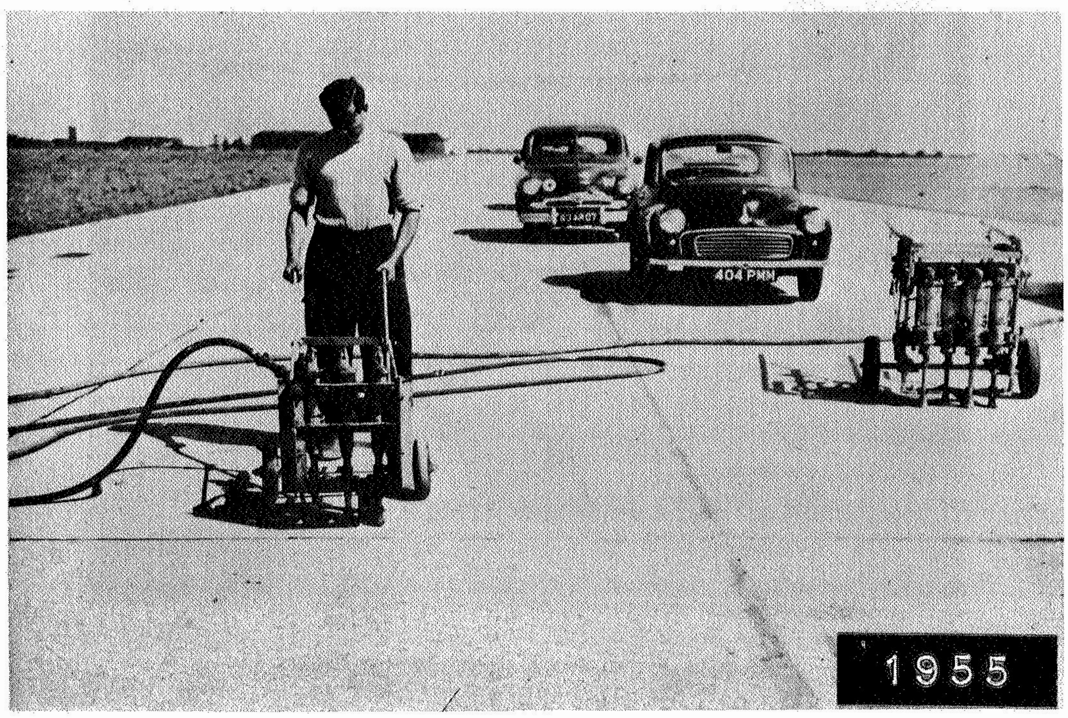

Figure 5.- High-speed percussion rotary hammers to texture concrete or asphalt.

