Pavement Design: Art or Science?

Mike Mamlouk
ASU
Roman Design (200 AD)
Roman Design (200 AD)

4”
Lime Grouted Slabs

10”
Stone & Lime

16”
Local Oolite

5”
Rubble Stones
Telford Design (Early 1800s)

- 2 Layers of 2” Gravel
- Broken Stone & Gravel
- Flat Subgrade
- 4” Stone

15”
Early 1800s
Maximum aggregate size:

“No stone larger than will enter a man’s mouth should go into a road” (Macadam)
Early Bituminous Pavement (Mid-1800s)

- **Tar Macadam (Tarmac)**
  - 2” wearing course (6% coal tar + aggregate)

- **Sheet Asphalt**
  - 1.5”-2” wearing course (AC + sand)
  - 1.5” Binder course (AC + crushed stone)
  - 4”-6” Base (PCC, granite block, bricks, etc.)
Trinidad Lake Asphalt
Bitulithic Pavements (Early 1900s)

- 6% AC + Agg.
- 3” max. agg. size
- Later reduced to ½”
Early Traffic

- Light load
- Solid rubber tires
Early Thickness Trend

- Improved material quality
- Reduced thickness
Early Concrete Pavements (Early 1900s)

- Until 1910 PCC was used as a “stiff” base to support the wearing course
Early Concrete Pavements

• In 1910 PCC started to be used as a pavement wearing course
Today's Pavement
Current Pavement in U.S.

- 2.3 million miles of paved roads
- Boom of road construction in 1960s-70’s
- Largest highway network in the world
- Smoother surface
Pavement Types

- Flexible (Asphalt)
- Rigid (Concrete)
- Composite
Asphalt Pavement

- Surface: 4”-16” or more
- Base: 4”-12”
- Subbase: 6”-20”
- Subgrade
- HMA Unstabilize or stabilized Aggregate
- Aggregate
Evolution of Asphalt Concrete Mix Design

1. Hubbard-Field method (mid-1920s)
2. Hveem method (1940s)
3. Marshall method (1950s)
4. Superpave method (1990s)
Concrete Pavement

8”-12”

PCC Slab

6”

Subbase

Subgrade
Jointed Plain Concrete Pavement (JPCP)

12 to 20 ft

Transverse Joints (with dowels)

Longitudinal Joint (with tiebars)
Asphalt vs. Concrete Pavements

- Load distribution

![](diagram)

- Lower quality material

- Initial cost

- Durability
• 93% asphalt roads
• Selection should be based on life-cycle cost
Function of Base/Subbase

- Asphalt Pavement
  - Structural support
  - Drainage
  - Control of frost effect
  - Reduce effect of volume change of subgrade
**Function of Subbase**

- **Concrete Pavement**
  - Drainage
  - Prevent pumping
  - Control frost effect
  - Reduce effect of volume change of subgrade
  - Construction platform

Diagram:
- PCC Slab
- Subbase
- Subgrade
Unique Properties of Pavements

1. Continuous and fast deterioration with time (traffic)

2. Different load magnitudes and configurations

- Single axle
  - Single wheels
- Single axle
  - Dual wheels
- Tandem axle
  - Dual wheels
Unique Properties of Pavements

3. Unpredictable traffic growth
4. Environmental effects
   - Temperature
   - Rain
   - Freeze and thaw
   - Aging of asphalt
5. Multilayered system
6. Unconventional definition of failure
Distresses in Asphalt Pavement

- Rutting
- Fatigue Cracking
- Thermal Cracking
- Roughness
- Shoving
- Bleeding/Flushing
Distresses in Concrete Pavement

- Cracking
- Faulting
- Pumping
- Alkali-Silica Reactivity
- Scaling
- Joint Spalling
Challenge of Pavement Design

- Longitudinal Cracking
- Fatigue Cracking
- Low Temperature Cracking
- Roughness
- Rutting
Factors Affecting Pavement Performance

- Solar
- Temperature
- Aging
- Moisture
- Traffic loads
Factors Affecting Pavement Performance

1. Traffic
2. Soil and pavement materials
3. Environment
4. Construction and maintenance
Improved Truck Technology (Mid-1900s - Present)

- Increased average truck load
- Increased tire pressure
- Increased traffic volume
  - Large effect on Pavement design
Load, Tire Pressure & Contact Area

Load

Tire Pressure

Contact Pressure

Contact Area
Tire Pressure & Contact Pressure

• Contact pressure is not constant throughout the contact area
• Usually we assume:
  ➢ Constant contact pressure
  ➢ Tire pressure = contact pressure

\[ \text{Contact Area} = \frac{\text{Load}}{\text{Contact Pressure}} \]
Effect of Increasing Load
Increasing Load Magnitude

• Increasing load affects deeper layers

• Required pavement thickness is mostly determined by load magnitude
Effect of Increasing Tire Pressure
Increasing Tire Pressure

- Increasing tire pressure affects upper layers

- Required quality of surface is mostly determined by tire pressure
Increasing Traffic Volume

Traffic volume accumulates pavement damage
Load Duration

Parked cars have larger effect than moving car
Pavement does not last forever
How Long Does Pavement Last?

