

Beyond Mechanistic-Empirical Design: Toward a Paradigm Shift in Pavement Engineering



Tasos M. Ioannides

Anastasios.Ioannides@UC.Edu

Associate Professor of Civil Engineering

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Presentation Abstract

- Release of Mechanistic-Empirical Pavement Design Guide (NCHRP 1-37) in 2005 allows a retrospective look at what has been achieved and a glance into what the future may hold
- A sketch is offered of significant changes to be made in order to address pervasive limitations by 2020

Presentation Outline

- Introduction to Mechanistic-Empirical Design
- Fundamental Definitions
- Data in the Engineering Process
- Urgent Research Needs
- Proposed *Modus Operandi*
- Pitfalls and Roadblocks
- A Vision to Behold

NCHRP 1-37

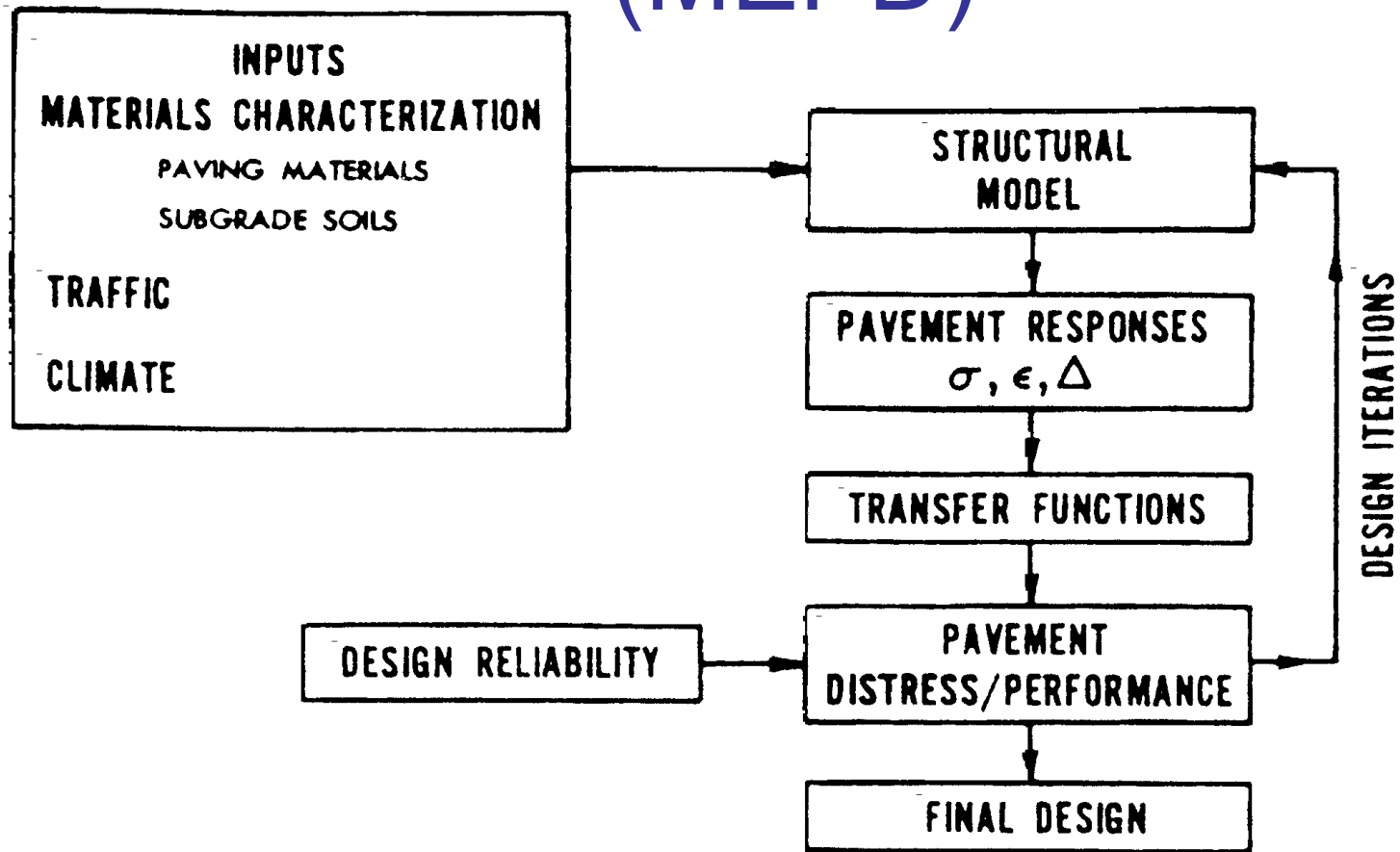
- Mechanistic-Empirical Pavement Design (MEPD) Guide
- Developed by ARA, Inc. for USA National Cooperative Highway Research Program (State Highway Agencies), 1999-2002(2005)
- Best existing technology
- To replace AASHTO Design Guide (1961-1993)

