The Institute of Asphalt Technology
Irish Branch

Foundation & Pavement Design
Analytical Approach

Tom Casey

TII Head of Pavements, Construction Materials & Innovation

March 13th 2018

Bonneagar Iompair Éireann
Transport Infrastructure Ireland

Brief Overview of Design Origins

- Empirical trials IN US (AASHO) & UK (RRL)
- UK Road Note 29 in 1960’s & 1970’s
  - Simplified modelling of pavement structure
  - Related traffic loading to subgrade strength (CBR) & pavement layers
- TRL LR 1132 in 1984 based on Empirical observations of extended trials
- Concept of long life pavements in 1997 TRL report – indeterminate life beyond 80msa

Structural Design Approach

Definition of a Structure:

built from different interrelated parts with a fixed location on the ground.

responsible for maintaining shape and form under the influence of subjected forces

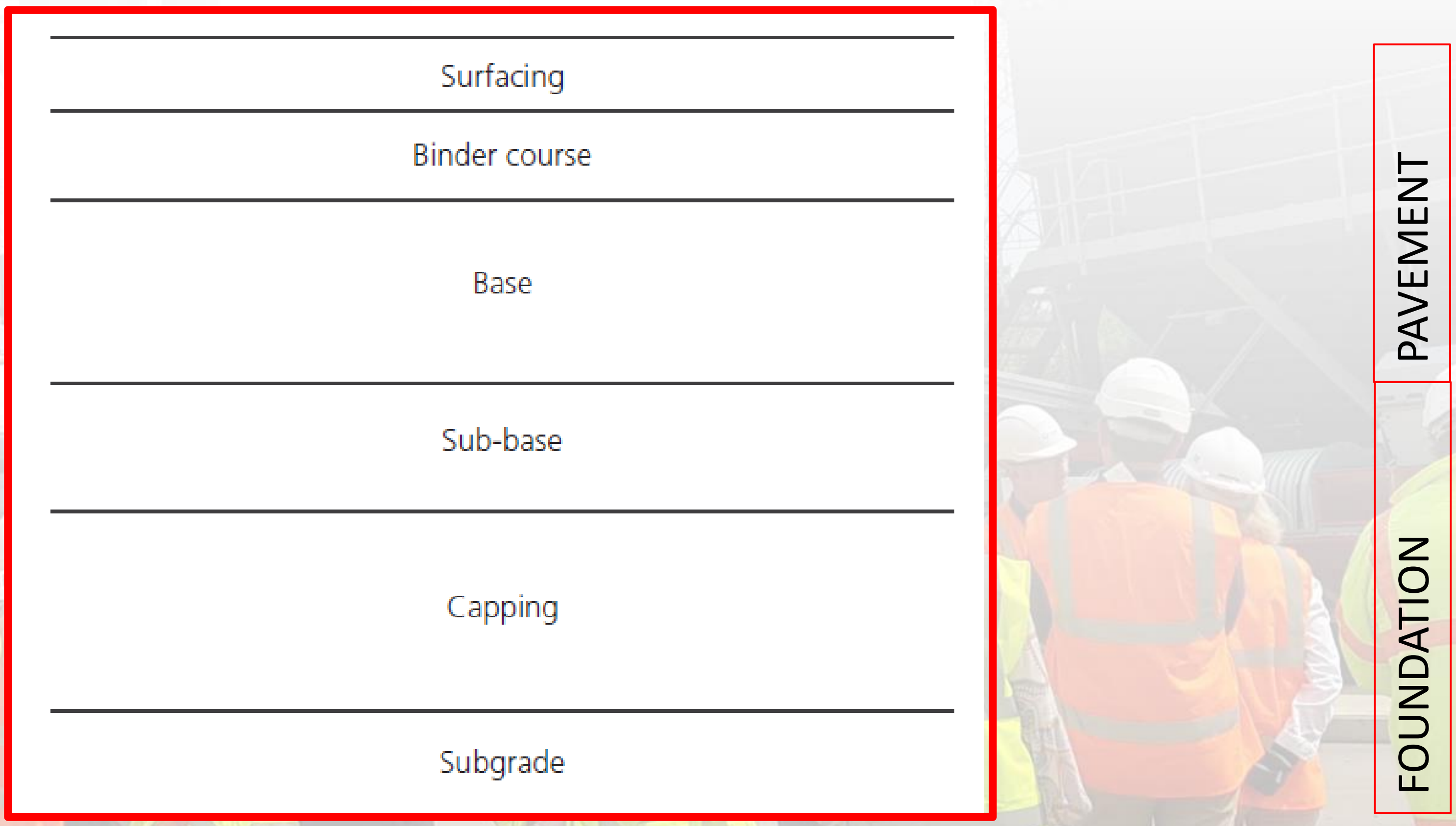
Structural analysis :

calculates the effects of the forces acting on any component and on the structure overall.

