Getting the Best Asphalt Pavement Performance: The Importance of Compaction and Bonding of Layers

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Erik Updyke, P.E.
Summer 2022
CCPIC Mission and Vision

• **Mission**
  - CCPIC works with local governments to increase pavement technical capability through timely, relevant, and practical support, training, outreach and research

• **Vision**
  - Making local government-managed pavement last longer, cost less, and be more sustainable
• Sponsored by the League of California Cities, County Engineers Association of California, and the California State Association of Counties
• Chartered September 28, 2018
• University of California Partners
  ▪ University of California Pavement Research Center (lead)
  ▪ UC Berkeley ITS Tech Transfer
• California State University Partners
  ▪ CSU-Chico, CSU-Long Beach, Cal Poly San Luis Obispo
CCPIC Organization

• **Governance**
  ▪ Governance Board consisting of 6 city and 6 county transportation professionals

• **Current Funding**
  ▪ Seed funding from SB1 through:
    ▪ Institute of Transportation Studies at UC Davis, UC Berkeley, UC Los Angeles, UC Irvine
    ▪ Mineta Transportation Institute at San Jose State University
CCPIC Scope

• **Technology Transfer:**
  ▪ Training courses
  ▪ Pavement engineering and management certificate program for working professionals through UC Berkeley ITS Tech Transfer
  ▪ Outreach

• **Technical Resources:**
  ▪ Technical briefs, guidance, sample specifications, tools, and other resources

• **Resource Center:**
  ▪ Outreach, questions, pilot study documentation, and forensic investigations

• **Research and Development:**
  ▪ For local government needs that are not covered by State and Federal efforts
  ▪ Adapting work done for state government
Pavement Engineering & Management (PEM) Certificate Program

• **PEM Certificate Program Overview**
  ▪ For engineers, asset managers, upper-level managers, technicians and construction inspectors
  ▪ 88.5 hours of training
    • 56.5 hours in core classes, 32 hours in electives
    • Majority of classes to be offered online
  ▪ In four categories:
    • Fundamentals
    • Management
    • Materials and Construction
    • Design
## Pavement Engineering & Management Certificate: Curriculum

<table>
<thead>
<tr>
<th>Core Requirements</th>
<th>Total Hrs Required</th>
<th>Elective offerings</th>
<th>Total Hrs Offered</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fundamentals</strong></td>
<td>56.5</td>
<td><strong>Core</strong></td>
<td>84</td>
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<tr>
<td><strong>Management</strong></td>
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<td><strong>Materials and Construction</strong></td>
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<td><strong>Core</strong></td>
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<td><strong>Design</strong></td>
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<td><strong>Elective</strong></td>
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### Core Requirements

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Hrs</th>
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<tbody>
<tr>
<td>CCA-01</td>
<td>Introduction to Pavement Engineering and Management</td>
<td>10</td>
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<td>CCA-02</td>
<td>Pavement Sustainability</td>
<td>4</td>
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<tr>
<td>CCB-01</td>
<td>Life Cycle Cost Analysis</td>
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<tr>
<td>CCB-02</td>
<td>Pavement Management Systems and Preservation Strategies</td>
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<tr>
<td>CCC-01</td>
<td>Asphalt Concrete Materials and Mix Design</td>
<td>8</td>
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<tr>
<td>CCC-02</td>
<td>Pavement Preservation Treatments, Materials, Construction, Quality Assurance</td>
<td>8</td>
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<tr>
<td>CCC-03</td>
<td>Pavement Construction Specifications and Quality Assurance</td>
<td>12.5</td>
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### Elective Requirements

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Hrs</th>
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<tbody>
<tr>
<td>CCB-21</td>
<td>Financing and Cash Flow for Pavement Networks</td>
<td>4</td>
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<tr>
<td>CCB-22</td>
<td>Integrated Asset Management for Multi-Functional Pavements</td>
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<tr>
<td>CCC-21</td>
<td>Concrete Materials &amp; Mix Design</td>
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<tr>
<td>CCC-22</td>
<td>In-Place Recycling</td>
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</tr>
<tr>
<td>CCC-23</td>
<td>Gravel Roads Engineering, Construction, and Management</td>
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<tr>
<td>CCC-24</td>
<td>Roadway Construction Phasing, Scheduling, and Traffic Control</td>
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<tr>
<td>MISC</td>
<td>Classes from Pavement Construction Inspection Certificate curriculum</td>
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<td>CCC-25</td>
<td>Pavement Construction Management</td>
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<tr>
<td>CCC-27</td>
<td>Asphalt Pavement Maintenance Construction</td>
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<td>TS-10</td>
<td>Work Zone Safety</td>
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<td>CCD-21</td>
<td>Asphalt Pavement Structural Section Design</td>
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<tr>
<td>CCD-22</td>
<td>Design, Construction, and Maintenance of Interlocking Concrete Pavers</td>
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<tr>
<td>CCD-23</td>
<td>Concrete Pavement Design</td>
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### Total Hours

