Study on Effects of Nonlinear Temperature Distribution and Slab Thickness on Thermal Stress of Airport Concrete Pavement

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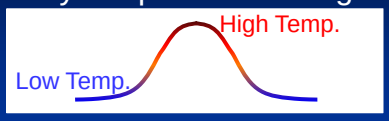
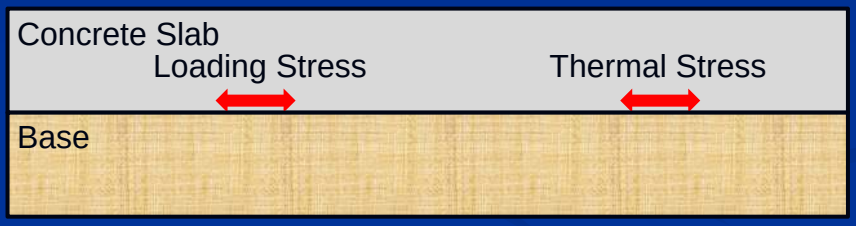
Background

Aircraft gear load

Daily temperature change





Design of airport concrete pavement in Japan (until 2008) is empirical design method based on U.S. PCA method.

loading stress: stress at slab center is calculated.
thermal stress:
fatigue damage: considered by Safety Factor (1.7 – 2.2).

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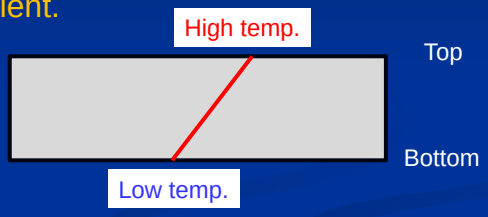
Background

Westergaard (1927)

Theoretical thermal (warping) stress equation for linear temperature gradient.

$$\sigma = \frac{E\alpha}{2(1-\nu)}\theta$$



Thermal stress σ increases with temperature difference θ.

σ: thermal stress
θ: temperature differential between top and bottom
E, α, ν: property of concrete

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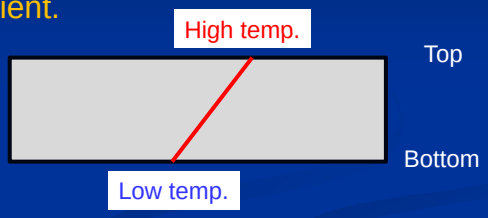
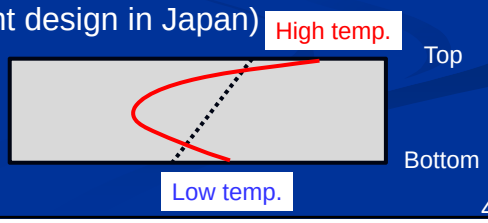


Iwama (1964)

Practical thermal (warping and internal) stress equation for nonlinear temperature distribution (used for road pavement design in Japan)

$$\sigma = 0.7\frac{E\alpha}{2(1-\nu)}\theta$$



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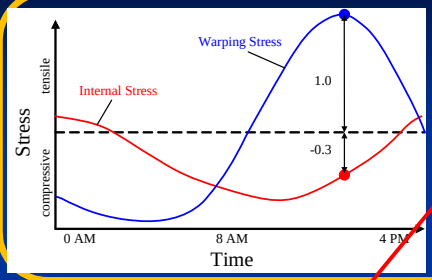
Background



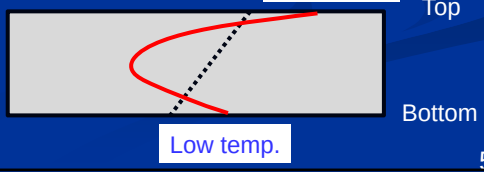
Iwama's Observation

Internal stress tend to be -30 % of daily maximum warping stress for 20 and 25 cm thickness

Iwama (1964)

