This proceedings is a collection of 31 papers presented at the 27th International Air Transportation Conference in Chicago, Illinois, August 5–8, 2001. These papers present the state of the art in airfield pavement technology, discussing practical and applied research findings related to all aspects of airfield pavements. A variety of topics cover the planning, design, construction, operation, management, and maintenance of airports, including: landside, terminal, and airfield related issues. The technical papers span a broad range of subjects such as pavement design; pavement materials; construction methods; environmental, operations, and planning concerns; and implications of future aircraft. Numerous well-documented case studies are included.

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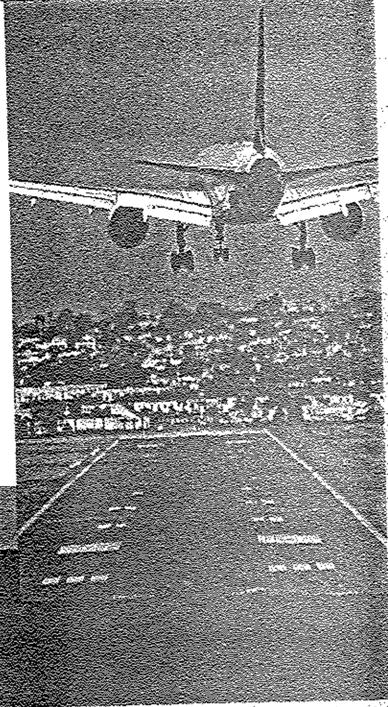

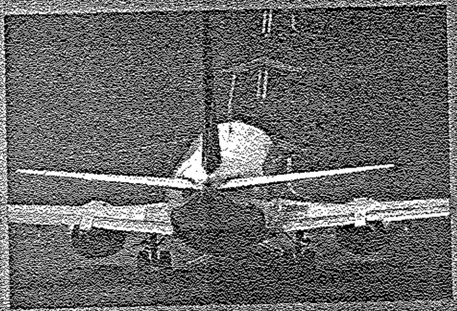

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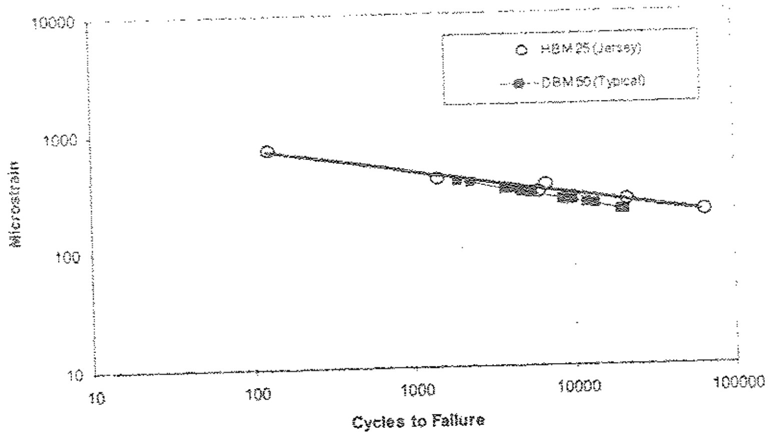

Figure 3. Comparison Between Jersey HMB25 and Typical DBM50 Fatigue Lines

TKUAPAV: A New Thickness Design Program for Rigid Airfield Pavements

Ying-Haur Lee[1] and Shao-Tang Yen[2]

Abstract

The main objective of this study is to develop a new thickness design program for rigid airfield pavements in attempts to accommodate the new Boeing 777 airplanes based on the plate theory approach. The differences of the conventional FAA design method and the newly developed LEDFAA design methodology are investigated. The original concept of pass-to-coverage ratio is reevaluated. The prediction models developed by Lee, *et al.* are utilized for the estimation of critical edge stresses. The concept of cumulative damage factor is used to account for the combined damages of different aircraft types and departures. Structural deterioration relationships are compared and tentative modification alternatives are investigated. An equivalent stress factor and an alternative structural deterioration model are proposed. The proposed approach has been implemented in a user-friendly computer program (TKUAPAV) and a case study is presented for practical trial applications.

