Pavement Analysis and Design
TE-503

Lecture-1
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Course Outline

Focusing on the empirical as well as mechanistic design procedures both for highway and airfield pavement systems. Introduction to multi-layered elastic and slab theories, properties of pavement materials and methods of characterization, stochastic treatment of design variables, economic principles of design alternates and the effect of environment upon pavement performance. Review of design methods including AASHTO, AI, PCA and USACE.

Pavement Analysis and Design
Books

• Pavement Analysis and Design (*Second Edition*)
  By
  Yang H. Huang

• Principles of Pavement Design
  By
  Yoder and Witczak

• AASHTO Design Guide-1993

• Road Note-31

Pavement Analysis and Design
Evaluation

Type-A (Theory)- Marks 100:
• Quiz 1-Weightage 10%
• Mid Term-Weightage 30%
• Quiz 2-Weightage 10%
• End Term-Weightage 50%

Type-B (Practical)-Marks 100:
• Class Performance-Weightage 20%
• Mini Project/Presentation and Report-Weightage 40%
• Assignments/Design problems-Weightage 40%

Pavement Analysis and Design
Historical Developements

• Although pavement design has gradually evolved from art to science, empiricism still plays an important role even up to the present day.

• Prior to the early 1920s, the thickness of pavement was based purely on experience. The same thickness was used for a section of highway even though widely different soils were encountered.

• As experience was gained throughout the years, various methods were developed by different agencies for determining the thickness of pavement required.

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Flexible Pavement

Flexible pavements are constructed of bituminous and granular materials.

The first asphalt roadway in the United States was constructed in 1870 at Newark, New Jersey.
Design Methods of Flexible Pavement Design

Five categories:
• Empirical method
• Limiting shear failure method
• Limiting deflection method
• Regression method based on pavement performance or road test
• Mechanistic-empirical method
Design Methods of Flexible Pavement Design

**Empirical method**

The use of the empirical method without a strength test dates back to the development of the Public Roads (PR) soil classification system in which the subgrade was classified as uniform from A-1 to A-8 and non-uniform from B-1 to B-3. The PR system was later modified by the Highway Research Board (HRB), in which soils were grouped from A-1 to A-8 and a group index was added to differentiate the soil within each group.

Steele (1945) discussed the application of HRB classification and group index in estimating the sub-base and total pavement thickness without a strength test.

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Design Methods of Flexible Pavement Design

**Empirical method (Contd.)**
The empirical method with a strength test was first used by the California Highway Department in 1929.

The thickness of pavements was related to the California Bearing Ratio (CBR), defined as the penetration resistance of a subgrade soil relative to a standard crushed rock.

The CBR method of design was studied extensively by the U.S. Corps of Engineers during World War II and became a very popular method after the war.
Design Methods of Flexible Pavement Design

Limiting Shear Failure Methods

The limiting shear failure method is used to determine the thickness of pavements so that shear failures will not occur. The major properties of pavement components and subgrade soils to be considered are their cohesion and angle of internal friction.

Barber (1946) applied Terzaghi's bearing capacity formula (1943) to determine pavement thickness. With the ever increasing speed and volume of traffic, pavements should be designed for riding comfort rather than for barely preventing shear failures.
Design Methods of Flexible Pavement Design

Limiting Deflection Methods
The limiting deflection method is used to determine the thickness of pavements so that the vertical deflection will not exceed the allowable limit.

The Kansas State Highway Commission (1947) modified Boussinesq's equation (Boussinesq, 1885) and limited the deflection of subgrade to 0.1 in.

The U.S. Navy (1953) applied Burmister's two-layer theory (Burmister, 1943) and limited the surface deflection to 0.25 in.
The use of deflection as a design criterion has the apparent advantage that it can be easily measured in the field.

Unfortunately, pavement failures are caused by excessive stresses and strains instead of deflections.
Design Methods of Flexible Pavement Design

Regression Methods Based on Pavement Performance or Road Tests

A good example of the use of regression equations for pavement design is the AASHTO method based on the results of road tests.

The disadvantage of the method is that the design equations can be applied only to the conditions at the road test site. For conditions other than those under which the equations were developed, extensive modifications based on theory or experience are needed.

Although these equations can illustrate the effect of various factors on pavement performance, their usefulness in pavement design is limited because of the many uncertainties involved.

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Design Methods of Flexible Pavement Design

Mechanistic-Empirical Methods
The mechanistic-empirical method of design is based on the mechanics of materials that relates an input, such as a wheel load, to an output or pavement response, such as stress or strain.

The response values are used to predict distress from laboratory-test and field-performance data.

Dependence on observed performance is necessary because theory alone has not proven sufficient to design pavements realistically.

