Methodology Changes in Pavement Research

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The contents of the paper reflect the views of the author, who is responsible for the facts and accuracy of the data presented within. The contents do not necessarily reflect the official views and policies of the FAA.

OUTLINE

1) Different philosophies in the history of pavement design are reviewed;
2) Different methodologies in design of concrete structures and concrete pavements are compared;
3) Questions for discussion:
   a. Which methodology change does match the needs of the objective change? Which does not?
   b. What fundamentals (in modeling, testing, and practicing) are truly needed for improving pavement research?

Different Design Philosophies From 1967 to 2009

FAA AC150-5320 6A, 1967, 14a

"Determination of pavement thickness requirements is not an exact science. …it has been impossible to arrive at a formula that would provide a direct mathematical solution of thickness requirements"

Thickness (output) was directly calculated using parameters (input) based on full-scale test data. Neither critical stress nor pavement life was calculated. 5,000 coverages were used as a reference for "life".

FAA AC150-5320 6E, item 301, 2009

"This chapter presents pavement mechanistic design procedures that are implemented in the FAA Rigid and Flexible Iterative Elastic Layer Design (FAARFIELD) program."

Pavement thickness and life are quantified using:

(1) Critical stress by mechanistic model;
(2) Results of tests;
(3) Empirical Calibration.

Are all steps equally important ?

The "Mechanistic Tool" is a hot topic now

- "Overview of South African Mechanistic Pavement Design Method" - TRB 1539;
- "Towards Mechanistic Pavement Design in China", key note speech in the third International Conference GeoShanghai, May 2014;
- AC150/5320-6E under the FAA
- MEPDG under the FHWA

Why is the "Mechanistic Method" such a hot topic?

1. Pavement life and performance have been added as objectives for design. The "time" unknown was not needed prior to 1970 but is required now. That may be why a fatigue model was adopted as an element in the design model.
2. Finite element methods have been increasingly successful when applied to engineering;
3. Computers are faster and faster;

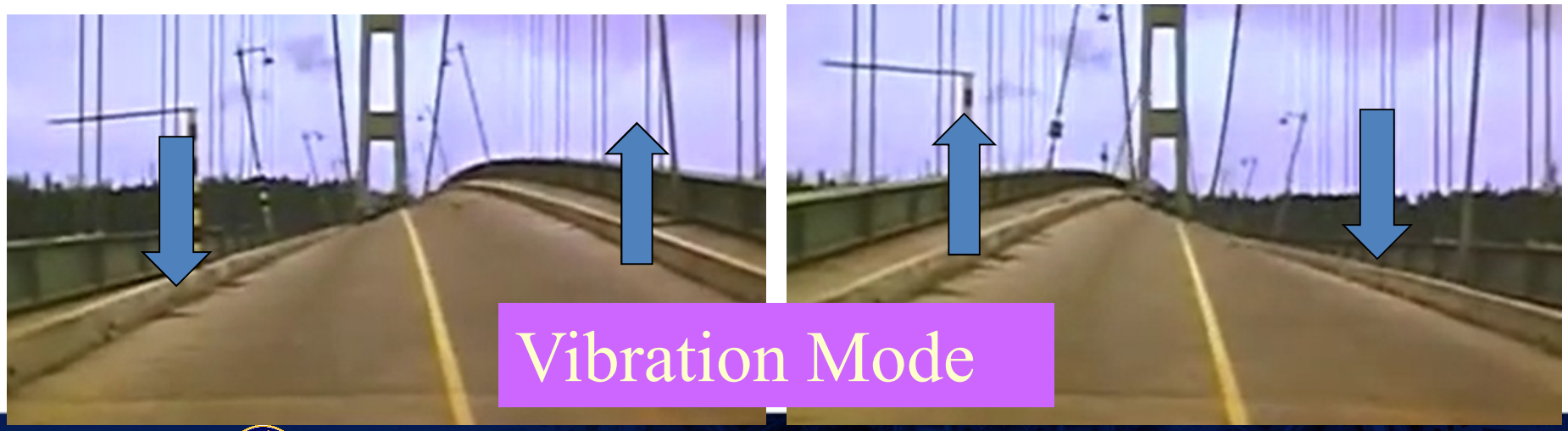
How does a mechanistic procedure improve pavement research?
Is a pavement truly failed by fatigue?