Introduction

The conventional Federal Aviation Administration's (FAA, 1995a) thickness design methodology for rigid airfield pavements was based on "the plate theory" and Westergaard's analytical solution for edge loading condition. When the main gear assembly is analyzed using the conventional FAA design procedures, however, the pavement thickness requirements are considered to be "unduly conservative" (FAA, 1995b), especially noticeable for flexible pavements on weak subgrades. Thus, FAA has recently utilized "the multi-layered linear elastic theory" for the design of both flexible and rigid airfield pavements to accommodate the new Boeing 777 airplanes (FAA, 1995b). Nevertheless, the applicability of layered elastic theory for concrete pavement design has always been questioned and debated over the decades, which warrants the need for further investigations. Consequently, the main objective of this study was to develop a new thickness design program for rigid airfield pavements based on the conventional plate theory approach (Lee, *et al.*, 1998).

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Reevaluation of Pass-to-Coverage Concept

Pass-to-coverage ratio concept was developed based on the assumption of normally distributed aircraft traffic. It was considered that a coverage represents the maximum number of tire prints applied to the pavement surface at the point where maximum accumulation occurs. The effect of the edge of a tire at one location is assumed as detrimental as the effect of the tire centerline at that location. The area under the normal distribution curve is equal to 1.0. Thus, the reciprocal of coverage or $(C_x)(W_t)$ is referred as the pass-to-coverage (P/C) ratio, where C_x is the maximum ordinate on the normal distribution curve or the maximum frequency of aircraft centerline passes per unit width and W_t is the tire width. This method was extended to aircraft having many wheels by graphical addition of any number of single-wheel traffic distribution curves. (Ahlvin, *et al.*, 1971, pp. 75-80)

The P/C ratio concept was reexamined in this study. The P/C ratios reported in the conventional FAA design procedures for various gear assemblies and aircraft types are used for the analysis (FAA, 1995a). The wheel spacing and tire width values for specific aircraft types were not clearly specified in the conventional FAA method and thus were obtained from the LEDFAA program. The standard deviation of the lateral placement of wheel centerline was assumed as 77.5 cm (30.5 in.) for all aircraft types. Customized functions were written using the S-PLUS statistical package (MathSoft, Inc., 1997) to conduct this analysis. The P/C ratios of Boeing 777 airplanes were also determined. As a result, the P/C concept was found to be in good agreement with that described in the literature (Lee, 1999).

Estimation of Critical Edge Stress for Design

The conventional FAA pavement design curves were developed using Westergaard edge loading analysis for rigid pavements. The edge loading stress was reduced by 25 percent to account for the effect of load transfer across the joints. This factor was chosen from test results and experience and continues in use today. As coded in the R805FAA program, the critical edge stress (σ_e) was determined by:

$$\sigma_e = \frac{P}{h^2}\left[RC0 + RC1\times\ln(\ell) + RC2\times(\ln(\ell))^2\right] \tag{1}$$

$$DF = \frac{S_c}{0.75*\sigma_e}$$

Where RC0, RC1 and RC2 are coefficients obtained using Pickett and Ray's influence charts for various aircraft types. P is the main landing gear load, lbs; σ_e is the critical edge tensile stress, psi; $\ell=(E*h^3/(12*(1-\mu^2)*k))^{0.25}$ is the radius of relative stiffness, in.; E is the elastic modulus of the slab, psi; k is the modulus of subgrade reaction, psi/in; μ is the Poisson's Ratio, and h or h_1 is the slab thickness, in. The ratio of the concrete flexural strength (S_c) to the allowable slab tensile stress (σ_a = 0.75 * σ_e) is called a design factor (DF) or analogous to a safety factor.

