THE CIVIL AVIATION AUTHORITY RECOMMENDATIONS FOR THE USE OF PAVERS ON AIRCRAFT PAVEMENTS

J. Knapton
University of Newcastle, Newcastle upon Tyne, UK

Summary

This Paper describes the UK Civil Aviation Authority (CAA) recommendations for the use of pavers on aircraft pavements and shows how the Federal Aviation Administration (FAA) flexible pavement design method had been modified such that it can be used to design pavements surfaced with pavers. It includes the modified design chart for aircraft with dual tandem undercarriage arrangements. Conclusions are drawn regarding the categories of aircraft pavements where pavers are recommended. It explains why pavers are excluded from runway and other high speed/high thrust surfacing applications. The Author undertook the CAA investigation and prepared the recommendations which are set out in this Paper.

Introduction

CAA is a licensing, advisory and regulatory body which seeks to ensure the safety of civil aviation in the UK. Its recommendations are adopted in many parts of the world and in the field of pavers, it has adopted a leading role following the first worldwide usage of pavers in the UK The CAA became involved in the surfacing of aircraft pavements in 1993 following several minor incidents and one major incident when pavers were displaced from a runway turning circle by the effects of jet engines operating under significant thrust. The Author was commissioned to prepare guidelines to ensure that all future airside applications of pavers would be safe. This CAA commission has led to a Report[1] which is available from CAA to interested parties. This Paper deals with the major issues in the CAA Report. These are pavement structural design, categories of pavement where pavers should be permitted, material specification, geotechnical assessment, pavement overlaying and detailing.

Civil Aviation Authority Recommendations

The Report sets out the CAA recommendations for the use of pavers on aircraft pavements are as follows:

Recommendation 1

Pavers may be used to surface the following categories of aircraft pavements:

i) Aircraft stands.
ii) Low speed taxiways not subject to significant jet blast or propeller wash.
iii) Aircraft maintenance areas not subjected to significant jet blast or propeller wash.

Pavers should not be used on the following categories of aircraft pavements:

i) Runways.
ii) Areas where aircraft engines are run at high thrust values.
iii) High speed taxiways.

Recommendation 2

All proposed pavements to be surfaced with pavers should be rigorously structurally designed using an appropriate method. Where pavers are to be used to surface an existing pavement, a structural evaluation of that pavement should be undertaken. Recommendation 2 needs to be followed to ensure that the support offered to the pavers by the structure and the foundation of the pavement is sufficient to eliminate the possibility of interlock being lost and to ensure that the pavement retains its structural integrity.

Recommendation 3

In relation to paver and laying course materials, the recommendations presently used for pavers in non-aircraf applications (British Standards Institution(1988) *Precast Concrete Paving Blocks. Part 1 Specification for Paving Blocks. Part 3 Code of Practice for Laying.* BS6717:1988, BSI, London) can be applied with the following amendments:

i) Only those pavers which when laid develop a joint of width of less than 4mm should be used. Normally, this wil confine the choice of pavers to rectangular units.

ii) Methods of mechanical installation whereby a "cluster" of pavers is placed onto a sand bed should be avoided Experience indicates that the cluster perimeter joint may be too wide.

iii) The laying course should comprise a Category 1 or a Category 2 material as described in the County Surveyors Society *Pavement Design Manual* ENG/6-94. Category 2 material will be sufficient in all cases except those where the topographical design of the pavement could induce a 1m or more height pressure head in the laying course in which case a Category 1 material is required. Essentially, these two sand categories limit the choice of sand to naturally occurring materials: Category 1 sand must have less than 0.3% passing a 75μ sieve and Category 2 sand must have less than 1% passing the same sieve.

iv) In all cases, the paver joints should be formed in such a way as to minimise the erosion of the jointing materia by jet blast or propeller wash. Frequently, this will involve the use of a proprietary joint stabilising material introduced into the jointing sand.

v) Pavers should be laid to a herringbone pattern. The orientation of the pattern need not be conditioned by the direction of principal trafficking. There should be no discontinuity within the laying pattern and in phased construction pavers laid at different times should always be fully interlocking across construction phase boundaries.

