PCC Pavement Models in FAARFIELD - How Were They Determined?

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Acknowledgements

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- All determinations for the modeling in FAARFIELD and FEAFAA were decided by the FAA through the team works. The author present his explanations on the decisions. He also sincerely appreciates the discussions from many of his colleagues and friends.
- This presentation does not represent a standard, specification, or regulation, nor does it necessarily represent a methodology to be introduced into pavement design standards. The contents are for further discussions only.

OUTLINE

(1) Why was the "25%" LT reduction factor selected in FAARFIELD for PCC design?

(2) Why was a single slab, rather than multiple slabs, selected as the structural model for PCC pavement design in FAARFIELD?

(3) Why was the load induced critical stress in a flat slab, rather than the total stress in a curled slab, used as the failure indicator for PCC design in FAARFIELD?

Disagreements among the influential findings are presented for Discussions

What is right is more important than who is right. All efforts should be respected regardless.

(I) Why the "25%" LT reduction factor was selected in FAARFIELD for PCC design? Following report neglected or mis-understood some important researches under the FAA.

Report IPRF-01-G-002-05-2

JOINT LOAD TRANSFER IN CONCRETE AIRFIELD PAVEMENTS:

Evaluating the Effect of Concrete Slab Curling on Joint Load Transfer Responses

Transportation Research Record 2305

"Historically, FAA has not directly simulated the effects of slab curling and stress reduction from concrete pavement joints in structural analysis models used for pavement thickness design (*4, 5*)." "This research project was performed to support the ongoing development of advanced structural analysis tools for rigid pavement thickness designs and to evaluate critically the historical global 25% LT factor commonly used in airfield pavement thickness design." – copied from above report

(1) In theory, the slab thickness is determined by a design procedure as a whole system rather than as independent components including the calculated stress;

(2) In detail, the thickness is mainly controlled by the empirical factors A, B or a, b, c, d, Fs, … .

(3) LT=0.25 was selected because it had been used for long rather than it represents the load transfer capability for most joints in service. Other value of LT may lead to similar thickness by changing “A”

$$DF = \left[\frac{F_s' bd}{(1-\alpha)(d-b)+F_s' b}\right] \times \log C + \left[\frac{(1-\alpha)(ad-bc)+F_s' bc}{(1-\alpha)(d-b)+F_s' b}\right]$$

DOT/FAA/AR-09 David Brill

$$DF = \frac{R}{0.75 \times \sigma_e} = A \times Log\, C + B$$

Equation (19), Page 15

$$C = 10^{\left(\frac{DF}{A} - \frac{B}{A}\right)}$$

(II) Why a single slab, rather than multiple slabs, has been selected as structural model for PCC pavement design in FAARFIELD?

The multiple-slab model has disadvantages more than benefits in design procedure for airfield concrete pavements. The disadvantages include

(A) Time Consuming;
(B) More uncertainty of input data – joint stiffness;
(C) Static model under-estimate LT;
(D) Possible numerical instability by 3D model.