Contribution of Theoretical Study to Structural Engineering

The 1940 Tacoma Narrows Bridge

Lessons Learned from Tacoma Bridge collapse (I)?

- These pictures were copied from film footage taken during the collapse.
- The measured vibration amplitude was up to 5 feet before the collapse.



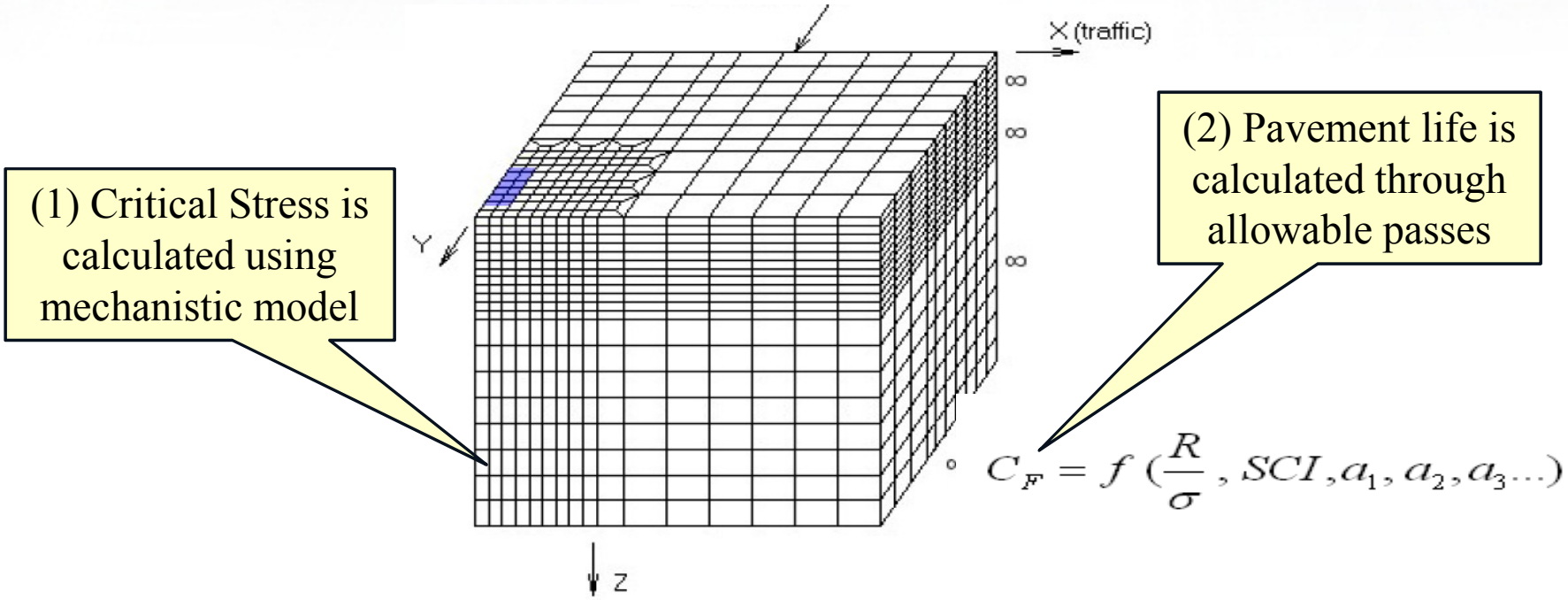
Lessons Learned from Tacoma Bridge collapse (II)?

- Vibration mode and natural frequency (Eigenpair in MATH), not the vibration amplitude, is the most important structural characteristics for avoiding the bridge collapse.

Is there any structural characteristics in a pavement similar to the EIGEN PAIR in a bridge?