AASHTO Guide (1961-1993)

- AASHO Road Test (1958-1960), at Ottawa, IL (near Chicago)
- File data, interpreted using primarily statistical methods
- Serviceability Oriented Design Approach, with user as the ultimate authority
- Equivalent Single Axle Loads; Fourth Power Law; Structural Number; Present Serviceability Index
- Not enough data
- Multiple revisions (1961-1993)

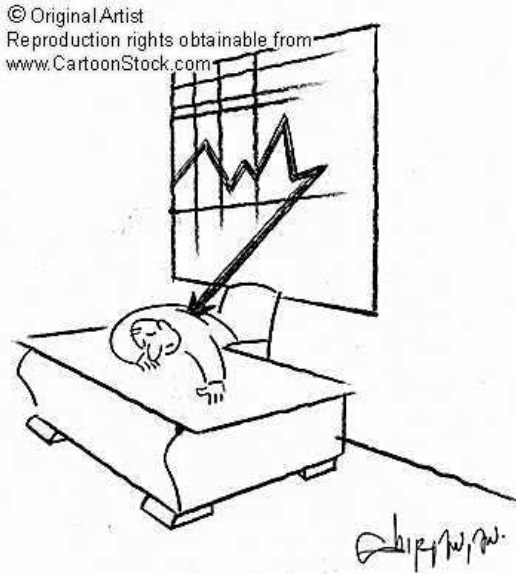


Mechanistic-Empirical Design (MEPD)



Advantages⁺ and *Limitations*⁻ of MEPD

- +Best available technology
- +Distress Prevention Oriented Design Approach
- +Data interpretation using engineering mechanics, as well as statistics
- Dead end*
- Does not address user overtly*
- Retains statistical constructs*



Fundamental definitions

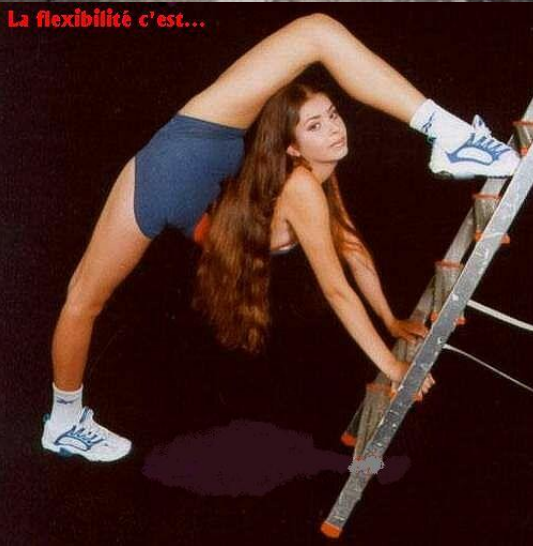
A pavement is a complex engineering system, whose analysis and design involve the interaction of three equally important components:

- The natural supporting layers
- The man-made layers
- The geometry of the applied loads



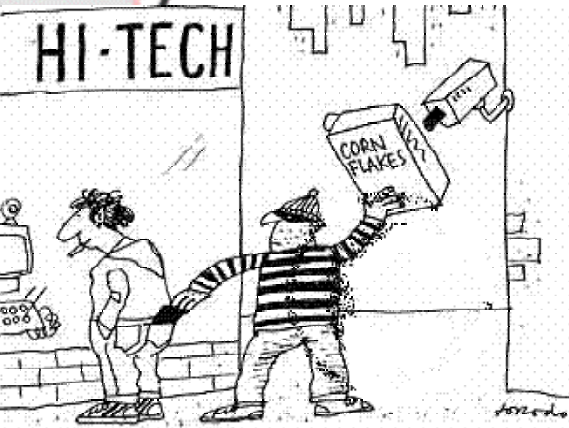
Fundamental definitions

- Pavements must be classified in terms of behavior, not materials
- *Rigid* = not deforming; concrete surface; white
- *Flexible* = deforming without breaking; asphalt surface; black



La flexibilité c'est...

