REHABILITATION OF AGED CONCRETE AIRCRAFT PAVEMENTS BY OVERLAYING WITH PRECAST INTERLOCKING CONCRETE BLOCKS

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SUMMARY

This paper presents the concept of precast interlocking concrete blocks as a rehabilitative overlay on aged concrete pavements and draws on some experiences gained with a small trial section constructed at Melbourne International Airport in 1992 for reflection crack alleviation. The Melbourne Airport trial is seen as an innovative use of concrete blocks on aircraft pavements and highlighted some unforeseen problem areas associated with block cracking, bedding sand support and underlying slab joint movement. However, the treatment is considered tol have failed in preventing reflection cracking.
The paper goes on to explore the possible structural advantages of concrete blocks as an overlay on aged concrete pavements in terms of stress reduction and the consequent increase in allowable load repetitions.
Analysis of pavement models to assess the structural benefits of the concrete block overlay was carried out using the Portland Cement Association computer program for design of rigid aircraft pavements and the elastic layer program CIRCLY.
The analysis indicated that there could be significant benefits in the structural capacity of the pavement (or extended life) to be realised from overlaying aged concrete pavements with precast interlocking concrete blocks.
These benefits are enhanced by other advantages of the concrete block overlay in respect of the potential for shape correction, elimination of cracking and spalling and the opportunity for reduced closure times of aircraft movement areas for maintenance.
Some perceived deficiencies in bedding sand quality and the apparent requirement to stabilise slabs against vertical movement are also discussed.
The work presented in this paper is only an introduction but it has identified the potential for the use of precast interlocking concrete blocks to upgrade aged concrete aircraft pavements, and a number of issues emanating from the field trial and subsequent considerations requiring further investigation have been highlighted.

Acknowledgment

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1. INTRODUCTION

The rehabilitation of aged concrete aircraft pavements is generally perceived as not an easy task due to the need to either demolish existing badly cracked slabs and reconstruct them, or provide a rigid pavement overlay with it's attendant problems. Both of these more conventional methods of rehabilitation pose serious operational difficulties at busy airports because of the duration of closure of the pavement required for construction and consequently neither method has been used to a significant extent at Australian Airports.
This paper offers an alternative rehabilitation approach for rigid pavement which have distressed to the point of being excessively cracked, or spalled, and involves the use of precast interlocking concrete blocks as an overlay.
Interlocking concrete blocks were first used in Australia on aircraft pavements at Cairns International Airport (1) where the new international apron pavements were surfaced with the blocks.
The success of this construction and the high degree of serviceability afforded to both airport owner and aircraft operator encouraged further consideration of their use.

arly in 1992, as part of mostly asphalt overlay trials at Melbourne Airport to evaluate reflection crack leviation treatments, interlocking concrete blocks were used as one of the overlay treatments on an geing concrete taxiway. The general success of this trial to date has stimulated the thought of possible rther use of interlocking concrete blocks as rehabilitative overlays on a larger scale on aged concrete rcraft apron and taxiway pavements generally.

f necessity, this paper draws on information and experience that is limited to the very few applications interlocking concrete blocks on heavy aircraft pavements in Australia and the design methodology r structural purposes postulated in the paper has not yet been tested or evaluated in the field.

HISTORICAL USE OF CONCRETE BLOCKS ON AIRCRAFT PAVEMENTS

1 *Use on Overseas Airports*

ıe first use of concrete blocks on aircraft pavements occurred at Luton Airport in the UK (6) where the ocks were used only as an overlay, first on old asphalt surfaced aprons and later over aged concrete ı the runway ends, in the latter instance replacing a distressing asphalt overlay.

ıese were the only known concrete block overlays on aircraft pavements that had been carried out ior to the Melbourne Airport trials.

ther concrete block surfaced aircraft pavements have been constructed in Norway (Sola Airport), ermany (Dusseldorf Airport), USA (Dallas Fort Worth Airport) and it is understood that a new apron r B747 aircraft is currently under construction at Kuala Lumpur in Malaysia. However, these usages e all in new pavement construction.

