Re-evaluating the relationship between load transfer characterisation values for rigid aircraft pavement construction joints

S. Jamieson, G. White
University of the Sunshine Coast, Sippy Downs, Queensland, Australia

ABSTRACT: Rigid aircraft pavement load transfer is typically characterised by load transfer efficiency via deflection (*LTE*$_\delta$), or free-edge stress transferred (*LT*). *LTE*$_\delta$ is relatively easily calculated from falling weight deflectometer field measurements and is routinely assessed for existing slabs. In contrast, *LT* is commonly used as an input for thickness design. However, *LT* is difficult to measure in the field. Consequently, understanding the relationship between *LTE*$_\delta$ and *LT* can improve rigid aircraft pavement design and evaluation strategies. Although relationships exist for load transfer characterisation values, they are built on generalised assumptions for free-edge deflection and stress. This study re-evaluated the relationships between typical load transfer values for three different construction joint types using finite element methods. It was determined that the relationship between *LT* and *LTE*$_\delta$ is largely dependent on construction joint type. Furthermore, predictive models for different construction joints were developed to relate *LTE*$_\delta$ to *LT*. The findings from this research can be used to better relate load transfer field measurements, to thickness design assumptions, for rigid aircraft pavements.

1 INTRODUCTION

Rigid aircraft pavements are typically comprised of unreinforced Portland cement concrete base slabs over an unbound or bound sub-base layer, constructed on the subgrade (AAA 2017). The concrete slabs are square or almost-square, typically ranging from 4 m to 8 m in length, (Jamieson and White 2023, FAA 2021). The slabs are separated by joints, which also provide load transfer to the adjacent slabs, resulting in reduced slab-edge stresses. Because the edge stress is usually the critical stress for pavement thickness determination (FAA 2021), effective load transfer reduces the required slab thickness.

It is generally assumed in airport pavement thickness design programs that joints provide 25% load transfer to adjacent slabs (FAA 2021). However, load transfer is variable, and is affected by many factors, including loading regime, sub-layer support, joint gap width and joint details, which includes dowel spacing (Byrum 2011b). To predict load transfer, multiple relationships have been developed for typical load transfer values that can be measured through instrumented slabs or a falling weight deflectometer (FWD). However, these relationships require assumptions for loading condition (Guo 2003), and generally characterise load transfer through a stiffness value to simplify the complex interaction between dowels, aggregate interlock, and formed concrete faces (Byrum 2011b). Recent research has challenged the assumptions for load transfer loading condition (Jamieson and White 2025), and due to the advances in finite element (FE) models for load transfer analysis, the interaction between dowels and formed concrete faces can now be more accurately modelled, enabling the assessment of different types of commonly used joints.

The aim of this research was to re-evaluate the relationships between typical load transfer characterisation values, and to determine if load transfer is consistent for a range of loading conditions and construction joint types. This was achieved through FE methods, using a previously validated load transfer model.

2 BACKGROUND

2.1 *Load transfer characterisation*

Load transfer is possible due to joint stiffness, which is provided by dowels, aggregate interlock and elastic solid base effects (Byrum 2011b). Load transfer is generally characterised by load transfer efficiency, via deflection (*LTE*$_\delta$) (Equation 1) or stress (*LTE*$_\sigma$) (Equation 2), or free-edge stress transferred (*LT*) (Equation 3). *LTE*$_\delta$ can be relatively easily calculated from deflections measured in the field using a FWD (White 2018, Gkyrtis et al. 2021). In contrast, *LT* is the portion of stress that is transferred to an unloaded slab, relative to the loaded slab, when under a free-edge loading condition. That is the condition when no adjacent slab is connected. Although LTE_δ is routinely measured for existing pavements, LT is commonly used for thickness design, is a fundamental first principle of aircraft pavement load transfer, has a range of 0% to 50%, and as discussed earlier, is assumed to be 25% in contemporary thickness design methods (Byrum 2011a, FAA 2021).

$$LTE_\delta = \frac{\delta_U}{\delta_L} \times 100 \tag{1}$$

$$LTE_\sigma = \frac{\sigma_U}{\sigma_L} \times 100 \tag{2}$$

$$LT = 100 \times \frac{(\varepsilon_F - \varepsilon_L)}{\varepsilon_F} \tag{3}$$

Where, LTE_δ = Load transfer efficiency by deflection (%); LTE_σ = Load transfer efficiency by stress (%); LT = Percent of free-edge stress transferred (%); δ_L = Deflection of loaded side of the joint (mm); δ_U = Deflection of unloaded side of the joint (mm); σ_L = Stress of loaded side of the joint (MPa); σ_U = Stress of unloaded side of the joint (MPa); ε_L = Bending strain in the loaded slab edge at the joint; and ε_F = Bending strain in the free-edge loading condition for the loaded slab edge.