Practical thermal (warping and internal) stress equation for nonlinear temperature distribution (used for road pavement design in Japan)

$$\sigma = 0.7 \frac{E\alpha}{2(1-\nu)}\theta$$



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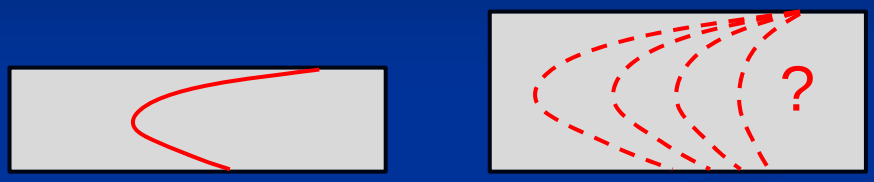
Objective

Can the coefficient 0.7 be used for thicker airport pavement ?
Is nonlinearity of temperature distribution same ?



Road concrete pavement (20-30cm)

Airport concrete pavement (30-50cm)

Coefficient = 0.7

Coefficient = ?

Practical thermal stress equation for thicker airport concrete pavement

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Contents

1. Observation of 42cm thick concrete pavement
   Temperature and strain were measured for 1 year.

2. Relationship between warping stress and internal stress
   Thermal stress equation for 42cm slab thickness was developed.

3. Relationship between thermal stress and thickness
   By means of heat balance analysis, temperature distributions and thermal stress of various thicknesses are estimated.

4. Comparison of thicknesses

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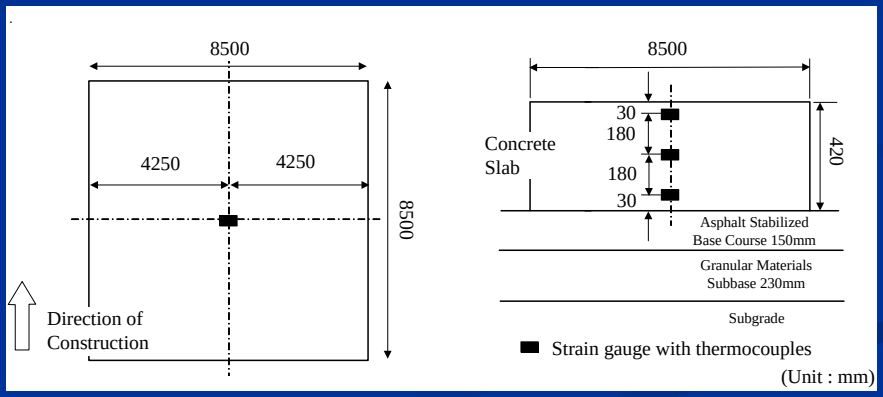
Observation of Experimental Pavement

Slab Size — length 8.5m, width 8.5m, thickness 42cm
Measurement — strain and temperature at slab center every hour for one year.



Plan Section

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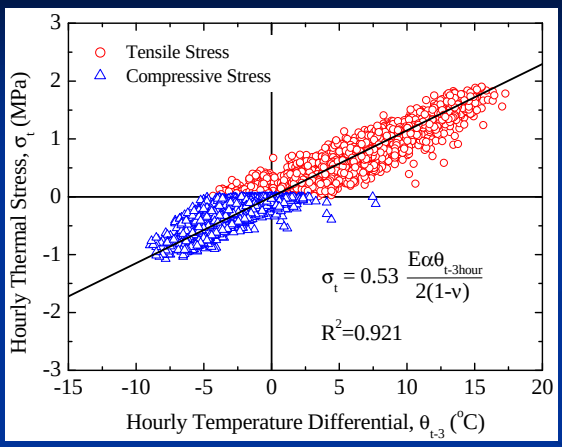
Thermal Stress Equation (42cm thick)



Coefficient is 0.53 for a slab 42cm thick.

