78th Annual Meeting of Transportation Research Board

Mechanistic Reappraisal of the Current Design Methodology for Rigid Airfield Pavements

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Introduction

- Conventional FAA Design Procedure
  - Plate theory
  - Westergaard edge stress
- LEDFAA Design Procedure
  - Multi-Layered Linear Elastic Theory
- Question of B-777 Airplanes
  - Unduly Conservative
- Reevaluate Rigid Airfield Pavements Design Procedure

Research Approach

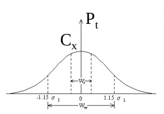
- Reevaluate Pass-to-Coverage Ratio Concept
- Estimation of Edge Stress for Design
- Conversion of Different Aircraft Types and Departures
- Fatigue Relationship and Thickness Design Criteria
- Investigation of Tentative Modification Alternatives
- Determination of Equivalent Stress Factor
- Alternative Structural Deterioration Relationship

Conventional FAA Design Method

- The Plate Theory & Westergaard Edge Stresses
- Pass-to-Coverage Ratio (P/C)
- Design Aircraft & Conversion Factors
- Fatigue Relationship
  - Coverages & Basic Thickness

Reevaluate P/C Ratio Concept

- Effect: Edge of a tire at 0 = Tire centerline at 0
- Extended to Multi-Wheels
- Reevaluated the P/C Concept



$$Coverages = \int_{-\frac{W_t}{2}}^{\frac{W_t}{2}} P_t(x)\,dx \approx (C_x)(W_t)$$

$$P_t(x) = \frac{1}{\sigma_x\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-u}{\sigma_x}\right)^2}$$

$$P/C = \frac{1}{(C_x)(W_t)}$$

Aircraft Type	FAA P/C Ratio	Calculated P/C Ratio	Aircraft Type	FAA P/C Ratio	Calculated P/C Ratio
SINGLE WH-30	5.18	6.22	C-130	4.15	4.58
SINGLE WH-45		5.56	L-1011	3.62	3.40
SINGLE WH-60		5.20	A-300-B2	3.51	3.45
SINGLE WH-75		4.97	A-300-B4	3.45	3.57
DUAL WH-50	3.48	3.71	B-757	3.88	3.90
DUAL WH-75		3.57	B-767	3.9	3.89
DUAL WH-100		3.53	DC-10-10	3.64	3.80
DUAL WH-150		3.24	DC-10-30	3.38	3.54
DUAL WH-200		3.25	DC-10-30Belly		2.88
DUAL TAN-100	3.68	4.55	B-747-200	3.7	3.53
DUAL TAN-200		3.73	B-747-SP		3.66
DUAL TAN-300		3.34	B-777-200A	N/A	4.21
DUAL TAN-400		3.14	B-777-200B		4.21
			B-777-200C		3.97

- Wheel spacing and tire width obtained from LEDFAA
- The standard deviation is assumed as 77.5 cm.

Stress Analysis of Conventional FAA Design Method

- Westergaard Critical Edge Stresses
- Pickett and Ray's Influence Charts
- Analysis of B-777 Airplanes
  - Unduly Conservative

$$\pm_e = \frac{P}{h^2}\left[RC0 + RC1\times\ln(\alpha) + RC2\times(\ln(\alpha))^2\right]$$

- Only Applicable to U.S. Customary System

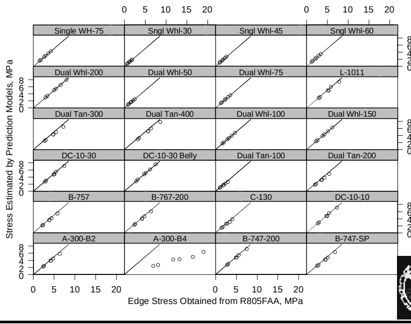
Estimation of Critical Edge Stress

$$\pm_e = \pm_{we} * R_1 * R_2 * R_3 * R_4 * R_5 + \pm_{ce} * R_T$$

- σ_{we} : Westergaard edge stress
- R_1 : Gear configurations adjustment factor
- R_2 : Finite slab size adjustment factor
- R_3 : Concrete shoulder adjustment factor
- R_4 : Widened outer lane adjustment factor
- R_5 : Second layer adjustment factor

(Ref: Lee, et al., 1997)