Pavement Condition

Age (Years)

Performance

Unacceptable Condition

Pavement Life
Pavement Design Approaches

1. Engineering judgment
2. Standard thicknesses
3. Empirical
4. Mechanistic or mechanistic/empirical
The Continuum of Development

Empirical

Mechanistic-Empirical

State-of-Practice

State-of-the-Art

Actual Current Practice??
Moving from Art to Science

• AASHO Road Test
• Strategic Highway Research Program (SHRP)
• Mechanistic-Empirical Pavement Design Guide
AASHO Road Test

• Late 1950’s and early 1960’s

• Ottawa, Illinois

• Loops of pavements with different materials & different numbers of layers

• Traffic loads

• Continuous observations
Layout of AASHO Road Test

Loop 1
Loop 2
Loop 3
Loop 4
Loop 5
Loop 6

N

OTTAWA

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2

7

3
Historical Perspective

AASHO Road Test
AASHO Road Test

- Produced the equivalent single axle load (ESAL) concept
- Relationship between traffic and performance
1993 AASHTO Design

Required Data

1. Traffic (cumulative ESAL)
2. Soil properties
3. Layer material properties (surface, base & subbase)
4. Initial and terminal serviceability
7. Structural layer coefficients
8. Drainage coefficients
1993 AASHTO Design Nomograph

- DARWin software
- Both asphalt and concrete pavements
Limitations of 1993 AASHO Design

- Empirical performance models
- Specific climate, subgrade, and materials
- Short performance period of AASHO Road Test
Strategic Highway Research Program (SHRP)

- 5-year program (1987-1993)
  - Asphalt
  - Concrete and construction
  - Highway operation
  - Long-term pavement performance (LTPP)
Mechanistic-Empirical Pavement Design Guide (MEPDG)

- An Analysis Method
- An Iterative Design Method

• DARWin-ME software
MEPDG Design Process Overview

Inputs
- Traffic
- Foundation
- Climate
- Material Properties

Analysis
- Trial Design Strategy
- Pavement Analysis Models
- Damage Accumulation
- Distress Prediction Models

Select Strategy
- Viable Alternatives
- Life Cycle Cost Analysis
- Constructability Issues
- Meet Performance Criteria?
- Modify Strategy

No

Yes
A hierarchical approach for determining the design inputs.

<table>
<thead>
<tr>
<th>Input Level</th>
<th>Determination of Input Values</th>
<th>Knowledge of Input Parameter</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Specific Measurements, Extensive data input</td>
<td>Good</td>
</tr>
<tr>
<td>2</td>
<td>Correlations, Regional values</td>
<td>Fair</td>
</tr>
<tr>
<td>3</td>
<td>Defaults, Educated Guess</td>
<td>Poor</td>
</tr>
</tbody>
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MEPDG Critical Response Values

$\varepsilon_t$ at surface + bottom of all bound layers (cracking)

$\varepsilon_c$ at mid-thickness of all layers + top of subgrade (rutting)
MEPDG Predicted Distresses

Fatigue Cracking

Thermal Cracking

Longitudinal Cracking

Rutting

IRI
MEPDG Rutting in HMA

Truck Speed, mph
Asphalt Rubber

• About 1” overly on existing pavement is common in Arizona (AR-ACFC)

  ➢ Binder
  ➢ 80 % Asphalt
  ➢ 20 % Ground tire rubber
  ➢ Gap graded aggregate
Asphalt Rubber (Cont.)

- Reduces cracking
- Reduces noise
- Improves skid resistance
- Reduces standing water
- Improves driver visibility
Concept of Perpetual Pavement

- Extended-life HMA pavement
- Limit distresses in the surface layer
- Has been used in Europe
### Example of Perpetual Pavement

<table>
<thead>
<tr>
<th>SMA 1.5” – 3”</th>
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<tbody>
<tr>
<td>High Modulus</td>
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<tr>
<td>Rut Resistant Material</td>
</tr>
<tr>
<td>4” – 7”</td>
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</tbody>
</table>

| Flexible Fatigue Resistant Material 3” – 4” |

| Pavement Foundation |

*ASU*
Endurance Limit

- Strain level below which HMA would endure indefinite load repetitions without developing fatigue cracks.
We have not solved the whole problem yet!
Conclusions

• Pavement design evolved throughout the years
• Combination of art and science
  ❖ Started with empirical
  ❖ Gradually becoming mechanistic (scientific)
  ❖ A completely mechanistic design is yet to come