2 *Australian Experience*

terlocking concrete blocks were first used in Australia on new heavy commercial jet aircraft apron avements at Cairns International Airport (1) in 1990.

ore recently, it has been reported that aircraft aprons at the Naval Air Station (Albatross) at Nowra SW, were reconstructed in concrete block surfaced flexible pavement during 1992.

ıe Federal Airports Corporation (FAC), Melbourne Airport engaged AIRPLAN in 1991 to investigate flection crack alleviation treatments for their ageing concrete pavements and in 1992 an interlocking oncrete block overlay trial was included with various asphalt overlay trials on part of the parallel orthsouth taxiway.

REVIEW OF MELBOURNE AIRPORT TRIAL

1 *Purpose*

ıe interlocking concrete block trial at Melbourne Airport was one of a number of experimental overlay ections constructed for the FAC to evaluate treatments to alleviate reflection cracking in possible future sphalt maintenance overlays. The other overlay sections were all constructed of asphalt incorporating ress relieving materials.

ıe concrete block section was perceived as providing inherent resistance to crack reflection due to ıe segmental nature of the layer with its capacity to accommodate minute movements in the multiple ints, together with the stress absorbing function of the unbound granular bedding sand layer.

2 *Construction*

ıe construction of the interlocking concrete block overlay trial involved the laying of a small pproximately 500 square metre) section on the north-south taxiway (Taxiway A), over the full width 2.6m) of the pavement surrounded by an edge restraint of 14mm size asphalt. This edge restraint onstituted an overlay to the taxiway shoulder pavement at the sides of the block section and formed ıe adjacent asphalt trial sections at either end.

ıe concrete blocks used were Type A (indented shape) 80mm thick, laid in standard herringbone attern. The existing concrete pavement beneath the block section was initially covered with a light eight geofabric to prevent loss of bedding sand through the joints and cracks in the underlying oncrete slabs since only some joints were presealed.

Jointing sand was a natural material complying with the Concrete Masonry Association of Australia's recommended grading and it was sealed into the joints using cutback bitumen on one side of the trail and dilute PVA glue on the other.
The construction of the trial was carried out easily within a one day working period except for two sides of the asphalt edge restraint which were constructed on the previous day.
Generally, the construction techniques adopted were those successfully developed and used in the construction of the international apron at Cairns International Airport, with some modifications as follows:

- bedding sand thickness was reduced to a nominal 15 mm compacted thickness;
- natural sand was used for jointing and a sealer was applied to the surface of the blocks as previously mentioned;
- small galvanized iron pipes were installed in the edge restraint to drain off accumulated water from the bedding sand.

3.3 Performance

The trial areas are being monitored by AIRPLAN for the FAC and to date the concrete block overlay has performed well.
However, minor distress has occurred where full blocks in the wheel tracks span underlying transverse slab joints. These blocks developed transverse hair cracks due to the passage of aircraft wheel loads. No significant structural or functional problems occurred as a result of the cracking but most of the cracked blocks were replaced with half blocks in September 1992 to avoid serious spalling problems. This cracking was unexpected and was noticed very soon after opening the trial area to traffic. Following some investigation of the reasons for the cracking it has become clear that the vertical differential movement of the slabs at joints and cracks is probably the primary cause. The thin bedding sand layer thickness is also believed to be a contributing factor but a second trial will be required to confirm this

3.4 Slab Joint Movement

Prior to the construction of the trials the existing concrete pavement was tested with the Falling Weight Deflectometer (120 kN dynamic load) to determine the presence of any vertical movement at joints and the degree of load transfer being achieved. Vertical movements of the order of 0.15 to 0.2 mm were recorded but these were not considered to be significant. The load transfer expressed in terms of the efficiency of the joints under the test load varied between 89 and 100%.
During subsequent monitoring of the numbers of cracked blocks occurring at each joint it has recently been noticed that there are more cracked blocks where joint movement is greatest, (Refer Table 3.1) particularly the differential movement.