Different Opinions on Joint Stiffness

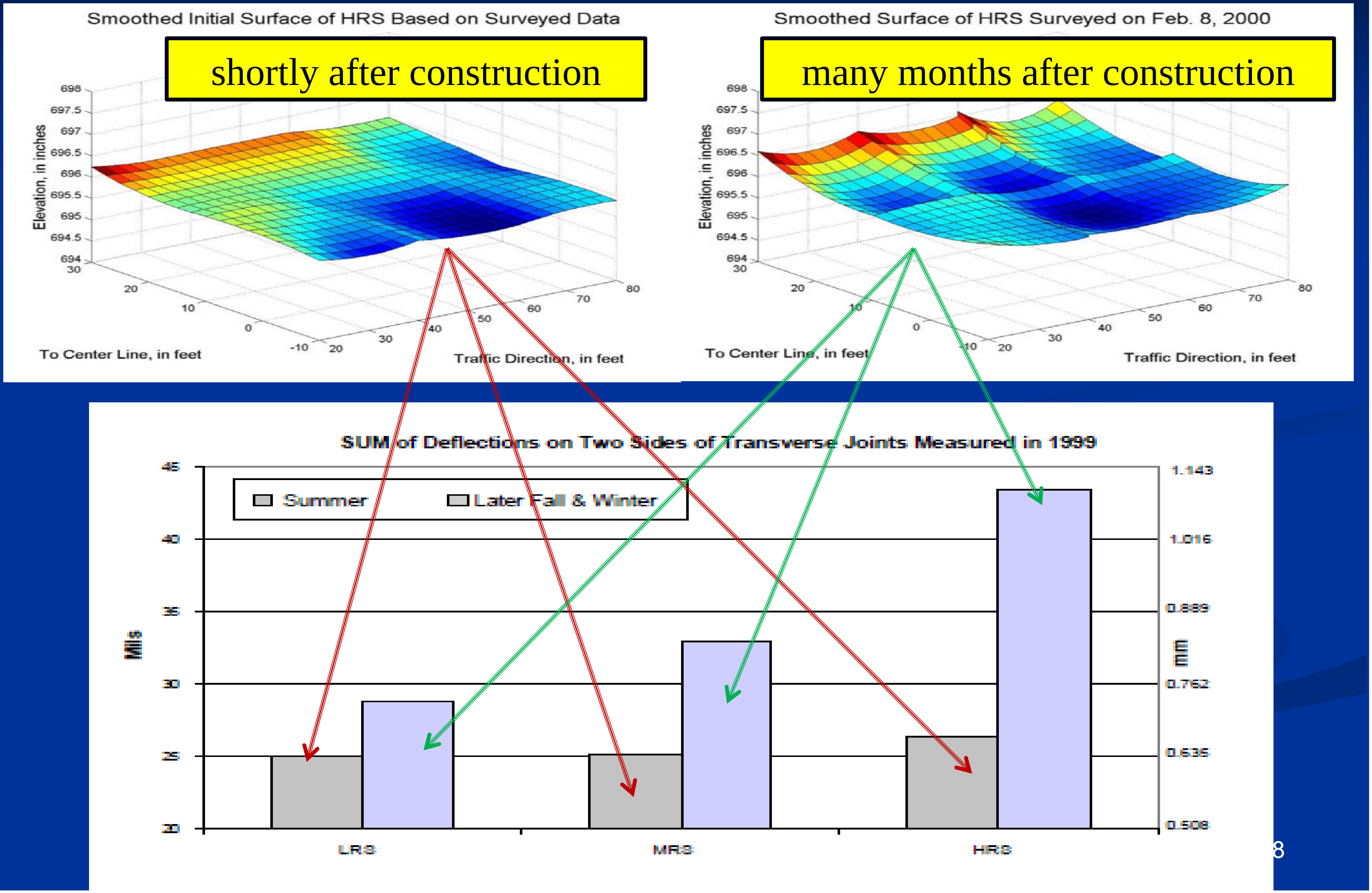
Report IPRF-01-G-002-05-2

JOINT LOAD TRANSFER IN CONCRETE AIRFIELD PAVEMENTS:

Christopher R. Byrum etc

- The report emphasizes that they successfully conducted **"Field Measurements of Joint Stiffness".** Unfortunately, joint stiffness is a parameter that **Can't be Measured as It is Defined.**
- Are the "back-calculated" joint stiffness **behavior of pavement** or **behavior of the model** ?
- **Single- and multiple-slab models are employed for PCC design by FAARFIELD (airport pavements) and AASHTO2004(highway pavements). Advantages and disadvantages of the two models are worth for further discussions**

How Was The Joint Behavior Discovered ?
Step One: Observations in Tests



Step Two: Observations in Tests were Proved by Theoretical and Logical Derivation (A)

Proof and Comments on Extensively Used Assumption in PCC Pavement Analysis and Evaluation

Edward H. Guo[1]

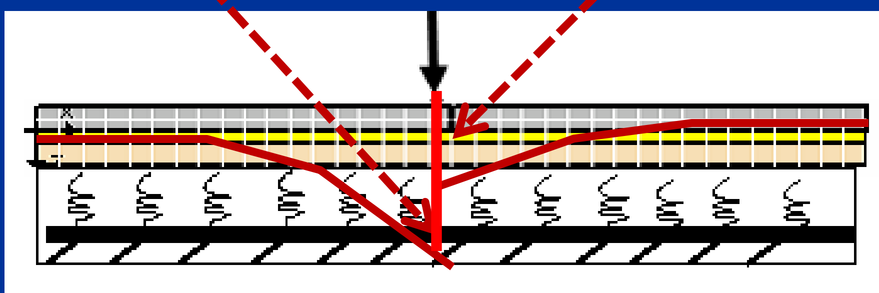
JOURNAL OF TRANSPORTATION ENGINEERING

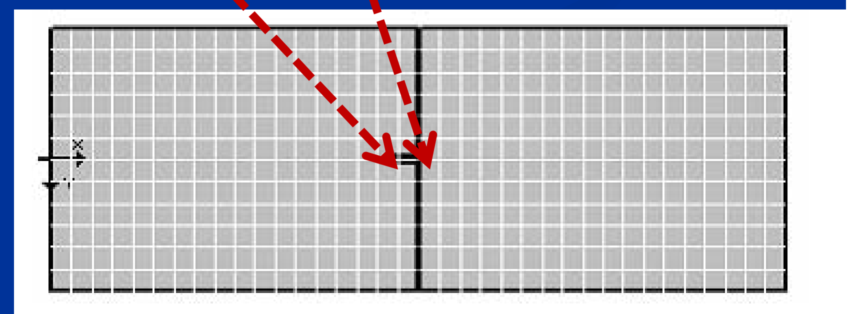
ASCE / MARCH/APRIL 2003 / 1

$$\delta_L + \delta_U = \delta_E \quad (1)$$

$$\frac{\delta_U}{\delta_L} \quad (2)$$

$$\sigma_L + \sigma_U = \sigma_E \quad (3)$$





- It was theoretically proved that for a joint of two flat slabs, the sum of responses on two sides of the joint is equal to the free edge response. For a joint of two curled slabs, the sum of deflections indicates degree of curling.

Step Two: The Test Results Were Verified by Theoretical and Logical Derivation (B)