Philosophy in Design of Concrete Pavement

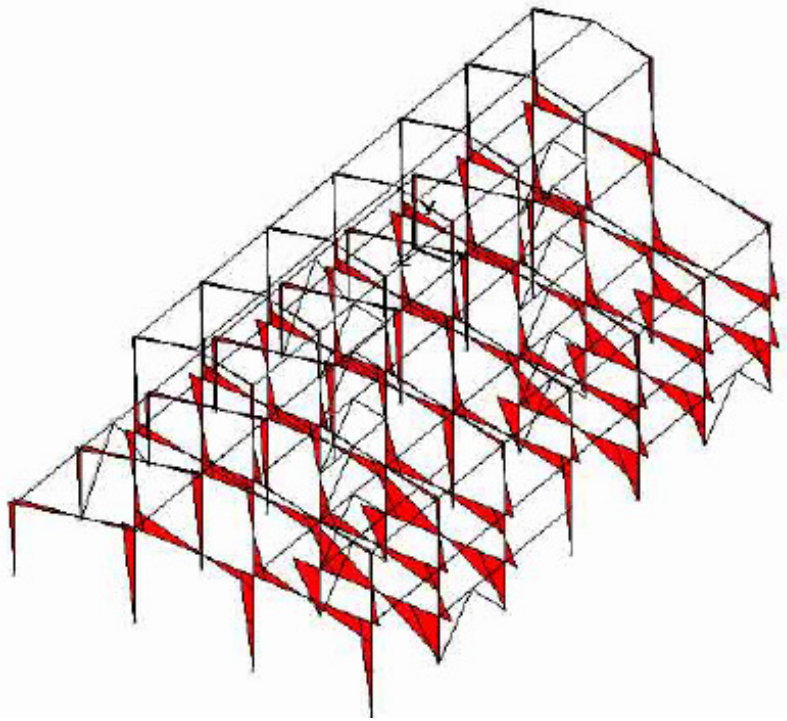
The pavement is evaluated by the ratio between critical stress and material strength at a point

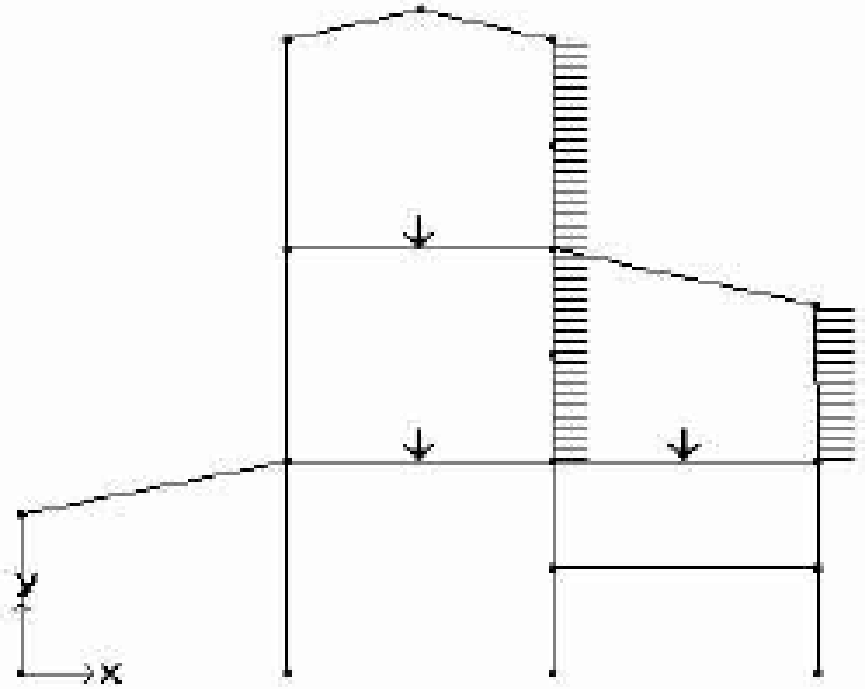


Is it possible to accurately calculate the critical stress at a point in a concrete pavement?

Philosophy in Design of Concrete Structure (A)

Load induced Section bending moment, M(L), is calculated by mechanistic model





Why is the "bending moment" for a section, M(L), rather than the critical stress, σ, calculated at a point?

