Department of Highway Engineering Techniques Department
College of Technical Engineering
University of Polytechnic
Subject: Pavement Design
Course Book – Year 4
Lecturer's name: Ass. Prof. Dr. Faris M. Jasim
Academic Year: 2019/2020
# Course Book

<table>
<thead>
<tr>
<th>1. Course name</th>
<th>Pavement Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Lecturer in charge</td>
<td>Ass.Prof.Dr. Faris M. Jasim</td>
</tr>
<tr>
<td>3. Department/ College</td>
<td>Highway Engineering Techniques Department</td>
</tr>
<tr>
<td>4. Contact</td>
<td>e-mail: @epu.edu.krd&lt;br&gt;Tel: 00964 (0) 7507587248</td>
</tr>
<tr>
<td>5. Time (in hours) per week</td>
<td>Theory: 3&lt;br&gt;Practical: 0</td>
</tr>
<tr>
<td>6. Office hours</td>
<td>Sunday to Wednesday: 8:30AM – 11:30PM,</td>
</tr>
<tr>
<td>7. Course code</td>
<td>HE406</td>
</tr>
<tr>
<td>8. Teacher's academic profile</td>
<td>Started professional work since 1983 as a professional Highway Design Engineer in Consultancy Firms and started the academic career since 2007 to date. Currently hold the position of the Head of Scientific committee in Highway Engineering Department and a Lecturer as Assistant professor since 2012-2013 at the same department.</td>
</tr>
<tr>
<td>9. Keywords</td>
<td>Pavement, Design</td>
</tr>
</tbody>
</table>

## 10. Course overview:
Increase student knowledge and learn the principles and practices for the investigation, design, contracting, and construction of different types of pavements, including maintenance and rehabilitations processes for more durable with high performance active highway system.

Highway pavements are divided into two main categories: rigid and flexible. The wearing surface of a rigid pavement usually is constructed of Portland cement concrete such that it acts like a beam over any irregularities in the underlying supporting material. The wearing surface of flexible pavements, on the other hand, usually is constructed of bituminous materials such that they remain in contact with the underlying material even when minor irregularities occur. Flexible pavements usually consist of a bituminous surface under laid with a layer of granular material and a layer of a suitable mixture of coarse and fine materials. Traffic loads are transferred by the wearing surface to the underlying supporting materials through the interlocking of.

## 11. Course objective:
The main objectives to be achieved after the completion of this course are summarized below:
1. To understand pavement engineering, terminology, and concepts.
2. To understand the different types of pavements.
3. To recognize the different types of flexible pavements as well as rigid pavements.
4. To get to know and understand the engineering properties and characteristics of the different materials that concern the pavement engineer.
5. To understand testing and evaluation of soil, granular, and bituminous materials for pavement analysis and design.
6. To understand the different Superpave aggregate tests and requirements.
7. To be familiar with the Superpave asphalt binder tests and specifications.
8. To conduct analysis of flexible pavements for stresses, strains, and deflections in one-, two-, and three-layered systems.
9. To conduct analysis of different types of drainage systems with their suitable design for highway projects.
10. To conduct analysis of rigid pavements for stresses, strains, and deflections.
11. To design flexible pavements using the AASHTO design procedure.
12. To design rigid pavements using the AASHTO design procedure.
13. Introduce the student to certain case studies.

12. Student's obligation
a. To attend the classes regularly with minimum absence.
b. To participate actively in the class discussion and Q&A session.
c. Study on daily basis to digest the class material.
d. To write notes off-handouts.
e. Prepared for sudden quizzes.
f. Vet through the references provided by the lecturer and to solve as much as possible of homework and exercises for the subjective materials.
g. Prepare the assignment and the seminar as instructed by the lecturer.

13. Forms of teaching
Basically, a handout shall be given to the students at the beginning of the academic year. The page-by-page read shall be performed by the lecturer and to illustrate the points with aide of white board whenever necessary. The video clips that illustrates further the subject material shall be illustrated with the aid of overhead projector.

