TOP-DOWN AND BOTTOM-UP CRACKING MECHANISM IN FAILURE STAGE TWO

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Outline

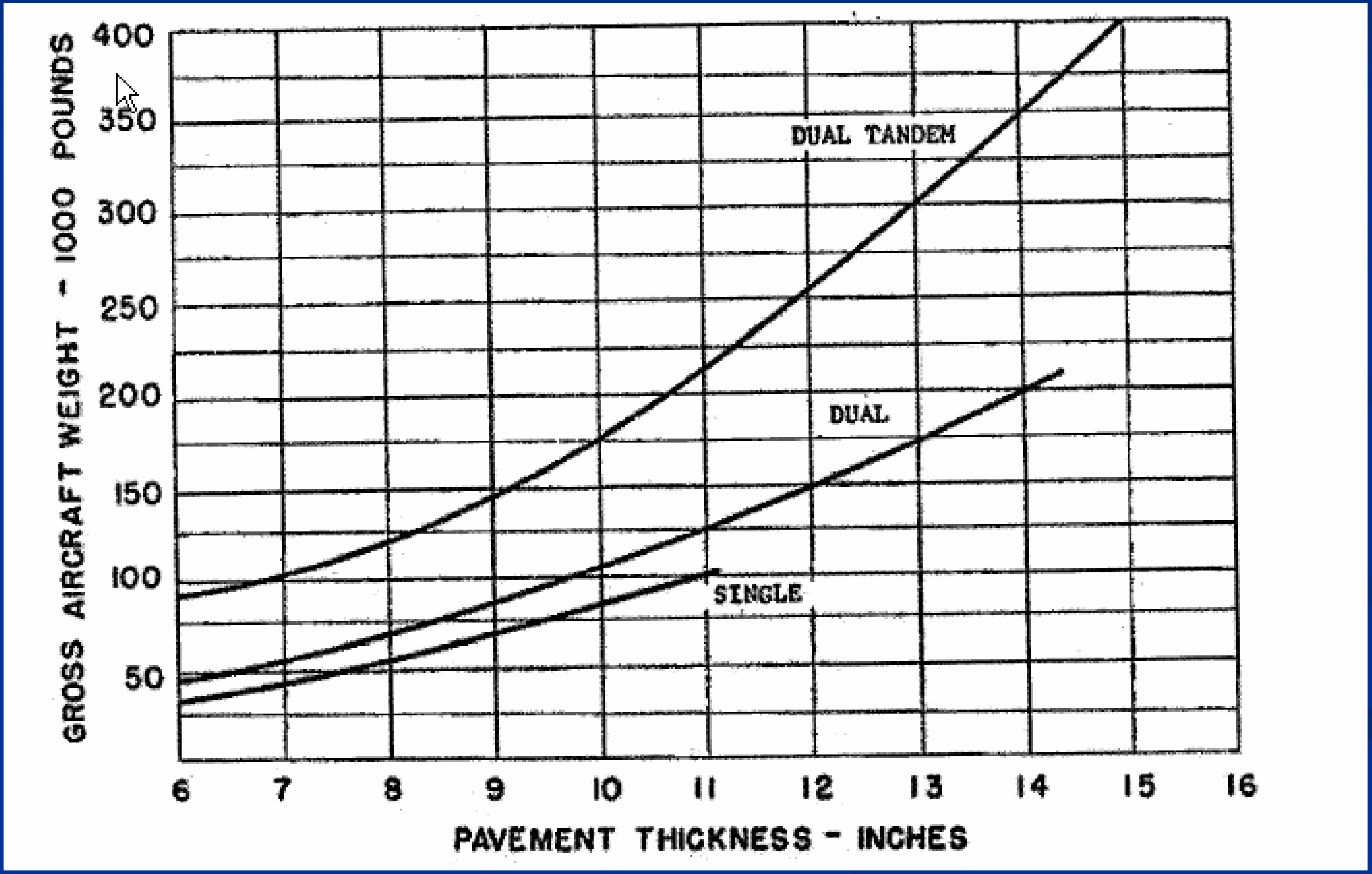
- (1) Why failure mechanism should be studied stage by stage?
- (2) Top-down crack mechanism
- (3) Bottom-up crack mechanism
- (4) Conclusions

Why Failure Mechanism Should be Studied Stage by Stage? – Review of the Development of Design Procedure

Stage One in History: Empirical Period

- Both FAA and FHWA procedures were based on full scale tests;
- Critical stress was not used as failure indicator under FHWA until M-E Model was introduced for AASHTO 2002;
- Critical stress was assumed as failure indicator under FAA in 1970´s. However, no performance parameter was used in design until 1986;

Example of Empirical Method Design Curve in 150/5320-6A, 1967



Example of Empirical Method

AASHTO Pavement Design Guide, 1986

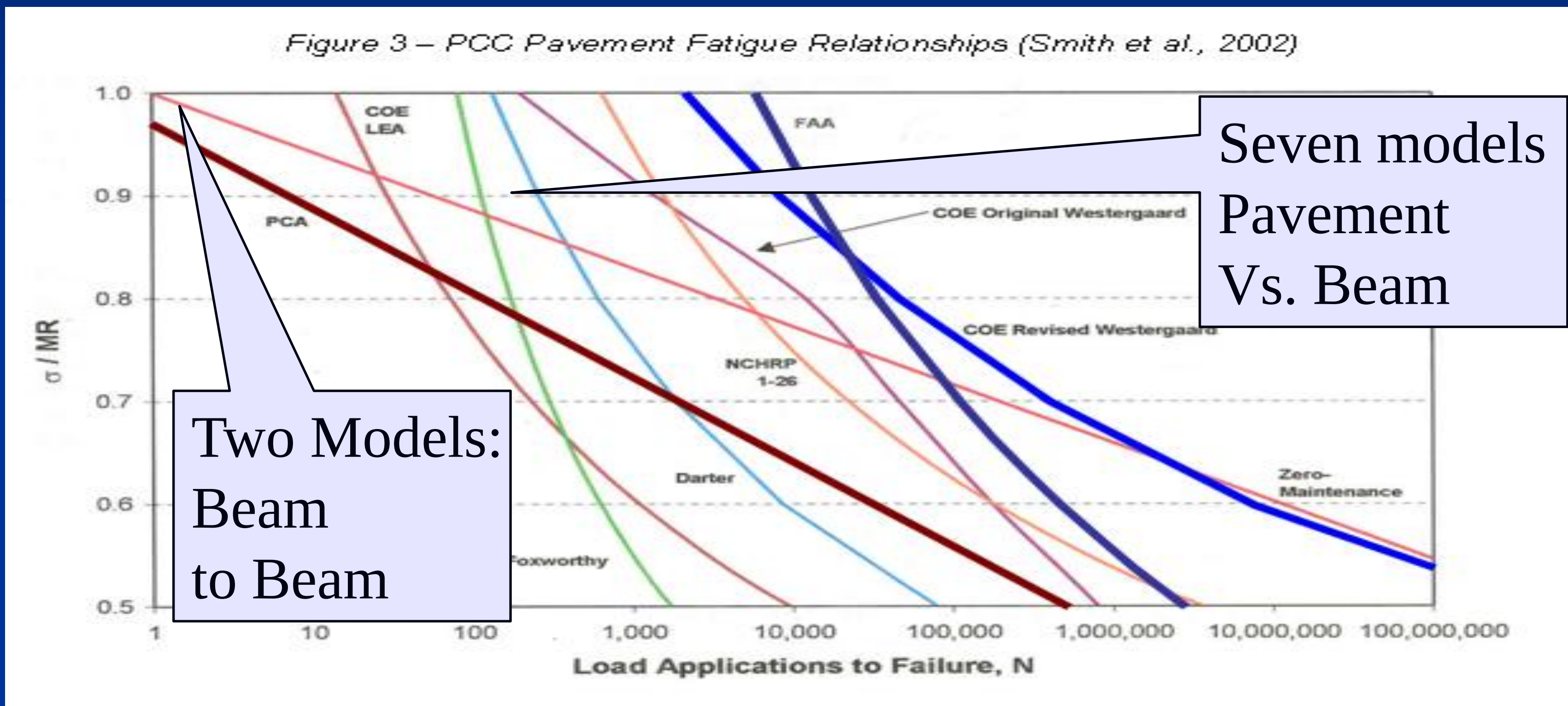
- Equations are developed based on data from following tests: Bate Experimental Road Tests, Illinois 1922; Road Test One, Maryland, 1950; WASHO Road Tests, 1952, Idaho, AASHO Road Tests, 1951, Illinois. 468 AC sections and 368 concrete sections.
- All traffic is equated to an equivalent 18 kips single axle load.
- **For AC pavement: One 50 kips single axle = 113 of 18 kips single axle**
- **For PCC pavement: One 50 kips single axle = 88 of 18 kips single axle**
- **Heavy vehicle was observed more damaging on AC than on PCC pavement. This was reliable finding.**

Stage Two: M-E Method

- Critical stress was found closely related to the damaging potential of a load;
- Stress ratio, not the stress itself, was used as failure indicator for design.

$$DF = \frac{\sigma}{MR}$$

Are used by all reviewed design models



The seven models are too far in "mechanistic" direction

FACTS AND QUESTIONS

- Stress is a parameter with many uncertainties;
- Beam and pavement are two different animals;
- Contributions of materials to pavement performance and life are from E, μ, R. R is the major one in calculation. Can the contribution of material be provided mainly by R of a beam?
- Are the seven models too far in "mechanistic" direction?