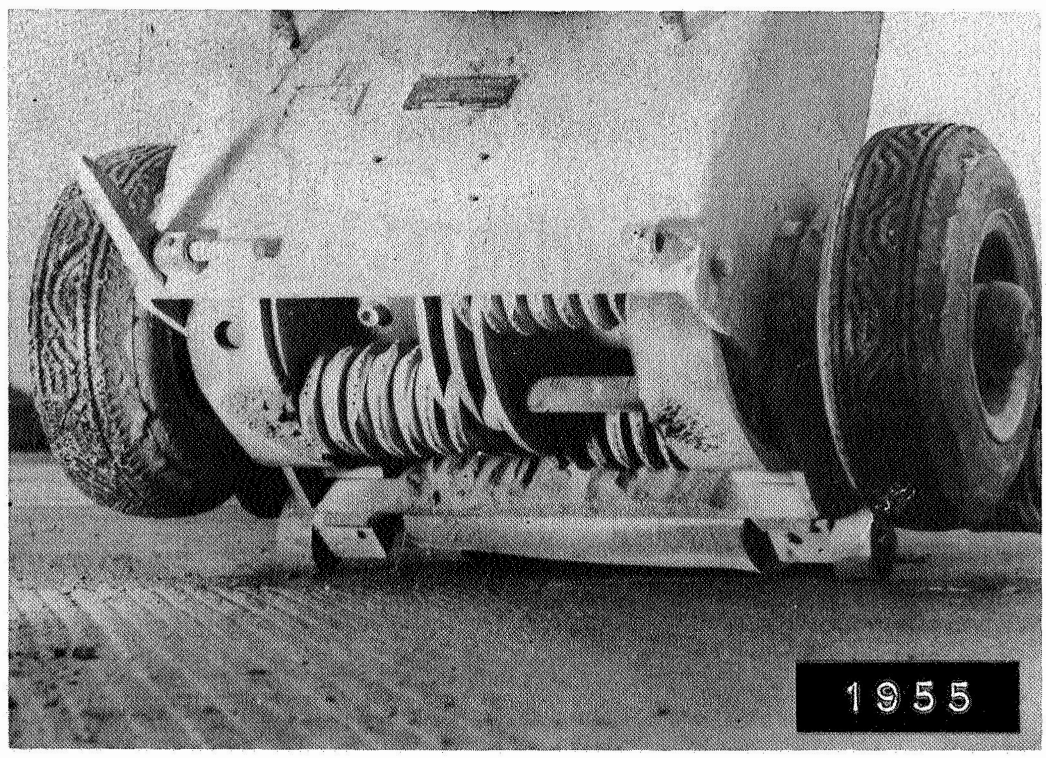

Figure 6.- Disc flails to groove concrete or asphalt surfaces.

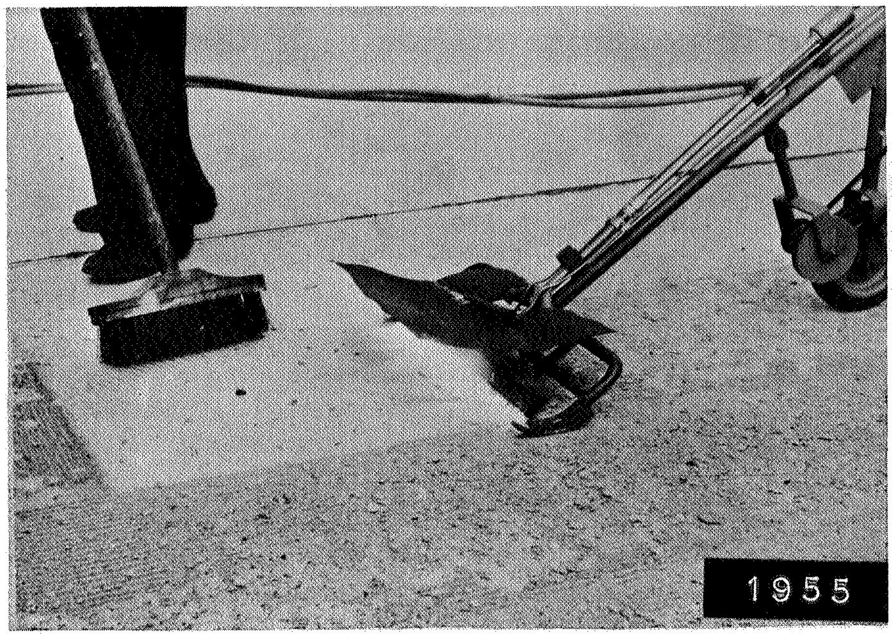

Figure 7.- Thermal shock to roughen concrete surfaces.

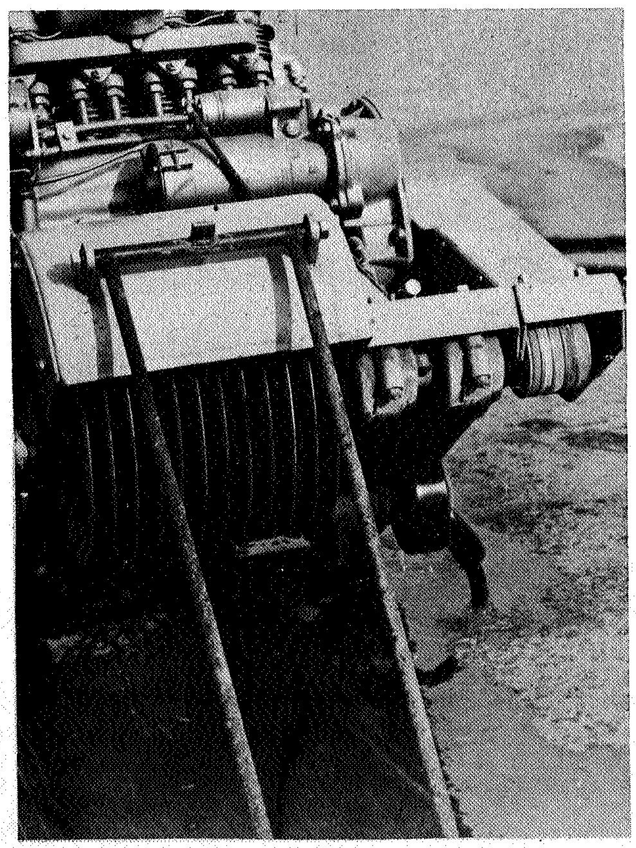

Figure 8.- Grooving saws for concrete or asphalt.