Because LT is difficult to measure, due to requiring a loaded strain from a slab in the free-edge condition, past researchers have used the stress based LT_σ as an approximation (Ahmed et al. 2021, Guo 2003). LT_σ can be calculated without a free-edge slab by determining LTE_σ from strain gauges embedded in unloaded and loaded slabs, using Equation 4. This assumption holds true if approximations for free-edge deflection and free-edge stress are satisfied, as described in Equation 5 and Equation 6, respectively. However, these approximations also require a Winkler foundation, small aircraft loads, full contact between the slab and sub-base, and flat slabs (Byrum 2011b, Guo 2003). These conditions are not always met for aircraft pavements, requiring re-consideration of the relationship between LT_σ and LT.

$$LT_\sigma = 100 \times \frac{LTE_\sigma}{(1 + LTE_\sigma)} = 100 \times \frac{\sigma_U}{(\sigma_L + \sigma_U)} \tag{4}$$

$$\delta_L + \delta_U = \delta_F \tag{5}$$

$$\sigma_L + \sigma_U = \sigma_F \tag{6}$$

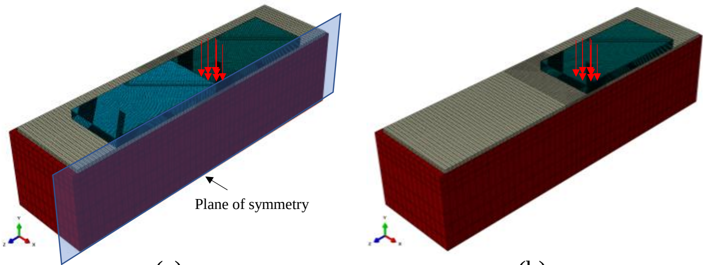
Where, LT_σ = LT stress-based approximation (%); δ_F = Deflection of loaded slab in free-edge condition (mm); σ_F = Stress of loaded slab in free-edge condition (MPa).

2.2 *Load transfer relationships*

Early work to determine relationships between load transfer values was performed by Mikhail S. Skarlatos in 1949, and revisited in the 1990s by Ioannides and Hammons (1996). Their work produced a general solution for edge load transfer, whereby maximum deflection and bending stress of an unloaded slab could be calculated. Also developed was a relationship between LTE_σ and LTE_δ. Recently, the relationship between LTE_δ and LT has become of high importance, because FWDs can easily measure LTE_δ, which can in turn be used to determine if a joint has failed (Gkyrtis et al. 2021), or is achieving the load transfer design assumption (LT). For example, the US Department of Defense pavement design program PCASE has an in-built relationship between LTE_δ and LT_σ, that can be used to assess the structural capacity of an existing rigid aircraft pavement (Tingle 2023). Ensuring the relationship between LTE_δ and LT is accurate will significantly enhance rigid pavement design and evaluation strategies.

3 METHODS

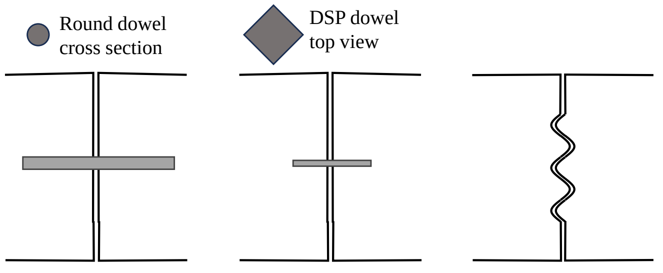
The primary objective of this study was to determine the relationships between load transfer values for a range of loading conditions and construction joints. This was achieved using an FE model developed by Jamieson and White (2024a), and validated against full scale physical testing (Jamieson and White 2024b). The model was built in the general-purpose FE program Abaqus 2023 (Dassault Systemes 2023), and assessed loading in two conditions, one with the slabs connected, and one in the free-edge condition, as shown in Figure 1.