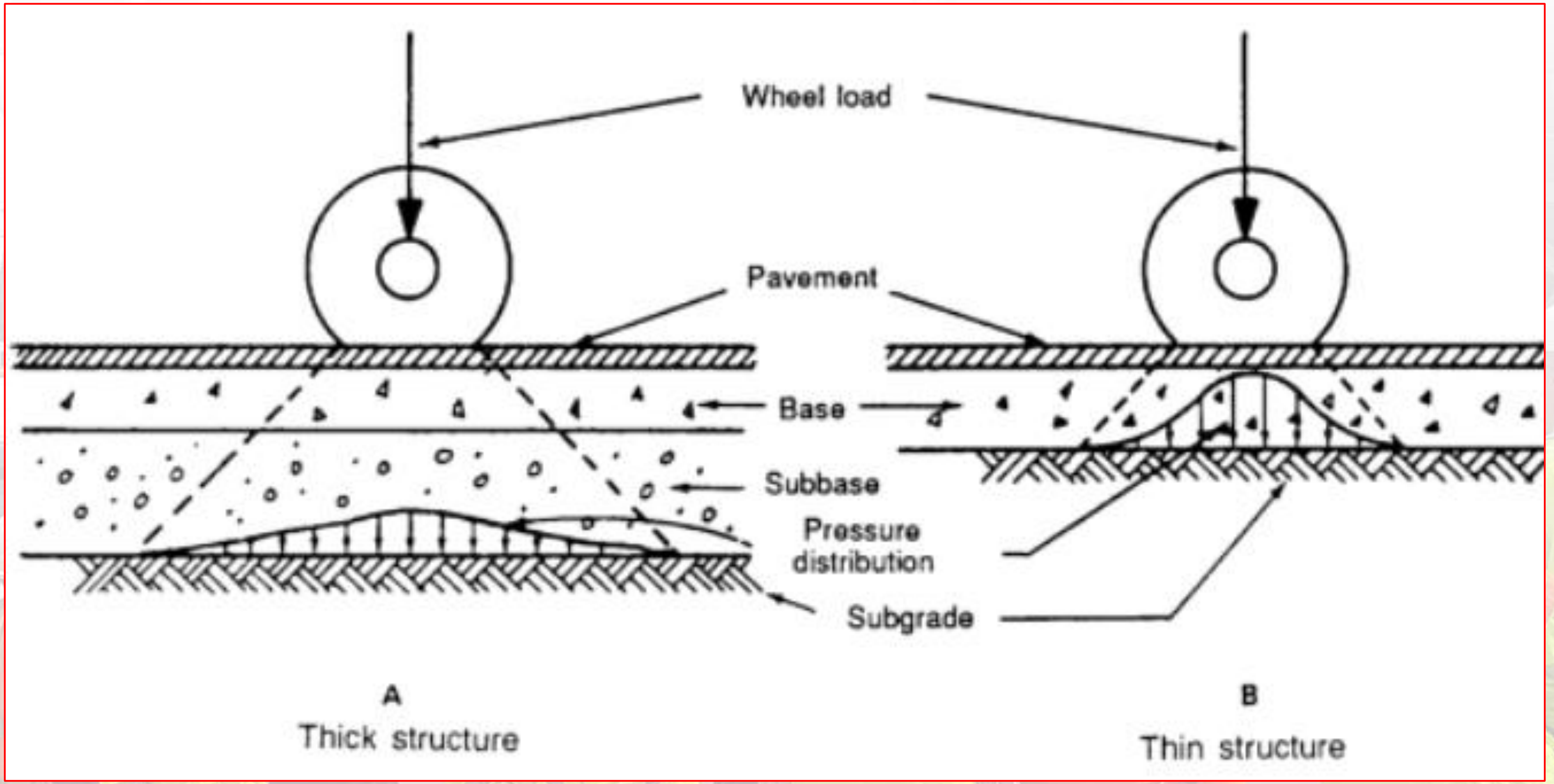
Effectiveness of a structure :

depends on the mechanical properties of the materials from which it is constructed

Pavement as a Structure



Pavement as a Structure



Key Engineering Principles

Fundamental purpose of pavement design :

provide a soil structure system that will carry traffic smoothly and safely with minimum cost

Based primarily on Boussinseq theory (1885)

& Burmisters (1943) formulated a solution for a system having two or three layers subjected to a uniformly distributed load over a circular area

Boussinesq’s Method

Theorem :

- point load acting on the surface of a semi infinite solid produces a vertical stress at any point in addition to lateral and shear stress.

Assumptions :

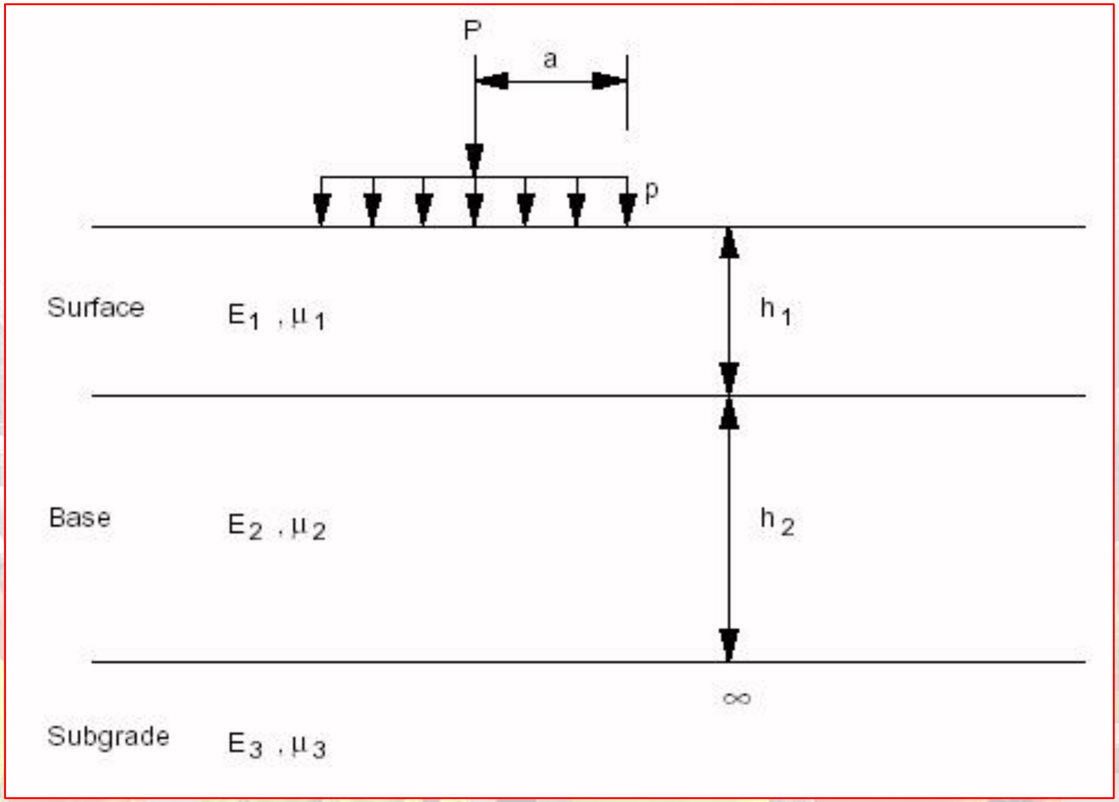
- soil is elastic, isotropic, homogeneous and semi-infinite.
- the soil is weightless.
- the load is vertical, concentrated acting on the surface.
- Hook’s Law applicable: constant relationship between stress and strain

Pavement as Layered Elastic Model

Assumptions

- Pavement layers extend infinitely in the horizontal direction
- The bottom layer (usually the subgrade) extends infinitely downward
- Materials are not stressed beyond their elastic ranges
- The layered elastic approach works with relatively simple mathematical models