3.5 Bedding Sand, Thickness and Quality

At Luton Airport the bedding sand layer under the concrete block overlay on the old concrete pavement of the turning areas was reported (6) to be approximately 50 mm thick. No cracking of the blocks in these pavements has been reported.
In the Melbourne Airport trial, the bedding sand was fine and was observed not to drain freely and the thickness was only approximately 15 mm. This thickness was chosen due to concern that compaction under load would occur in the bedding sand and it was considered in this application the potential for such compaction should be minimized.
On the basis of observations to date it is now suggested that there may be good reason to require the bedding sand layer to act as a cushioning medium to some extent where there is differential joint (vertical) movement to ensure adequate support to the blocks under load.
A similar concern exists in regard to the grading of the bedding sand. It has been previously shown Hudson, et al (3) that the bedding sand course is required to be a high quality material with the percentage passing the 75 um sieve restricted to 4 - 6%. Beaty (4) suggests general limits of 2 - 8% passing this sieve size while Cook, et al (5) suggests a maximum of 1% for aircraft and similar pavements.
In view of the above it is suggested that the upper limit of 10% on the 75 um sieve specified for the bedding sand course in the block overlay trial section may be excessive and that a maximum limit of

r 2% passing the 75 um sieve is required where the performance demands of the bedding sand are reme.

ADVANTAGES OF INTERLOCKING CONCRETE BLOCKS AS AN OVERLAY

erlocking concrete blocks used as an overlay on aged and/or concrete pavements offer a number advantages, but the most significant of these was seen to be the potential for the block overlay to minate reflection cracking problems from joints and cracks.
wever, in the light of the early performance of the block trial at Melbourne Airport, it appears that the atment has failed in this respect and that some attention to slab support may be required before erlaying (eg mud jacking, grouting), or a thicker bedding sand layer used.
e perceived advantages of block overlays are as follows:

- possible prevention of reflection cracking;
- elimination of joints/cracks and the attendant maintenance sealing requirements;
- retention of the fuel resistant and abrasion resistant qualities of the concrete surface type;
- reduction in long term maintenance costs;
- increase in structural strength of the pavement;
- provision of the opportunity to shape correct and improve the riding quality of the concrete pavement caused by faulted joints, etc.

Elimination of Joints, Cracks and Reflection Cracking

e interlocking concrete block overlay provides a multi-jointed (preshrunk) concrete layer in which it unlikely for concentrated horizontal stresses due to warping and differential temperature effects to velop. Both the block layer and the bedding sand provide stress release due to the unbound nature the latter and the opportunity for infinitely small movements at the joints in the blocks in the case of former.
e normal requirement for maintenance of joints and cracks by periodic cleaning out of the old filler terial and resealing is eliminated. Cracks and spalls likewise do not present the same maintenance mands which are both difficult to carry out and tend generally to have a limited life.

Fuel Resistance

their nature interlocking concrete blocks are unaffected by fuel and oil spills as is conventional ncrete pavement. The additional advantage with the concrete blocks is the absence of sealed joint ere joint sealers may be affected by fuel spills causing a nuisance on apron areas, although, generally t sealers used in Australia are resistant to jet fuel.
way of example in this regard, the concrete block surfacing on the international apron at Cairns rnational Airport suffered a very large fuel spill (approximately 7000 l) within a few months of opening raffic. Now, over a year since that occurrence, no detrimental effects to the block pavement are parent as a consequence of this fuel spillage.

Reduction in Maintenance Costs

potential distress modes in concrete block pavements are;

- edge/corner spalling due to excessive rotation;
- cracking due to loss of base course support;
- erosion of jointing sand due to weathering and jet blast;
- surface abrasion of blocks due to traffic.

ncrete blocks as an overlay on concrete pavements are unlikely to suffer from excessive rotation or of support due to the rigid concrete base, provided that the bedding sand layer is thin, and the ace abrasion of concrete surfaces on aircraft pavement is very low due to the absence of debris and ign material on the surface.
maintenance of concrete block pavements requires the breaking out of the damaged blocks in the ressed area and replacement with new blocks. Cost savings may be realised due to:

- only replacing the extent of the damaged area;
- the replacement procedure being carried out by hand using simple tools and techniques;

the ability to restrict the repair area to suit the available closure period of the pavement due to aircraft operational requirements.