Since equation (1) is only applicable to U.S. customary system and some fixed gear configurations, it is desirable to find an alternative solution, which is dimensionally correct, applicable to both U.S. customary system and metric system and various gear configurations. Consequently, the following equation proposed by Lee, *et al.* (1997b) was adopted in this study in determining critical edge stresses:

$$\sigma_e = \sigma_{we} * R_1$$

$$\sigma_{we} = \frac{3(1+\mu)P}{\pi(3+\mu)h^2}\left[\ln\frac{Eh^3}{100ka^4} + 1.84 - \frac{4}{3}\mu + \frac{1-\mu}{2} + 1.18(1+2\mu)\frac{a}{\ell}\right] \tag{2}$$

Where, σ_e is the predicted critical edge stress, $[FL^{-2}]$; σ_{we} is the Westergaard's (1948) closed-form edge stress solution, $[FL^{-2}]$; P is main landing gear load, [F]; a is the applied load radius, [L]. R_1 is an adjustment (or multiplication) factor, which represents the combined effect of several prediction models for different gear configurations including dual-wheel, tandem axle, and tridem axle.

To reexamine the applicability of equation (2), critical edge stresses resulted from the main landing gear loads of different aircraft types on a very long slab were estimated. The default characteristics of all aircraft types used in the analysis were obtained from the LEDFAA program. A wide variety of different pavement designs including h = 30.5~50.8 cm (12~20 in.), E = 27.6~41.3 GPa (4~6 million psi), and k = 27~108 MN/m^3 (100~400 pci) was chosen for the analysis. As shown in Figure 1, the critical edge stresses obtained from equation (2) are indeed in very good agreement with those determined using equation (1) with the only exception of A-300-B4 aircraft type, which is believed as an error in the R805FAA program.

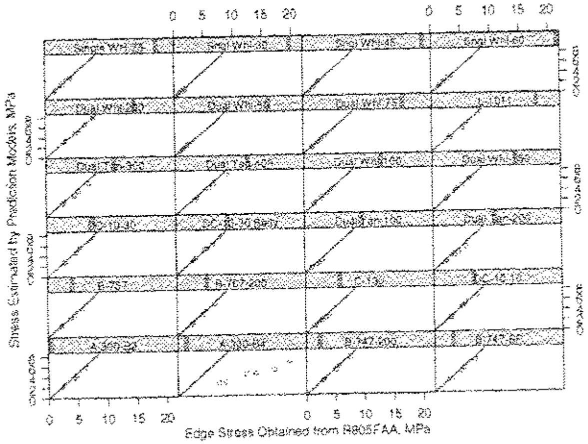

Figure 1 - Verification of the Proposed Stress Prediction Models

Conversion of Different Aircraft Types and Departures

Since the traffic forecast is a mixture of a variety of aircraft having different landing gear types and weights, the "design aircraft" concept was introduced to account for the effects of all traffic in the conventional FAA design methodology. Commonly, equivalency factors for the relative fatigue effects of different gear types are defined for a selected pavement structure. However, it is noted that the presently formulated load equivalencies are not single valued and may vary widely for different levels of aircraft departures. This observation is similar to the statement by

Ahlvin (1991, p. 10-9) that "any simple ratio will be different for different magnitudes of load repetitions so that the adopted practice is arbitrary and unverified." "Much more precise and theoretically rigorous factors could be developed for different types and thickness of pavements." (FAA, 1995a, p.25)

Consequently, the conventional "design aircraft" concept, conversion factors for different landing gear types, and equivalencies have been replaced by the concept of cumulative damage factor (CDF) in the new LEDFAA design methodology (FAA, 1995b) using Miner's hypothesis. This approach is more mechanistically based and will result in a single valued factor to represent the relative fatigue effects of different aircraft types for a given pavement structure. Thus, the conversion of different aircraft types and departures to equivalent annual departures of a specific aircraft type is no longer necessary and thus will not be further discussed.