(a) (b)

Figure 1. FE model with (a) two slabs connected, and (b) free edge condition.

Three different construction joint types were investigated: round dowelled, diamond-shaped plate (DSP) dowel, and sinusoidal, as shown in Figure 2. The joints were subject to 24.9 t wheel loads in either dual or tridem gear arrangement, in either longitudinal or transverse alignment across the edge of joint. Multiple joint arrangements were modelled, with different joint openings, subgrade strengths, sub-base types, dowel details, dowel looseness, and where applicable, sinusoidal shape. The interactions between concrete slabs, dowels and sub-layers were modelled by assigning normal and tangential contact properties that aligned with previous literature. In total, 43 round dowelled joints, 24 DSP dowelled joints, and 32 sinusoidal joints were assessed. For all FE model runs, the rigid pavement consisted of 350 mm thick concrete slabs, over a 152 mm thick sub-base, over the subgrade.



(a) (b) (c)

Figure 2. Side view of construction joints analysed, (a) round dowelled, (b) DSP dowelled, and (c) sinusoidal.

4 RESULTS

Figure 3 shows the relationship between *LTE*$_\delta$ and *LT*$_\sigma$ for round dowelled and DSP dowelled construction joints. Figure 4 shows the relationship between *LTE*$_\delta$ and *LT*$_\sigma$ for sinusoidal construction joints. For this graph, any zero *LTE*$_\delta$ results were omitted to avoid skewing the trendline R^2 value. Also included in both figures is the relationship between *LTE*$_\delta$ and *LT*$_\sigma$ used in the PCASE program.

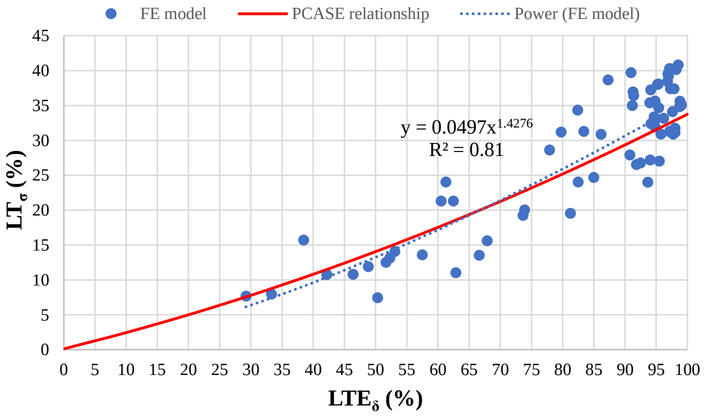


Figure 3. *LTE*$_\delta$ versus *LT*$_\sigma$ for dowelled construction joints.

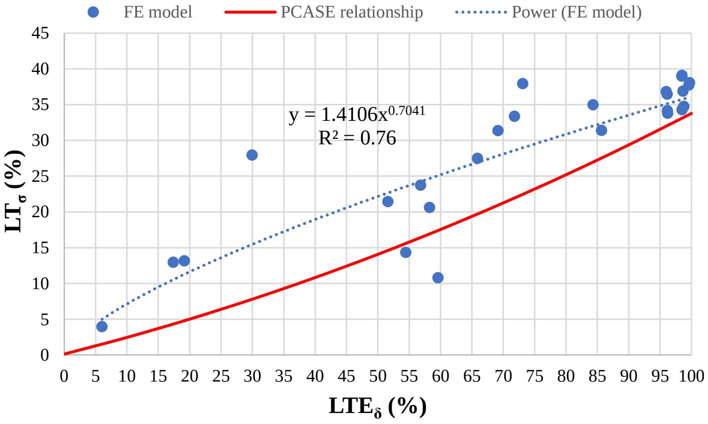


Figure 4. *LTE*$_\delta$ versus *LT*$_\sigma$ for sinusoidal joints.

Figure 5 shows the relationship between *LT*$_\sigma$ and *LT* for round dowelled and DSP dowelled construction joints. Figure 6 shows the relationship between *LT*$_\sigma$ and *LT* for sinusoidal construction joints. Included in both figures is the line of equality for the condition that *LT*$_\sigma$ equals *LT*.