The coefficient is smaller than 0.7 for 20 and 25cm

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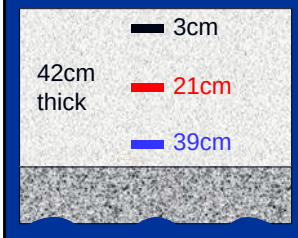
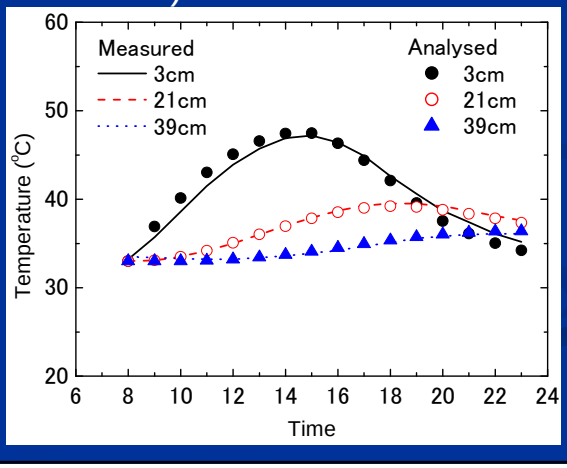
Heat Balance Analysis

Temperature distribution in various slab thicknesses was estimated through heat balance analysis (heat conduction, heat transfer, solar radiation are considered in 2D FEM).





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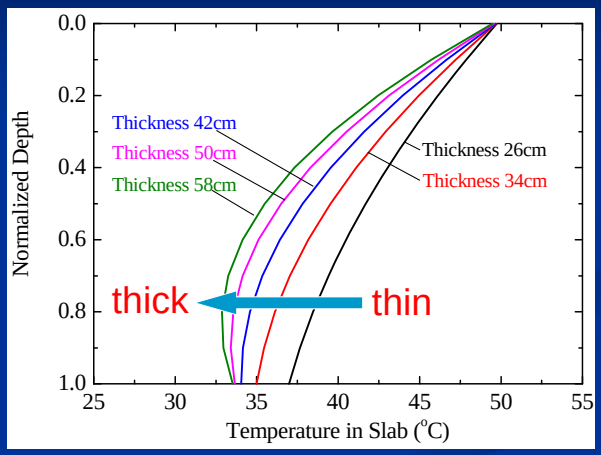
Temperature Distribution in Various Slab Thicknesses



Top

Bottom

Nonlinearity of temperature distribution increased along with slab thickening.

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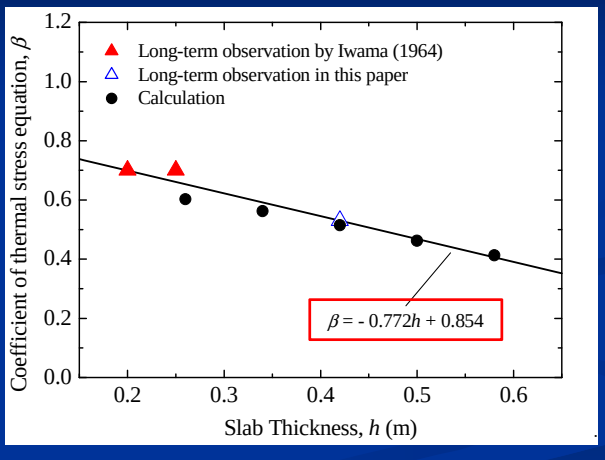
Practical Thermal Equation

$$\sigma = \beta \frac{E\alpha}{2(1-\nu)}\theta$$



The coefficient tended to decrease with an increase in slab thickness.

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Comparison of Thicknesses

Design of Airport Concrete Pavement in Japan was revised based on this research results.
Previous design method : Empirical method
Current design method : Mechanistic-Empirical method

	Design coverage (traffic volume)		
	10,000	20,000	40,000
Previous	42 cm		
Current	39 cm	41 cm	43 cm

Previous design method
Slab thicknesses are 42 cm in all cases because safety factors are same in 3 conditions.
Current design method
Slab thicknesses are 39 to 43 cm because safety factor is not used.

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Summary and Conclusion

(1) The coefficient of thermal stress equation decreases as the slab thickness increases because internal stress due to nonlinearity of temperature distribution across the slab is larger with increasing of slab thickness.

(2) We propose practical thermal stress equation for various thicknesses of slabs.

$$\sigma = \beta \frac{E\alpha}{2(1-\nu)}\theta \qquad \beta = -0.772 + 0.854h$$

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Thank you for your attention !

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