Fatigue Relationship and Thickness Design Criteria

The conventional FAA thickness design methodology was based on an earlier fatigue curve developed by the Corps of Engineers from test track data and observation of full-scale test pavements. The fatigue curve originally adopted a bilinear relationship between a design factor (DF) and the number of load repetitions (in terms of coverages, C) at the specified failure criteria. However, no explicit fatigue relationship is available in the literature (FAA, 1995a). A design factor of 1.3 was chosen to determine the allowable slab tensile stress for 5000 coverages. The thickness of pavement required to sustain 5,000 coverages of the design loading is considered as the basic thickness. The minimum required slab thickness is defined as the product of basic thickness (h_1) and percent thickness or relative thickness (RH):

$$\sigma_e = \frac{S_c}{1.3*0.75}$$

$$h_1 = \left[\left(RC0 + RC1\times\ln(\ell) + RC2\times(\ln(\ell))^2\right)\times\left(\frac{P}{\sigma_e}\right)\right]^{0.5} \quad (3)$$

$$RH = \begin{cases} 1 + 0.15603*(\log(C) - 3.69897) & if\ C > 5000 \\ 1 + 0.07058*(\log(C) - 3.69897) & if\ C < 5000 \end{cases} \quad (4)$$

The above equations are analogous to a fatigue relationship in that the allowable number of load repetitions (in terms of coverages) of a specific aircraft and wheel load may be determined for any given pavement structure with known slab thickness, concrete modulus of rupture, elastic modulus of the slab and subgrade modulus. However, it is worth mentioning that the relationship between a design factor (DF) and coverages (C) derived from the above equations is not a unique curve. As shown in Figure 2 (a), three fatigue curves showing a bilinear relationship and coincided at the point of DF=1.3 and C=5,000 are obtained for different sets of P, E, h, k, and S_c values for illustration purposes.

Rollings and Witczak (1990) developed a structural deterioration model for rigid airfield pavements that predicts performance in terms of a structural condition index (SCI). The SCI is derived from the pavement condition index (PCI) considering the distresses associated with tensile fatigue loading only and is on a scale from 0 to 100. The design factor (DF) is defined as the ratio of flexural strength of concrete (S_c) and the critical tensile stresses (σ) calculated using the layered elastic pavement model. Failure is defined as the number of coverages (C_{80}) to reduce the pavement SCI from 100 to 80 at any given value of DF. The basic fatigue relationship used to find the number of coverages (C) to failure in the LEDFAA program (FAA, 1995b; Rollings and Witczak, 1990) is as follows:

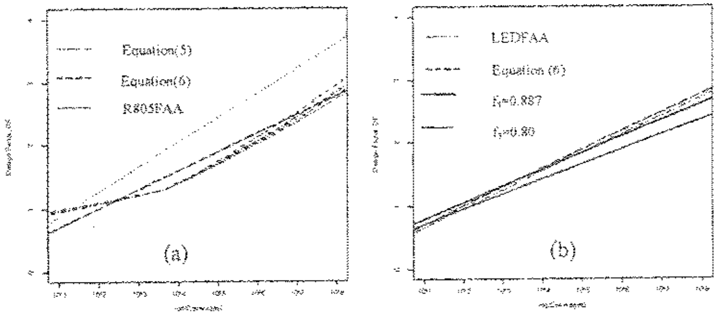

Figure 2 - Fatigue Relationships for Rigid Airfield Pavement Design

$$SCI = \frac{DF - 0.2967 - (0.3881 + 0.000039*SCI)\log(C)}{0.002269} \quad (5)$$

$$DF = 0.4782 + 0.3912*\log(C_{80})$$

Gucbilmez and Yuce (1995) reanalyzed the Corps of Engineers accelerated traffic data and provided an alternative rigid airfield pavement deterioration relationship using stresses calculated by the Westergaard edge loading idealization, i.e., plate on Winkler foundation. This relationship can be used to determine the expected structural condition of the pavement at a specified level of coverages or vice versa for pavements with joints capable of load transfer. The design factor is defined as DF = S_c / (0.75 * σ_e) and the fatigue equation is given by:

$$SCI = \frac{100*\log(C) - 320.61558DF + 56.4417}{0.20903DF - 0.99336} \quad (6)$$

$$DF = 0.40289 + 0.29644*\log(C_{80})$$

Figure 2 (a) shows a comparison of the conventional FAA and the basic LEDFAA fatigue equations with the fatigue curve given in equation (6). It is noted that the fatigue curve obtained by Gucbilmez and Yuce (1995) performs similarly with the conventional FAA fatigue curve given by equations (3) and (4), though the specified failure criteria may be different. Generally speaking, equation (6) requires a thicker pavement than the conventional FAA curve for a coverage level above 1,000.