Fundamental definitions



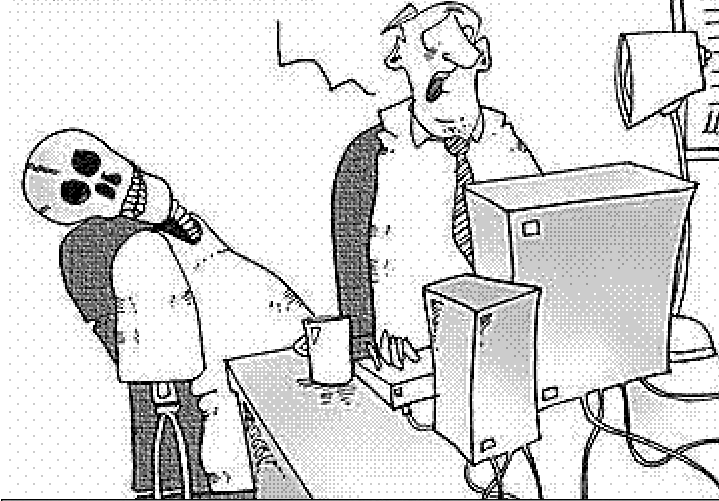
- *Mechanistic*: Pertaining to mechanics as a branch of physics; rational; derived using analytical techniques based on theory, for the purpose of unraveling cause-and-effect connections.
- *Empirical*: Based on experience; rule-of-thumb; derived using statistical analysis, without knowledge of cause-and-effect connections.



The Engineering Process

- Data collection
- Data interpretation

SORRY SHOULDN'T TAKE MUCH LONGER...COULD YOU JUST CONFIRM THE MAIDEN NAME OF YOUR MOTHERS UNCLAS SECOND COUSIN?



Sources of Data

- Trial-and-error experiences
- Analytical simulations
- Laboratory testing of representative small component specimens
- Small-scale model tests (similarity concepts)
- Field testing of full-scale assemblies: destructive or non-destructive



Credit: J. Mack, ACPA

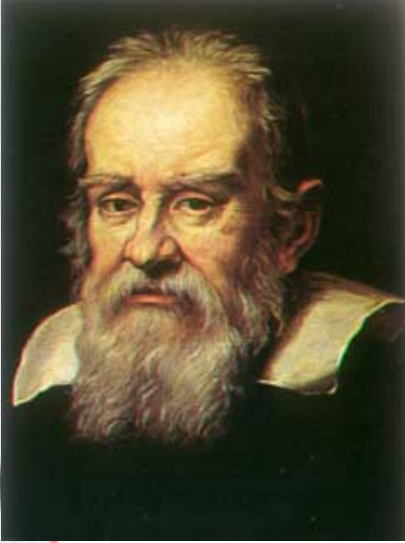
Data Collection



"Mr. Paxburton is out of town this week. Would you like to speak to a computer simulation of him?"



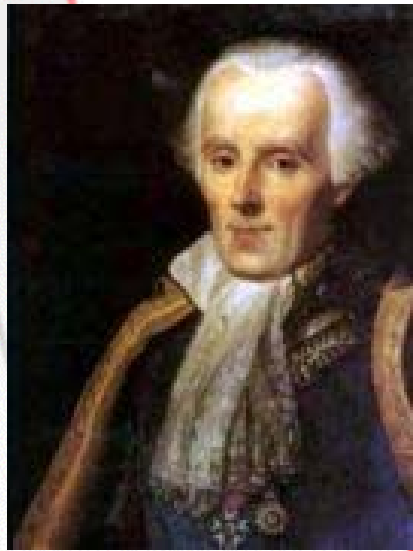
- *Analytical*: From simulations on computer using engineering mathematics tools, e.g., the finite element method
- *Experimental*: From laboratory or field tests, on individual component specimens, or entire system assemblies, on a reduced- (“model”-) or full-scale



Data Interpretation

- *Engineering Mechanics*: Trends using of engineering analysis tools, e.g., theory of elasticity; dimensional analysis. Cause-and-effect connections revealed
- *Statistical*: Trends using statistical mathematics tools, e.g., regression analysis. Cause-and-effect connections obscured. *Science of Ignorance*

Galileo (up) and Laplace (dn)



Where Do We Go Next?