Recommendation 4

Areas of pavers should be inspected regularly. The frequency of inspection should take into account the volume and character of traffic. Those areas subject to regular movements of heavy aircraft using engines at more than half thrust should be inspected on a monthly basis. Areas subject to zero or minor levels of thrust should be inspected at frequencies up to 6 months. Each inspection should include an examination of the paver joints and any evidence of joint erosion should be recorded. Also, the surface of the pavers should be tapped with a steel bar or similar implement to determine whether the pavers are seated intimately on the laying course material. Any defects should be rectified immediately Erosion treatment will comprise the removal of jointing material and the refilling and stabilising of the joints.

Recommendation 5

A record should be maintained of each area of pavers. The record should include the construction drawings and the design assumptions and calculations. Each inspection should be recorded and the details of any remedial work should be kept.

Recommendation 6

Careful attention should be paid to detailing of the pavement.

Maintenance of Aircraft Pavements

The CAA Guide includes the following information on pavement maintenance. The comments made by owners o aerodromes where pavers have been in service for several years indicate that on correctly designed, specified and constructed paver pavements, maintenance has been minimal. The principal concern lies in those projects where paver

have been laid on runways or on areas subjected to loading similar to that experienced by runways. For example, the experience on the Luton Eastern Turning Circle shows that paver pavements in such areas can fail in a dramatic way with little advance warning. Because of the experience at Luton, it is recommended that pavers should not be installed on runways or on areas where engines are run at high thrusts but in cases where pavers already have been installed on runways, engine test bays or on similar high speed areas they should be subjected to an inspection regime as follows.

It is recommended that pavers should be inspected regularly. A typical suggested regime for pavers installed on runways and similar high speed areas would include regular inspections at intervals of between one week and one month according to the level of loading. During those inspections, attention should be focused on bedding sand erosion and tapping the surface to detect separation of pavers from bedding sand. Because each $1m^2$ of paving contains approximately 14m length of joint, examining all of the area exhaustively would be impractical. It is recommended that at least five representative locations be chosen and an exhaustive examination of $1m^2$ be undertaken at each location. The degree of joint erosion should be assessed by probing the joint with a calibrated gauge. Where 5mm or more erosion is measured, remedial work should be undertaken on the eroded area. This will involve lifting the pavers, rescreeding the bedding material and relaying either new pavers or those recovered. The joints should be refilled and stabilised.

The frequency of inspection of other paver areas should depend upon several factors. Areas subjected to jet blast or propeller wash should be inspected more frequently than areas subjected to rolling aircraft. Areas trafficked by heavy aircraft should be inspected more frequently than those trafficked by light aircraft. Areas including lighting or other features where pavers have been cut to obstructions should be inspected particularly thoroughly.

There should be no reason to question the slipperiness of pavers. After initial installation, pavers maintain a level of skidding resistance which cycles through high and low values on an annual basis. It is recommended that pavers should be dealt with in exactly the same way as bituminous surfacing materials.

The results of each inspection should be recorded even when no adverse comments are made. A standard recording system should be introduced and the following items should be incorporated in the recording system:

i) Date, time, location, inspector
ii) Number of $1m^2$ areas inspected
iii) Representative erosion depth
iv) Any paver spalling, cracking or surface defect
v) Surface irregularity including steps between pavers
vi) Ponding or evidence of recent standing water
vii) Pavement surface draining fully

Detailing of Aircraft Pavements

Experience in the construction and use of pavements surfaced with pavers both in aircraft pavements and in other types of pavements indicates that the following areas require particularly careful consideration:

Drainage, falls and laying tolerances

The falls which are normally recommended in highways applications are often too steep to permit the efficient operation of aircraft and maximum falls of 1 in 100 are commonly specified in aircraft pavements. In such flat pavements, high quality installation is required to avoid ponding. This can usually be achieved only by precompacting the bedding sand and by ensuring that the pavers and installation conform in all respects with BS6717:1988:Part 1 *"Precast Concrete Paving Blocks. Part 1 Specification for Paving Blocks. Part 3 Code of Practice for Laying"*.

Edge Restraint

Edge restraint is a crucial component of the stability of pavers. In many aircraft applications, standard highway practice will be insufficient and edge restraint will need to be designed from first principles taking into account the horizontal forces transmitted by aircraft wheels and the internal forces generated by thermal expansion of the pavers where they have been installed in large contiguous areas. For example, buckling took place on a 50,000m^2 area during warm weather as a result of the edge restraint rotating on an overlay project where the edge restraint had been fixed to the underlying course by adhesive and not by dowel bars. Particular care in this respect needs to be taken for pavers laid in cold conditions. It may be that expansion joints can be incorporated to reduce internal forces but care must be taken to avoid losing restraint.