The coverages at failure (C_{80}) obtained from both fatigue equations (5) and (6) were implicitly tied to the manner in which critical tensile stress, or consequently the design factor, was determined. To make the layered elastic design procedure compatible with the conventional FAA thickness design procedure, an adjustment is made to the calculated layered elastic interior stress to provide an equivalent edge stress. The subgrade is assumed to be infinite in thickness and is characterized by either an elastic modulus (E) or modulus of subgrade reaction (k-value) in the current LEDFAA program. If a k-value is specified, it is converted to an equivalent E-value using a logarithmic relationship. In the current LEDFAA method, a scaling factor of 0.753 is applied to stresses used to compute the design factor. As shown in Figure 2 (b), the resulting fatigue curve is similar to the conventional FAA curves and slightly less conservative than the relationship based on the Gucbilmez and Yuce study.

Fatigue failure expressed in terms of a "cumulative damage factor" (CDF) using Miner's hypothesis is adopted in the new LEDFAA thickness design approach. CDF is the amount of the consumed structural fatigue life and is expressed as the summation of the ratio of applied load repetitions to allowable load repetitions to failure. The LEDFAA program automatically calculates the damaging effects of each aircraft in the traffic mix. When the damaging effects of all aircraft sums to 1.0, the design conditions have been satisfied and the required slab thickness is determined.

Tentative Modification Alternatives

The coverages at failure obtained from the fatigue curves were implicitly tied to the manner in which critical tensile stress was determined. The load magnitude and load repetitions to failure are certainly interrelated with the material properties of a given pavement structure. The P/C concept implies that maximum tensile stress should be used throughout when the centerline location of the lateral wheel load placement (L_c) falls within this tire print area as shown in Figure 3, in which P_t is the frequency of aircraft centerline passes per unit width. Thus, the well-recognized effect of stress reduction due to the wandering of the L_c, moving away from the maximum tensile stress location, is totally neglected. The P/C concept is indeed embedded with a very conservative means in estimating the cumulative fatigue damages of each aircraft type. The centerline location of lateral wheel load placement of each aircraft is considered to be coincident, which is not necessarily true and a further refinement is warranted. (Ahlvin, 1971; 1991; Parker, *et al.*, 1979)

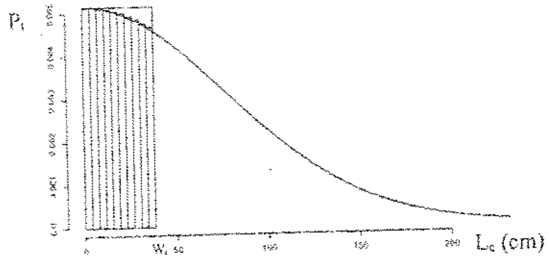

Figure 3 - Lateral Placement of the Centerline Location of the Wheel Load

The effect of edge stress reduction due to the wandering of the L_c is often recognized as the effect of a widened outer lane in the literature. As a supplement to equation (2), an additional adjustment factor (R_4) proposed by Lee, *et al.* (1997a) was adopted here to account for the stress reduction due to the load location moving away from the slab edge. Tentative modification alternatives are further investigated.

Determination of Equivalent Stress Factor

The Corps of Engineers accelerated traffic data provided by Gucbilmez and Yuce (1995) was reanalyzed in this study. The traffic at failure in terms of coverages assigned to each of the test pavements was for one type load and is implicitly tied to the manner in which the traffic was applied (Parker, *et al.*, 1979, p. 80). Otherwise, the P/C concept may be given up if the concept of cumulative damage factor is precisely employed to evaluate pavement remaining life.