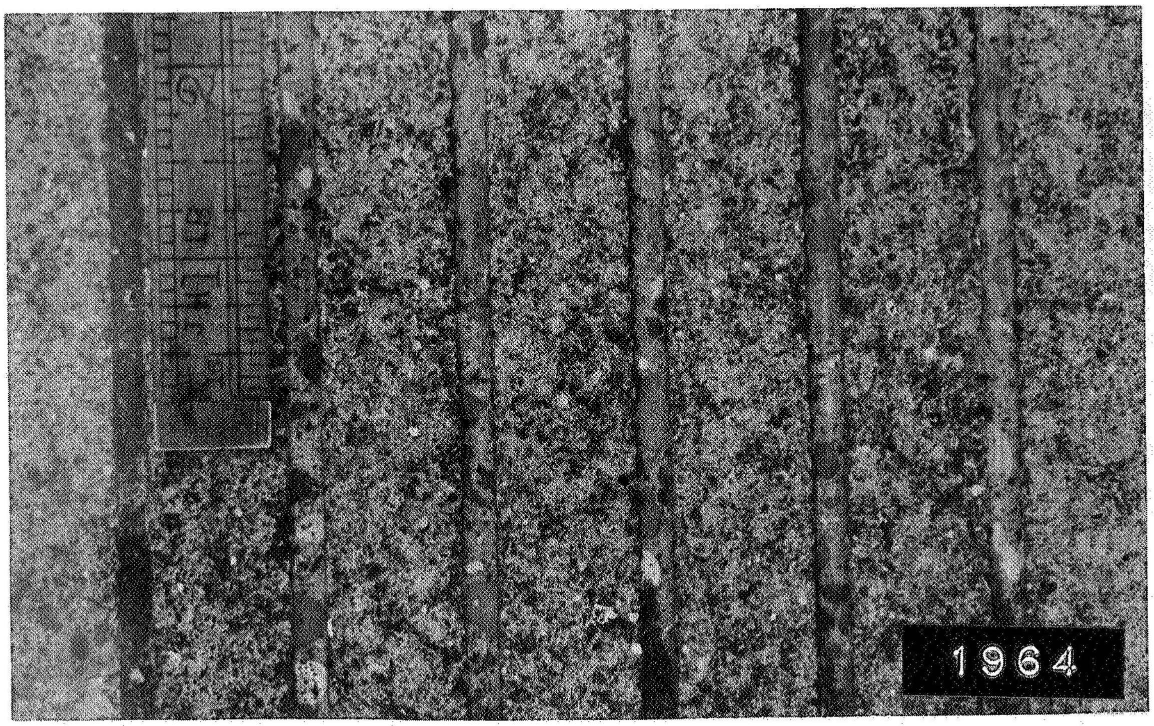

Figure 9.- Grooved concrete.