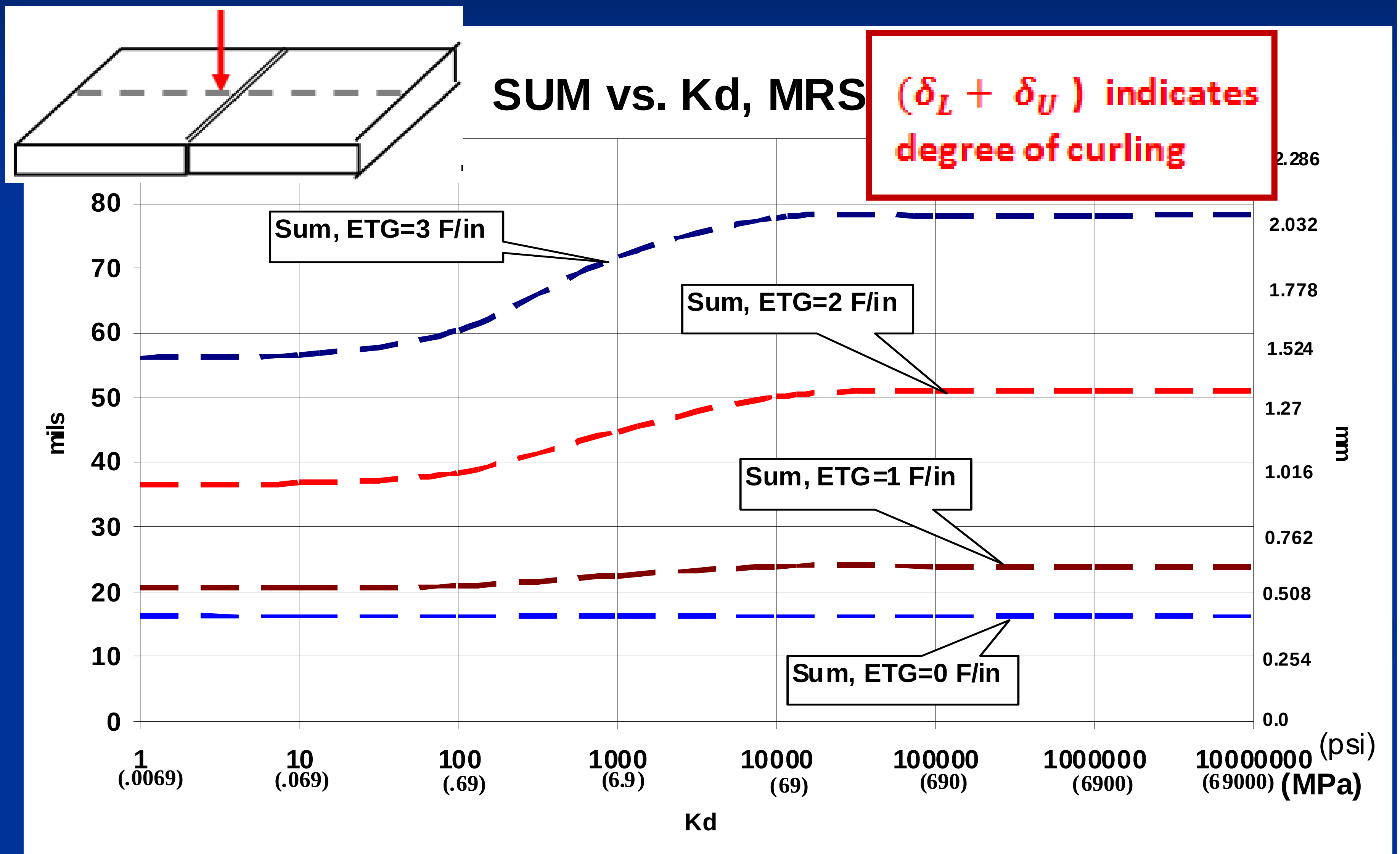
- Contribution of Dr. Crovetti (1994 & 1996) was the earliest one intending to use information of $(\delta u + \delta_L)$;
- Mis-understanding: Equation (1) is true for all pavements, flat and curled.

Crovetti, M.R.T, (1994) "Evaluation of Support Conditions Under Jointed Concrete Pavement Slabs," Nondestructive Testing of Pavements and Backcalculation of Moduli, ASTM STP.
Crovetti, James A (1996)"Field Evaluation of Support Uniformity Under Jointed Concrete Slabs", Presented in TRB 75th Annual Meeting, January 7 – 11, 1996, Washington D.C.

Guo, Edward H. and Wayne Marsey, 2001. "Verification of Curling in PCC Slabs at the National Airport Pavement Test Facility", 2001 ASCE Airfield Pavement Specialty Conference, Chicago, August 5 – 8.

Guo, Edward. H, & Mingyao Dong, 2003 "Evaluation Criteria Of A Computer Program For Pavement Response Analysis." Proceeding of International Conference on Highway Pavement Data, Analysis and Mechanistic Design Applications, Sep. 7-10, 2003

Step Three: The previous Two Steps Were Verified by Numerical Analysis by FEM



How Was the Model Simplified and Improved? Contribution of The Unified Joint Model

- Load transfer mechanism is "Shear". This is true not only for saw-cut joints, but also for doweled joints. **A dowel transfers load by bending but a doweled joint transfers load by shear.** The above concept was first provided by Dr. Ioannides in 1992 and the same idea was published by Dr. Huang in 1993.
- Above two publications in 1992 and 1993 offered two results to convert a doweled joint into an equivalent interlock joint. The difference in the results was 100% that could lead to different understandings on the dowel's main contributions. **Does the joint transfer a lot of forces or does it only minimize the capability of the LT between summer and winter to improve the pavement performance?**

The Difference of Two Results Made Us Headache

- FAA's team verified that the equations in Huang's book "Pavement Design and Analysis, page 194, 1993 was right..

Iaonnides. A etc, "Analysis and Design of Doweled Slab-on-Grade Pavement System", ASCE J. of Transportation Engineering, Vol. 118, No. 6, Nov/Dec, 1992

Huang, Y. "Pavement Analysis and Design", Prentice Hall, 1993

Brill, David R. and Edward H. Guo 2000. "Load Transfer in Rigid Airport Pavement Joints", Proceedings of the 26th International Air Transportation Conference, San Francisco, June 18-21, 2000

Why FEAFAA Does Not Use Model for Dowels?

- The model for multiple slabs was first studied by Skarlatos in 1949; Both saw-cut and doweled joint were used by Dr. Barenberg in FE program in 1978; The doweled joint model was significantly improved by Dr. Nishizawa in 1989; The first theoretically correct model for doweled joints in 2D FEM was finalized in 1992 by Edward Guo. In 2000, Dr. Khazanovich verified the reliability of the component model and installed it into Illislab 2000. It is still being used up to now.
- After the unified joint model was developed and proven reliable, only unevenly distributed dowels still need the component dowel model. The evenly distributed dowels are used in airport pavements. Therefore, no any FAA model now uses the dowel model.

Skarlatos, M. S. (1949). “Deflections and Stresses in Concrete Pavements of Airfields with Continuous Elastic Joints” Report AD 628501, US Army Engineer Ohio River Division Laboratories.

Tabatabaie, A.M, Barenberg, E.J, Smith, R.E, “Load Transfer System in Concrete Pavements”, Report FAA-RD-79-4, 1979.

Khazanovich, L, etc, “Application of ISLAB2000 for Forensic Studies”, Finite Element Modeling of Pavement Structures”, Proceedings edited by Shoukry, S, 2000.

Other Joint Studies Under the FAA
(A) Field Survey

- The finding of static model: a joint with higher LT (δU / δL) leads to lower critical stress on the loaded side of the joint. Survey data indicated that the higher values of LT (such as pavement with higher curling) do not always lead to better performance for airport pavements.
- 200 testing slabs (16 inches) in Runway 16L/34R, Denver Airport have continuously surveyed by WES since 1995. The values of LT were very low in winters and very high in summers. The section has been under heavy aircraft load more than sixteen years. Almost no typical longitudinal cracks have been observed at the transverse joints, including the saw-cut joints.
- Five airports were surveyed by myself, supported by the FAA to study the performances of doweled and saw-cut joints under the same conditions. Every four transverse joints, one was doweled and three were saw-cut. The joint related distresses at saw-cut joints were not always worse than the doweled joints.