Calculated stress is not sensitive to value of E

$$\sigma = \alpha \frac{P}{h^2} \left(Ln(E) + Ln \frac{h^3}{100ka^4} + b \right)$$

Ln(4000000) = 15.2

Ln(5000000) = 15.4

Ln(6000000) = 15.6

Stress from measured strain is sensitive to value of E

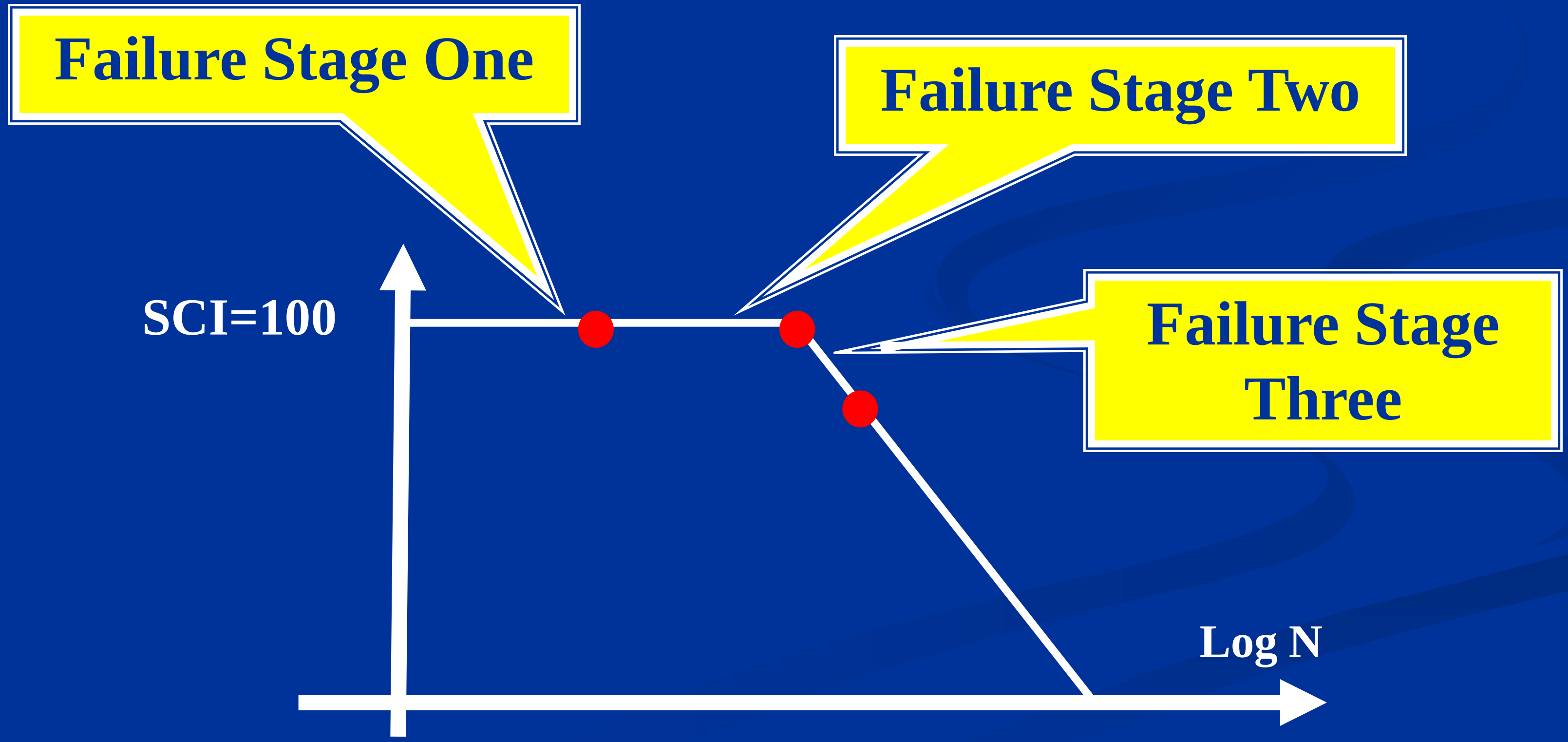
$$\sigma = E \times \varepsilon$$

"Three Stage Failure" Model Was Proposed based on Ray Rolling's Two Stage Failure Model

Rollings, R, 1988

"Design of Overlays for Rigid Airport Pavements," DOT/FAA/PM-87/

Witzack, 1976
Objective: to predict pavement future performance apart from only to determine thickness



Basic Concepts in Failure Models

$$C_F = f\left(\frac{R}{\sigma}, SCI, a_1, a_2, a_3 \ldots\right)$$

→ **FAARFIELD**

Special Case I

$$C_F = f\left(\frac{R}{\sigma}, a_1, a_2, a_3 \ldots\right)$$

Most Existing Models

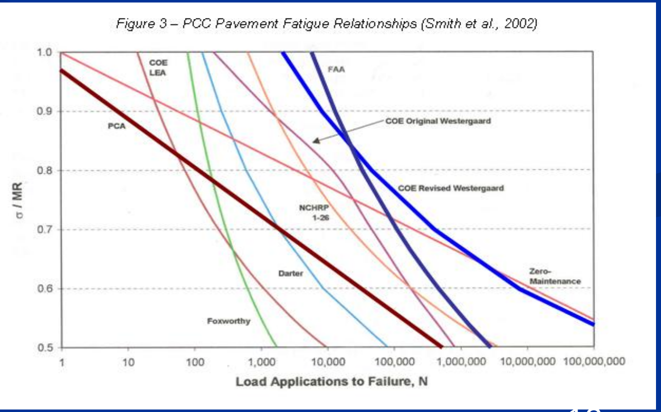
REFERENCES

Thuma, Richard G. 2002: "A comparison of Rigid Airfield Pavement Design Methods", Prepared for American Concrete Pavement Association.

Smith, Kurt. D, Jeffrey R. Roesler, John E. Naughton, 2002, "Review of Fatigue Models for Concrete Airfield Pavement Design", Prepared for American Concrete Pavement Association.

Thuma, Richard and James L. Lafrenz, 2003, "A Comparison of Rigid Airfield Pavement Design Methods", Proceedings of the Specialty Conference, Sept. 21-24, 2003, Las Vegas, Nevada, pp. 231-258.

Smith, Kurt. D, Jeffrey R. Roesler, John E. Naughton, 2003, "Review of Fatigue Models for Concrete Airfield Pavement Design", Proceedings of the Specialty Conference, Sept. 21-24, 2003, Las Vegas, Nevada, pp279-303



Special Case II. Full Scale Test, next page

$$C_F = f\,(SCI)$$

Construction Cycle 2: Trafficking Test Item MRS

$$C_F = f\,(SCI)$$

MRS
After
30,996 Passes

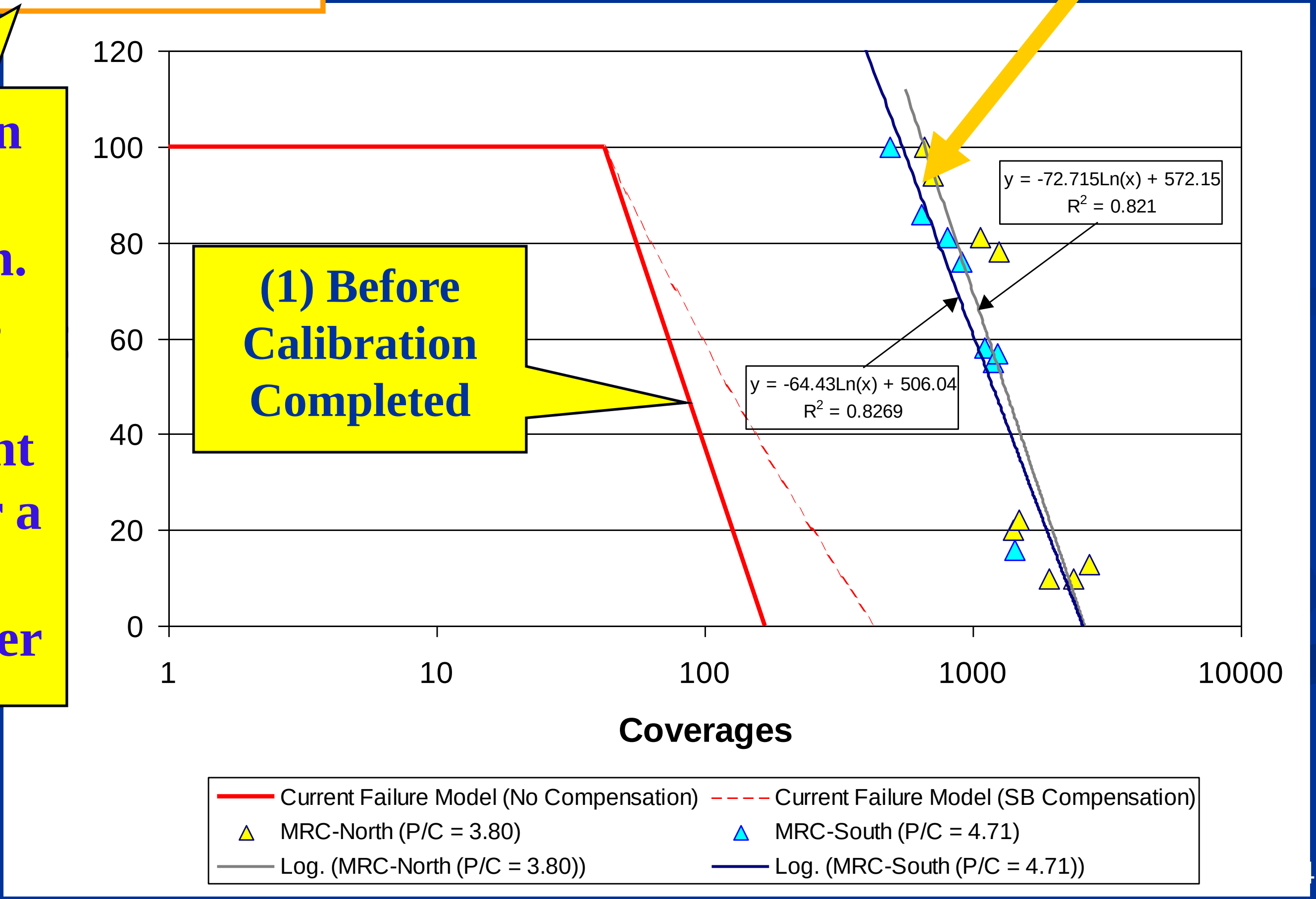
- 7/13/2004
- 7/14/2004
- 7/16/2004
- 7/19/2004
- 7/20/2004
- CS Corner Spall
- 7/21/2004
- ☆ Core
- 8/2/2004
- 8/5/2004
- 8/9/2004
- 8/11/2004
- 8/12/2004
- 8/16/2004
- 8/18/2004
- 8/20/2004
- 8/24/2004
- 8/26/2004
- 8/27/2004
- 8/31/2004
- 9/7/2004
- 9/9/2004
- 9/14/2004
- 9/21/2004
- 9/28/2004
- 10/5/2004
- 10/13/2004
- 10/29/2004
- 11/9/2004
- 11/16/2004
- 11/23/2004
- 12/02/2004
- 12/07/2004
- 12/14/2004