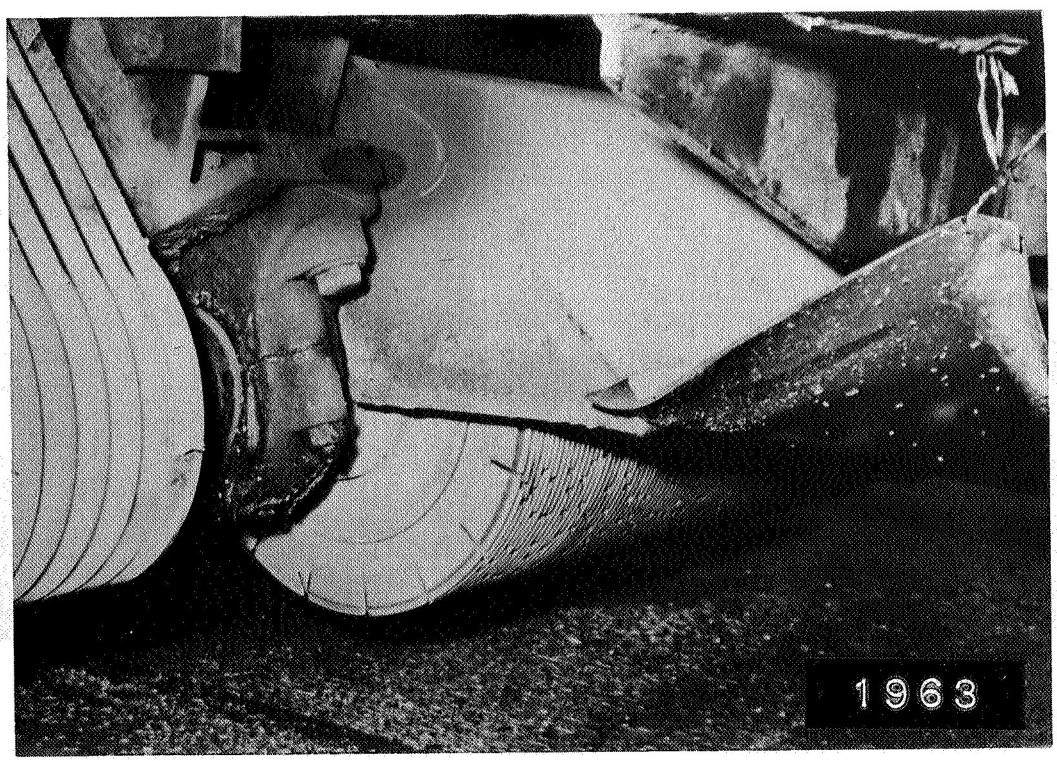

Figure 10.- Diamond cutting drums to score concrete.

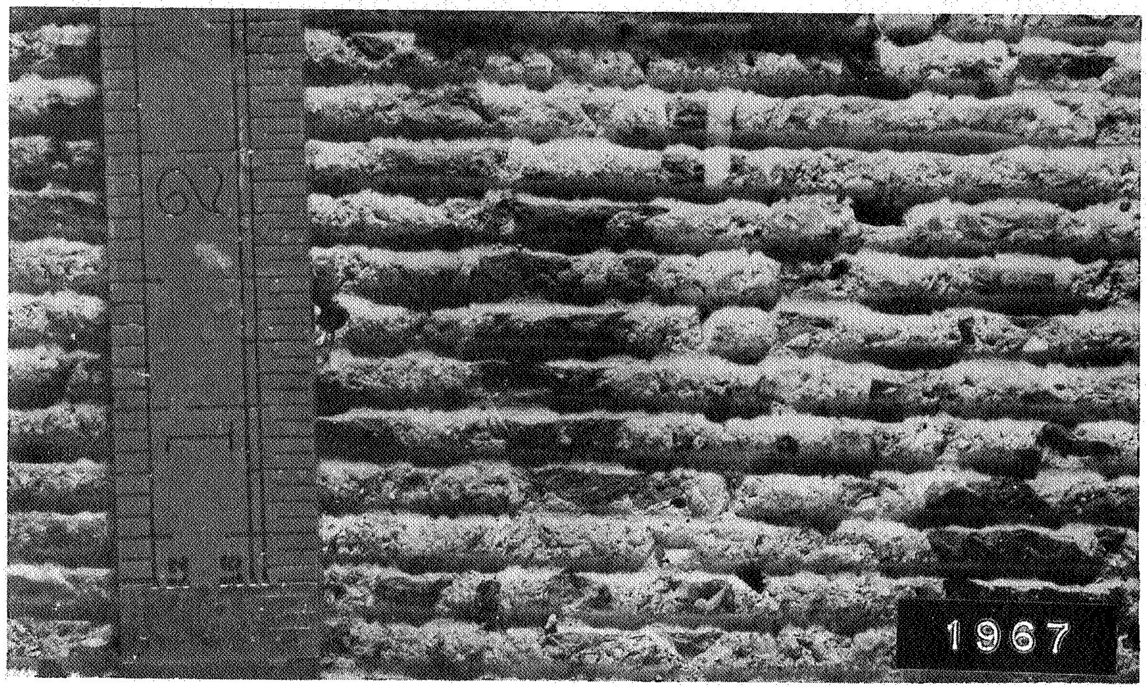

Figure 11.- Scored concrete.

Figure 12.- Surface dressing of existing asphalt.

Figure 13.- "Friction course" surfacing of asphalt.