Other Joint Studies Under the FAA
(B) Full Scale Tests and Dynamic Analysis

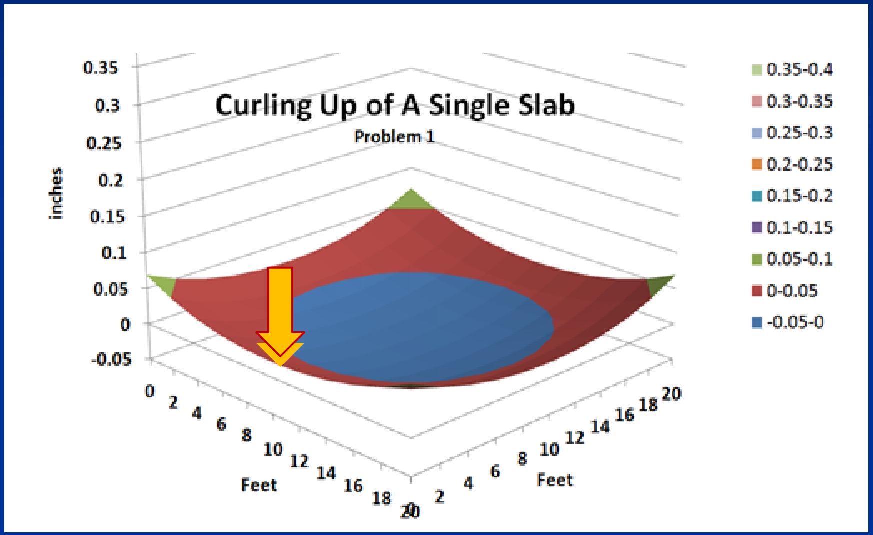
- Since 1999 the vehicle of NAPTF was put in service, FAA-SRA team has taken advantage of all concrete testing sections for understanding the responses and failure mechanism of joints, see related reports and papers for projects CC1, CC2, CC4, CC6.
- The LT capability was analyzed in detail by the team led by Dr. Y. Mehta, Rowan University, not only for FWD but also for static and slow moving loads by the vehicle.
- Dynamic model was used by Rowan and Tongji Universities and concluded that the LT under moving load is higher than under static loads

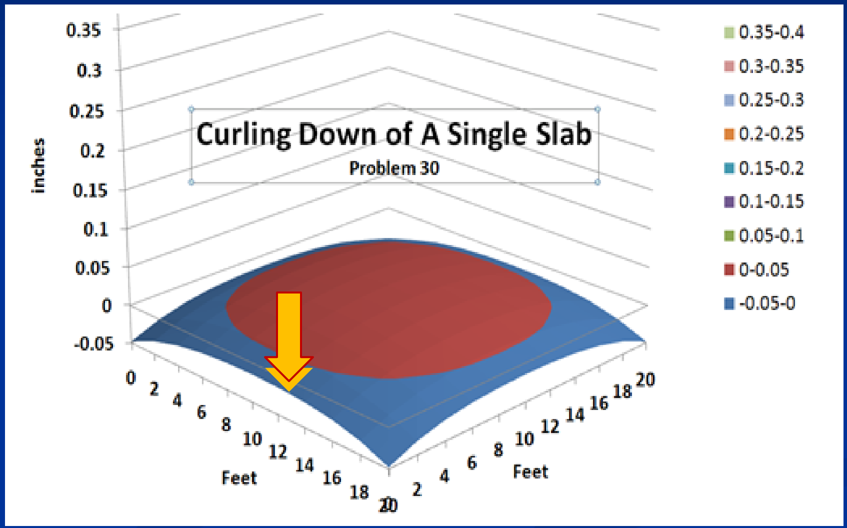
Joshi, A. P., Y. Mehta and D. Cleary: "A Study to Determine the Effect of Pavement Damping and Aircraft Speed on Stress-based Load Transfer Efficiency (LTE (S)) using 3D Finite Element Analysis" TRB Journal Issue, Aviation 2012, No. 2300,

(III) Why the load induced critical stress in a flat slab, rather than the total stress in a curled slab, has been used as failure indicator for PCC design in FAARFIELD?

The criteria for selecting "Failure Indicator" (I)