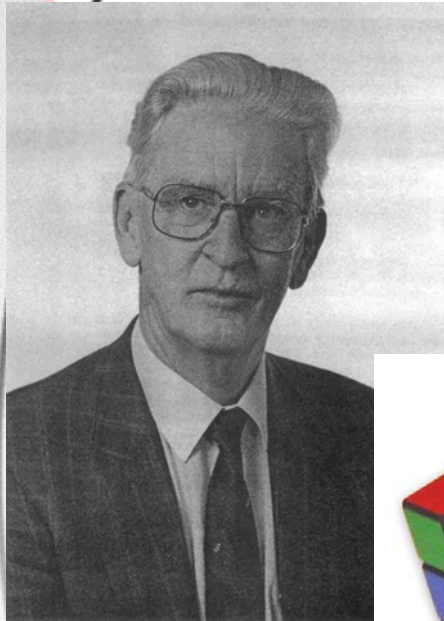
© Cartoonbank.com



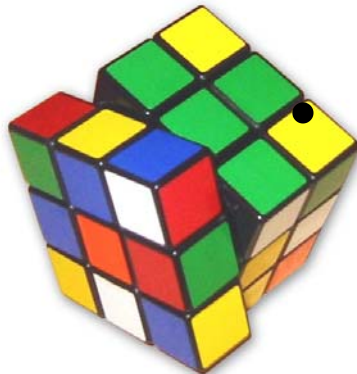
"Never, ever, think outside the box."

- Paradigm Shift
- Think Outside the Box
- Innovate
- *Carpe diem*
- Probe the future
- But how?

Urgent Research Needs



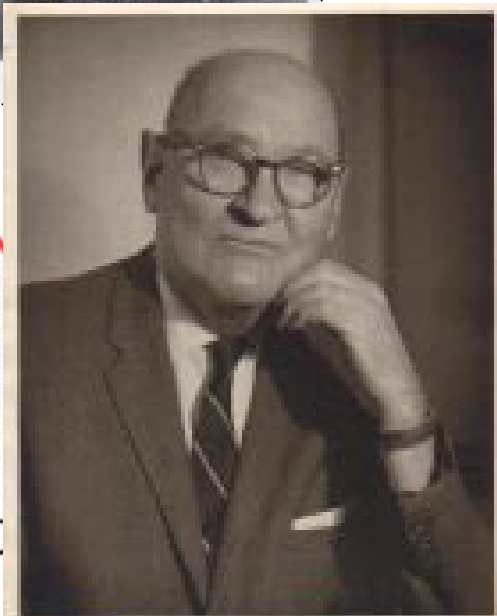
Arne Hillerborg



- *Improved failure criteria:* Beyond fatigue; toward deflection- or stress-based limit states and fracture mechanics
- *Material characterization:* Beyond cubes or beams; toward fracture energy testing
- *Stochastic considerations:* Beyond determinism and factor of safety; toward risk and reliability assessment