Philosophy in Design of Concrete Structure (B)
Resistance bending moment of a section, M(R), is calculated based on assumptions

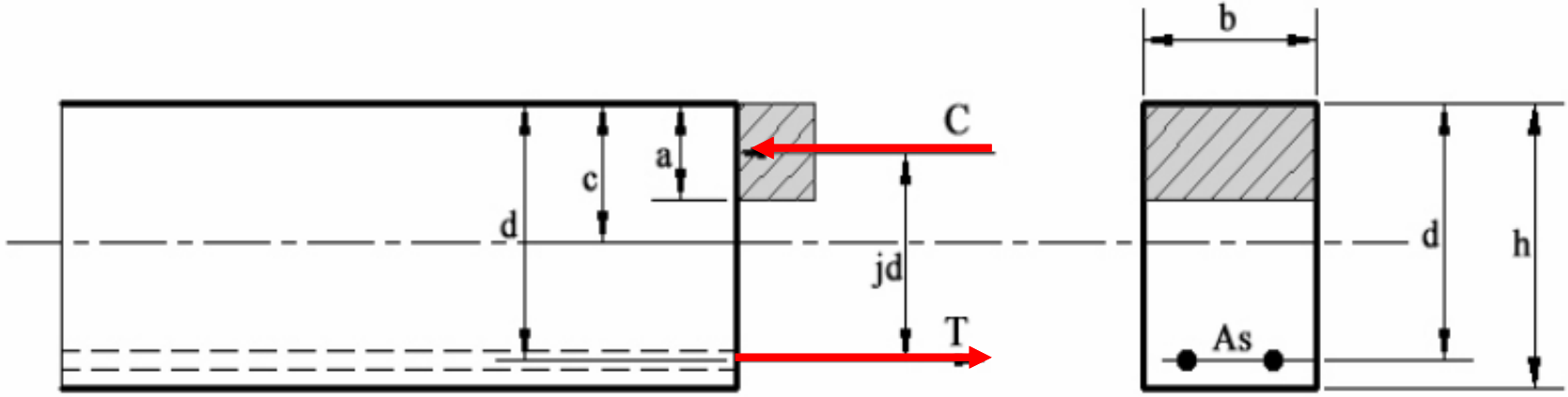
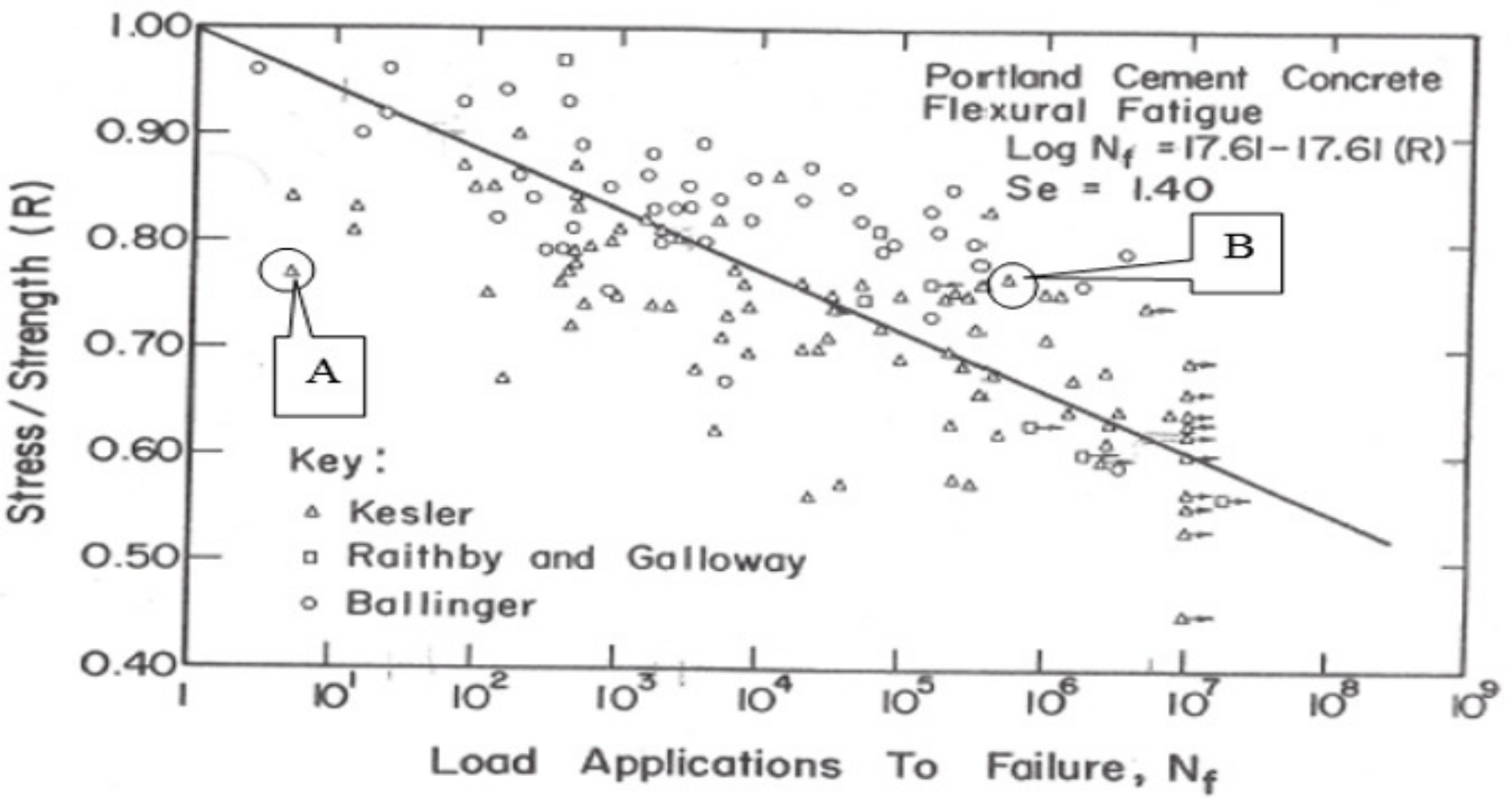