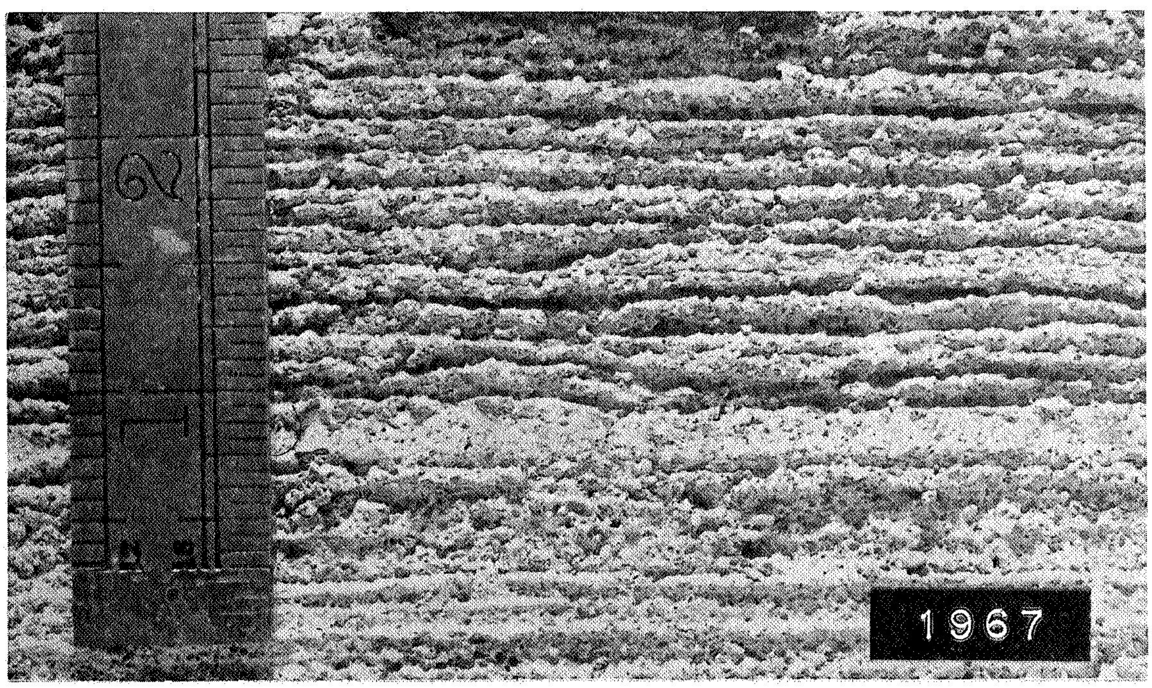

Figure 14.- Wire combed concrete.

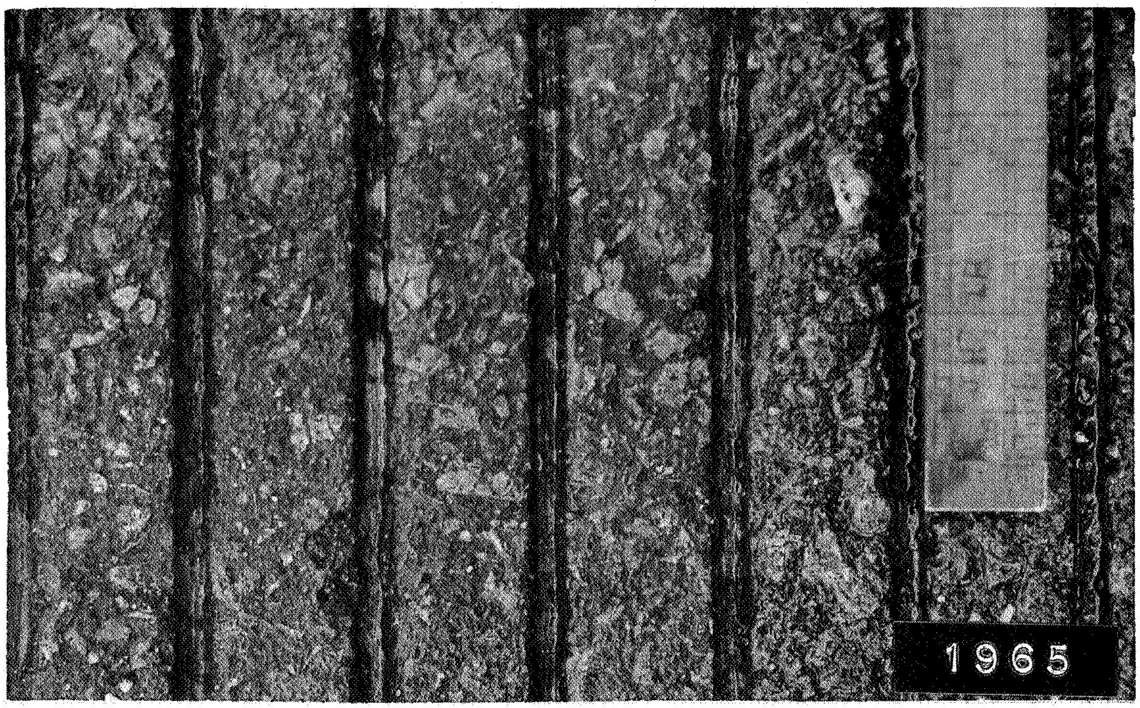

Figure 15.- Grooved asphalt.