14. Assessment scheme
The overall year-work mark is set to 5 marks with to semester exams, each held 17.5 marks. The (5) is basically divided into two portions one of which holds (3) marks for 2 quizzes and the remaining (2) marks are left for presence and absence. As an effort to enhance the student knowledge, another (5) marks is intended to be readdressed to a seminar and keep the semester exam marks to 15 instead of 17.5

15. Student learning outcome:
By the end of the current course, the student shall be able to learn the major activities related to the pavement design which is the part the makes the backbone for any constructional project. This course is aimed at providing the Highway Engineering students with basic understanding of the Highway Engineering materials and the basic and fundamental design concept of highway pavements structures. Students will be able to design and analyse flexible pavements in addition, they will be able to understand the basic elements of rigid pavement design. Students will be able to conduct a thorough analysis of stresses, strains and deflections developed by different axle configurations and loads in multilayer flexible pavement structures. Students will study the effect of both traffic and environment on pavement damage. The pavement course provide sufficient coverage of highway materials using SUPERPAVE characterisation methods, hot mix asphalt design by using Marshall design methods. Students will learn how to design new pavement structure using Mechanistic-Empirical Pavement Design and by using empirical design methods such as AASHTO guide 1993 method. Students will also learn how to evaluate the structural capacity of an existing pavement structure by utilising the surface deflection.
measurements and back analysis (back calculation) methods. Overlay design will also be covered.

16. Course Reading List and References:

- Principles of Highway Engineering and Traffic Analysis, Fifth Edition -2013 by Fred L. Mannering and Scott S. Washburn,,Purdue university ,USA
- Highway and traffic engineering …by N.J. Garber and L.A. Hoel,,2009 4th edition.. University of Virginia,USA
- Pavemen Design and Materials by A.T. Papagiannakis and E.A.Masad. 2007….University of Texas USA
  Foundation Analysis and Design: Joseph E. Bowles

17. The Topics:

1. **INTRODUCTION**
2. **MATERIALS PROPERTIES AND TESTING REQUIREMENTS**
3. SOIL ENGINEERING AND EARTHWORK
4. GRANULAR TYPES AND EVALUATION
5. DRAINAGE DESIGN
6. BITUMINOUS and PORTLAND CEMENT AS Binder MATERIALS
7. PAVEMENT MIX DESIGN (Marshall and Superpave methods)
   a- flexible pavement design
   b- rigid pavement design
   c- Runway and Taxiway design
   d- composite design
9. HIGHWAYS MAINTENANCE AND REHABILITATION

18. Practical Topics (If there is any)  NONE

19. Examinations:
1. **Compositional:**
The exams shall cover all the topics studied in detail in class. The number of the questions shall depend upon the time for the exam and shall be solved and provide the solution for the questions to the student at the end of the exam. Attached is a sample for the final exam for the first attempt of the academic year (2016 – 2017) with the solution for easy reference.
20. Extra notes:
In spite of the fact that, the topics above sound rich but the pavement design is related to the highway materials course. A close coordination shall be conducted between the two courses lecturers to ensure the full convey of information to the receiver (the student). The topics shall be enriched year by year and kept it in contact with latest technology developed worldwide in the science of highway pavement Engineering.

21. Peer review
Checked and found satisfactory for the purpose of its use

NOTE : Use the attached equations, and graph paper in solution:

Theory part:

Q-1- (14mark )

a-Performance Grade( PG) as Superpave System when has been adopted by SHRP 1993 , it had great target in establishing PG classification for different asphalt binders as neat or modified compositions ..for sake that clarify the importance of the following aided by required sketches :

I. Evaluating of short and long term aging.
II. Role of using DSR(dynamic shear rheometer) and BBR(bending beam rheometer) tests in PG selection.

b- (13mark )

The latitude of Erbil region (sector two), is 35 ° where a high-speed rural road (Masif-permam-kore Highway ). The seven-day average high air temperature is (42 °C ) and the low air temperature is (- 3 °C). The standard deviation at (98% reliability ) ,for both the high and low temperatures is ( 1 °C). Determine a suitable binder (PG) that could be used for the pavement of this highway if the depth of the pavement surface is (245 mm) . It is anticipated that this road has the expected ESAL is more than $10^6$ axle loads.
Q-2 – (17 mark)

A flexible pavement is designed to last 10 years to withstand truck traffic that consists only of trucks with two 18-kip single axles. The pavement is designed for a soil CBR of (3.5), an initial PSI of 5.0, a TSI of 2.5, an overall standard deviation of 0.40 and \( Z_R = -1.282 \), and the structural number was determined to be 6. On one section of this roadway, beneath an underpass, an engineer uses an 8-inch rigid pavement in an attempt to have it last longer before resurfacing. How many years will this rigid-pavement section last? (Given the same traffic conditions, modulus of rupture = 850 lb/in², modulus of elasticity = 4,500,000 lb/in², load transfer coefficient of 3.02 and drainage coefficient of 1.0.).