Fig 4-3: Reinforced rectangular beam (Ambrose, 1997)

Why is the characteristics of a section, not a point, employed to evaluate the capability of a structure?

Answer: It is impossible to get an accurate stress at a point.

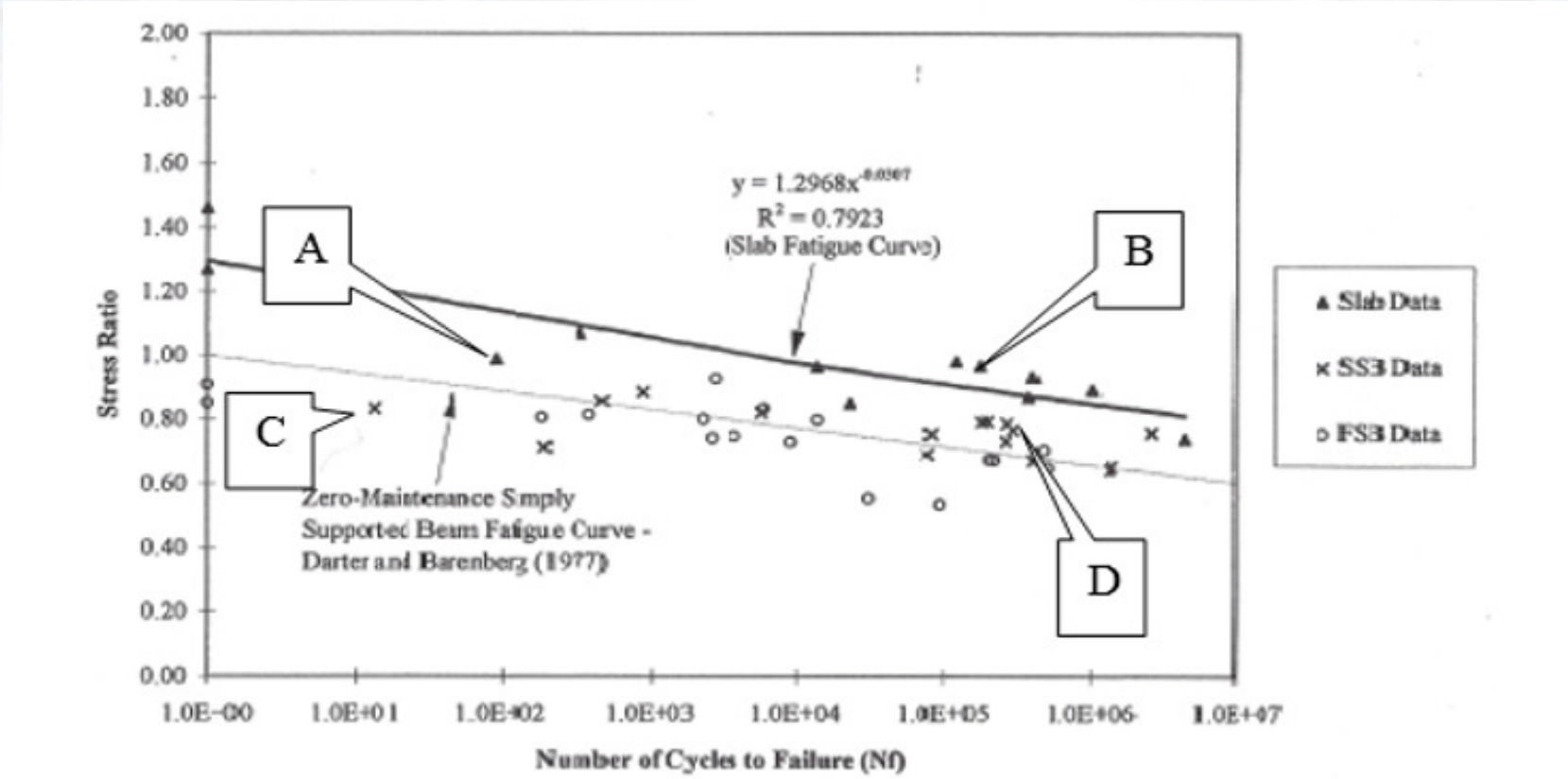
Is a Concrete Pavement Truly Failed by Fatigue (I)? – Results from simply supported beams



