Foundation & Pavement Design
Analytical Approach

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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

- Surfacings
- Binder course
- Base
- Sub-base
- Capping
- Subgrade
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:

\[ E = \frac{\text{stress}}{\text{strain}} \]

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.
Pavement as Layered Elastic Model

**Outputs**

- **Stress**: internally distributed forces experienced within the pavement structure (N/m², 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)

<table>
<thead>
<tr>
<th>Location</th>
<th>Response</th>
<th>Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom of asphalt layer</td>
<td>Horizontal Tensile Strain</td>
<td>Predict fatigue failure in the flexible asphalt material</td>
</tr>
<tr>
<td>Top of Intermediate Layer (Base or Subbase)</td>
<td>Vertical Compressive Strain</td>
<td>Predict rutting failure in the base or subbase</td>
</tr>
<tr>
<td>Top of Subgrade</td>
<td>Vertical Compressive Strain</td>
<td>Predict rutting failure in the subgrade</td>
</tr>
</tbody>
</table>
Pavement as a Layered Elastic Model

Tensile Strain in Bituminous layers

Subgrade Compressive Strain
Typical Output Values

- **Asphalt**
  - $E = 2 - 3.5 \text{ GPa}$
  - $\mu = 0.3 - 0.35$

- **Unbound**
  - $E = 150 - 600 \text{ MPa}$
  - $\mu = 0.35$

- **Subgrade**
  - $E = 10 - 400 \text{ MPa}$
  - $\mu = 0.4 - 0.5$
Design Method Review

- Empirical Method
- Limiting Shear Failure Method
- Limiting Deflection Method
- Regression Method
- Mechanistic-Empirical Method
Design Method Review

- **Empirical Method**
  - Subbase and pavement thickness estimated
  - Pavement thickness related
  - Valid only for a given set of conditions
  - Without strength test
  - California Bearing Ratio (CBR)
  - Environmental Materials
  - Loading Wheel loads

- **Limiting Shear Failure Method**
  - Determine thickness provided that
  - Shear failures will not occur
  - Bearing capacity
  - Pavement thickness
Design Method Review

Limiting Deflection Method

- Determine thickness
- Vertical deflections will not exceed allowable limit

Example

Regression Method

- AASHTO Method based on results of Road Tests
- Applied to the conditions of the road site
- Under different conditions
- Needs extensive modifications
Design Method Review

Based on Mechanics of Materials

Input
Wheel Load

Output
Stress or Strain

Mechanistic-Empirical Method

Vertical compressive strain used to control pavement deformation

Plastic strains are proportional to elastic strains in paving materials

Limiting the elastic strains on the subgrade will control strains on other components above the subgrade and permanent deformation on the surface

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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

- Climate Inputs
- Material Properties
- Traffic

Transfer Functions

- Predicted Performance
- Mechanistic Analysis
  - Materials response
  - Damage accumulation

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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
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