How to Improve the Model for Design Using the Data from Full Scale Tests?

$$C_F = f\left(\frac{R}{\sigma}, SCI, a_1, a_2, a_3 \ldots\right)$$

(2) The model in FAARFIELD after calibration. The model has capability to predict pavement performance for a given load repetition number

$$C_F = f\,(SCI)$$



Advantage of Full Scale Tests

- DF = Strength of Pavement / Stress in pavement; – The same animal
- All seven models

$$DF = \frac{Strength\ of\ Beam}{Critical\ Stress\ in\ pavement} = = \frac{R}{\sigma(E)}$$

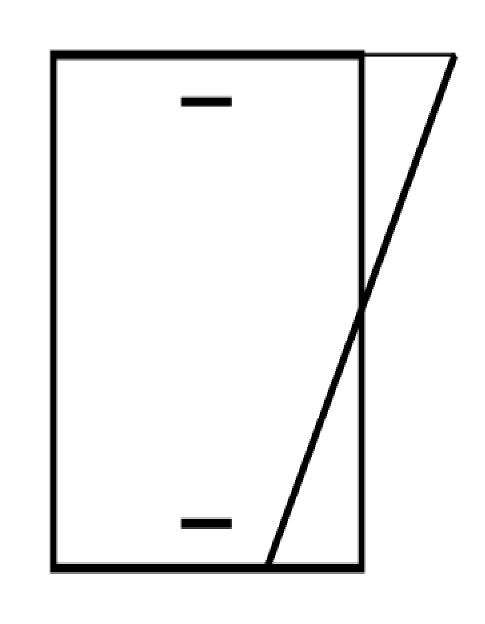
- Full Scale Test at NAPTF

$$DF = \frac{E \times \varepsilon\ (Pavement\ Cracking)}{E \times (Pavement\ under\ critical\ load)} = \frac{\varepsilon\ (Pavement\ Cracking)}{\varepsilon\ (Pavement\ under\ critical\ load)}$$

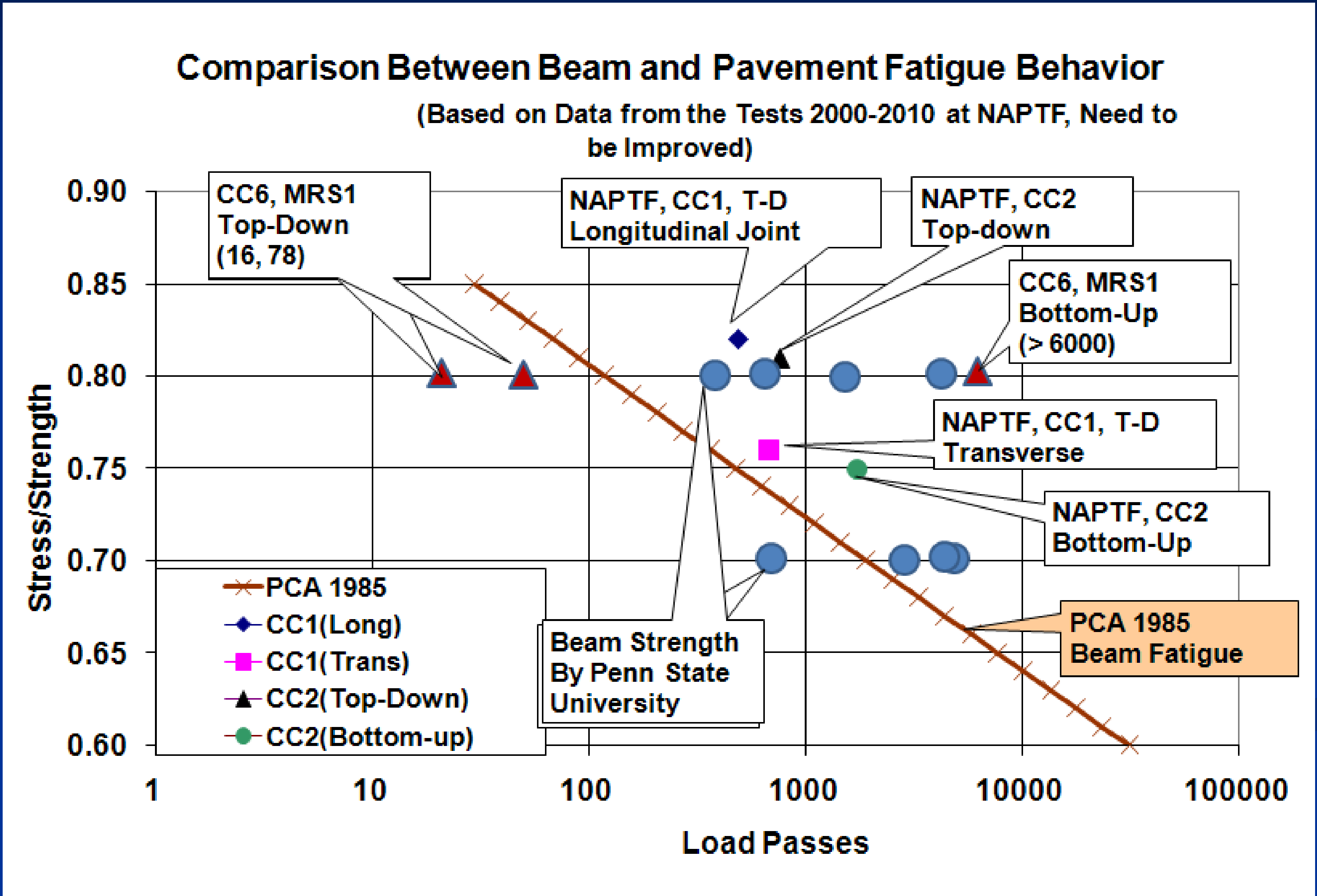
DF at the NAPTF is independent to E of concrete

More Advantages

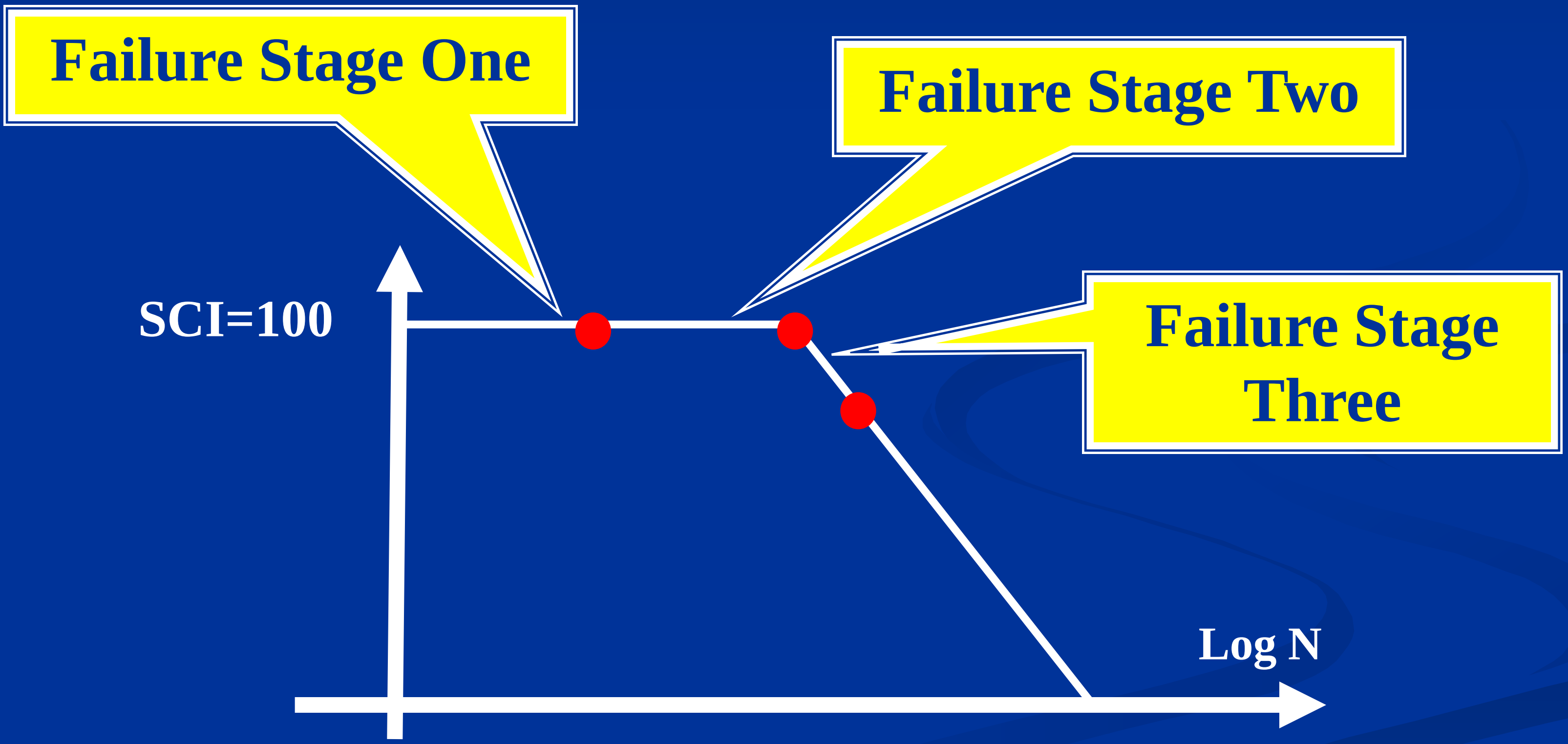
- Without measuring pavement strength, the DF not only will be affected by value E, but also affected by residual stress;
- After measuring pavement strength, the effects of residual stress will be minimized;
- The effects of interface friction might also be minimized