Verification of the Stress Prediction Models



Conversion of Different Aircraft Types and Departures

- **Conversion Factors**
  - Conversion to equivalent annual departures of the design aircraft
  - "Arbitrary and Unverified" (Ahlvin 1991, p. 10-9) $\log R_1 = \log R_2 \times \sqrt{\frac{W_2}{W_1}}$
- Cumulative Damage Factor (CDF) in LEDFAA
  - Conversion is no longer necessary

Fatigue Relationship and Thickness Design Criteria (1)

- **Conventional FAA Design Procedure**
- Basic Thickness
- Design Factor = 1.3 $\pm_e = \frac{S_c}{1.3 * 0.75}$
- Fatigue Relationship $h = \left[\left(RC0 + RC1\times\ln(\alpha) + RC2\times(\ln(\alpha))^2\right)\times\left(\frac{P}{\pm_e}\right)\right]^{0.5}$

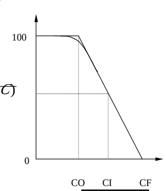
$$RH = \begin{cases} 1 + 0.15603 * (\log(C) - 3.69897) & \text{if } C > 5000 \\ 1 + 0.07058 * (\log(C) - 3.69897) & \text{if } C < 5000 \end{cases}$$

Fatigue Relationship and Thickness Design Criteria (2)

- **LEDFAA's Basic Fatigue Relationship**
- Rollings and Witczak(1990)
  - Structural Condition Index (SCI;100~0)

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

$$DF = 0.4783 - 0.2913 * \log(C80)$$



- Interior Stress of Layered Elastic Theory
  - A scaling factor of 0.753 is applied to reduce the conservatism of the basic fatigue relationship in the current LEDFAA method

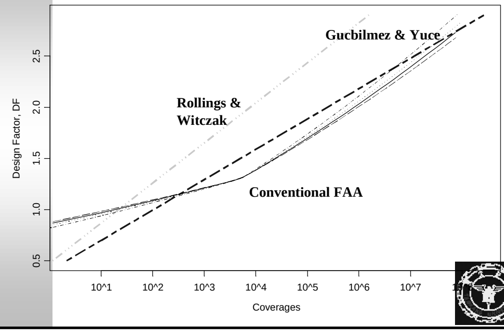
Fatigue Relationship and Thickness Design Criteria (3)

- **Gucbilmez and Yuce's Fatigue Relationship**
- Re-analyzed Corps of Engineers Full-size Test Data
- Westergaard edge stress
- DF = S_c / (0.75 * σ_e)

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

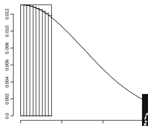
$$DF = 0.40289 + 0.29644 * \log(C80)$$

Comparison of Fatigue Relationships



Investigation of Tentative Modification Alternatives

- P/C Concept Assumed:
  - Effect: the edge of a tire at 0 = the tire centerline at 0
  - 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
- Very crude & conservative application of CDF
- Prediction model for stress reduction due to D_o effect



Re-analyze Corps of Engineers Full-size Test Data

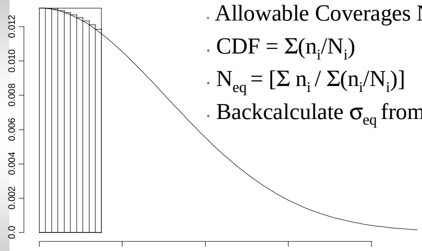
- Fatigue Relationships developed for CO, CI & CF

Tentative Fatigue Equations	SSE	R^2	N
DF = 0.4561 + 0.2928*log(CO)	0.108	0.822	24
DF = 0.3470 + 0.3013*log(CI)	0.125	0.818	36
DF = 0.1760 + 0.3119*log(CF)	0.122	0.775	24
DF = 0.3171 + 0.2894*log(PO)	0.114	0.804	24
DF = 0.2124 + 0.2953*log(PI)	0.131	0.800	36
DF = 0.0338 + 0.3074*log(PF)	0.127	0.755	24

- Similar to Gucbilmez and Yuce's Equation

Determination of Equivalent Stress Factor

- **Equivalent Stress Factor (f_3)**
- Equivalent Damage Effect
- Cumulative Fatigue Damage $\Sigma(n_i/N_i)$
- Stress Prediction Models $\sigma_e = \sigma_{we} * R_1 * R_4$
  - σ_{we}: Westergaard edge stress
  - R_1: Gear configurations adjustment factor
  - R_4: Widened outer lane adjustment factor
- DF = S_c / (0.75 * σ_e)