The load induced stresses are more stable than total stresses

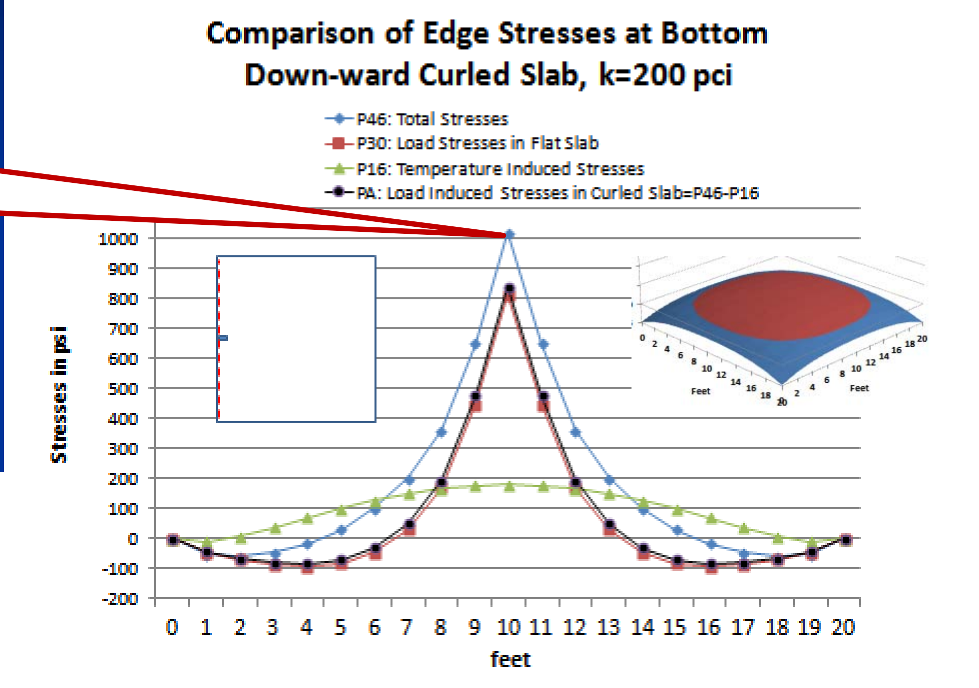


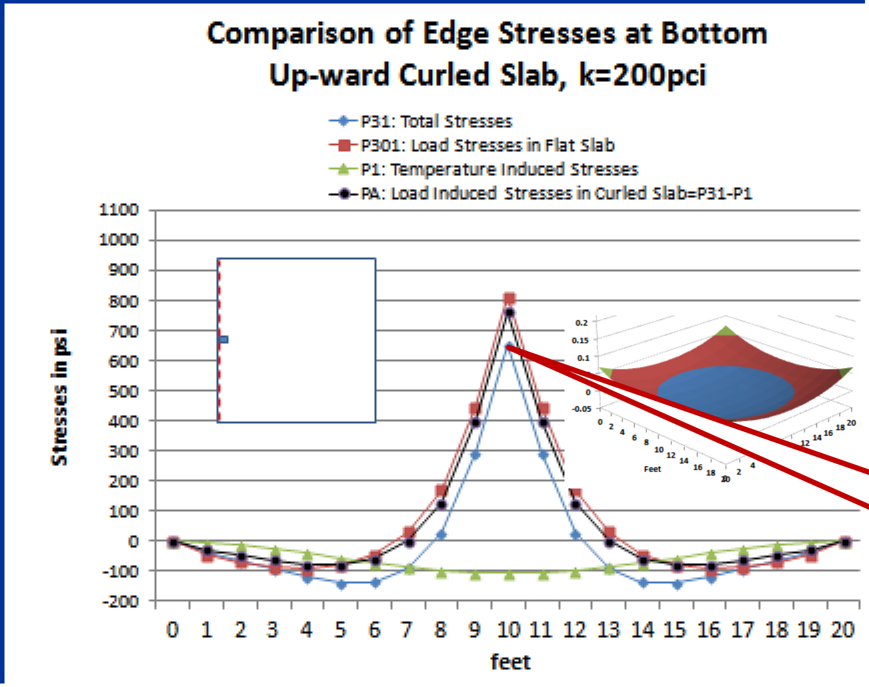


The critical stresses at bottom of a curled-up, curled down and flat slabs are relatively similar – the results are stable as failure indicator. The calculated total stresses for above three cases are significantly different.

The Load induced critical stresses are Similar (more stable) for curled-up, curled down and flat slabs

Total Stresses are Significantly different (>1000 psi for downward curled slab)



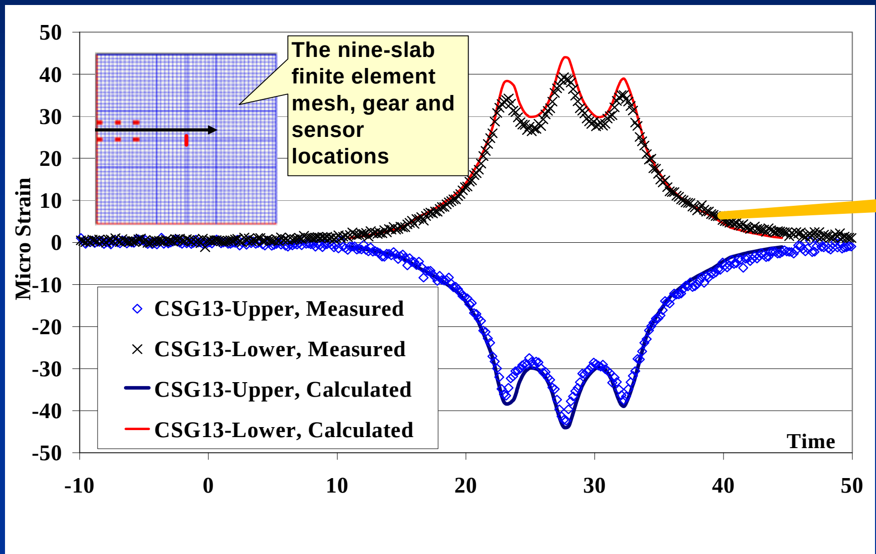


Dozens of cases have been calculated and the results are similar

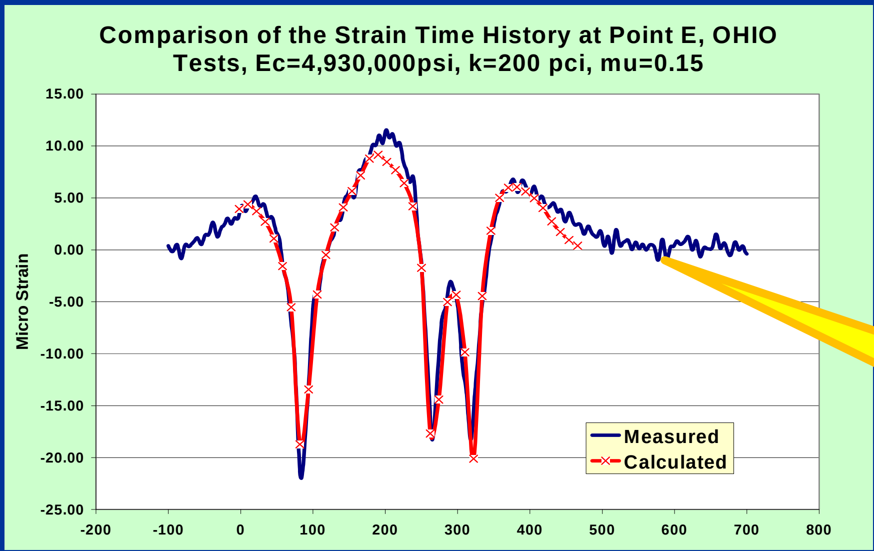
Total Stresses are Significantly different (650 psi for a upward curled slab

