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Shear stresses in an asphalt surface under various aircraft braking conditions

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Abstract

Aircraft braking forces have increased in the past and will continue to increase in the future. This has resulted in instances of shear related distress in asphalt runway surfaces. The shear stresses transferred from braking tyres to the pavement surface can initiate failures of poorly bonded interfaces. Shear creep deformation within the mix can also occur. Octahedral shear stress (OSS) has been recommended as an indicator of asphalt distress. OSS is unaffected by the geometry of loading and reference coordinate system. In this research, the peak surface forces in three dimensions were calculated. Stresses through the surface layer were then calculated using mePADS/GAMES software. The calculated stresses in the surface layer were compared under various braking conditions. The OSS was used as the primary basis for these comparisons.

The maximum calculated OSS induced by a heavy braking truck was only 53% of that for the aircraft during only moderate braking. Contrary to expectation, the peak shear stress under the leading edge of the tyre did not increase significantly with increased aircraft braking effort. Analysis of the shear stress distributions, however, identified a significant change with increased braking effort. For non-braking aircraft, a zone of near-zero shear stress was found under the central portion of the tyre. As the horizontal surface force increased, this became a zone of near-constant shear stress. Observed differences in field performance of nominally identical asphalt in landing/braking zones of an airport were not explained by the peak OSS values calculated. It was, however, concluded that the near-steady shear state under a passing tyre during aircraft braking could explain different asphalt responses in the field. This conclusion was consistent with the observed nature of such failures, which are creep related, rather than the result of conventional slip circle shear. It was suggested that the presence of shear related failures only in the braking area would be indicative of shear creep deformation within the mix rather than delamination at the surface interface.

Keywords: Octahedral shear stress; GAMES; mePADS; Runway surface; Asphalt shear; Shear creep

1. Introduction

Asphalt is a common surfacing for airport pavements around the world. Most airport asphalt mixtures are designed using Marshall's methods and the principles developed by the US Army Corps of Engineers in the 1950s [1]. Since that time, rheological properties and performance of bitumen binders used in asphalt production have changed [2–4]. Aircraft have become more demanding, with higher wheel loads operating on increased tyre pressures [5–6]. This trend to higher aircraft tyre pressures is not expected to abate in the near future. At the same time, the pressure to minimise runway occupancy times during landing operations has led to increased use of rapid exit taxiways [7]. As a result, aircraft braking forces have increased and will continue to increase in the future.

The increase in braking forces during aircraft landing operations has resulted in an increase in shear related

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distress. This includes groove closure and what has been described as horizontal cyclic shear deformation [8–9]. The failures result from cumulative shear creep in the upper 100 mm of pavement where shear stresses are high [10]. Delamination or de-bonding of asphalt surfaces from the underlying pavement has also been reported more frequently, despite improvements in tack coat materials and interface construction techniques [11]. The shear stresses transferred from braking tyres to the pavement surface and through the surface layer can initiate such failures at poorly bonded interfaces.

A number of investigations into the impact of increased tyre pressures have been driven by aircraft manufacturers. A Boeing funded study performed by the FAA concluded that full scale test results were insensitive to tyre pressure because the dominant failure mode was asphalt rutting [5]. It went further to state that the pavements would be unaffected by increased tyre pressure as long as the asphalt remained stable. The failures described as asphalt rutting were likely to be slip circle shear failures. The practical ability to manufacture stable asphalt mixes under these increased tyre pressures was not considered. Despite the study conclusions, it actually demonstrated how higher tyre pressures are pushing the limits of the current airport asphalt specifications. It was not surprising that an increase in tyre pressure affected the asphalt surface but had no significant impact on the lower layers and the subgrade.

Current pavement design methods calculate pavement life based on subgrade rutting and bound material fatigue. Progress made in modelling pavement structures provides the ability to incorporate other failure modes into analysis tools and to more accurately model the tyre-pavement interaction. Such advances, however, remain in the domain of researchers and are currently beyond inclusion in practical design tools [12]. Therefore, shear related asphalt failures will not be identified during pavement design, as this failure mode is not considered in current design methods.

As part of a broader investigation into horizontal shear creep deformation of new asphalt surfaces at a major airport in Australia, it was observed that the failures occurred in one runway but not the other. The two runways were surfaced in the same year with two different asphalt mixtures. It was also observed that for the affected runway, failures occurred in the landing/braking zone of one landing direction but not the other. This prompted a specific assessment of the comparative shear forces experienced in the various braking zones of the pavement system. The aim of this paper was to investigate these relative shear stresses at critical locations within the asphalt surface and to determine whether differential shear stresses may explain the difference in asphalt performance in the various braking zones.

Typical aircraft operations are outlined as critical inputs to the modelling process. The surface stress calculations and stress analysis results are compared for the various braking zones of the pavement system at critical locations around the tyre footprint. Comparison is also made to highway pavement shear stresses. Conclusions address the importance of aircraft induced shear stresses on the differential asphalt performance observed in the field.

2. Aircraft pavement stress modelling

During aircraft ground manoeuvering, takeoff and landing operations, forces are transferred between the aircraft tyre and the pavement surface [13]. Shear stresses in the upper 100 mm of flexible pavements have been shown by various researchers to be important to pavement performance. Su et al. [14] noted that shear stresses are a critical loading for pavement performance. Computer-based analysis tools are commonly used for calculating stresses in pavements. The tools used by researchers vary significantly in their capabilities and different stress modes are adopted as the basis for comparison of critical conditions.

2.1. Modelling tools

Both Layered Elastic (LE) and Finite Element (FE) methods have been used to calculate stresses and strains in pavements and their surfaces. Discrete element methods have been less commonly adopted. FE models are less accurate for calculating stresses at interfaces and discontinuities between elements, whereas LE tools lose accuracy at the load boundaries and at the pavement surface [15].

FE methods allow more precise modelling of tyre tread patterns, contact load shapes and interface conditions. Many studies have shown these factors can significantly influence the stress distribution and peak stress imparted on the surface of the pavement [12,15–18]. However, Horak et al. [19] suggested that circular contact areas of uniform stress distribution were a reasonable simplification for many applications. Various computer based tools are available to perform the numerical calculations using LE or FE techniques. The most commonly reported tools include ANSYS, ABAQUS, BISAR and mePADS/GAMES.

The FE tool ANSYS was used to model 3D tyre and pavement surface interactions by [14]. Hu & Walubita [20] also used ANSYS in a 3D surface stress model. Pasindu et al. [21] utilised ADINA in a similar work while De Beer et al. [16] adopted NASTRAN. Tran et al. [22] utilised the 3D model BISAR to evaluate the effect of interface condition on pavement response and distress. Hachiya & Sato [23] used BISAR to estimate the magnitude of stresses at the interface between the surface layer and underlying asphalt layer.

ABAQUS has been more widely used in these applications. Buonsanti & Leonardi [24] performed surface layer stress analysis of aircraft during landing and braking with a 3D model in ABAQUS. ABAQUS was also used by Ali Shafabakhsh & Akbari [25] for modelling of aircraft loads on concrete pavements. Wang et al. [26] and Al-Qadi & Wang [12] both used ABAQUS in related studies of tyre-pavement interaction. Hernandez & Al-Qadi [27] furthered