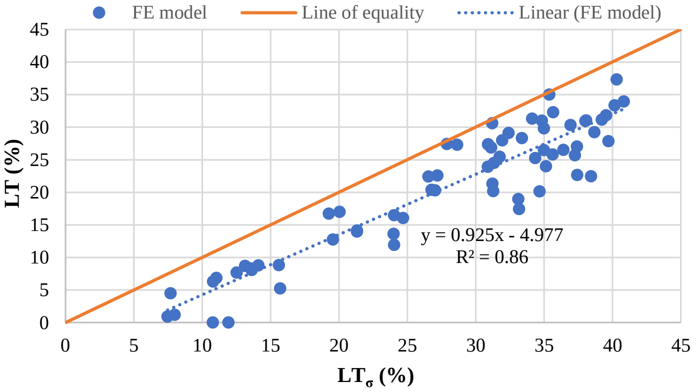


Figure 5. *LT*$_\sigma$ vs *LT* for dowelled construction joints.

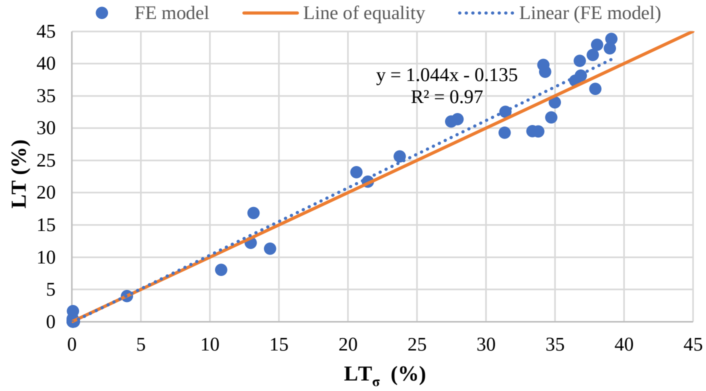


Figure 6. *LT*$_\sigma$ vs *LT* for sinusoidal construction joints.

5 DISCUSSION

As demonstrated in Figure 3 and Figure 4, the relationship between *LTE*$_\delta$ and *LT*$_\sigma$ is not consistent for all construction joints. Rather, joints with dowels have a strongly correlated relationship to existing literature, as evidenced by the closeness to the PCASE relationship. Sinusoidal joints, in contrast, respond differently to dowelled joints, when subject to aircraft loads. Evidenced by a lower R^2 value, *LTE*$_\delta$ does not predict *LT*$_\sigma$ as well as it does for dowelled joints. That is because sinusoidal joint load transfer is affected by joint openings. When an opening is present, the loaded slab and unloaded slab act as two separate elements. This contrasts with dowelled joints that are always connected by the dowels, meaning that there is always some interaction between the loaded and unloaded slabs. When a sinusoidal joint with a joint opening is loaded, there will be a certain distance where the loaded slab deflects but does not engage with the unloaded slab. Because this un-engaged distance is related to load type, subgrade strength and sinusoidal shape, there will be a large range of *LT*$_\sigma$ for a specific *LTE*$_\delta$.

Similarly for *LT*$_\sigma$ and *LT* is that the construction joint type affects the relationship between the two values. As demonstrated in Figure 5, there is a strong linear relationship between *LT*$_\sigma$ and *LT* for dowelled construction joints. However, LT_σ is not equivalent to LT, rather, LT_σ over-predicts LT. For the dowelled construction joint model runs, the free-edge deflection and stress equations (Equation 5 and Equation 6) had an absolute mean error of 37.0% and 8.8%, respectively, indicating that the free-edge assumptions were not met. Consequently, LT_σ is not a good predictor of first-principles LT for dowelled construction joints, without a transform equation. For sinusoidal construction joints, the LT_σ and LT were determined to be equivalent. Because the load configurations, sub-layer support, and interaction between sub-base and slab was the same for both joint types, it is expected the difference in LT_σ and LT relationship was due to the simpler continuous interaction between the two slab elements for sinusoidal joints, when compared to the more complex interaction for joints with dowels, where load transfer is due to joint stiffness provided at discrete points. Interestingly, the free-edge stress absolute mean error was 3.3%, whereas the deflection error was 18.6%. This demonstrates that free-edge stress is a better indicator of equivalence of LT_σ and LT than free-edge deflection, when using the FE model.