Pavement Fatigue Strengths



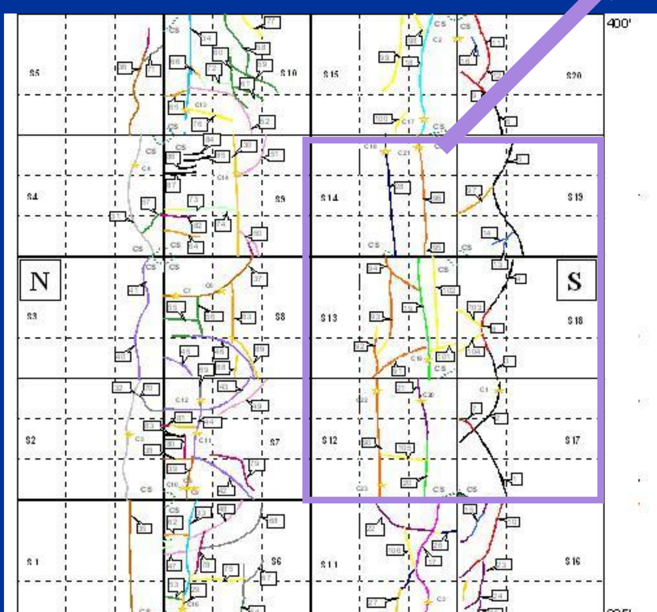
Summary of Three-Stage Failure

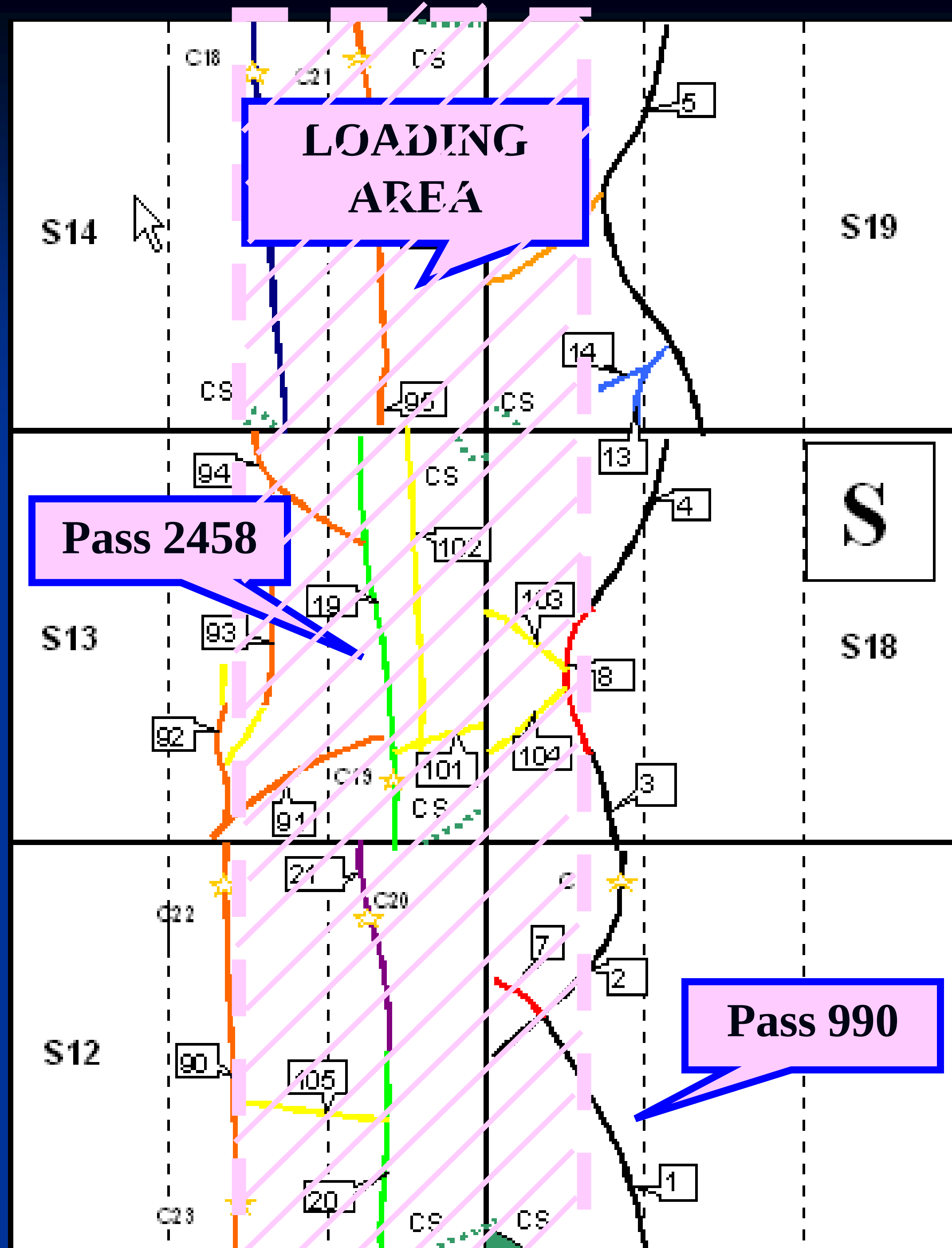


Top-down Crack Mechanism

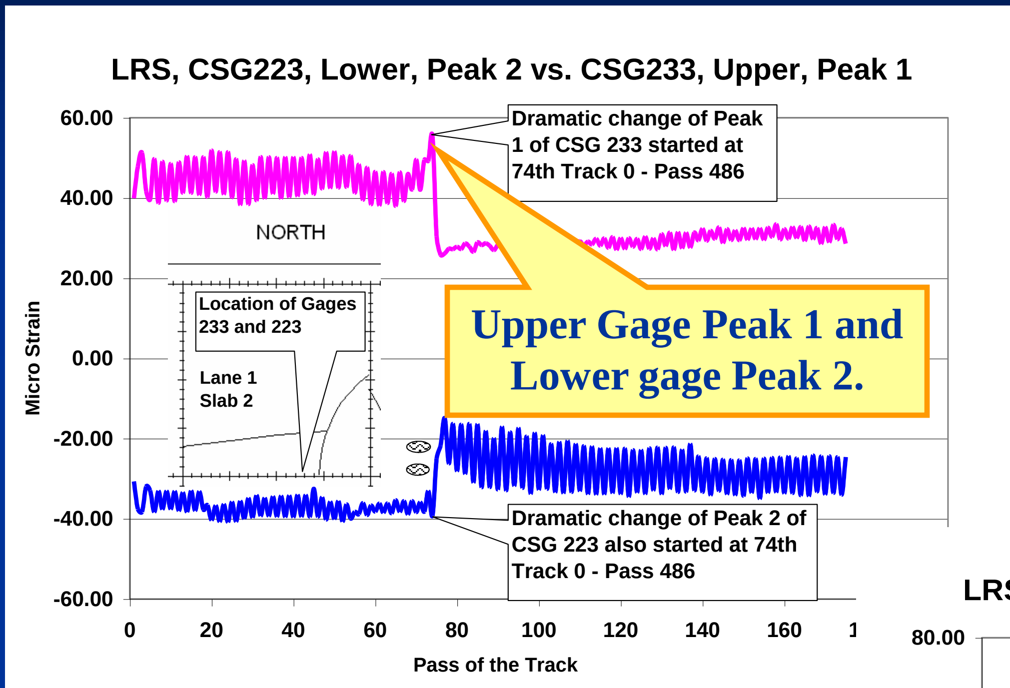
Mechanism: The means by which an effect is produced or a purpose is accomplished (copied from dictionary). The effects of top-down cracks on pavement failure process are discovered in full scale tests.

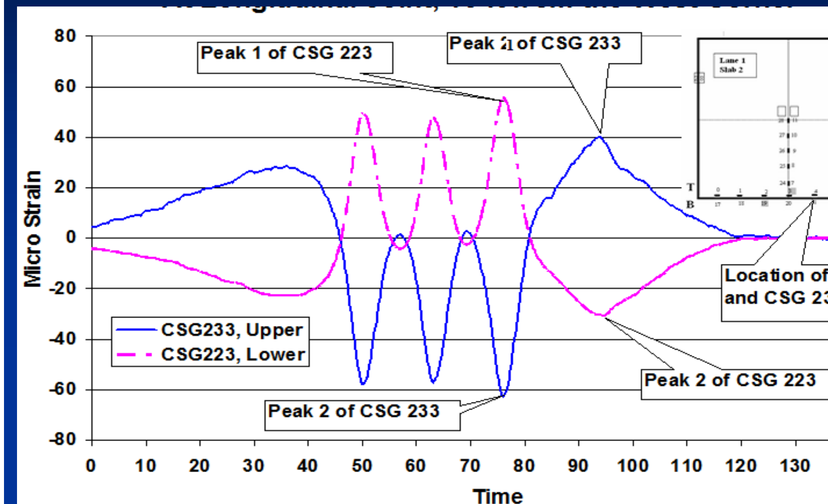
2004. 12” thick MRC, flat, top-down cracks were still observed earlier than the bottom-up cracks, even restricting the load on one side of longitudinal joint.