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Design Methods of Flexible Pavement Design

Mechanistic-Empirical Methods (Contd.)

The use of the above concepts for pavement design was first presented in the United States by Dormon and Metcalf (1965).

The advantages of mechanistic methods are the improvement in the reliability of a design, the ability to predict the types of distress, and the feasibility to extrapolate from limited field and laboratory data.
Rigid Pavements

Rigid pavements are constructed of Portland cement concrete.

The first concrete pavement was built in Bellefontaine, Ohio in 1893.
Design Methods of Rigid Pavements

The development of design methods for rigid pavements is not as dramatic as that of flexible pavements, because the flexural stress in concrete has long been considered as a major, or even the only, design factor.

Two categories of solutions:
- Analytical Solutions
- Numerical Solutions
Design Methods of Rigid Pavements

Analytical Solutions

Analytical solutions ranging from simple closed-form formulas to complex derivations are available for determining the stresses and deflections in concrete pavements.

-Westergaard's Analysis
Design Methods of Rigid Pavements

**Numerical Solutions**

All the analytical solutions mentioned above were based on the assumption that the slab and the subgrade are in full contact.

It is well known that, due to pumping, temperature curling, and moisture warping, the slab and subgrade are usually not in contact.

With the advent of computers and numerical methods, some analyses based on partial contact were developed.

- *Finite-Element Methods*

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Pavement Types

Three major types:

1. Flexible pavements
2. Rigid pavements
3. Composite pavements
Conventional Flexible Pavement

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Conventional Flexible Pavement

Conventional flexible pavements are layered systems with better materials on top where the intensity of stress is high and inferior materials at the bottom where the intensity is low.

Adherence to this design principle makes possible the use of local materials and usually results in a most economical design.

This is particularly true in regions where high-quality materials are expensive but local materials of inferior quality are readily available.

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Full Depth Asphalt Pavement

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Full Depth Asphalt Pavement

Full-depth asphalt pavements are constructed by placing one or more layers of HMA directly on the subgrade or improved subgrade.

This concept was conceived by the Asphalt Institute in 1960 and is generally considered the most cost-effective and dependable type of asphalt pavement for heavy traffic.

This type of construction is quite popular in areas where local materials are not available.

It is more convenient to purchase only one material, i.e., HMA, rather than several materials from different sources, thus minimizing the administration and equipment costs.
Jointed Plain Concrete Pavements (JPCP)

Transverse Joints with or without Dowels

15 to 30 ft 15 to 30 ft

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Jointed Plain Concrete Pavements (JPCP)

All plain concrete pavements should be constructed with closely spaced contraction joints.

Dowels or aggregate interlocks may be used for load transfer across the joints.

Depending on the type of aggregate, climate, and prior experience, joint spacings between 15 and 30 ft have been used.

However, as the joint spacing increases, the aggregate interlock decreases, and there is also an increased risk of cracking.
Jointed Reinforced Concrete Pavements (JRCP)

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Jointed Reinforced Concrete Pavements (JRCP)

Steel reinforcements in the form of wire mesh or deformed bars do not increase the structural capacity of pavements but allow the use of longer joint spacings. Joint spacings vary from 30 to 100 ft.

Because of the longer panel length, dowels are required for load transfer across the joints.

The amount of distributed steel in JRCP increases with the increase in joint spacing and is designed to hold the slab together after cracking. However, the number of joints and dowel costs decrease with the increase in joint spacing.
Continuous Reinforced Concrete Pavements (CRCP)
Continuous Reinforced Concrete Pavements (CRCP)

The advantages of the joint-free design were widely accepted.

It was originally reasoned that joints were the weak spots in rigid pavements and that the elimination of joints would decrease the thickness of pavement required.

As a result, the thickness of CRCP has been empirically reduced by 1 to 2 in. or arbitrarily taken as 70 to 80% of the conventional pavement.
Pre-stressed Concrete Pavements (PCP)

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Pre-stressed Concrete Pavements (PCP)

Concrete is weak in tension but strong in compression.

The thickness of concrete pavement required is governed by its modulus of rupture, which varies with the tensile strength of the concrete.

The pre-application of a compressive stress to the concrete greatly reduces the tensile stress caused by the traffic loads and thus decreases the thickness of concrete required.

The prestressed concrete pavements have less probability of cracking and fewer transverse joints and therefore result in less maintenance and longer pavement life.
Composite Pavements

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Composite Pavements

A composite pavement is composed of both HMA and PCC. The use of PCC as a bottom layer and HMA as a top layer results in an ideal pavement with the most desirable characteristics.

The PCC provides a strong base and the HMA provides a smooth and non-reflective surface.

However, this type of pavement is very expensive and is rarely used as a new construction, rather employed as rehabilitation of concrete pavements using asphalt overlays.

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