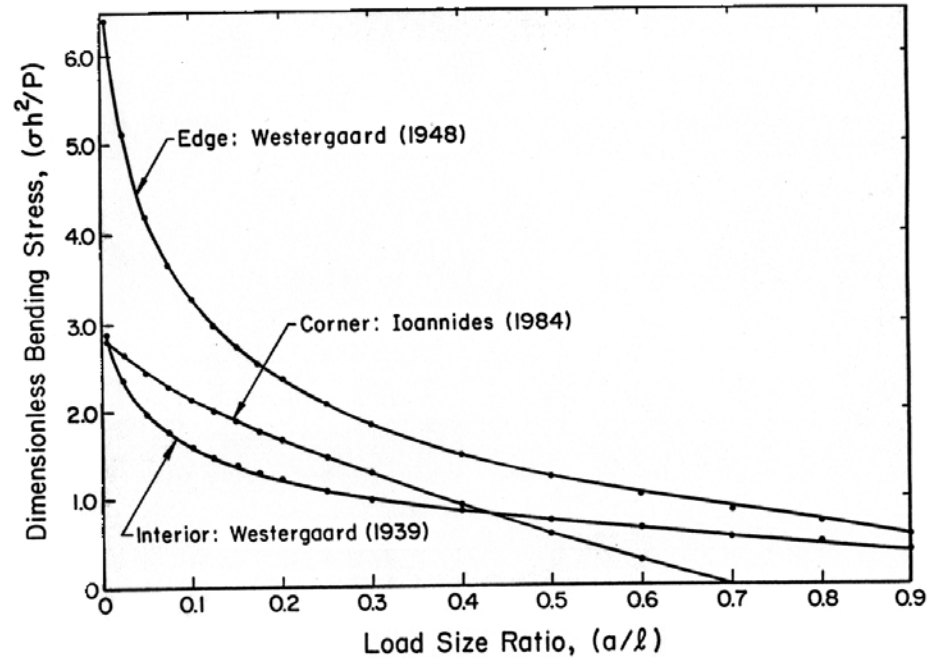
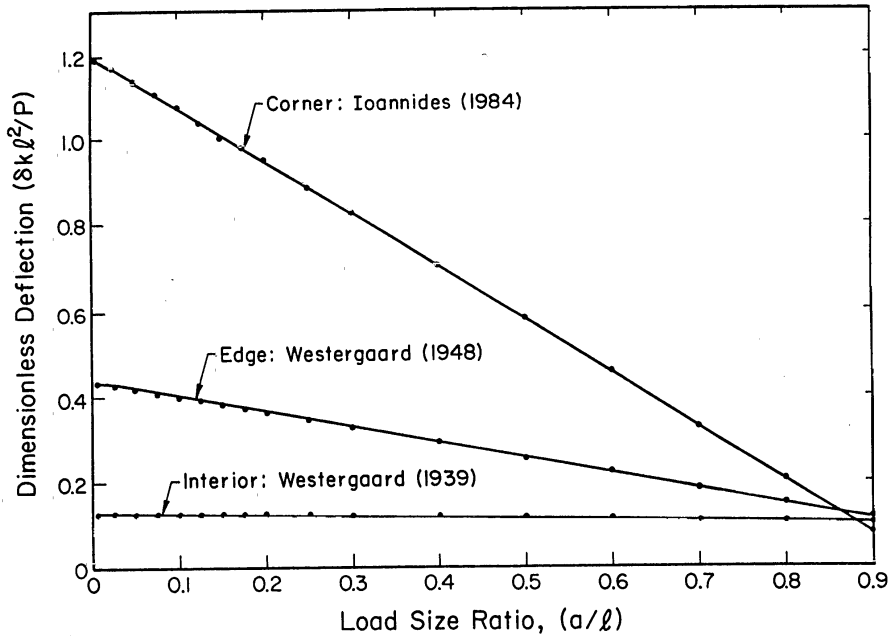
Return to Basics

- Greeks, Romans, Chinese, local population
- The pioneers' *modus operandi*
- Beyond the... great derailment of 1960



H.M. Westergaard (up) and D.M. Burmister (dn)

Westergaard and Dimensional Analysis



After Ioannides (1990)