The criteria for selecting "Failure Indicator" (II)

The load induced stress is behavior of pavement



Tested By FAA's NAPTF



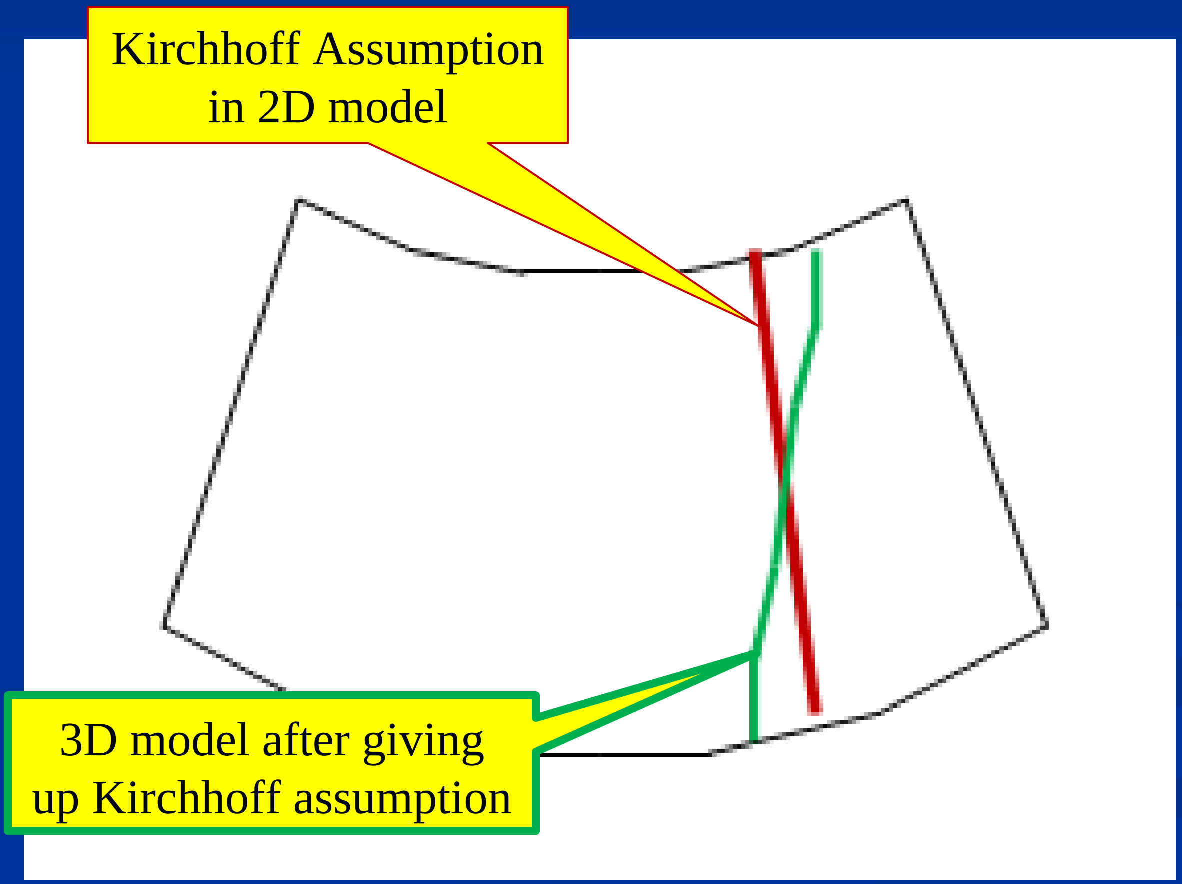
Excellent match between tested and calculated results for LOAD INDUCED STRESSES

Lack of similar verification for total stress

Tested By Univ. Ohio, Supported by FHWA

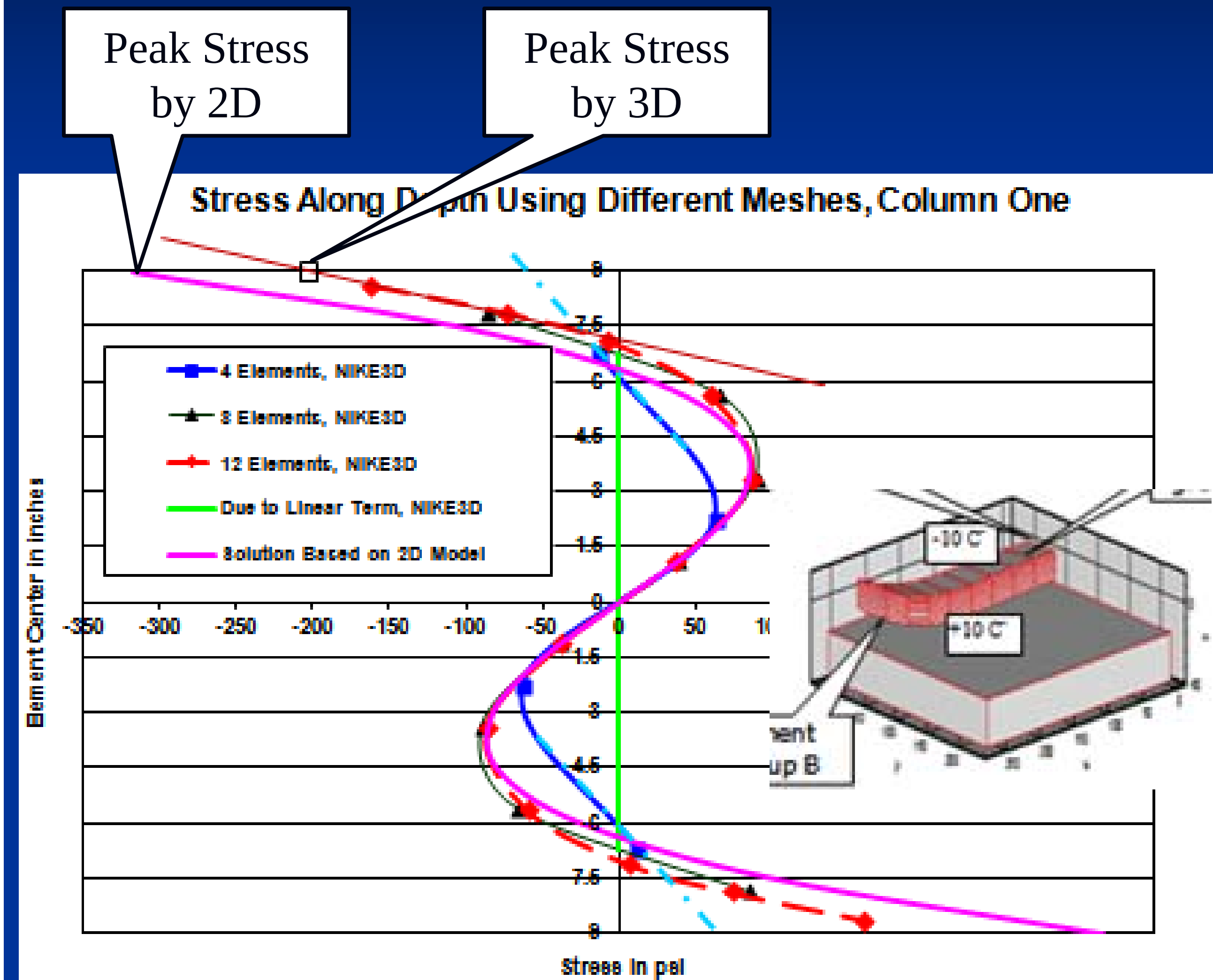
The Criteria for Selecting "Failure Indicator" (III)