Because the relationship between load transfer values were found to be dependent on the joint type, two predictive relationships between LTE_δ and LT were developed. These equations are based on data provided in Figure 3 to Figure 6, and should aid practitioners in converting serviceability checks of LTE_δ when using an FWD to the first-principles LT used in airport pavement thickness determination. Equation 7 provides the relationship between LT and LTE_δ for a dowelled construction joint. Equation 8 provides the relationship between LT and LTE_δ for a sinusoidal construction joint.

$$LT_{DCJ} = 0.046 \times {LTE_\delta}^{1.427} - 4.98 \qquad (7)$$

$$LT_{SCJ} = 1.411 \times {LTE_\delta}^{0.704} \qquad (8)$$

Where, LT_{DCJ} = LT of a dowelled construction joint (%); LT_{SCJ} = LT of a sinusoidal construction joint (%).

6 CONCLUSION

The relationship between LT and LTE_δ is important to develop rigid pavement design and evaluation strategies that are accurate, and well-defined. This study investigated the relationships between typical load transfer values using FE methods for three different construction joint types. Based on the analysis of the results from 99 model runs, it was concluded that the relationship between LT_σ, LT and LTE_δ is largely dependent on the construction joint type. Furthermore, predictive models for dowelled construction joints and sinusoidal construction joints were developed to relate LTE_δ to LT. Consequently, the findings from this research can be used to better relate FWD results to design assumptions used in aircraft pavement thickness determination.

7 REFERENCES

AAA, 2017. *Airport Practice Note 12 - Airfield Pavement Essentials.* Australia: Australian Airports Association.

Ahmed, M., *et al.*, 2021. Evaluation of Concrete Pavement Joint Performance at the FAA National Airport Pavement Test Facility. *12th International Conference on Concrete Pavements.* Virtual Conference.

Byrum, C. R., 2011a. *Report IPRF-01-G-002-05-2 Joint Load Transfer in Concrete Airfield Pavements: Appendix B: Literature Review Summary.* Rosemont, United States: Innovative Pavement Research Foundation.

Byrum, C. R., 2011b. *Report IPRF-01-G-002-05-2 Joint Load Transfer in Concrete Airfield Pavements: Final Report.* Rosemont, United States: Innovative Pavement Research Foundation.

Dassault Systemes, 2023. Abaqus CAE 2023.

FAA, 2021. AC 150/5320-6G - Airport Pavement Design and Evaluation. Washington D.C., United States: Federal Aviation Administration.

Gkyrtis, K., *et al.* 2021. Structural Performance Assessment of Airfield Concrete Pavements Based on Field and Laboratory Data. *Infrastructures,* 6.

Guo, E. H. 2003. Proof and Comments on Extensively Used Assumption in PCC Pavement Analysis and Evalutation. *Journal of Transportation Engineering,* 129(2), 219-220.

Ioannides, A. M. and Hammons, M. I. 1996. Westergaard-Type Solution fo Edge Load Transfer Problem. *Transportation Research Record,* 1525(1), 28-34.

Jamieson, S. and White, G., 2023. Review of Rigid Aircraft Pavement Joint Types, Effectiveness, Distress, Maintenance and Analysis. *International Airfield & Highway Pavment Conference.* Austin, Texas, USA.

Jamieson, S. and White, G., 2024a. Developing a Theoritical Model for Load Transfer of Common Joints in Rigid Airport Pavements. *13th International Conference on Concrete Pavements.* Minneapolis, USA.

Jamieson, S. and White, G. 2024b. Validating a Finite Element Model for Rigid Aircraft Pavement Load Transfer against Full Scale Testing. *International Journal of Pavement Engineering*.

Jamieson, S. and White, G. 2025. Parametric analysis of a dowelled construction joint for rigid aircraft pavement load transfer using finite element methods. *International Journal of Pavement Engineering*.

Tingle, J., 2023. Unpublished presentation - Performance of dowelled versus undowelled joints for relatively thin airfield pavements. Woolongong, Australia: Australian Society for Concrete Pavements (ASCP).

White, G., 2018. Use of Falling Weight Deflectometer for Airport Pavements. *5th GeoChina International Conference.* HangZhou, China.