Pavement as Layered Elastic Model



Pavement as Layered Elastic Model

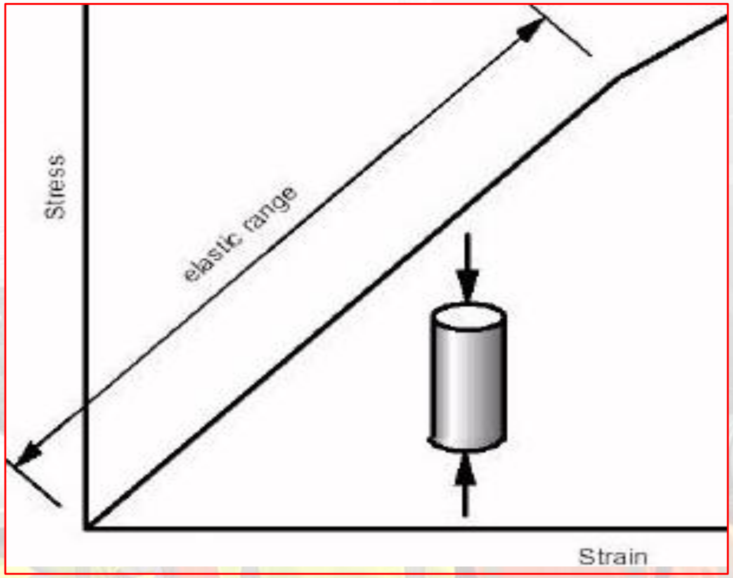
Inputs

- Material properties of each layer
  - *Modulus of Elasticity (*E)
  - *Poisson's Ratio (*μ)
- Pavement layer thicknesses
- Loading conditions

Modulus of Elasticity (E)

Elastic modulus (Young's modulus) can be determined for any solid material and represents a constant ratio of stress and strain:

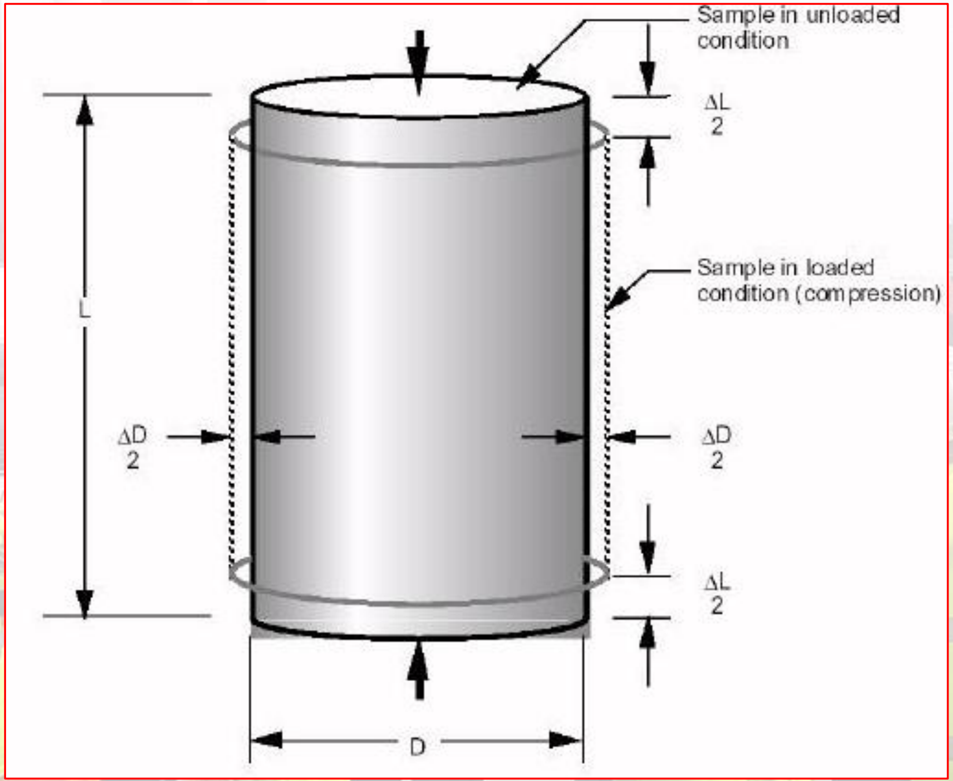
$$E = \frac{stress}{strain}$$



Elastic: ability to return to its original shape immediately after loading
Most materials are considered to be elastic

Poisson’s Ratio (μ)

Poisson’s ratio - ratio of transverse to longitudinal strains of a loaded specimen. can vary from 0 to about 0.5. Generally, “stiffer” materials will have lower ratio



$$\mu = -\frac{\varepsilon_D}{\varepsilon_L}$$

Where

$\mu =$ Poisson's ratio

$\varepsilon_D = \frac{\Delta D}{D}$ = strain along the diametrical (horizontal) axis

$\varepsilon_L = \frac{\Delta L}{L}$ = strain along the longitudinal (vertical) axis