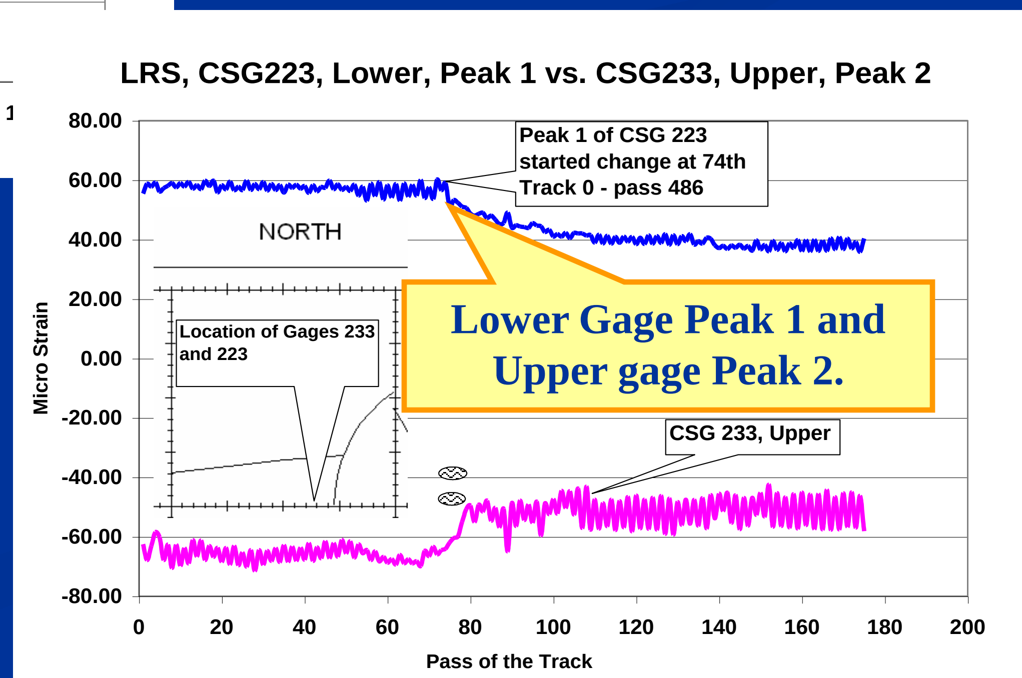




Measured Fatigue Failure, 2000, LRS (1)
Peak Histories of The Gages at Longitudinal Joint



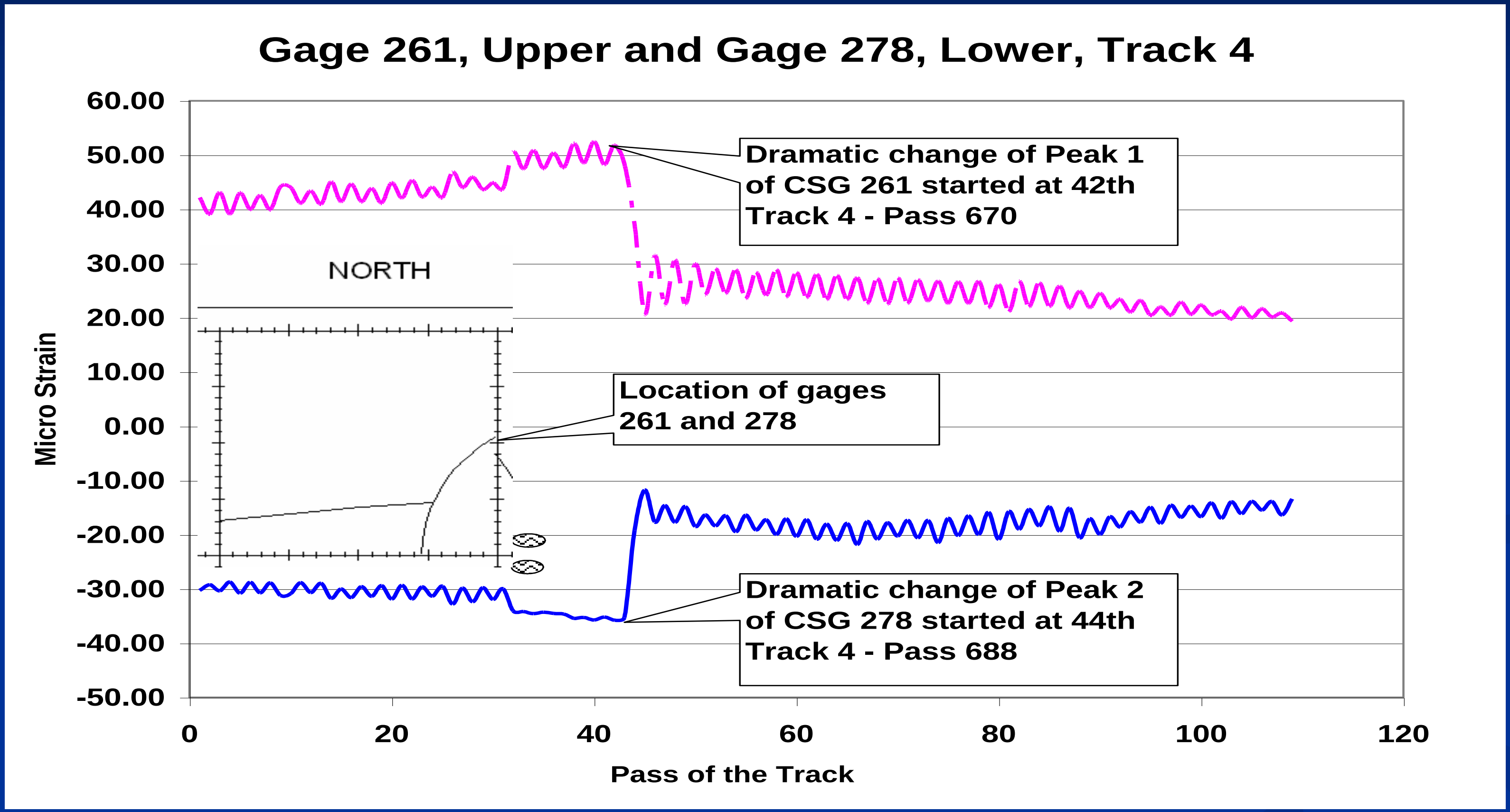




Comparison of the two figures indicates that Crack initiated from the surface, not from the bottom.

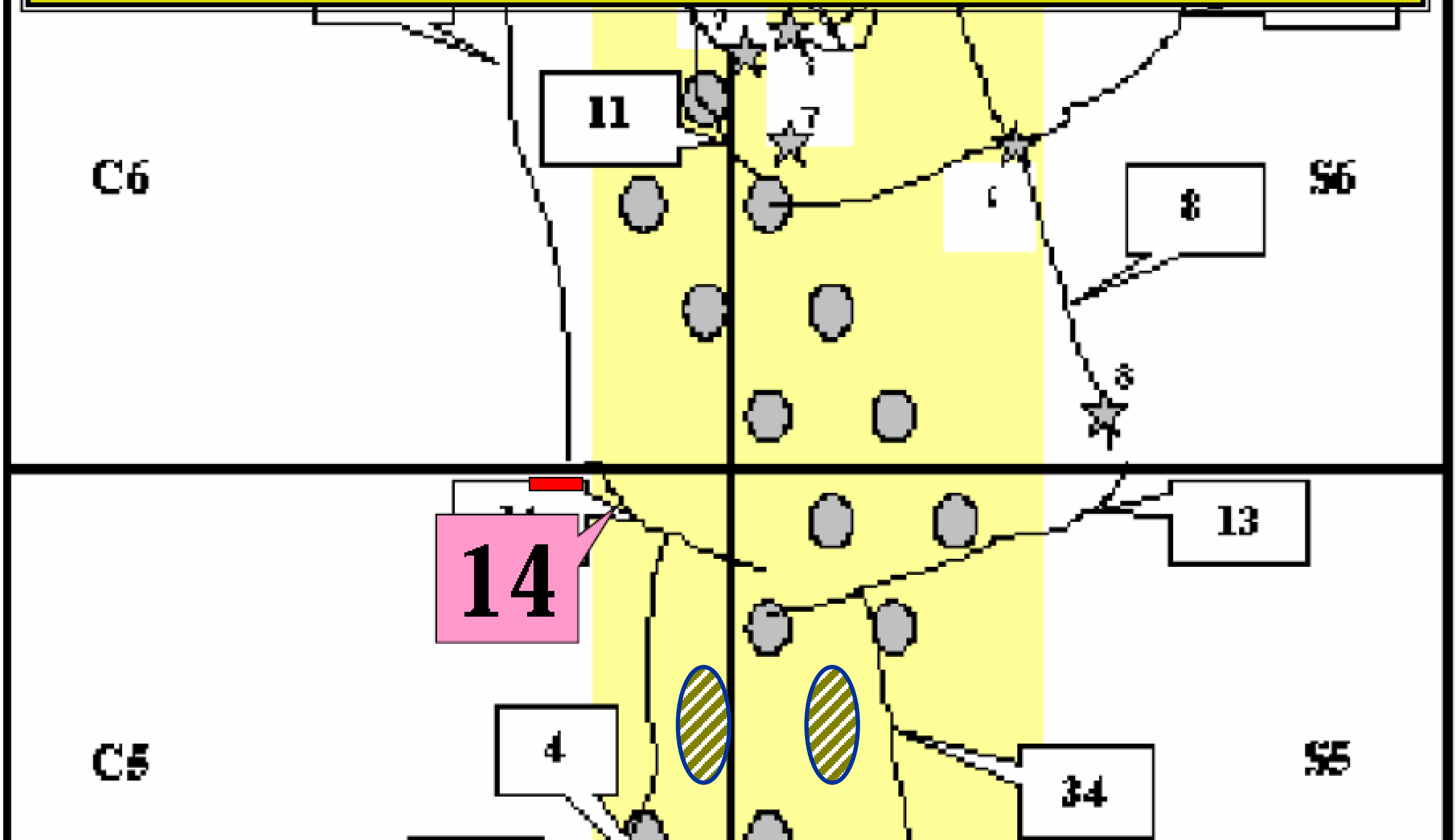
Measured Fatigue Failure, 2000, LRS (2)