Edge Detailing

Poor workmanship in forming edging not only looks unattractive but can lead to pavement failure. In general, BS6717:1988:Part 3 *"Precast Concrete Paving Blocks. Part 3 Code of Practice for Laying"* should be followed. Where special edge units are available, consideration should be given to their use and where cutting cannot be avoided, units should be sawn and not split. A higher quality edge can often be achieved by installing an end to end stretcher course around the perimeter of the project so that cut blocks adjoin other blocks rather than other material.

Drainage of bedding sand

Several failures in highway pavements have occurred as a result of the bedding sand losing stability in wet conditions. As a result, there has been a move towards creating positive drainage in the bedding sand and in some cases, failure has occurred because of migrating water transporting the finer fractions of the bedding sand. Positive sand drainage should be provided only where there would otherwise be the opportunity for a significant pressure head to develop within the bedding sand. This will depend upon the difference in levels between areas of paving. In cases where levels across a paved area vary by more than one metre, consideration should be given to specifying bedding sand drainage. This is true even when joint stabilising materials are used since they do not normally fully prevent the ingress of water.

Intermediate restraint

The construction of restraint within an area is sometimes necessary in phased construction and has been used to avoid the build up of internal forces generated by thermal expansion. It is not considered to represent good practice unless there is a compelling reason for its provision. It can generate significantly increased costs, particularly in relation to paver cutting and can lead to differential settlement and ponding. Its benefit in reducing internally generated forces has never been demonstrated and there have been cases where the weakening of the pavement at the intermediate restraint has resulted in relatively high levels of maintenance.

Joint tightness

A fundamental feature of pavers is their simplicity of laying whereby a paver is placed "hand tight" against its neighbours. Where attempts have been made to lay pavers tighter than usual, spalling and surface buckling has occurred. Where pavers have been laid deliberately loose, the surface has remained loose and failed to develop interlock. Experience indicates that rectangular pavers take up the "hand tight" spacing more reliably than do pavers of dentated shaped: indeed, all of the commercially available pavers in the UK include spacers or nibs to help to regulate the joint width and to thereby prevent spalling and ensure that interlock is developed. In larger projects, care should be taken to ensure that pavers manufactured at similar mould wear rates are laid together: there can be a significant growth in paver plan dimensions during the wearing of a mould so much so that trying to integrate the two extremes is virtually impossible.

Regulating courses in overlay work

It is frequently the case that new surface levels will not follow the profile of the original surface and a make up course will be needed. Whilst some variation can to achieved by deliberately adjusting laying course thickness, the minimum thickness should be 20mm and the maximum should be 50mm. Even then, precompaction should be carried out and an initial layer of constant thickness should be pre-compacted followed by the tapering layer. In cases where a greater make

up is required, Dense Bitumen Macadam has been found to be suitable. Often, the material can be laid directly over the existing surface but it may be necessary to treat the surface. For example, cracks and joints in the pavement below should first be sealed and a bituminous tack coat may be required to ensure waterproofing and to assist in adhesion. Unless a significant proportion of the regulating course is of constant thickness, it should not be considered to contribute to the strength of the pavement.

Paver types

Rectangular pavers of nominal plan dimensions 100mm x 200mm and of thickness 80mm and incorporating a chamfer around their upper perimeter have been found to be suitable. In some applications, dentated units have been preferred usually in conjunction with mechanical laying systems to increase the rate of working. The great majority of pavers used in the UK comprise rectangular units and unless there are compelling reasons to the contrary, rectangular units are suggested. The pavers should comply with BS6717:1988:Part 1 *"Precast Concrete Paving Blocks. Part 1 Specification for Paving Blocks"*.

Structural Design Method

The Federal Aviation Administration(FAA) flexible pavement design method[2] has been modified to allow aircraft pavements surfaced with pavers to be designed. The modifications comprise firstly the substitution of pavers for bituminous material as the surfacing and secondly the transformation of the FAA design charts from imperial units to SI units. The design charts in FAA Advisory Circular 150/5320-6C[(2)] have been modified to accommodate concrete pavers. The pavement design method allows the thickness of the pavement courses to be proportioned and assumes that the pavement will be surfaced with 80mm rectangular concrete pavers bedded on 30mm sand. Figures 1 shows the modified FAA design chart in the case of dual tandem wheel gear.