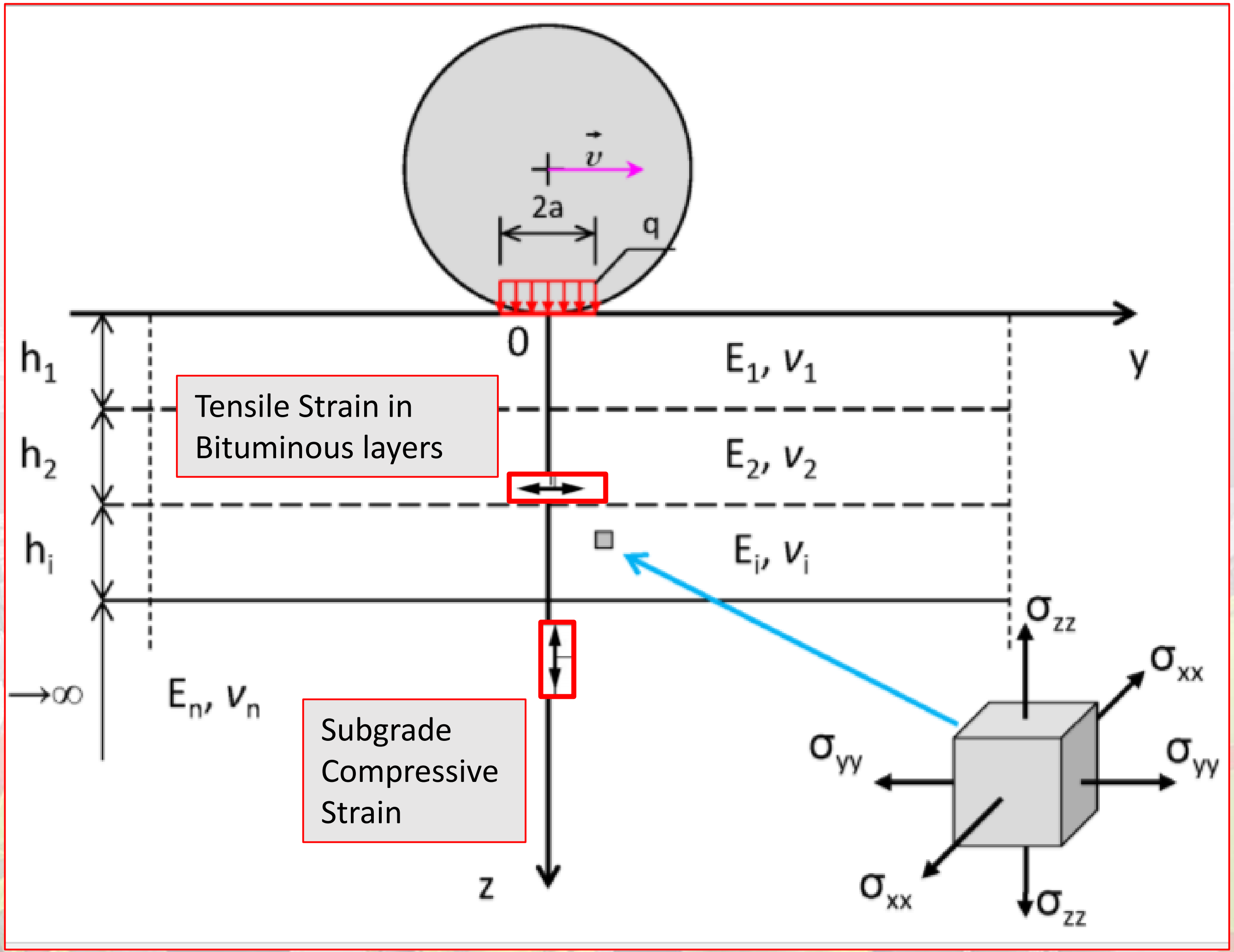
Pavement as Layered Elastic Model

Outputs

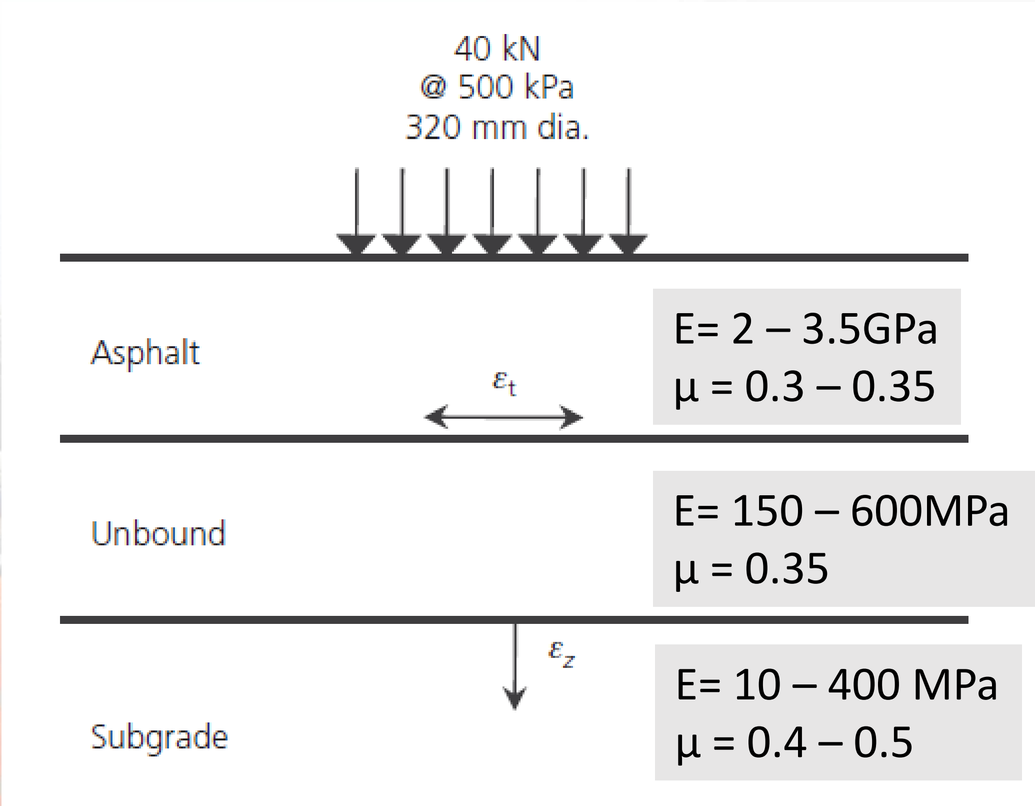
- **Stress**: internally distributed forces experienced within the pavement structure (N/m^2, Pa)
- **Strain:** displacement due to stress, ratio of change in dimension to the original dimension (mm/mm). normally expressed in terms of microstrain (10^{-6})

Location	Response	Required
Bottom of asphalt layer	Horizontal Tensile Strain	Predict fatigue failure in the flexible asphalt material
Top of Intermediate Layer (Base or Subbase)	Vertical Compressive Strain	Predict rutting failure in the base or subbase
Top of Subgrade	Vertical Compressive Strain	Predict rutting failure in the subgrade