Gages at Transverse Joint indicated the crack occurred later

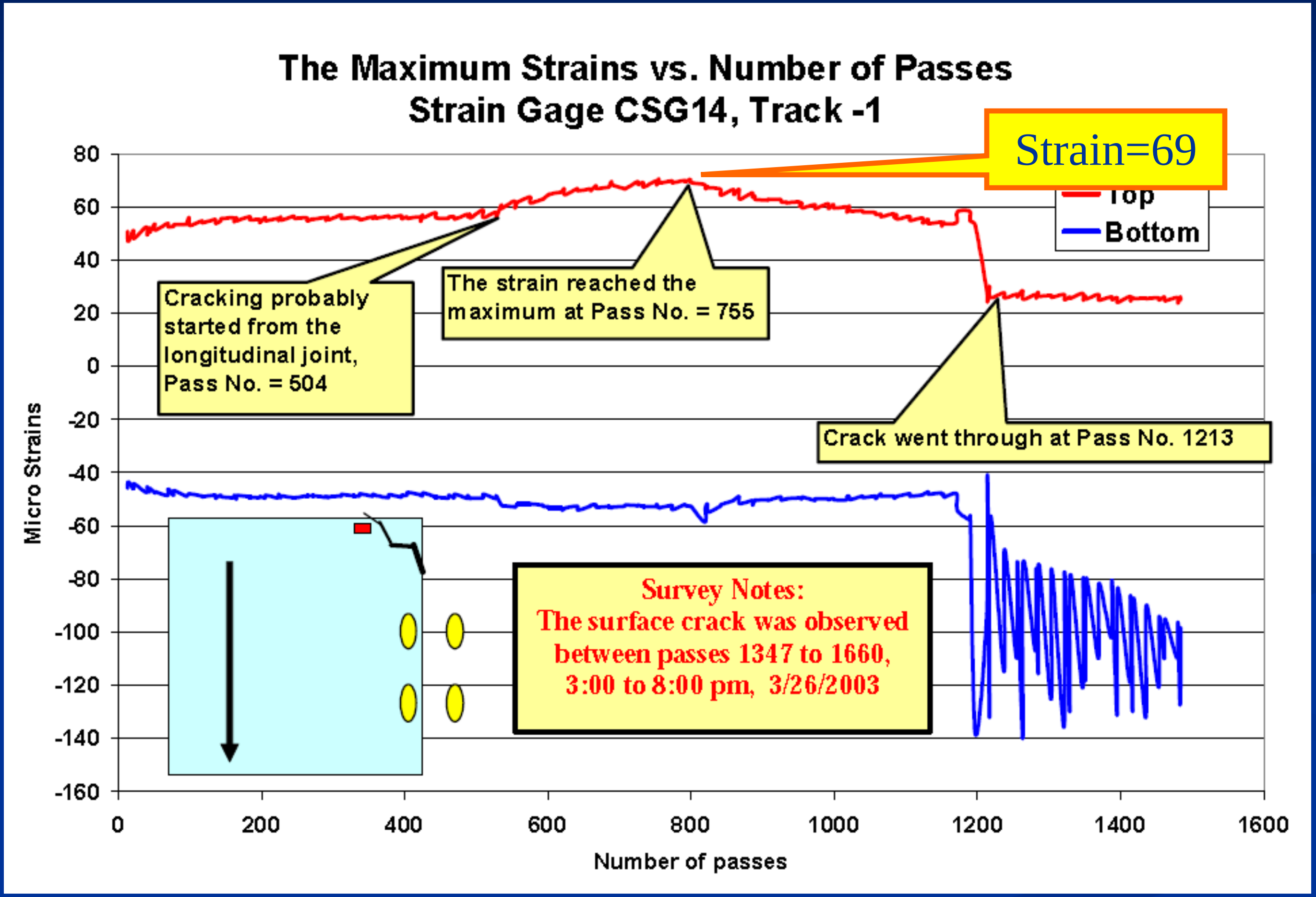


Notes: Appropriate definition of "pavement strength and pavement fatigue strength," Proof of data reliability and the way of showing the data are three necessary steps to accurately expose the mechanism embedded in the data.

History of The First Corner Cracking: Not Through the Sensor

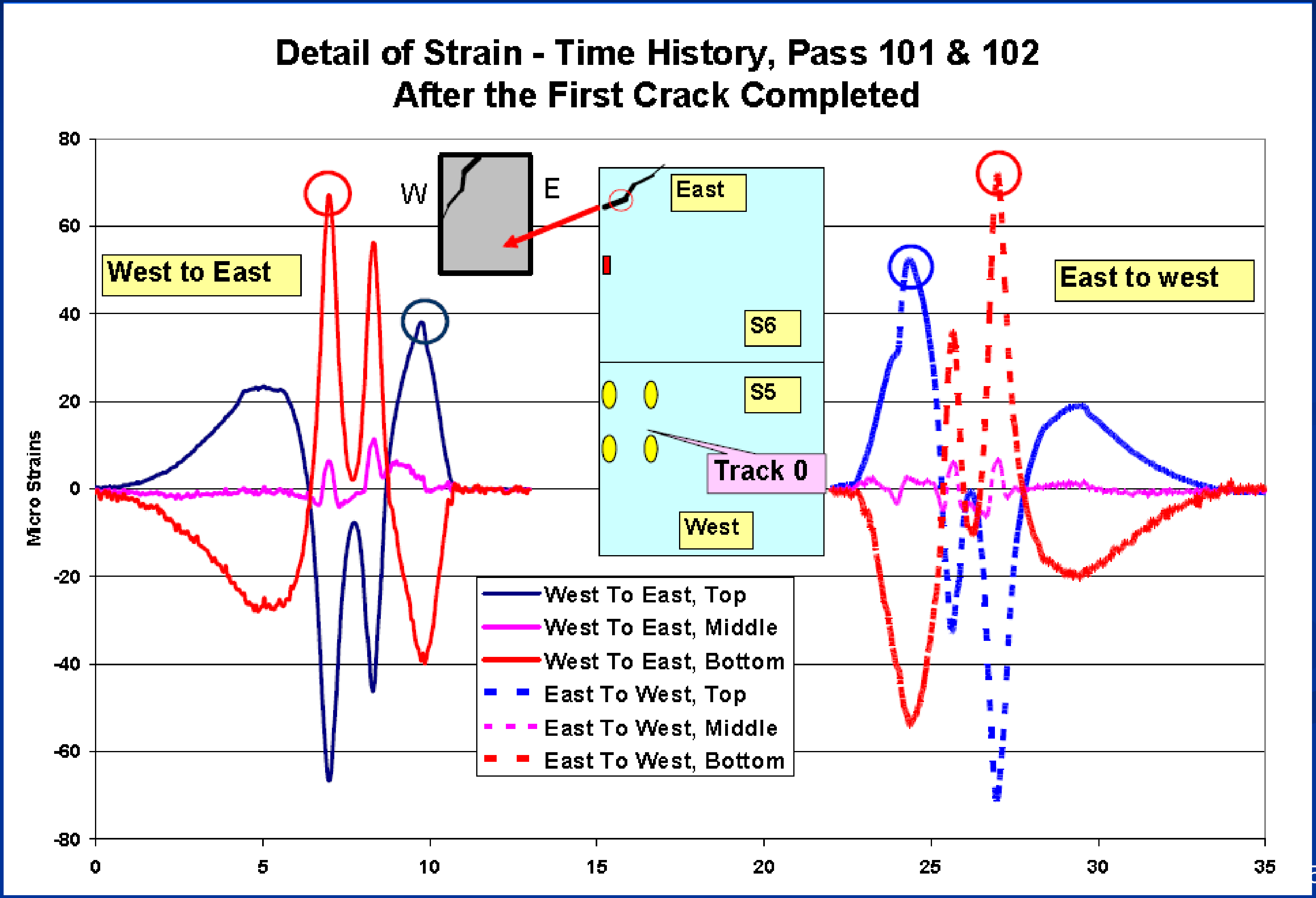


Test Strip, CC2, Tested in 2003. The First Type of Crack Detection: the Crack Was Going Near by a Gage