The pavement design charts can be used as shown in the following example to determine the total pavement thickness required including pavers. Figure 2 allows the minimum required thickness of cement bound base material to be determined for a given total pavement thicknesses and CBR value. The use of the design charts requires:

-CBR value for the subgrade material
-gross weight of the aircraft
-total number of annual departures of the design aircraft

The design charts are used as follows. First, select one of the charts such as the one shown as Figure 1 according to the aircraft gear configuration. Determine the pavement thickness by projecting a line down from the upper horizontal axis to the appropriate gross aircraft weight curve. From there, project a line horizontally to the appropriate annual departures line, then project a line down to the lower horizontal axis and read the total thickness of the pavement in millimeters.

The base thickness is determined using the base chart (Figure 2). The thickness is determined by starting with the overall pavement thickness (just obtained) and projecting a line horizontally to meet the appropriate subgrade CBR curve. From this point, project a line vertically down and read the base thickness.

Modified FAA Method Design Example

As an example of the use of the design curves, assume a paver pavement is to be designed for the mix of aircraft shown in Table 1. The subgrade was found to be a cohesive material which gave a CBR value of 7% and the sub-base to be used is Type 2 granular sub-base material. First, the design aircraft has to be determined. This is the one requiring the thickest pavement for the appropriate number of departures of the aircraft. Using Figure 1, the overall pavement thicknesses shown in Table 2 are obtained.

Aircraft	Gear Type	Annual Departures	Maximum Takeoff weight (kg)
737-200	Dual Wheel	6000	52,390
747-100	Double Dual Tandem	3000	272,155
L-1011-100	Dual Tandem	1200	211,374
DC-10-30	Dual Tandem	1200	267,619
Airbus A-320-100	Dual Tandem	3000	142,000

Table 1 Assumed mix of aircraft

Aircraft	Overall pavement thickness (mm)
737-200	650
747-100	810
L-1011-100	915
DC-10-30	940
Airbus A-320-100	840

Table 2 Pavement Thicknesses Required

The DC-10-30 requires the greatest pavement thickness and is therefore the design aircraft. This aircraft has dual tandem wheel landing gear, so all traffic must be grouped into the dual tandem wheel configuration. The equivalent number of annual departures is calculated as in Table 3.

Aircraft	Equivalent Dual Tandem Gear Departures	Maximum Wheel load (kg)	Maximum design aircraft wheel load (kg)	Equivalent Annual Departures Design Aircraft
737-200	3,600	12,440	16,160	1,319
747-100	3,000	16,160 ⅄	16,160	3,000
L-1011-100	1,200	16,160 ⅄	16,160	1,200
DC-10-30	1,200	16,160 ⅄	16,160	1,200
Airbus A-320-100	3,000	16,862 ⅄	16,160	4,231
				10,949

Table 3 Equivalent Annual Departures

⅄ *Wheel loads for wide body aircraft will be taken as the wheel load for a 136,100 kg aircraft for equivalent annual departure calculations.*

Therefore, the pavement would be designed for 11,000 annual departures of a dual tandem gear DC-10-30 aircraft weighing 267,619 kg. The DC-10 aircraft has a special Design Chart similar to the one shown in Figure 1 and the resulting base thickness from that chart is 350mm. Figure 2, which applies to all aircraft types, is then used to determine the thickness of the base. The following pavement section can be concluded (all of the values refer to course thicknesses):

Pavers	80mm
Laying Course	30mm
Cement Bound Material 3	350mm
Type 2 Granular Material	470mm
	930mm

Conclusion

It is concluded that the CAA aircraft paver pavement design guide can be used in the design and detailing of aircraft pavements and that the resulting pavements will remain safe and serviceable. Pavers should be used on a limited range of pavement categories (although, on a cumulative area basis the permissible categories represent approximately 80% of all aircraft pavements). The guide limits the type of pavers and bedding sand which should be specified and provides detailing guidance which is specifically orientated towards the special requirements of aircraft pavements. Special guidance is provided in the common case of existing concrete pavements being overlain. Advice is provided on pavement maintenance both in the case of pavements designed according to the guide and in the case of pavements which were constructed prior to the publication of the guide and which might not now be permitted to be surfaced with pavers.

References

1 Knapton J(1996) *"The Use of Pavers in Aircraft Pavements"* CAA Report No. 960XX. Civil Aviation Authority, London.

2 Federal Aviation Administration(1978). *"Airport Pavement Design and Evaluation"* FAA Advisory Circular AC 150/5320-6C. Department of Transportation, FAA, Washington, D.C.