Q-3– (16 mark)

A flexible pavement has a structural number of 4.8 (all drainage coefficients are equal to 1.0). The initial PSI is 4.5 and the terminal serviceability is 2.5. The soil has a CBR of 4. The overall standard deviation is 0.40 and the reliability is 95% \((z_R = -1.645)\). The pavement is currently designed for 3850 equivalent 18-kip single-axle loads per day. If the number of 18-kip single-axle loads were to increase by 35%, by how many years would the pavement’s design life be reduced?

Q -4 –(15 mark)

State Explanation briefly for the following :

a- superpave gyratory is very different than marshall compactor for asphaltic mix design

b- importance of nominal max sizes determination as properties consensus of superpave approach.

c- moisture damage and thermal cracking as two types of distresses are happened in asphalt mixes .

d- The effect of drainage on the performance of flexible pavements is considered in the 1993 guide with respect to the effect water has on the strength of the base material and roadbed soil. The approach used is to provide for the rapid drainage of the free water (non capillary) from the pavement structure by providing a suitable drainage layer: Explain That Two Approaches Cleared With Figures And Compare Between Them to specify Which One Is More Active As Drainage System.

e– Pumping is an important phenomenon associated with rigid pavements. State its reasons and how mitigate it to prevent it and how possess durable system of pavement .

Experimental part
a- According to the available data of asphalt (\( G_b = 1.015\)) , Aggregate, calculate the volumetric-mass properties of a compacted HMA binder layer (all mass-volume parameters), depending on Phase diagram method (note allowed to use any equations). 1-trial and errors (aided with equations depending on passing and retained %) to find \( G_{sb}\), and \( G_{se}\) (use equations below).

<table>
<thead>
<tr>
<th>Size (mm)</th>
<th>Filler</th>
<th>0-5 mm</th>
<th>5-12 mm</th>
<th>12-25 mm</th>
<th>Desired Blend Gradation</th>
<th>Specifications limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.4</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>19.1</td>
<td>100.0</td>
<td>100.0</td>
<td>100</td>
<td>55</td>
<td></td>
<td>90-100</td>
</tr>
<tr>
<td>12.7</td>
<td>100.0</td>
<td>100.0</td>
<td>64</td>
<td>8</td>
<td></td>
<td>70-90</td>
</tr>
<tr>
<td>9.5</td>
<td>100.0</td>
<td>100.0</td>
<td>20</td>
<td>0</td>
<td></td>
<td>56-80</td>
</tr>
<tr>
<td>4.75</td>
<td>100.0</td>
<td>80.0</td>
<td>1</td>
<td>0</td>
<td></td>
<td>35-65</td>
</tr>
<tr>
<td>2.36</td>
<td>100.0</td>
<td>53</td>
<td>0</td>
<td>0</td>
<td></td>
<td>23-49</td>
</tr>
<tr>
<td>0.300</td>
<td>100.0</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td></td>
<td>5-19</td>
</tr>
<tr>
<td>0.075</td>
<td>85.0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td></td>
<td>3-9</td>
</tr>
</tbody>
</table>

\( G_{sb} = 2.528\) \( G_{se} = 2.616\) \( G_{mb} = 2.664\) \( G_{mm} = 2.669\)

Table 1......Aggregate gradation analysis

Depending on data shown in table below and using USA asphalt institute procedure 1997, to find the OAC %, \( G_{mb}, \) and \( G_{mm} \) (((using graph papers to calculate the missing data))).

<table>
<thead>
<tr>
<th>Asphalt content %</th>
<th>Weight in air, gr</th>
<th>Weight in water, gr</th>
<th>Weight SSD, gr</th>
<th>( G_{mm}, \text{gr/cm}^3 )</th>
<th>Stability, kN</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0</td>
<td>1240</td>
<td>731</td>
<td>1244</td>
<td>2.575</td>
<td>13.3</td>
</tr>
<tr>
<td>3.5</td>
<td>1243</td>
<td>734</td>
<td>1245</td>
<td>2.542</td>
<td>14.1</td>
</tr>
<tr>
<td>4.0</td>
<td>1247</td>
<td>739</td>
<td>1251</td>
<td>2.513</td>
<td>13.4</td>
</tr>
</tbody>
</table>

Table 2……..Compacted asphalt mix (binder mix layer) data
b- (5 mark)

state importance and role of corrections processes for maximum dry density and optimum moisture content for unbound soft and granular materials as important mechanism to simulate side conditions.