Burmister and Dimensional Analysis

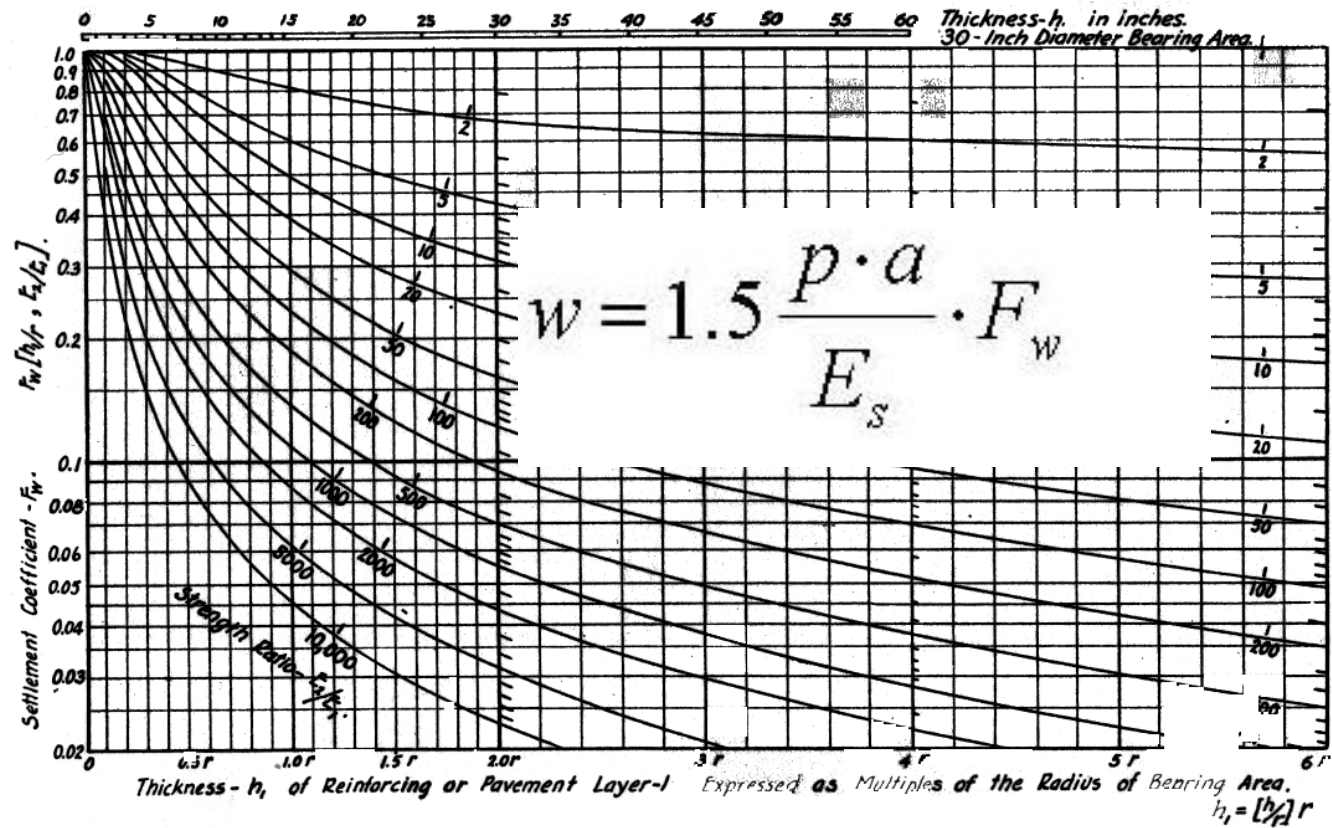


Figure 4. Influence Curves of the Settlement Coefficient - F_w for the Two-Layer System. Basic Load-Settlement Relation

$$W_c = 1.5 \frac{P \cdot r}{E_2} \cdot F_w \quad F_w = \frac{W E_2}{1.5 P r}$$

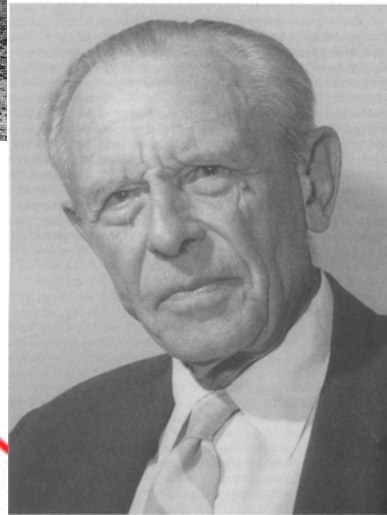
Interdisciplinary Fertilization

- *Structural engineering concepts:* structural analysis; limit state design; university training; prevent the unexpected



Nathan M. Newmark

Geotech engineering concepts: drainage; subgrade characterization; on-the-job training; learn to live with the unexpected