Pavement as a Layered Elastic Model



Typical Output Values

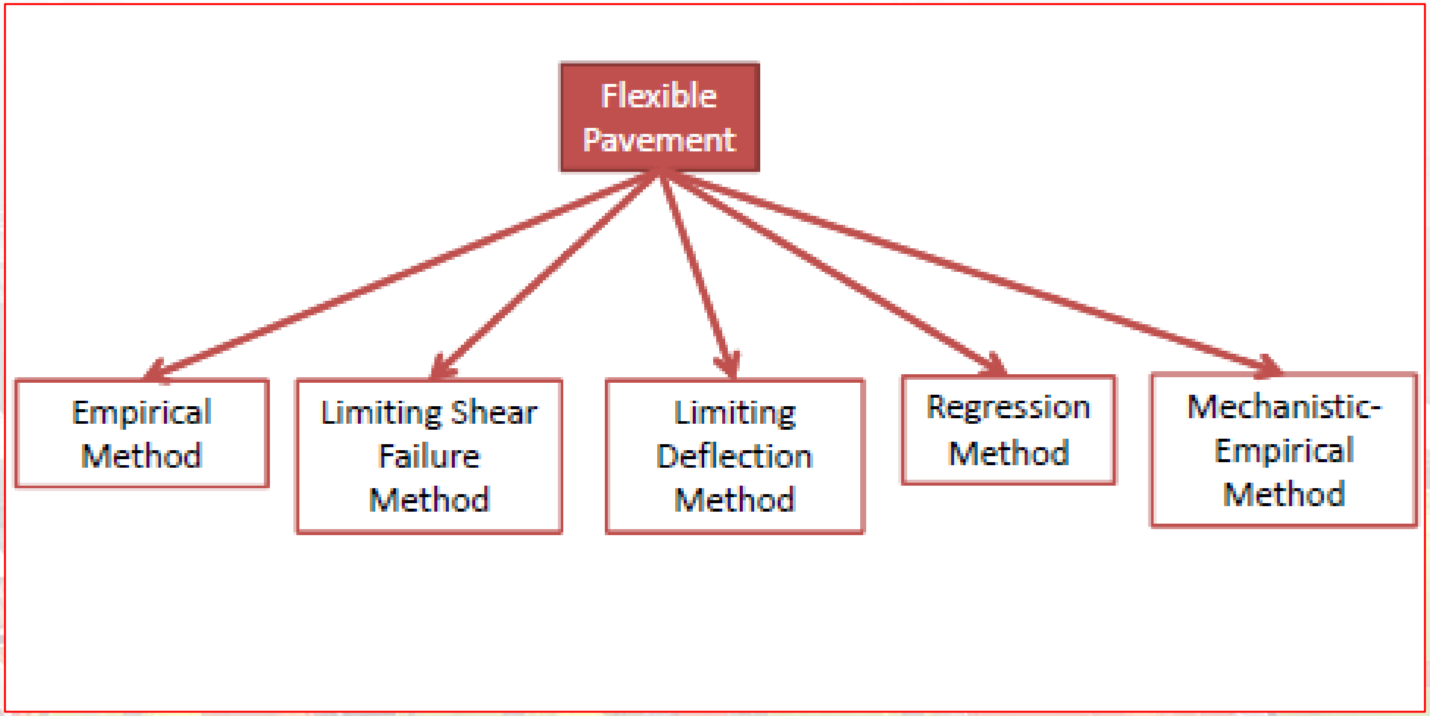


E= 2 – 3.5GPa
μ = 0.3 – 0.35

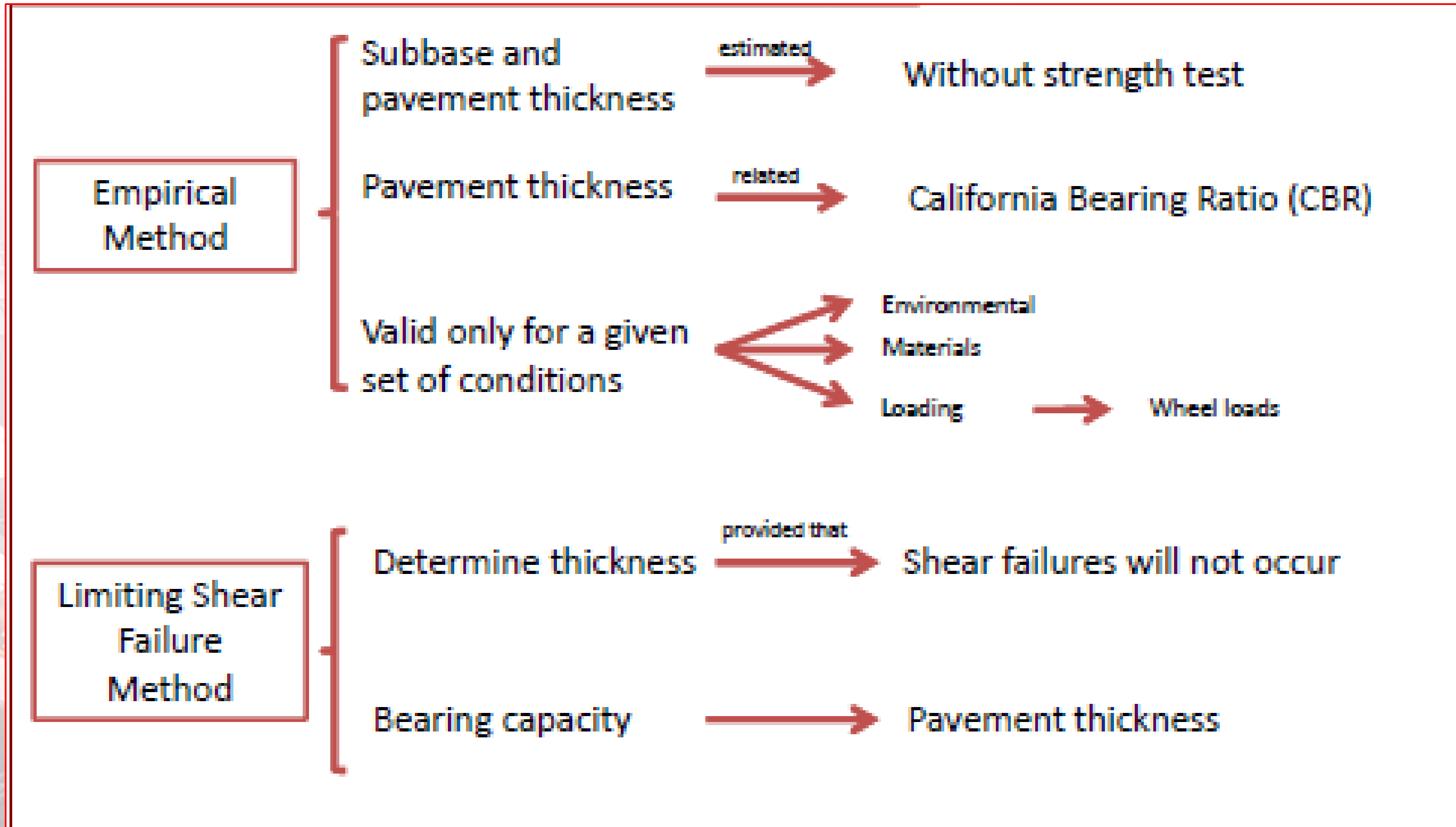
E= 150 – 600MPa
μ = 0.35

E= 10 – 400 MPa
μ = 0.4 – 0.5

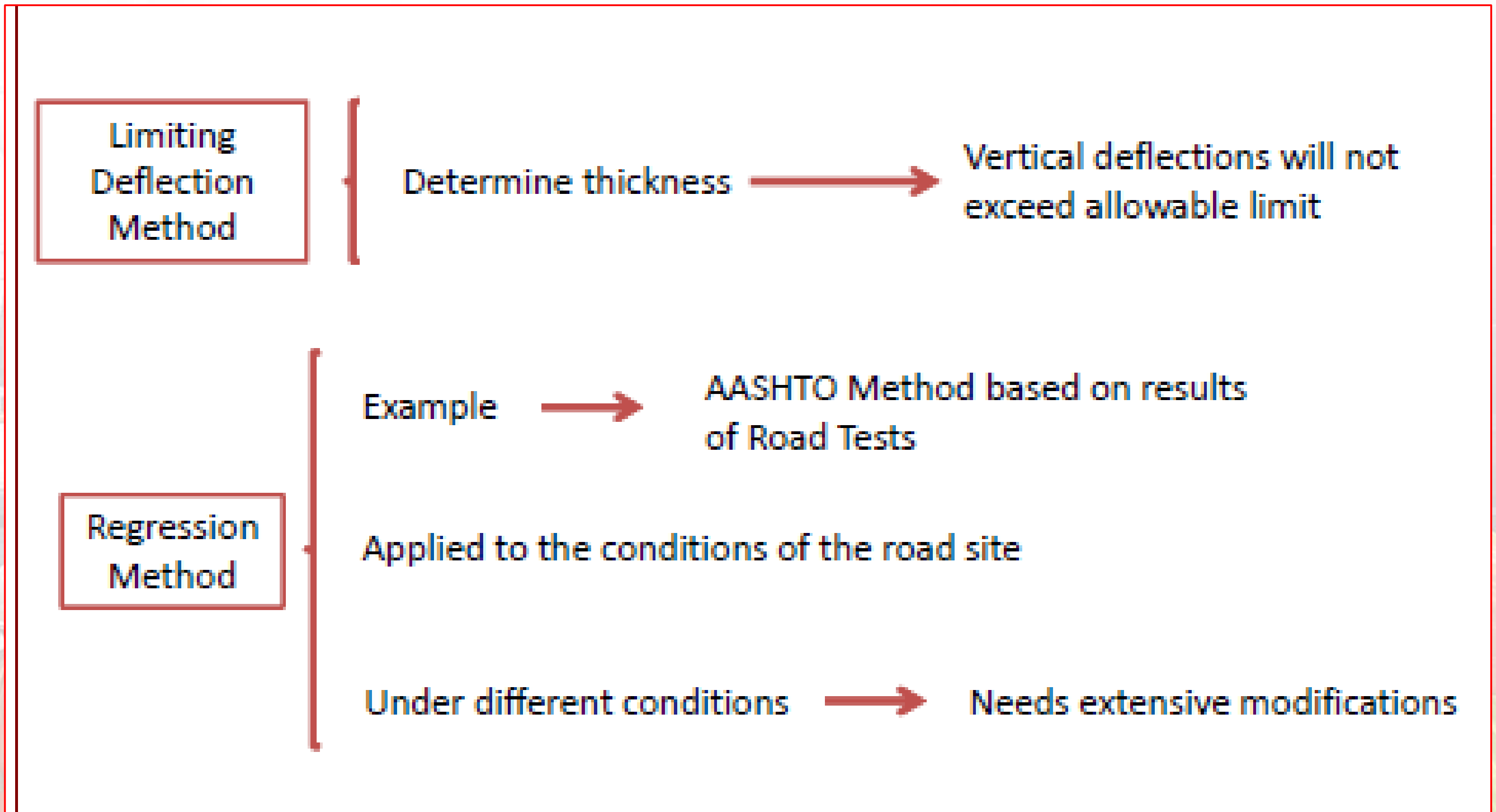
Design Method Review



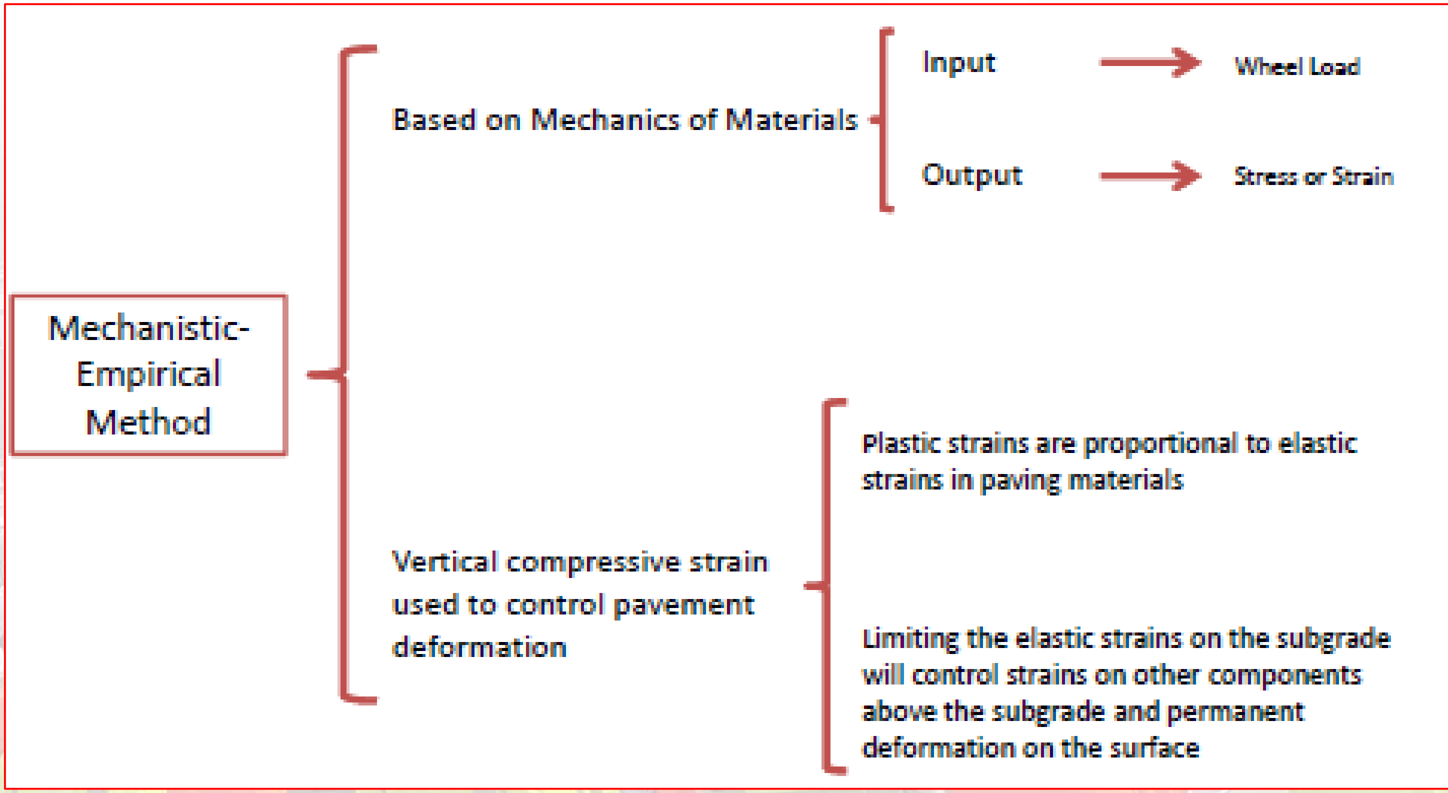
Design Method Review



Design Method Review



Design Method Review



TII Future Model Review

Fully Flexible Pavement Design

- Fundamental engineering **mechanics** as basis for modelling (stress, strain, deformation, fatigue, cumulative damage, etc.)
- **Empirical** data from laboratory and field performance.
- **M-E** Mechanics of materials coupled with observed performance.