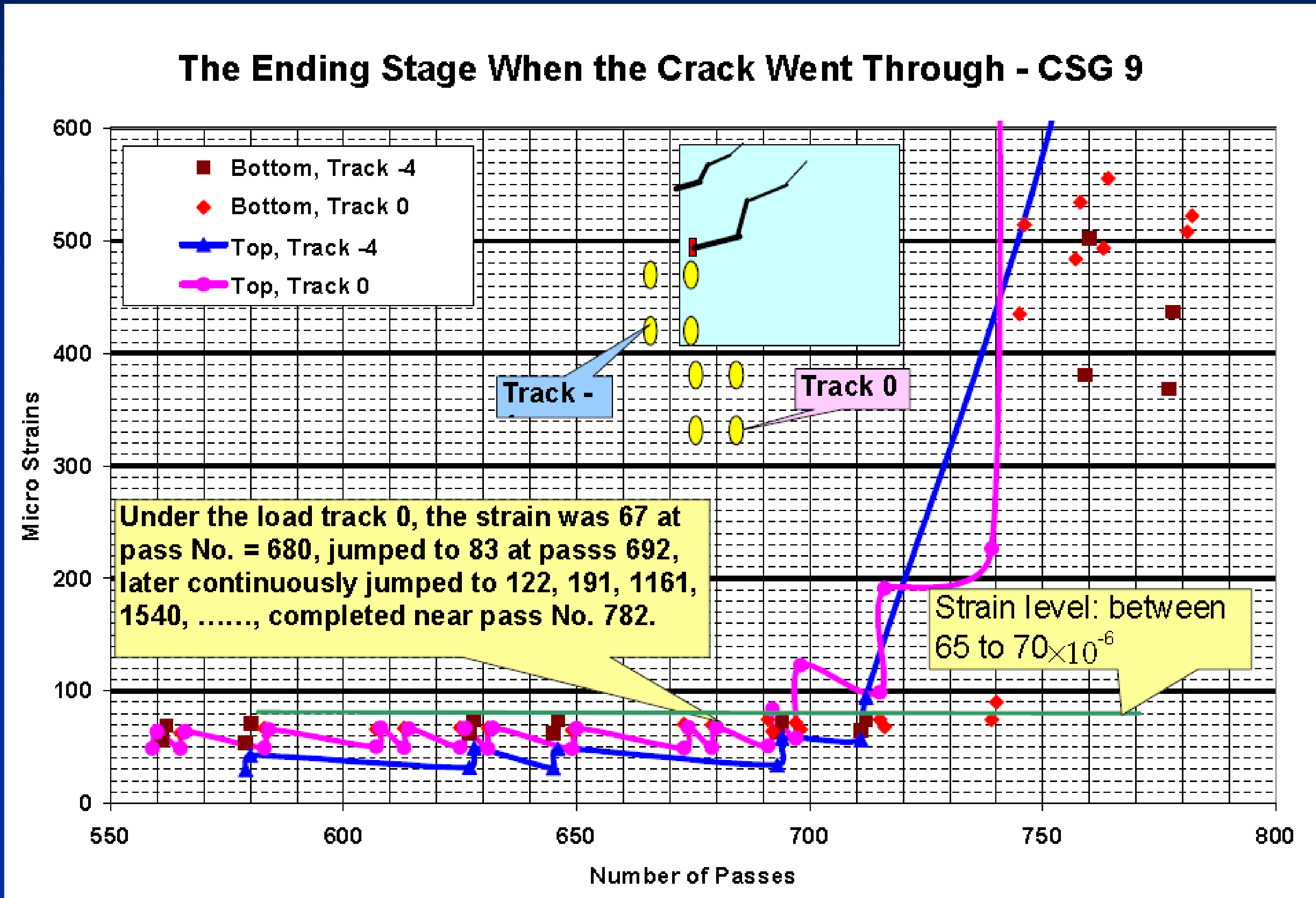


Notes: Which measured strain should be used to calculate "pavement fatigue strength"? 58 at pass 504, 69 at pass 755 or 60 at pass 1192? Conceptual analysis helps to find right answer.

Data Reliability Proof at the Second Crack Development By Theory and by Data Comparison



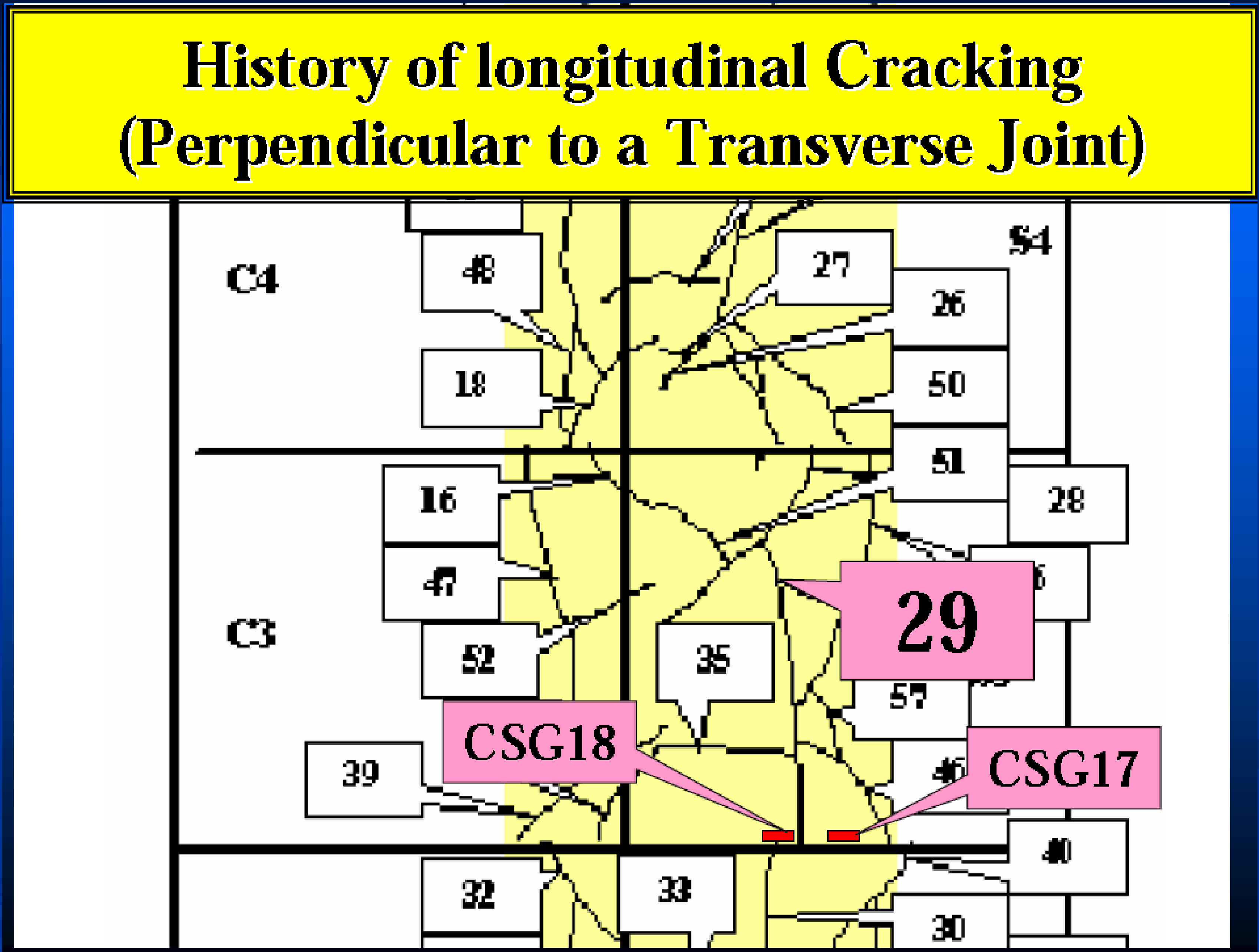
Second Type of Data Detected Crack: The Crack Was Going Through the Gage



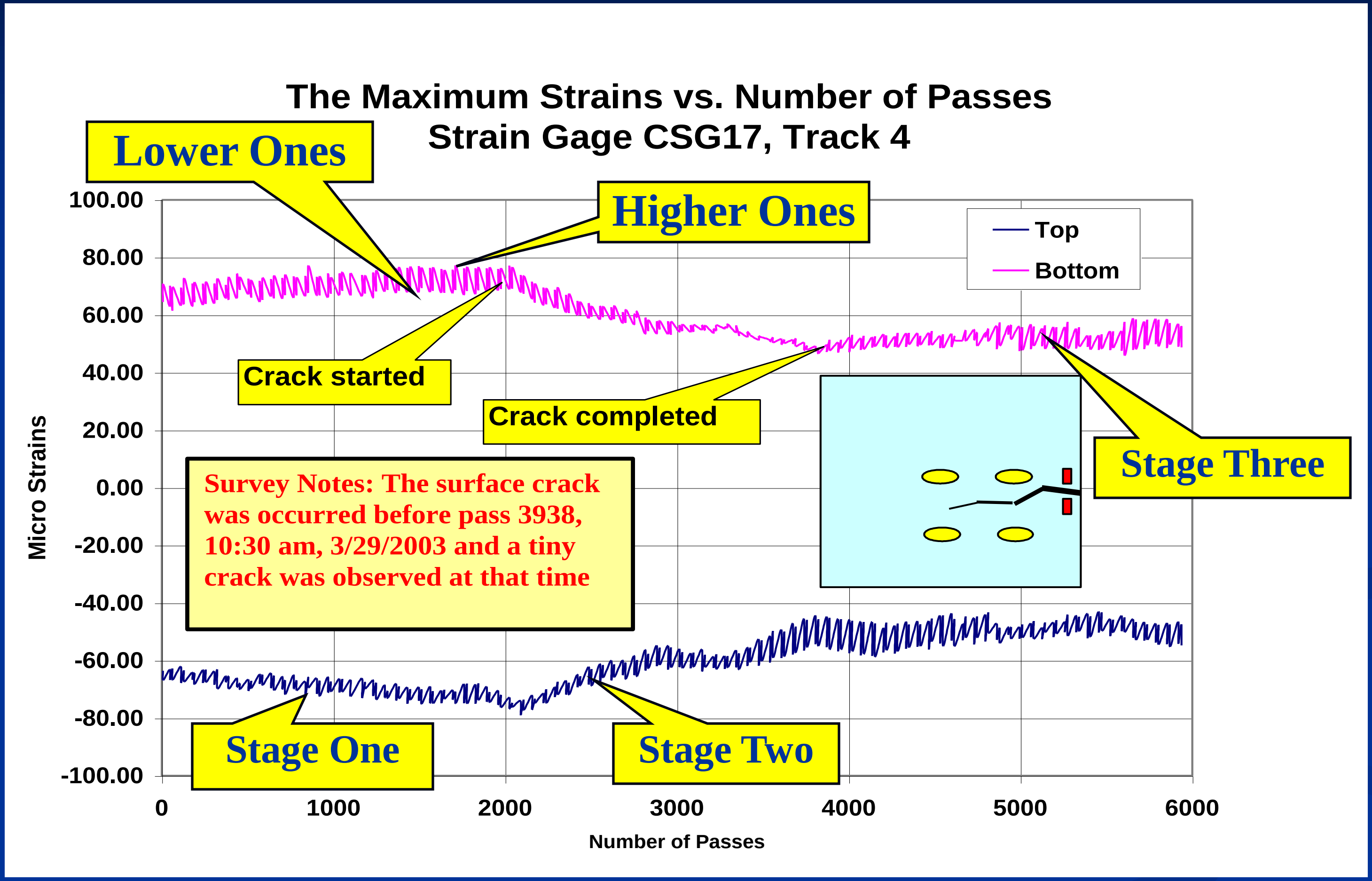
Bottom-up Crack Mechanism

Notes: **The Mechanisms of Bottom-up and Top-down are Different. The Difference Should be Reflected in Design and Evaluation Models.**