4.4 Structural Strength Improvement

The concrete block overlay effectively distances the applied wheel loads approximately 100mm above the existing concrete pavement surface.
If it is assumed that the surface pressures applied by the aircraft wheels (tyre pressure) are spread through the concrete block layer and bedding sand, the pressure at 100mm depth (ie at the top of the existing concrete) will be reduced resulting in some structural benefit to the pavement. This aspect is further discussed in the next section of the paper.
However, for concrete aircraft pavements in Australia where structural distress is generally not a wide spread problem as yet, this benefit is seen more as a bonus than a primary design consideration at this stage.

4.5 Shape Correction

Where the concrete pavement slabs may have cracked and the joints may have worked, and/or slabs may have faulted or where subsidence has occurred, the pavement may require shape correction prior to overlaying with interlocking concrete blocks.
This situation occurs sometimes but in many cases the loss of shape is corrected using an asphalt overlay or replacement of the distressed concrete slabs. The use of concrete blocks is seen as an alternative and the solutions presented here are somewhat speculative at present. Shape correction with fine mix asphalt (5mm and 7mm sizes) is considered to be not necessarily adequate due to the normally low stability of such mixes. The use of larger mixes would inhibit tapering the correction layer at the edges and is not seen as generally applicable.
Thicker layers of bedding sand are not favoured due to potential compaction in this layer. However, the use of crushed sand as bedding material may hold some possibilities for shape correction in layers up to 75mm thick.

5. STRUCTURAL CONSIDERATIONS

5.1 General

In all the applications of interlocking concrete blocks as surfacings to aircraft pavements in Australia, no structural value greater than that of unbound crushed rock has been assigned to them.
On the Cairns International Airport international apron the block layer replaced a 50mm thickness of asphalt.
At Melbourne Airport the overlay trials were intended as a resurfacing for non-structural purposes (ie reflection crack alleviation).
In this discussion, the condition of the overlaid existing concrete pavement is not given any consideration and the strength of the slabs and load transfer capacity of the joints are assumed to be not degraded by previous usage.
While these aspects are considered to be important and relevant in any full scale investigation of the structural behaviour of a concrete pavement overlaid with interlocking concrete blocks, a discussion of these points is beyond the scope of this introductory paper.
Two approaches to the assessment of the structural contribution of an interlocking concrete block overlay to the load carrying capacity of a concrete pavement are discussed below.

5.2 Simplistic Approach

To the authors knowledge the actual load distribution (pressure) through an interlocking concrete block overlay on either rigid or flexible bases has not been investigated, except that some work has been carried out in Australia (7) to measure in-situ moduli values in block surfaced flexible pavements. In this simplistic approach a conservative position is taken and it is assumed that the block overlay behaves as an unbound granular layer.

his case the formula for pressure distribution through a granular layer below a circular loaded area veloped by Boussinesq (Equation 1) has been used to determine the pressure transmitted to the face of the concrete slabs from the applied wheel loads on the surface of the block layer.

Stress at depth $z = q\,(1[1/1+\{R/z\}^2]^{3/2})$

ere: z = depth at which tensile stress is calculated
q = contact (tyre) pressure
R = radius of circular contact area

uation 1: Boussinesq Formula for Distribution of Pressure in a Granular Layer Under a Circular Loaded Area

e aircraft wheels applied at the surface of the block overlay are assumed to distribute their load via tyre contact pressure through the blocks and bedding sand by intergranular pressure, thus eading the load over a slightly greater area. The thickness of the blocks and sand layer is taken as 0mm nominal and no interference between adjacent wheels at a depth of 100mm is considered to cur.

e concrete slab is then analysed to determine the flexural stress at the lower face in accordance with nventional procedures using the reduced pressure/increased contact area at the surface of the slab. his instance the Portland Cement Association (PCA) computer program (2) was used to calculate concrete flexural stress under the applied aircraft loads (modified as described above). In using this cedure the assumptions normally applicable to the PCA method (eg full load transfer at all joints) ve been adopted, which may not in fact be true for an aged concrete pavement.

ng this simplistic approach described above, the PCA procedure has been used to calculate the ural stress in a plain unreinforced, jointed concrete slab of 400 mm thickness under a B747-400 craft loaded at 3000 kN, 3500 kN and 4000 kN all-up-mass.

e calculations have been carried out for the slab with and without the interlocking concrete block erlay for comparison of stresses and the results are listed in Table 5.1.