The total Stress may be over-estimated by 2D Model due to its assumption. Or, accuracy of the 2D Results is still a pending problem from the view of mechanistic analysis



Difference between 2D (Khazanovich) and 3D (NIKE3D)

The peak stress by 2D could be 30% higher than that by 3D for 3rd T gradient.



Khazanovich, L. (1994), *Structural Analysis of Multi-Layered Concrete Pavement System*, Chapter 7, Ph.D Thesis, University of Illinois, at Urbana-Champaign.

Or

Ioannides, A. M. and Khazanovich, L. (1997), *Nonlinear Temperature Effects on Multilayered Concrete Pavements"*, Journal of Transportation Engineering, Vol. 124, No. 2, March/April, 1998.

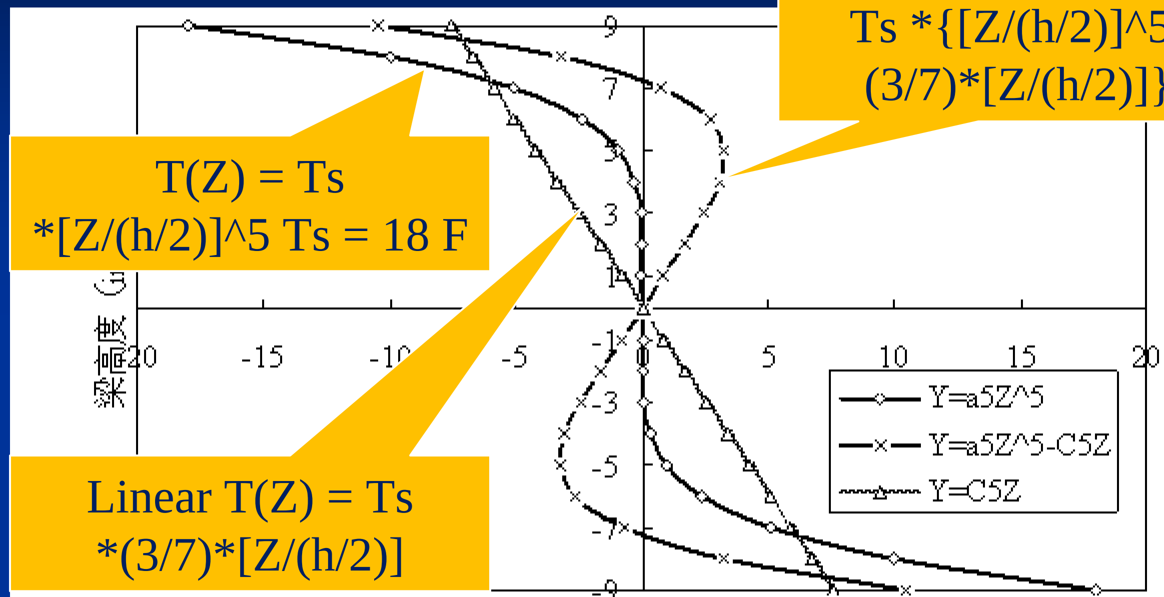
Double Check for Reliability of the Analysis

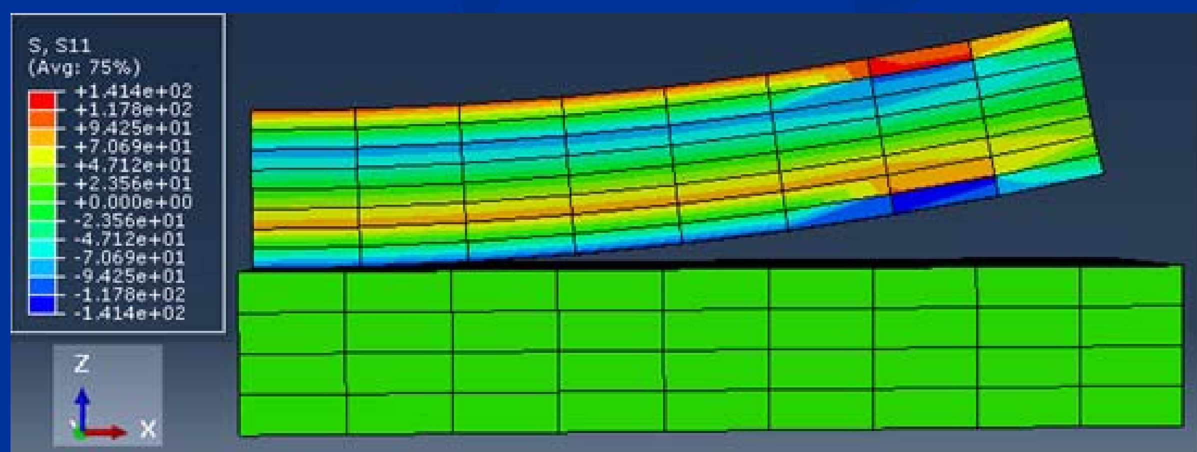
The Similar Problem was Analyzed Using ABAQUS (3D FEM) by HIT, China. The same conclusion was obtained.