B-U Crack from Initialization to Full Depth, 2003 (I)

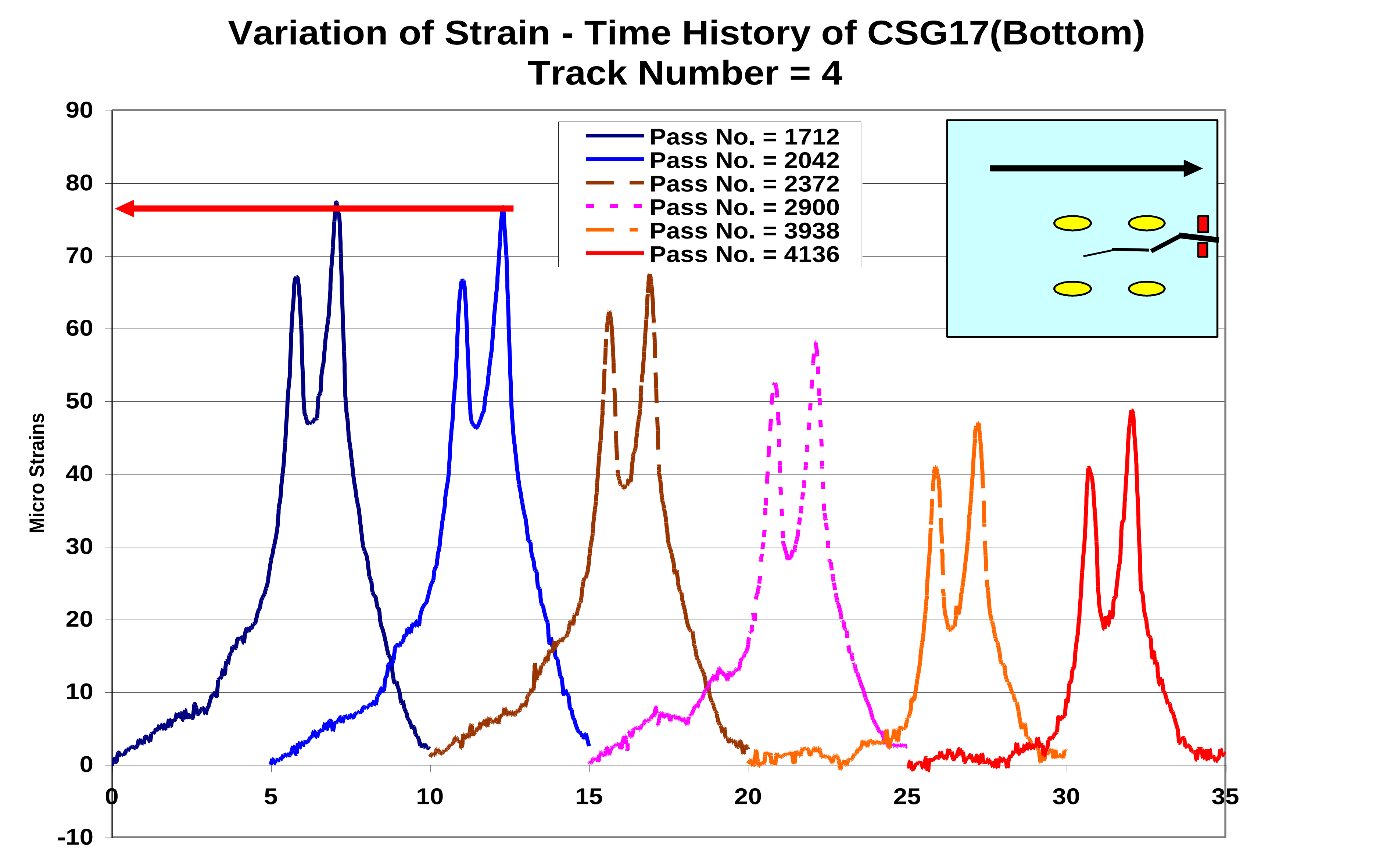


B-U Crack from Initialization to Full Depth, 2003 (II)
Three Failure Stages Are Clearly Shown

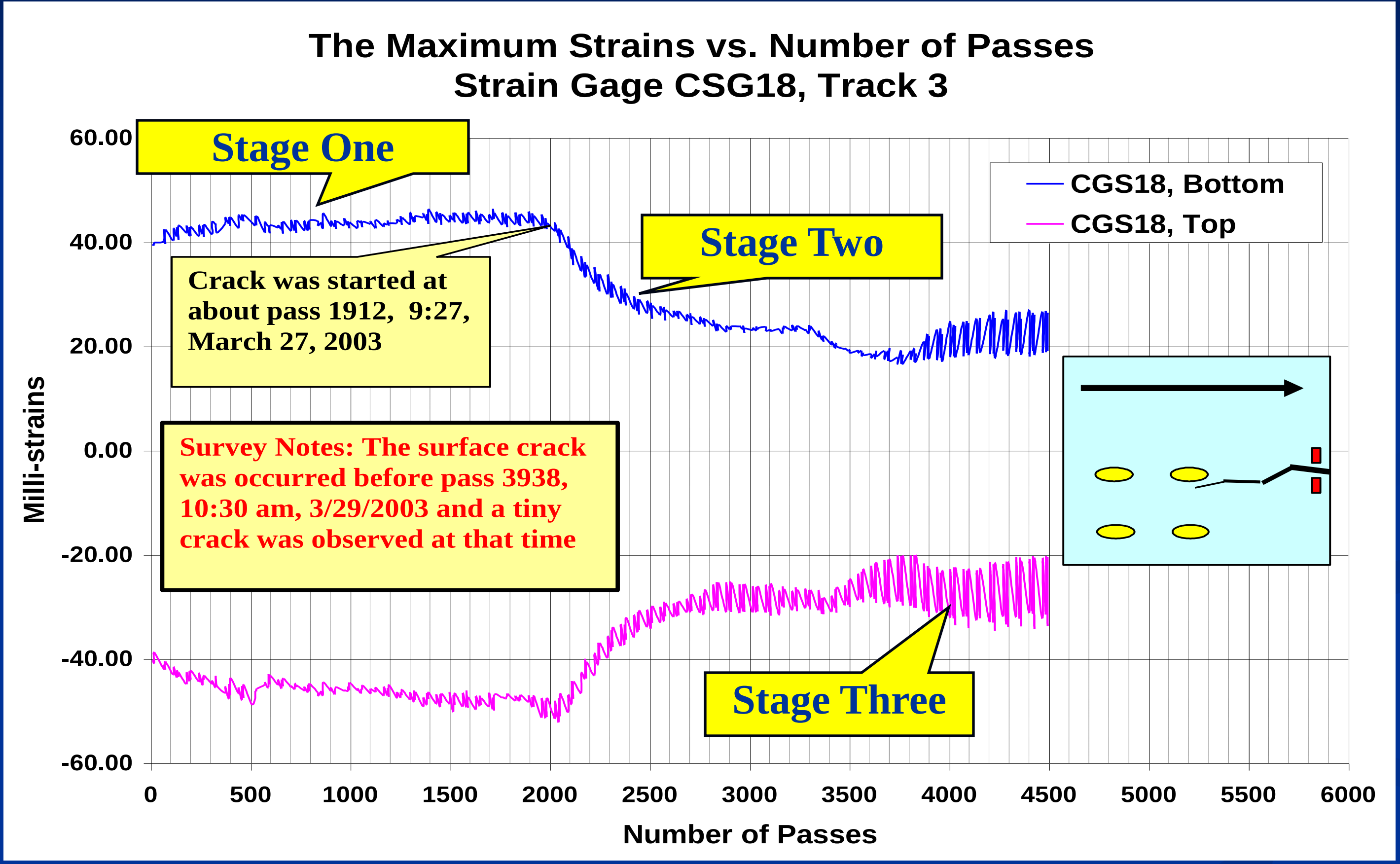


Notes: Which strain should be used to analyze the pavement fatigue strength? The Lower ones? The higher ones? The average of the all? Did friction contribute to the peak response? Conceptual analysis may help.

B-U Crack from Initialization to Full Depth, 2003 (III)
Another Proof of Data Reliability



B-U Crack from Initialization to Full Depth, 2003 (IV) Reliability Proof Again – Three Failure Stages



Notes: "Three failure stage" is a natural extension of "two failure stage" concept proposed by Ray Rollings in 1988. It has potential to offer capability for a design model to evaluate pavement condition during its service period and to support the needs of maintenance and rehabilitation. No existing design models can do this.

Significantly Different Propagation Rates of Top-down and Bottom-up Cracks

Type	Crack Initiated at		Crack completed at	
	Micro Strains	No. of Passes	Micro Strains	No. of Passes
Crack at Top (Longitudinal J., LRS, CC1)	56	486	28	670
Crack at Top (Transverse J., LRS, CC1)	52	670	25	688
Crack at Bottom (Transverse J., Test Strip)	77	1712	47	3938
Crack at Bottom* (Transverse J., Test Strip)	80	3004	>500	4942
Crack at Top (Transverse J., Test Strip, peak)	69	755	29	1192
Second Crack at Top * (longitudinal J., Test Strip)	67	480	>500	740

* Crack went through the gage

CONCLUSIONS (1)

- (1) Three-stage failure model makes it possible to predict future pavement performance. The relative lengths of the three stages is important in pavement evaluation, maintenance, rehabilitation, and design.
- (2) The mechanisms of top-down and bottom-up crack propagation are different – the effects of the two types of cracks on pavement performance are different.

CONCLUSIONS (2)

- (3) Appropriate definitions, proof of data reliability, the way of showing the data, and how to use the data are four necessary steps to accurately expose and understand the mechanisms.
- (4) Accurate use of the data is necessary in developing an acceptable design model for considering the three stage failure mechanism.

Thank You !