Critical edge stresses and P/C ratios were recalculated with very favorable agreements with the literature (Lee, 1999). The radius of the wheel load (a) and the tire width (W_t) are obtained using the relationship: $1.273(\pi a^2) = 1.6\,(W_t)^2$, similar to that used in the LEDFAA program. The concept of an "equivalent stress factor" (f_3) used in the Portland Cement Association's thickness design procedures (Lee, *et al.*, 1997b) is adopted in this study. The f_3 factor is defined as the stress adjustment factor (or reduction factor) based on the equivalency of the cumulative fatigue damages to account for the lateral wandering effect of the L_c within the full tire print area as shown in Figure 3 and may be determined by:

1. Select each test item or aircraft type, gear configurations and a standard deviation of the lateral distribution; input other pertinent design parameters such as subgrade modulus, slab modulus, thickness and flexural strength.
2. Assume a normally distributed aircraft pass data set (n_i) in smaller intervals, say 10 intervals, of the specified wheel width (W_t) as shown in Figure 3.
3. Calculate the critical edge stress for each interval, i.e., $\sigma_e = \sigma_{we} * R_j * R_4$.
4. Calculate the corresponding allowable number of load repetitions (N_i) in terms of coverages for each interval using equation (6).
5. Calculate the cumulative fatigue damage $\Sigma(n_i/N_i)$ for the given aircraft pass data within the full tire print.
6. Determine the maximum or critical edge stress (σ_{max}) of the first interval.
7. Determine the equivalent allowable number of load repetitions (N_{eq}) by calculating the ratio of $\Sigma(n_i)$ and $\Sigma(n_i/N_i)$ assuming all aircraft passes applied on the maximum edge stress location.
8. Backcalculate equivalent edge stress (σ_{eq}) using N_{eq} value and equation (6).
9. The equivalent stress factor (f_3) is determined by σ_{eq}/σ_{max}.
10. Repeat steps (1) - (9) for each test item or aircraft type.

Alternative Structural Deterioration Relationship

The f_3 value of each of the test item calculated based on the proposed procedure was conducted (Lee, 1999). An equivalent design factor (EDF) is defined by EDF = $S_c / (0.75 * \sigma_e * f_3)$ to account for the reduction of critical edge stress. As a result, the following alternative fatigue relationship is obtained:

$$SCI = \frac{100*\log(C) - 324.044(EDF) + 119.799}{0.184217(EDF) - 1.00098} \qquad (7)$$

$$EDF = 0.5900 + 0.2952*\log(C_{80})$$

$$DF = f_3 * [0.5900 + 0.2952*\log(C_{80})]$$

The f_3 factor may vary widely for different aircraft types, gear configurations, lateral distributions, and other pertinent design parameters. Sensitivity analysis of f_3 factor was conducted. Generally speaking, the f_3 factor increases when slab thickness (h), subgrade modulus (k), and/or concrete modulus of rupture (S_c) increases. The f_3 factor is not very sensitive to the increase in slab modulus (E), however, the f_3 value decreases when the tire width (W_t) increases. The structural deterioration relationship given by equation (7) is also compared to the fatigue curves discussed earlier. As shown in Figure 2 (b), the fatigue curve labeled as $f_3 = 0.887$, which is the average value obtained from the analysis, performs similarly to that defined by equation (6). A relative low value of $f_3 = 0.80$ was chosen and the corresponding fatigue curve is plotted in Figure 2 (b) just to show how differently the proposed model will perform. The fatigue curve labeled as $f_3 = 0.80$ requires the least slab thickness overall.

Implementation of the Proposed Approach

The following steps are proposed to determine the required minimum thickness:

1. Assume a trial slab thickness; input other pertinent design factors, material properties and the expected departures of different aircraft types.
2. Determine the P/C ratio for each aircraft type.
3. Determine the equivalent stress factor (f_3) for each aircraft type.
4. Convert the expected aircraft departures (or passes) to coverages (n_i).
5. Calculate the critical edge stress for each aircraft type using equation (2).
6. Determine the allowable number of load repetitions in terms of coverages (C80) for each aircraft type (N_i) using equation (7).
7. Check if the cumulative damage factor, CDF = $\Sigma(n_i/N_i) < 100\%$.
8. If not, assume a different slab thickness and repeat previous steps (1) - (7) again to obtain the minimum required slab thickness.

The proposed approach has also been implemented in a user-friendly computer program (TKUAPAV) using Microsoft Visual Basic software (Microsoft Taiwan Corp., 1997). Figure 4 depicts example input and output screens of the program.