Elastic Layer Theory Approach

as been suggested, that an interlocking concrete block layer in a conventional block pavement ucture may be assigned on elastic modulus (E) of up to 7,000 MPa (7).

e advantages of this significantly greater strength in the block layer (if realised) over that assumed the simplistic approach (i.e. approximately 500 MPa) previously discussed are evident in the greater der) spreading of the individual wheel loads and pressures. Thus this attribute was investigated using elastic layer program CIRCLY to calculate the flexural stress in the concrete slab both with and nout a concrete block overlay. In this instance elastic moduli values of 1000 MPa and 5000 MPa for block layer were adopted.

e results of these calculations are listed in Table 5.2.

nodelling the pavement to perform these calculations, the blocks and bedding sand are assumed be one layer and the subbase course and subgrade under the concrete slab are treated also as the homogeneous, semiinfinite layer.

Comparison of Stresses in Concrete Slab With and Without Block Overlay

ed on the simple calculations of the maximum horizontal tensile stress in the concrete using the PCA nputer program, (see Table 5.1) the interlocking concrete block overlay facilitates an approximate reduction in the tensile stress. By consideration of the conventional relationship between stress ratio allowable repetitions of load an increase in allowable repetitions of approximately 16% is obtained his 1% reduction in stress.

le the assumptions regarding the pressure distribution through the block layer are considered to be ewhat conservative, the apparent benefit due to the increase in allowable repetitions is seen as ificant.

en the concrete pavement with and without the concrete block overlay is analysed using the nputer program CIRCLY, the maximum horizontal tensile stress in the concrete in the latter case is wn to also be reduced (See Table 5.2). In this instance, the reduction in the tensile stress is rmined to be in the range 3.3 to 6.6% depending on the applied load.

a concrete strength of 4.5 MPa, the corresponding stress ratios and allowable repetitions were ulated (See Table 5.2).

This analysis indicates that the concrete pavement with the concrete block overlay could accommodate 70% to 200% more repetitions than the concrete without the overlay for a range of block moduli from 1000 MPa to 5000 MPa.
While the actual value of elastic moduli realistically assignable to the concrete blocks is not known with confidence even a relatively low value of 1000 MPa appears to have a significant effect on the tensile stress and thus the allowable repetitions (See Table 5.2).

6. OPERATIONAL ADVANTAGES

It is considered appropriate to state at this point that interlocking concrete blocks applied as a surfacing course in an overlay (or otherwise) are not suitable for runway pavements or high speed taxiways (eg rapid exit taxiways), or runway turning nodes due to the potential (however small) for the blocks to dislodge under traffic and cause damage to aircraft.
The discussion in this section is directed towards the use of interlocking concrete blocks on apron and low speed taxiway pavements.
Badly distressed concrete slabs on heavy aircraft aprons and taxiways have occurred from time to time at Australian Airports and the slabs are usually removed and replaced with new slabs. Sometimes, asphalt overlays are constructed to prevent loose material from spalls becoming a hazard to jet engines, but reflection cracking and fuel and temperature sensitivity of such pavement surfaces in apron locations can present some significant disadvantages where heavy traffic is prevalent. Instability of asphalt in hot weather and associated rutting is now also becoming a problem.
The use of interlocking concrete blocks to overlay distressed concrete pavement areas has the advantage of reducing the time that the pavement area is closed to traffic when compared to that required for slab replacement.
While the construction of the Melbourne International Airport trial section cannot be used with any certainly to estimate the duration of the construction task, some broad estimations are perhaps possible. Delivery of materials, laying and screeding of bedding sand, placing of blocks and jointing was all completed in one day shift, including some delays due to placing of edge restraints, and the area of block overlay constructed was approximately 500m² - equivalent to 9 No. 7.5m x 7.5m concrete slabs. The pavement area was then available for use by aircraft almost immediately.
The removal of this number of slabs and replacement in flexural strength concrete including curing, even if high early strength cement is used, is estimated to run into many weeks before the pavement could be opened to traffic again.
Even if the rate of laying of interlocking concrete blocks was halved and the construction time was doubled due to the ancillary works with edge restraints and ramps, the time required for installing a block overlay in still a fraction of that for replacement of the slabs in new concrete.