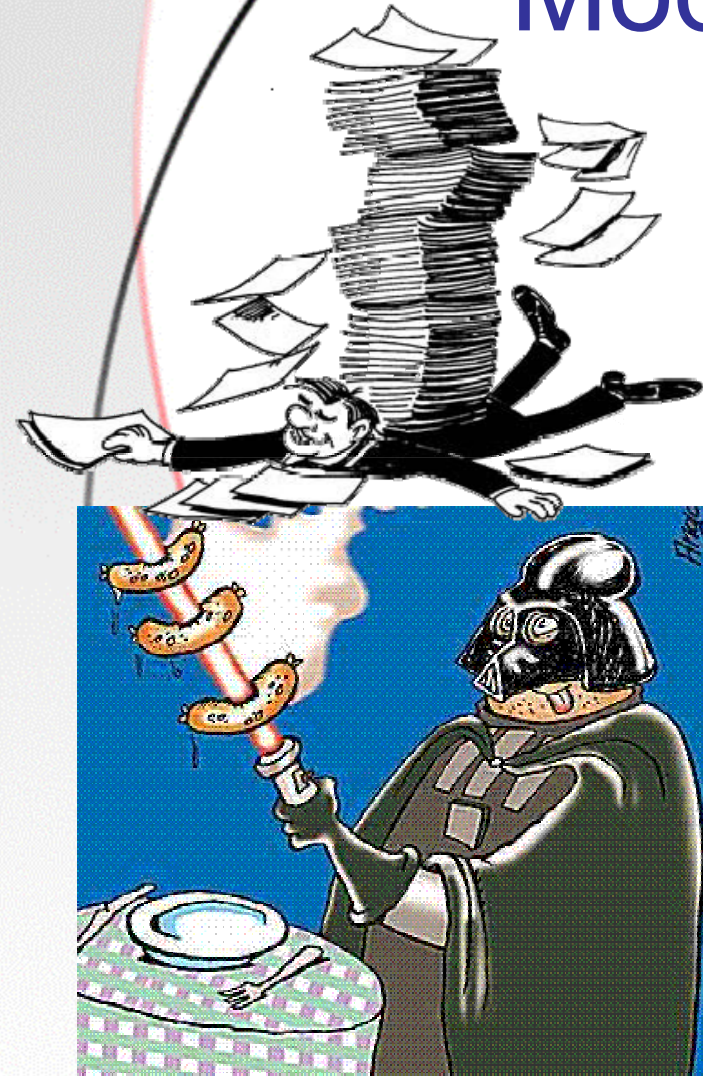
Karl Terzaghi, June 1958.

N.M. Newmark (up) and K. Terzaghi (dn)



*Credit:
USA Corps of Engineers*

Modern Fallacies



- Greed for data leads to endless calibration
- Fatigued with laws, hypotheses, and guesses
- Abuse of *models* and *equivalencies*
- Science gone awry: statistics; instrumentation

Computer: Friend⁺ or Foe⁻?



- +?-? Statistics
- +?-? Finite element analysis
- -!-!-! Blind faith (*cf.*, the tabloid press)

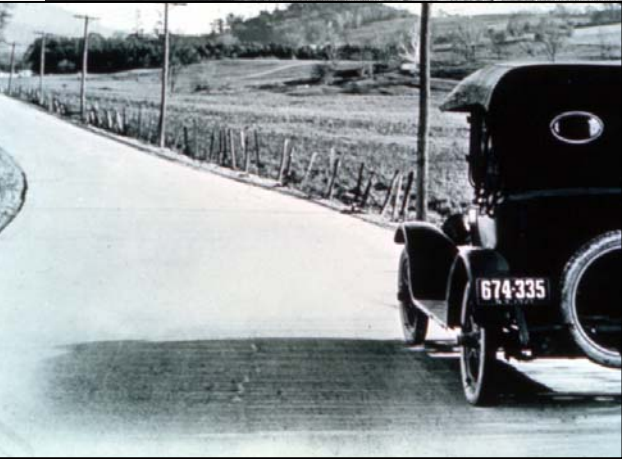
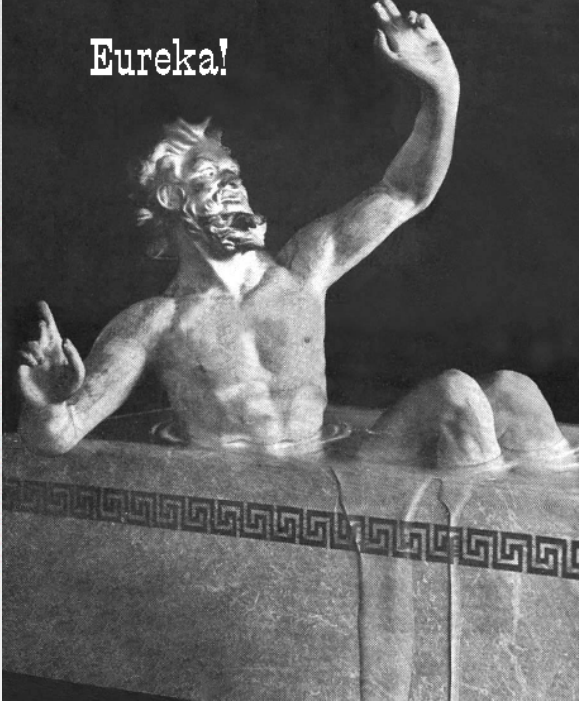
➔ Engineering judgment;
practical experience;
construction quality control;
workability; design-build