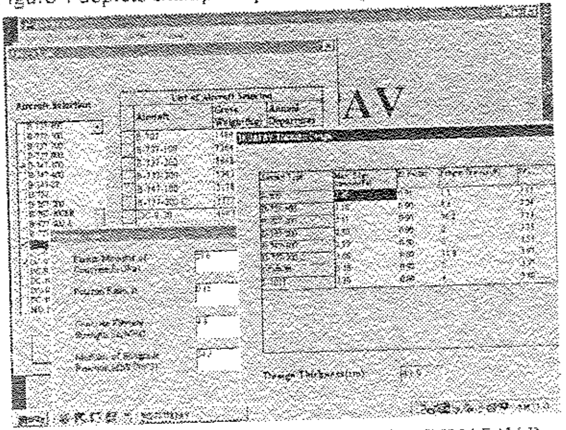

Figure 4 - Example Input and Output Screens of the TKUAPAV Program

Case Study for Illustration Purposes

Suppose a rigid airfield pavement is to be designed for the forecast traffic given in Table 1, assuming a 20-year design life. The modulus of subgrade reaction is 200 pci (54.3 MN/m^3) and the concrete flexural strength is 700 psi (4.8 MPa). An additional B-777-200C aircraft type with maximum takeoff weight of 722,000 lbs (327,788 kg) and forecast annual departures of 0, 1,200, and 12,000 is considered.

Conventional FAA, LEDFAA, and the proposed design procedures were applied to determine the minimum required slab thickness. Without B-777-200C aircraft, the LEDFAA approach results in more conservative design thickness as compared to the conventional FAA approach. In fact, the resulting slab thickness is invariant despite of three different levels of forecast traffic considered in this case study. The proposed approach based on the plate theory, however, results in more compatible minimum required slab thickness as compared to the conventional FAA approach.

Table 1 - Forecast Air Traffic and Minimum Required Slab Thickness

Aircraft Type	Gear Type	Forecast Annual Departures	Maximum Takeoff Weight, lbs (kg)
B-727-100	Dual	3,760	160,000 (72,640)
B-727-200	Dual	9,080	190,500 (86,487)
B-707-320B	dual tandem	3,050	327,000 (148,458)
DC-9-30	Dual	5,800	108,000 (49,032)
B-737-200	Dual	2,650	115,500 (52,437)
L-1011-100	dual tandem	1,710	450,000 (204,300)
B-747-100	double dual tandem	85	700,000 (317,800)

Without B-777-200C Aircraft			B-777-200C Annual Departures=1,200		B-777-200C Annual Departures=12,000	
FAA	LEDFAA	TKUAPAV	LEDFAA	TKUAPAV	LEDFAA	TKUAPAV
16.9 in. (42.9 cm)	17.6 in. (44.7 cm)	17.1 in. (43.4 cm)	17.6 in. (44.7 cm)	17.3 in. (43.9 cm)	17.6 in. (44.7 cm)	17.9 in. (45.5 cm)

Conclusions

Alternative prediction models, which are dimensionally correct and applicable to both of U.S. customary system and metric system for the estimation of critical edge stresses are proposed and verified. The concept of cumulative damage factor (CDF) is used to account for the combined damage effects of different aircraft types and departures. The Corps of Engineers accelerated traffic data was reanalyzed. An equivalent stress factor (f_3) based on the equivalency of the cumulative fatigue damages to account for the lateral wandering effect of the L_e within the full tire print area is introduced. An equivalent design factor (EDF) is also defined to account for the reduction of critical edge stress. Alternative structural deterioration relationship is obtained. This fatigue relationship is in very good agreement with the performance trend of the existing fatigue curves. The proposed approach has been implemented in a user-friendly computer program (TKUAPAV) for practical trial applications.

Acknowledgments

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References

Ahlvin, R. G., *et al.*, 1971. *Multiple-Wheel Heavy Gear Load Pavement Tests*, AFWL-TR-70-113, Vol. I-IV, Air Force Weapons Laboratory, Kirtland AFB, New Mexico.