7. FUTURE CONSIDERATIONS

Based on the experience gained with the Melbourne International Airport trial section and the preliminary investigative work of the authors reported in this paper, the following aspects in the use of interlocking concrete blocks as overlays on aged concrete aircraft pavements should be further considered:
- the use of crushed bedding sands;
- the optimum thickness of the bedding sand layer for various base materials and conditions;
- assessment of the structural support from the existing pavement;
- appropriate design methodology for determination of the structural capacity of overlaid pavement;
- appropriate block moduli;
- full scale field evaluation of interlocking concrete block overlays.

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ABLE 3.1 - MONITORING OF CRACKED BLOCKS

Location	Vertical Joint Movement (microns)	Differential Movement (microns)	Number of Cracked Blocks		
			30/7/92	4/12/92	14/9/93
Centre of Slab (no joint)	0	0	1	1	2
Joint 19	150 - 210	1 - 9	21	27	30
Joint 20	130 - 180	1 - 6	18	19	23
Joint 21	150 - 220	10 - 39	18	22	31
Centre of Slab (no joint)	0	0	1	1	1

ABLE 5.1 - MAXIMUM TENSILE STRESS AND REPETITIONS FOR B747-400 AIRCRAFT

Aircraft All-up-mass (kN)	Contact Pressure, psi (kPa)	Contact Area, in² (mm²)	Maximum Stress, psi (MPa)	Stress Ratio	Allowable Total Repetitions
3000					
vithout overlay	184.78 (1238)	216.86 (139909)	292.3 (1.958)	0.450	UNLIMITED
vith overlay	170.25 (1141)	235.03 (151632)	288.5 (1.933)	0.444	UNLIMITED
3500					
vithout overlay	184.78 (1238)	253.00 (163225)	333.6 (2.235)	0.513	366,300
vith overlay	172.78 (1158)	270.18 (174309)	329.9 (2.210)	0.508	428,400
4000					
vithout overlay	184.78 (1238)	289.14 (186542)	373.9 (2.505)	0.575	64,800
vith overlay	174.66 (1170)	305.46 (197071)	370.3 (2.481)	0.570	75,400

otes:

ncrete Thickness = 16" (400mm)
ck/Sand Overlay = 4" (100mm)
dulus of Subgrade Reaction = 200 psi/in (53kPa/mm)
ncrete Modulus = 4000000 psi (26,800MPa)

TABLE 5.2 - RESULTS FROM CIRCLY ANALYSIS FOR 400MM CONCRETE PAVEMENT WITH AND WITHOUT INTERLOCKING CONCRETE BLOCK OVERLAY.

Aircraft All-up-mass = 4000 kN	Thickness (mm) h1	h2	Maximum Tensile Stress (MPa)	Stress Ratio (1)	Allowable Total Repetitions
without overlay	400	-	2.687	0.597	35,000
-E Blocks = 1000 MPa with overlay	100	400	2.598	0.577	60,000
-E Blocks = 5000 MPa with overlay	100	400	2.510	0.558	110,000

Notes:

1. Concrete Flexural Strength = 4.5 MPa
2. Subgrade/subbase is assumed to be semi-infinite and behaving anisotropically with E = 100MPa and u = 0.45.
3. Concrete properties assumed : E = 27,600MPa, u = 0.25, isotropic behaviour.
4. Block properties assumed : E = 1000MPa or 5000MPa, u = 0.20, anisotropic behaviour.

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