Self Balanced T(Z) = Ts *{[Z/(h/2)]^5-(3/7)*[Z/(h/2)]}

T(Z) = Ts *[Z/(h/2)]^5 Ts = 18 F

Linear T(Z) = Ts *(3/7)*[Z/(h/2)]





Procedure for Reliability Verifications

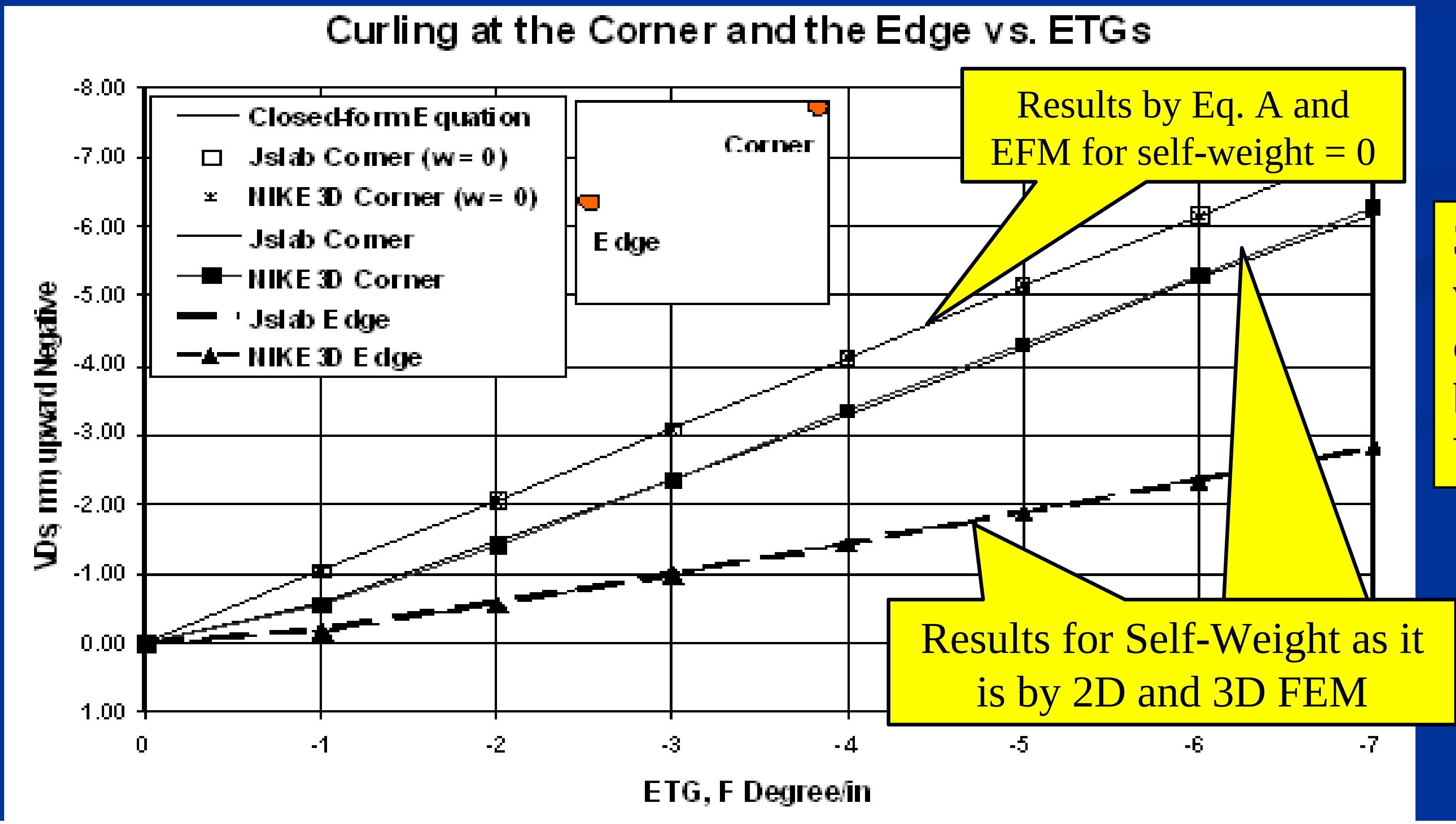
From Math and Physics by Multiple Models

$$\Delta_{Corner} = \frac{ETG \times \alpha \times L^2}{4}$$

$$\Delta_{Edge} = \frac{ETG \times \alpha \times L^2}{8}$$

Eq. A

Suprenant, Bruce A, and Discussion by R.E. Tobin, *Why Slabs Curl? Part I and II*, Concrete International March and April, 2002, discussion on October, 2002.



3D results were calculated by Dr. Qiang Wang

Conclusions (I)

(1) Different teams may have, and should have different considerations on development of a design procedure. No one is perfect. To learn from each other is necessary. This PPT shows some different ways in modeling PCC pavement for design;

(2) Any design procedure must be supported by fundamental theory to minimize the errors and to approach the goal for design. This PPT shows how the FAA-SRA team conducted the fundamental analysis, from theoretical to numerical;

(3) Both full scale tests and mechanistic procedure are powerful tool. To make the results valuable should include reliability verifications. This PPT shows how the reliabilities were checked by the FAA-SRA team in researches from 2000 to 2010;

Conclusions (II)

We want "pavement behavior" rather than "model behavior". Two most important sources:

(A) Tests in full scale and in Lab, plus field survey;

(B) The organized experiences of pavement engineers who are working on field;

“Leading is following in the footsteps of greater leaders”

The idea and results, rather than the name of authors, should be evaluated for finding truth

Thank You!