Ahlvin, R. G., 1991. *Origin of Developments for Structural Design of Pavements*, Report No. GL-91-26, US Army Corps of Engineers.

Federal Aviation Administration, 1995a. *Airport Pavement Design and Evaluation*, Advisory Circular, AC 150/5320-6D.

Federal Aviation Administration, 1995b. *Airport Pavement Design for the Boeing 777 Airplane*, Advisory Circular, AC 150/5320-16.

Gucbilmez E., and R. Yuce, 1995. Mechanistic Evaluation of Rigid Airfield Pavements, *Journal of Transportation Engineering*, ASCE, Vol. 121, No. 6, pp. 468-475.

Lee, Y. H., S. T. Yen, C. T. Lee, J. H. Bair, and Y. M. Lee, 1997a. Development of New Stress Analysis and Thickness Design Procedures for Jointed Concrete Pavements, *Proceedings*, Sixth International Purdue Conference on Concrete Pavement – Design and Materials for High Performance, Purdue University.

Lee, Y. H., J. H. Bair, C. T. Lee, S. T. Yen, and Y. M. Lee, 1997b. Modified Portland Cement Association Stress Analysis and Thickness Design Procedures. *Transportation Research Record 1568*, TRB, National Research Council, Washington, D. C., pp. 77-88.

Lee, Y. H., S. T. Yen, and P. K. Jeng, 1998. *Development of a Thickness Design Program for Rigid Airfield Pavements*, Final Report, NSC87-2218-E-032-007, National Science Council, Taiwan (In Chinese).

Lee, Y. H., 1999. Mechanistic Reappraisal of the Current Design Methodology for Rigid Airfield Pavements. *Transportation Research Record 1684*, TRB, National Research Council, Washington, D. C., pp. 90-100.

MathSoft, Inc., 1997. *S-PLUS User's Guide*. Version 4.0, Seattle, Washington.

Microsoft Taiwan Corp., 1997. *Microsoft Visual Basic. Programmer's Guide and Language Reference*. V.5.0.

Parker, F., Jr., W. R. Barker, R. C. Gunkel, and E. C. Odom, 1979. *Development of a Structural Design Procedure for Rigid Airport Pavements*, Report No. FAA-RD-77-81, WES-TR-GL-79-4, Government Doc. No. TD 4.509:77-81.

Rollings, R.S., and M. W. Witczak, 1990. Structural Deterioration Model for Rigid Airfield Pavements. *Journal of Transportation Engineering*, ASCE, Vol. 116, No. 4, pp. 479-491.

Westergaard, H. M., 1948. New Formulas for Stresses in Concrete Pavements of Airfields. *Transactions, American Society of Civil Engineers*, Vol. 113, pp. 425-444.

Joint Less Pavements for Heavy-Duty Airport Application: The Semi-Flexible Approach

Jean Mayer[1] & Mikael Thau[2]

ABSTRACT

In Copenhagen Airport, extensive developments in the field of Semi-Flexible pavement structures have demonstrated high potentials for very heavy loads and static loads in particular. The experience of the Semi-Flexible Pavement (SFP) concept dates back 25 years. However, during the late eighties, a new generation of this special product emerged which brought about further development towards high quality pavements exhibiting very high strength and durability. Today, it is possible to design Semi-Flexible Pavements for type E aircrafts in regard of aprons, stand gates, de-icing stands, start-up pads, taxiways and other heavy loaded areas. More than 300,000m² has been applied in Copenhagen Airport. Of this area, 165,000m² are constructed from 1988 through 2000 utilizing the enhanced second generation technique.

The general SFP concept consists of a joint less wearing course composed of an open-graded asphalt concrete filled with a special slurry grout. The underlying bituminous layers are designed for high strength and high load-bearing capacity. The Semi-Flexible wearing course will not develop cracks due to shrinkage, nor will it show any plastic flow.

The joint less SFP have provided Copenhagen Airport with a high performing pavement with a minimum of maintenance. The better economy and advantageous technology offered by the SFP have been desirable compared to concrete slab pavements. The new enhanced Heavy-Duty Semi-Flexible Pavement structures are expected to be the desired solution for pavements designed for heavy loads.

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