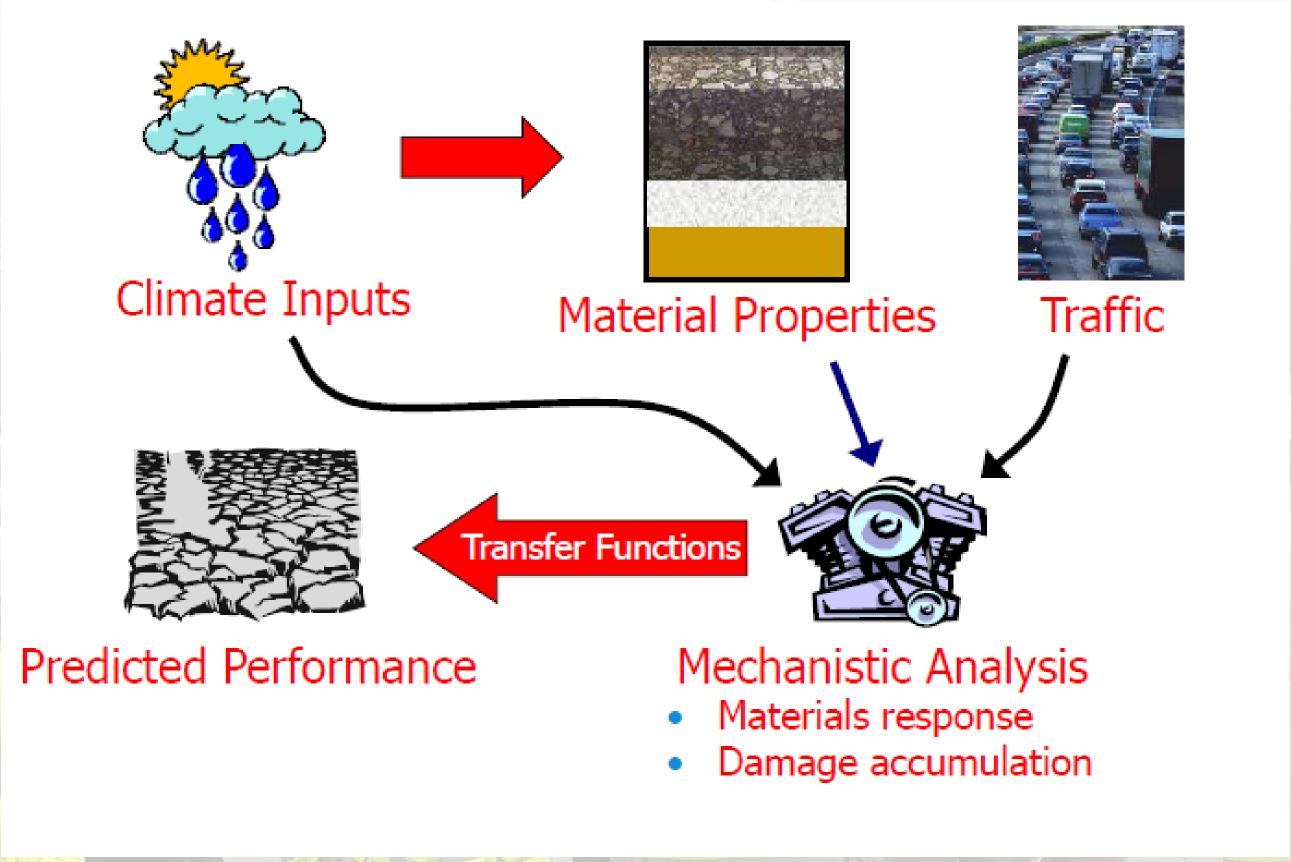
TII Future Model Review

- Mechanistic - empirical based design methods are used or under development in many countries

- Need to obtain information for modelling purposes on factors affecting pavement performances
  - Axle loading
  - Material properties
  - Weather and environmental conditions

- Need to calibrate and validate models to achieve agreement between real performance and estimation