GOOD LUCK

Examiner: Ass. Pro. Dr. Faris M. Jasim

SOLUTIONS OF THE QUESTIONS (FIRST ATTEMPT)

Q1

A:

RTFO(SHORT TERM AGING)

The RTFO simulates the aging that occurs in an HMA mixing facility as thin films of binder are exposed to heat and air. A sample is poured into a cylindrical bottle and rotated horizontally at 163°C. As the bottle rotates and air is blown over the sample, new thin films are exposed simulating the binder coating on the aggregate during mixing. Lighter oils are driven off and some oxidation occurs. A mass change determination is made and because RTFO-aged asphalt binder is approximately 2-3 times the viscosity of the unaged asphalt binder, it is tested to determine whether the desirable viscoelastic properties have been maintained.

PAV (LONG TERM AGING)

One of the limitations of some of the older grading systems is the inability to simulate actual aging conditions of asphalt binder as it goes through production, mixing placement and, particularly, long-term aging. After mixing and placement, further oxidation will occur over the service life of the pavement. The PAV was refined during the Strategic Highway Research Program (SHRP) to subject asphalt binders to the long-term aging expected after approximately 5-15 years of service in an asphalt pavement. Asphalt binders are exposed to high temperature (usually 100°C) and air pressure (2.10 MPa) for 20 hours to simulate long-term aging.
DSC:
Also known as an oscillatory shear rheometer. Is used to measure the flow properties of liquid asphalt binders at intermediate (i.e., 20°C) to high (i.e., 64°C) temperatures. Works by applying a sinusoidal shear stress to produce a resulting shear strain. The complex shear modulus ($G^*$) is a ratio of the applied shear stress ($\tau$) to the resulting shear strain ($\gamma$). The phase angle, $\delta$, (related to the time lag between input and output signals) provides a relative indication of the viscous and elastic behavior of the asphalt binder. Materials with a phase angle of 90 degrees are completely viscous; while materials with a phase angle of 0 degrees are completely elastic. At intermediate temperatures, such as 20°C, asphalt binders are said to be viscoelastic (phase angle near 45 degrees).

BBR:
Used to measure the flow properties of liquid asphalt binders at low (i.e., -12°C) temperatures. Is analogous to the DSR which is not used at low temperatures because of the torque capability of the equipment. Operates on engineering beam principles. A fixed static load is applied to an asphalt binder beam of known dimensions. The resulting deflection is measured and the flexural stiffness reported as a function of time. Provides an indication of the low temperature stiffness and cracking potential of an asphalt binder.

Q2
for determine high temperature of pavement ,use the following equation :

$$T_{20 \text{ mm}} = 0.9545 \left[ T_{\text{air}} - 0.00618 \text{ lat}^2 + 0.2289 \text{ lat} + 42.2 \right] - 17.78$$

$$T_{20 \text{ mm}} = 63$$

Again for determine low temperature of pavement, use the following equation

$$T_{\text{pav}} = 16.72 \text{ take it } + 2$$

hence the grade selection of binder as PG =64-2 for reliability 50%
again The standard deviation at (98% reliability ), for both the high and low temperatures is ( 1 °C)

$$T_{20 \text{ mm}} = 67, \text{ and } T_{\text{pav}} = +15$$

for 98% reliability PG (70-2)
FOR ESAL more than $10 \times 10^6$ axles the grade must increase one step

The required grade of PG (76-2)

Q3:

USING THE SIMPLE EQUATIONS TO FIND THE ANSWER
Ministry of Higher Education and Scientific research

For flexible type:

\[ Mr = 1500 \times 3.5 = 5250 \text{ p/in}^2 , \]

\[ \log_{10} W_{18} = 8.1 \]

\[ W_{18} = 125892541 \text{ AXLES} \]

\[ W_{18} = \text{LIFE(Y)} \times 365 \times \text{ESAL} \ldots \]

\[ 125892541 \text{ AXLES} = 10 \times 365 \times \text{ESAL} \times 2 \]

For 10 years

\[ \text{ESAL} = 17,245 \text{ AXLES} \]

For rigid pavement type as same traffic with thickness = 8 in = D

Same parameters

\[ W_{18} = 2348996 \text{ axles} \]

\[ \text{Life} \times \text{aadt} = w_{18} \]