Two tests had similar ratio, σ/R, but N(B)/N(A) = 50000

Copied from FHWA-RD-77-111, Vol. 1, 1977, by Darter, et al.

Is a Concrete Pavement Truly Failed by Fatigue (II)? – Results from fully supported beams and slabs



Two tests had similar ratio, σ/R, N(B)/N(A) = 1,000 and N(D)/N(C) = 5,000. Copied from Jeff Roesler's PhD thesis, 1998, University of Illinois

Is a Concrete Pavement Truly Failed by Fatigue (III)? – Results from the grandpa experts

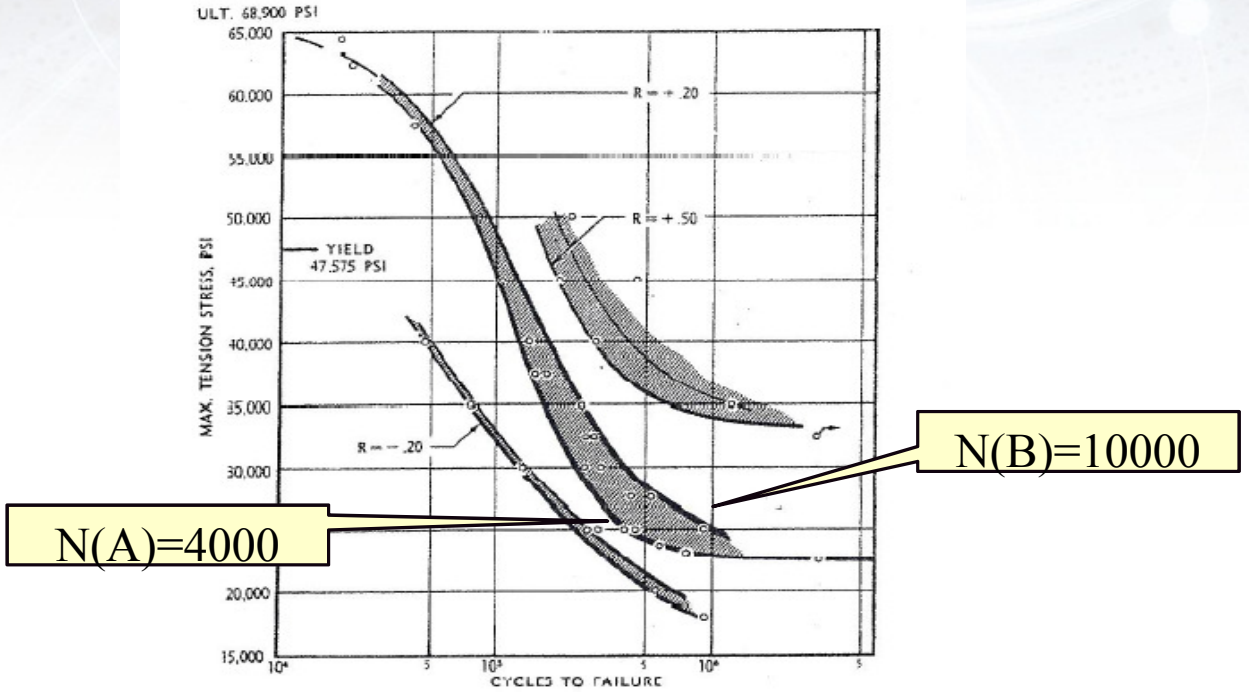


FIG. 7 *S-N* CURVES AT VARIOUS *R* VALUES FOR 24S-T ALCLAD

"Cumulative Damage in Fatigue", by M. Miner, 1945. For any two cases under the same σ/R, N(B) / N(A) was less than 2.5

Note: The tests were conducted using aluminum, not concrete.

Is a Concrete Pavement Truly Failed by Fatigue (IV)?

- Definition of "Fatigue" in dictionary: "Fatigue of material by cracking resulting from repeated or cyclic **stress**", McGraw-Hill Dictionary of Science and Technical Terms, Second Edition, 1978. – fatigue occurs under the same stress.
- The tests conducted by grandpa expert were under the same stress with 2.5 times of variation.
- The tests conducted by father and brother experts were under the same stress with 1000 to 50,000 times of variation.

Is a pavement under moving loads failed in the same way? Why we use fatigue equation for pavement design? Because of that a pavement is truly failed under fatigue following the definition in science or a time variable is available in fatigue equation ?

What is “Mechanistic” Modeling?

- Of, pertaining to, or connected with mechanics or mechanism. “The Oxford English Dictionary”, Second Edition, Volume IX, 1989. “Mechanistic” was not listed in McGraw Hill Dictionary in 1992 Edition.
- The earliest use was in 1884, “Nature”, 21 August, 383/I: “The series of curves of velocity given for different mechanistic combinations.”