Mechanistic – Empirical Pavement Design overview

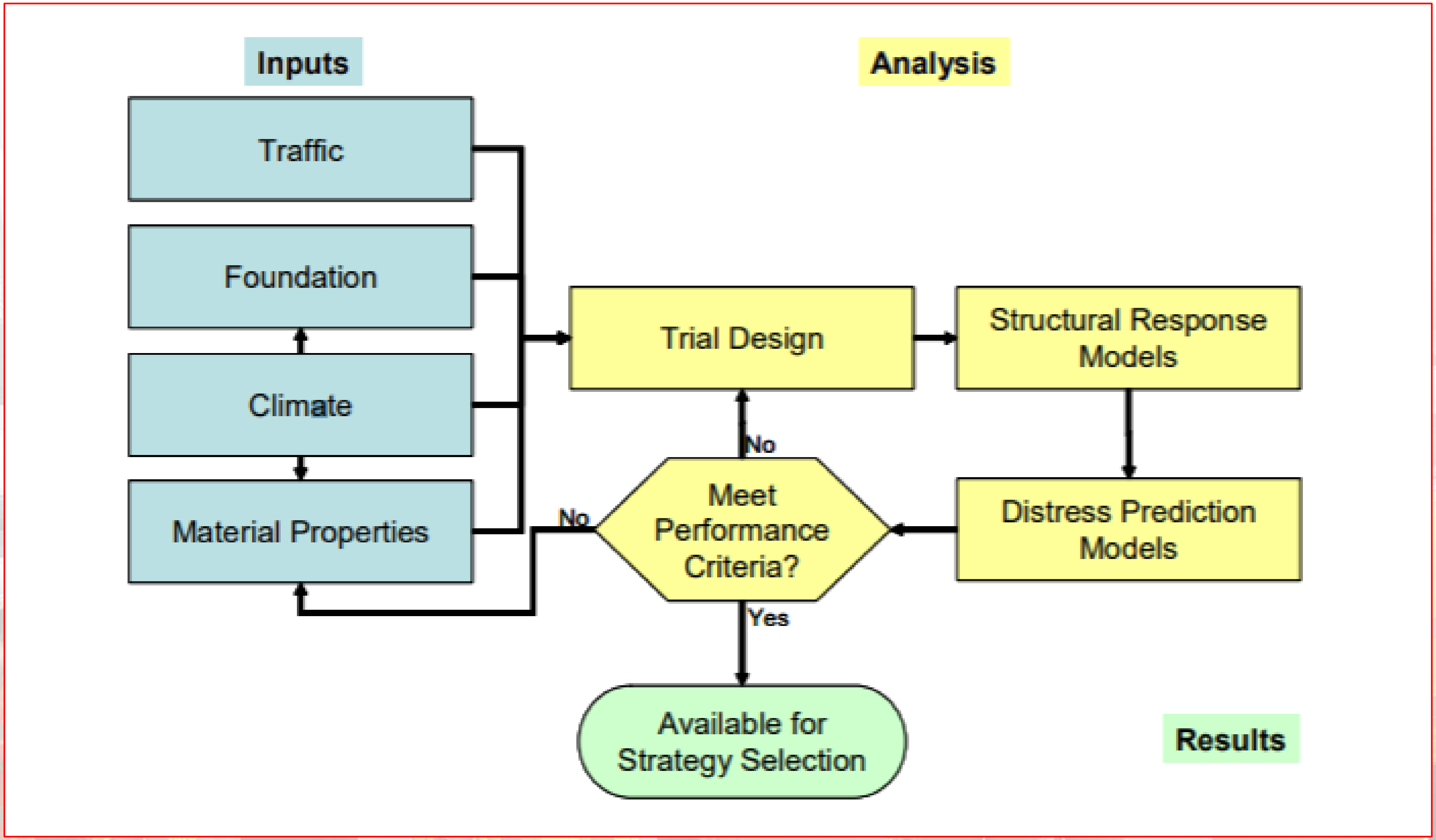


Mechanistic – Empirical Pavement Design

Key Advantages

- More robust (better understanding of mechanics of materials)
- Predicts types of distress
- Modular system that allows for incremental enhancement
- Produces a more reliable design
- No longer dependent on the extrapolation of empirical relationships
- Excellent for forensic analysis
- Answers “What if….” questions
- Calibrate to Local Materials, Traffic, Climate….

Flowchart of M - E Design Process



Dynamic Modulus, E*

Stiffness

- Property function of:
- Temperature
- rate of loading
- Age
- binder stiffness
- aggregate gradation
- binder content
- air voids

Inputs (typical)

- Asphalt mixture properties
- Asphalt binder
- Air voids

Subgrade

- influences (within c.3m) of the pavement surface structural response of the pavement layers
- Inputs
- Layer thickness (infinite)
- Unit weight
- Poisson's ratio
- Layer modulus

Why Change?

- The principal benefit of mechanistic design of pavements is not anticipated as a radically different pavement….
- It is rather a methodology, based on fundamental engineering principles to enable rapid analysis of changes to material properties and traffic loading

Mechanistic-Empirical Design

Mechanistically calculate pavement response (i.e., stresses, strains, and deflections) due to:

- Traffic loading
- Environmental conditions

Evaluate *damage* over time

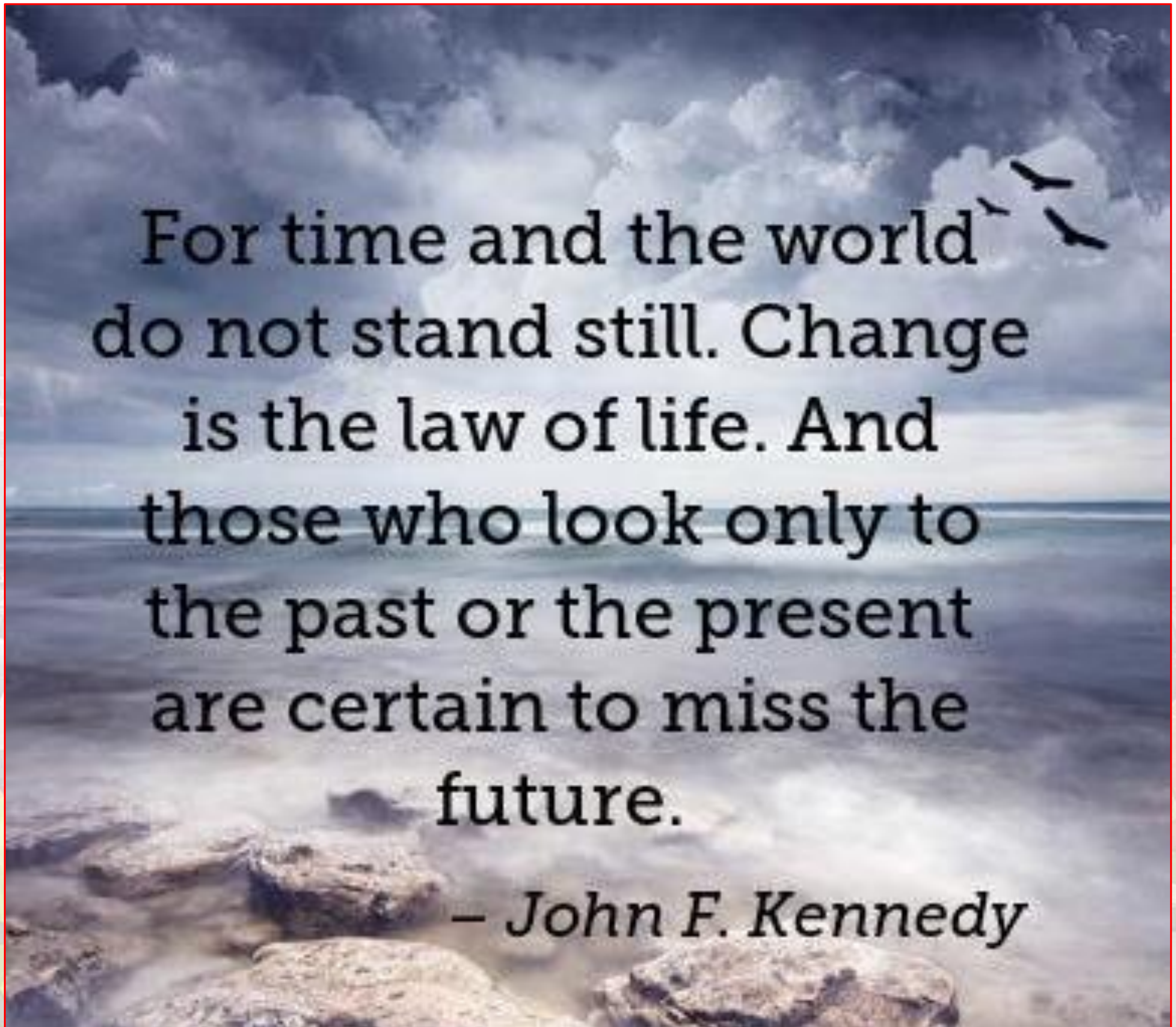
Empirically (validate) predictions of pavement distresses to observed field performance over time,

- Cracking
- Rutting

What will we gain

- More realistic pavement characterisation
- Evaluate new materials
- Better understanding of pavement performances
- Future enhanced or improved knowledge can be easily implemented
- Evaluate effects of new loading conditions such as increased loads, higher tyre pressure and multiple axle

Why Change?


For time and the world
do not stand still. Change
is the law of life. And
those who look only to
the past or the present
are certain to miss the
future.
– John F. Kennedy

The Institute of Asphalt Technology
Irish Branch

tom.casey@tii.ie

Bonneagar Iompair Éireann
Transport Infrastructure Ireland