Looming Dangers



- Water (elimination of sealants and permeable bases)
- Incompatibilities in evaluation and design
- Disproportionate emphasis on response vs. performance modeling
- Mingling of mechanistic and empirical concepts
- Proliferation of *black boxes* and proprietary materials

Eureka!



The Design of 2020

- Limit States Oriented Design Approach
- Twin criteria: stress and deflection
- Based on fracture mechanics
- Incorporates blend of conventional and exotic materials
- Recognizes significance of subgrade and continuity (rather than stiffness) of support
- Values drainage
- Surprises are the norm

Societal Connections



- The role of the user public.
- The interaction with policy makers: fees; weights; weigh stations; law enforcement; national defense; Economic growth.



Thank You!

Acknowledgements

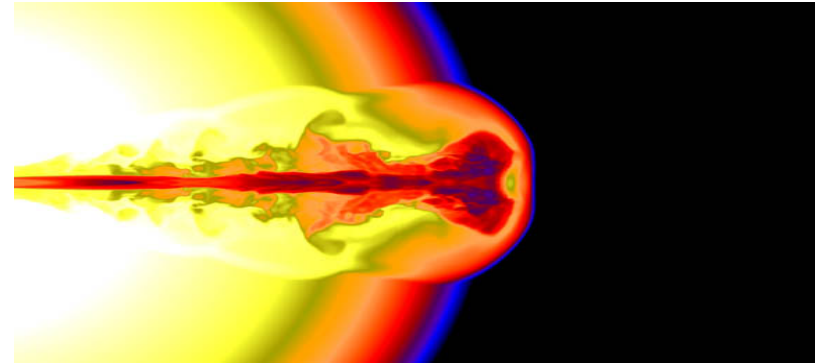
- Prof. Alex T. Visser
- Prof. Elsabè Kearsley
- Prof. Emile Horak



"This is my son, Nigel. He'll be taking credit for all of your work."



Computer Simulation



Small Scale Model



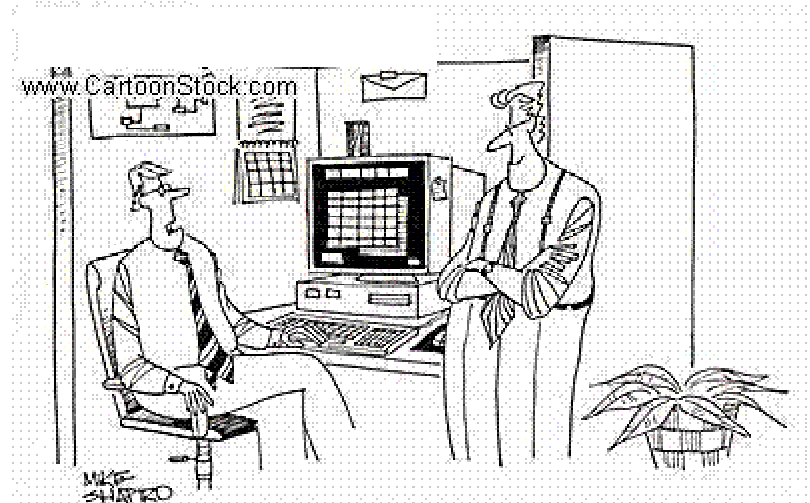
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"I thought I felt a paradigm shift, but it was just my undershorts riding up."

Paradigm Shift

Think outside the box



"I think I'd have an easier time thinking out-of-the-box if I didn't have to spend the entire day in a cubicle."