- Assumed aircraft pass n_i
- Allowable Coverages N_i
- CDF = $\Sigma(n_i/N_i)$
- $N_{eq} = [\Sigma n_i / \Sigma(n_i/N_i)]$
- Backcalculate σ_{eq} from N_{eq}

Item	f_3	Item	f_3	Item	f_3	Item	f_3
A1.60	0.808	K2.100	0.859	U1.60	0.819	72	0.912
B2.66L	0.826	N1.86	0.840	E-6	0.872	73	0.901
B1.66L	0.796	N2.86	0.809	M-1	0.873	1-C5	0.833
C2.66S	0.826	O1.106	0.862	M-2	0.892	2-DT	0.873
C1.66S	0.795	O2.106	0.830	-	0.810	3-DT	0.883
D1.66	0.796	P1.812	0.835	59	0.887	2-C5	0.834
E2.66M	0.835	P2.812	0.806	60	0.856	4-DT	0.865
E1.66M	0.806	Q1.102	0.865	61	0.873	3-200	0.892
F1.80	0.835	Q2.102	0.833	62	0.888	4-200	0.891

- Gucbilmez and Yuce (1995)
- Assuming $1.273(\pi a^2) = 1.6 (W_t)^2$

Alternative Deterioration Relationship

- Equivalent Design Factor (EDF) = $S_c / (0.75 * \sigma_e * f_3)$

Tentative Fatigue Equations	SSE	R^2	N
EDF = 0.6421 + 0.2920*log(CO)	0.119	0.793	24
EDF = 0.5266 + 0.3037*log(CI)	0.136	0.792	36
EDF = 0.3697 + 0.3086*log(CF)	0.134	0.735	24
EDF = 0.5056 + 0.2879*log(PO)	0.125	0.771	24
EDF = 0.3911 + 0.2976*log(PI)	0.142	0.774	36
EDF = 0.2319 + 0.3032*log(PF)	0.140	0.712	2[illegible]

Proposed Fatigue Relationship

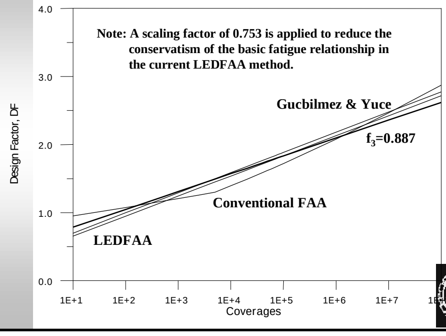
$$SCI = \frac{100*\log(C) - 324.044*EDF + 119.799}{0.184217*EDF - 1.00098}$$

$$EDF = 0.5900 + 0.2952*\log(C80)$$

$$DF = f_3*[0.5900 + 0.2952*\log(C80)]$$

- C80 is the coverages to reduce the pavement SCI from 100 to 80
- C is the coverage level at which the SCI is to be calculated

Comparison of Fatigue Relationships



Implementation of the Proposed Approach

- Application of the P/C & CDF Concept
- Prediction Models for Critical Edge Stress
- Application of Equivalent Stress Factor (f_3)
- Alternative Fatigue Relationship
- On-going Development of a User-friendly Computer Program Using VB5.0

Conclusions (1)

- Reexamined the P/C Concept
- Proposed and Verified the Stress Prediction Models
  - Dimensionally Correct: Metric and English Systems
  - Other features: finite slab size, second layer, curling, etc.
- Identified the Problems and Difficulties for the Conversions of Aircraft Types and Departures
- The CDF Concept Should Be Used
- Investigated Various Fatigue Relationships & Thickness Design Criteria

Conclusions (2)

- A scaling factor of 0.753 is applied to reduce the conservatism of the basic fatigue relationship in the current LEDFAA method
- Reanalyzed the Corps of Engineers traffic data
- Introduced an equivalent stress factor (f_3) & EDF
  - f_3 factor decreases when tire width (W_t) increases
- Proposed an alternative fatigue relationship
- On-going Implementation of a User-Friendly PC Program

Acknowledgments

- Research work was sponsored by National Science Council, Taiwan, Republic of China
- Very Precious Literature and Comments by:
  - Mr. Gordon F. Hayhoe, Galaxy Scientific Corporation
  - Mr. Richard G. Ahlvin, US Army Corps of Engineers, Waterways Experiment Station

THANKS FOR YOUR ATTENTION!

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