The terms “theoretical” and “analytical” were often used before the 1970s. However, the term "mechanistic" has almost replaced them in subsequent pavement research publications.

Requirements for Using Theoretical and Mechanistic Models

- All three modules should be satisfied: equilibrium, kinematics and constitutive equations;
- Solutions also require clearly defined boundary conditions;
- The quality of modeling should at least pass the following evaluations:

  (1) Definition; (2) Assumption; (3) Derivation;

  (4) Verification; (5) Application.

Since both are essentially the same, why is "mechanistic" favored, but "theoretical" is not?

Insufficiency of Mechanistic Model in Pavement Research

(1) Existing constitutive equations for concrete material are not qualified to produce accurate solutions to the critical stress at a point;

(2) Pavements do not have clearly defined boundary conditions – such as interface which has non-controllable and high variable effects on calculated results.

Literatures Recognizing the Methodology Changes

(1) Molenaar, Andre.A.A., 2012, Farewell speech, “Fragile Link Between Science and Practice of Road Engineering”;

(2) Thomas J. Pasko Jr, 1998 “Concrete Pavements, Past, Present, And Future”:

(3) Ray Rollings, Keynote Speech: “Models must be verified by field measurements but theory is the springboard for future advances”.

CONCLUSIONS

(1) It is time to evaluate: Which methodology change does match the needs of the objective change in pavement research, and which does not?

(2) Discovery of pavement failure mechanism needs a RATIONAL methodology rather than the "mechanistic" or "theoretical" procedure. The needed methodology relies on full scale tests plus field survey, Lab tests and fundamental theory in a simple form;

(3) The word "Rational" was used in "Airport Pavements – Solutions for Tomorrow's Aircraft", 1993 and "Airport Technology Research Plan … for NextGen Decade", 2012, page 29, see http://www.airporttech.tc.faa.gov/10YearPlan/

THANK YOU!