Life will be last after flexible = 136 days

Approximately = 5 month

Q4

A-GYRATORY compaction is used in superpave system as kneading type of compaction to find the density of HMA in any number repition loads at 1.25 under 600 Kp stress while Marshall type of compactor is impact with free falling 18 inch at 75 blows on each face

B- NMS is very important to arrange the limitations of max size in gradation of aggregate as superpave system is agreed to apply it in HMA produce.

c-Moisture damage of HMA pavements is not a distress by itself but represents a conditioning process after which several distresses may occur individually or simultaneously. The moisture first inflicts damage on the HMA mix by destroying the bond between the aggregate and the asphalt binder or by destroying the internal cohesive strength of the binder. Both actions create a weaker HMA mix that is unable to resist the stresses imposed by the combined effects of traffic loads and environment. As moisture damage reduces the internal strength of the HMA mix, the stresses generated by traffic loads increase significantly and lead to fatigue cracking or rutting of the HMA layer. In the case of environmental stresses, a weaker HMA mix is unable to resist the thermal stresses leading to transverse cracking and aging stresses that create block cracking of the HMA layer.

While thermal cracking in HMA:
- **Causes**
  - Contraction and Expansion of Pavement with Changing Temperatures
- **Cures**
  - Crack Filling
The effect of drainage on the performance of flexible pavements is considered in the 1993 guide with respect to the effect water has on the strength of the base material and roadbed soil. The approach used is to provide for the rapid drainage of the free water (non capillary) from the pavement structure by providing a suitable drainage layer, as shown in Figure 19.7, and by modifying the structural layer coefficient.

A major design consideration for preventing pumping is the reduction or elimination of expansion joints, since pumping is usually associated with these joints. This is the main reason why current design practices limit the number of expansion joints to a minimum. Since pumping is also associated with fine-grained soils, another design consideration is either to replace soils that are susceptible to pumping with a nominal thickness of granular or sandy soils, or to improve them by stabilization. Current design practices therefore usually include the use of 3 to 6 in. layers of granular subbase material at areas along the pavement alignment where the subgrade material is susceptible to pumping or stabilizing the susceptible soil with asphalt or Portland cement. The American Concrete Pavement Association method of rigid pavement design indirectly considers this phenomenon in the erosion analysis.

Q5

Table 1...Aggregate gradation analysis

<table>
<thead>
<tr>
<th>Size (mm)</th>
<th>Filler</th>
<th>0-5 mm</th>
<th>5-12 mm</th>
<th>12-25 mm</th>
<th>Desired Blend Gradation</th>
<th>Specifications limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.4</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>19.1</td>
<td>100.0</td>
<td>100.0</td>
<td>100</td>
<td>55</td>
<td>95</td>
<td>90-100</td>
</tr>
<tr>
<td>12.7</td>
<td>100.0</td>
<td>100.0</td>
<td>64</td>
<td>8</td>
<td>81</td>
<td>70-90</td>
</tr>
<tr>
<td>9.5</td>
<td>100.0</td>
<td>100.0</td>
<td>20</td>
<td>0</td>
<td>70</td>
<td>56-80</td>
</tr>
<tr>
<td>4.75</td>
<td>100.0</td>
<td>80.0</td>
<td>1</td>
<td>0</td>
<td>51</td>
<td>35-65</td>
</tr>
<tr>
<td>2.36</td>
<td>100.0</td>
<td>53</td>
<td>0</td>
<td>0</td>
<td>37</td>
<td>23-49</td>
</tr>
<tr>
<td>0.300</td>
<td>100.0</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>5-19</td>
</tr>
</tbody>
</table>
Using the following attached equation to find the data

\[ AC\% \text{ at max stability} = 3.75 \]
\[ Ac\% \text{ at max, density} = 4.25 \]
\[ Ac\% \text{ at AV (4\%)} = 4.10 \]

Hence the average of the above three values according to asphalt institute 1997:

\[ OAC\% = 4.03 \]
\[ G_{ab} = 2.634, \ G_{mb} = 2.345 \text{ and } G_{MM} = 2.487 \text{ at OAC\%} \]

**B-**

**THE** purpose of this test to put site condition with different granular materials especially that has size retained more 19 mm under real situation to equivalent as lab condition and consequently will gives more benefit to type of execution in site like increase lab density as MDD to accommodate the field density to reach the required target