- **Certificate**: 88.5 hours
- **Fundamentals**: 14 hours
- **Management**: 26 hours
- **Materials and Construction**: 78.5 hours
- **Design**: 22 hours

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City and County Pavement Improvement Center
Pavement Construction Inspection (PCI) Certificate Program

**PCI Certificate Program Overview**

- For engineers, material testing technicians and construction inspectors
- 80.5 hours of training
  - 68.5 hours in core classes, 12 hours in electives
  - Majority of classes to be offered online
# Pavement Construction Inspection Certificate: Curriculum

<table>
<thead>
<tr>
<th>Core Hrs</th>
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<td>68.5</td>
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<td>Concrete Pavement Construction Inspection</td>
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<td>Concrete Street Improvements Construction Inspection</td>
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<td>Pavement Preservation Construction Inspection</td>
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<td>CCC-02</td>
<td>Pavement Preservation Treatments, Materials, Construction, Quality Assurance</td>
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<td>CCC-03</td>
<td>Pavement Construction Specifications and Quality Assurance</td>
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<td>CCC-26</td>
<td>Pavement Construction Management</td>
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</tr>
<tr>
<td></td>
<td>TS-10</td>
<td>Work Zone Safety</td>
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### Electives (choose 12 hours from list below) 68.5 Hrs

<table>
<thead>
<tr>
<th>Elective Hrs</th>
<th>Course Code</th>
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<td>12 required</td>
<td>CCC-22</td>
<td>In-Place Recycling</td>
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<tr>
<td>26 offered</td>
<td>CCC-24</td>
<td>Roadway Construction Phasing, Scheduling, and Traffic Control</td>
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<td>CCI-06</td>
<td>Construction Inspection of Asphalt-Rubber Pavement Materials</td>
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<td>PD-02</td>
<td>Construction Inspection of Traffic Signals</td>
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<td></td>
<td>TS-18</td>
<td>Excavation and Trenching Safety</td>
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### Total required for certificate 80.5

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City and County
Pavement Improvement Center
## CCPIC Training: Upcoming Classes

<table>
<thead>
<tr>
<th>Code</th>
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<th>Date</th>
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<tbody>
<tr>
<td>CCC-02</td>
<td>Asphalt Pavement Preservation Treatments, Materials,</td>
<td>September 19-22, 2022</td>
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<td></td>
<td>Construction, and Quality Assurance</td>
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<tr>
<td>CCB-01</td>
<td>Pavement Life Cycle Cost Analysis</td>
<td>December 13-14, 2022</td>
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Overview
Compaction and the bonding of layers are keys to the performance of AC/HMA pavements.

- Poor compaction:
  - Reduces cracking life about 15% for every 1% more air-voids (than 8%)
  - If the specification requirement is 8% air voids:
    - 11% = half the life
    - 5% = double the life

- Lack of bonding of layers:
  - Can halve cracking life
  - Increase risk of water damage at interface
AC/HMA Compaction
Effect of Asphalt Compaction on Axle Loads to Fatigue Cracking

3 inch asphalt pavement

Axles to Cracking

- 500,000
- 1,000,000
- 1,500,000
- 2,000,000
- 2,500,000
- 3,000,000
- 3,500,000

6.1 percent air-voids
12.0 percent air-voids

Simulation based on FHWA Westrack project field results
Fatigue Life vs Asphalt Compaction

Lab Fatigue Life vs Air-Void Content

- 1 - 3 % air-voids
- 4 - 6 % air-voids
- 7 - 9 % air-voids

Tensile Strain
Effect of Compaction on Fatigue Life

*General Rule*: 1% increase in constructed air-voids = 10% reduction in fatigue life
Compaction/Density/Air Voids: Method Compaction

- **Caltrans Standard Specifications**: 39-2.01C(2)(c), 39-2.01C(15)(b)

- Specifies equipment and no. of passes of each type of roller required.

- *In-place density is not tested/air voids not measured.*
Compaction/Density/Air Voids: Method Compaction

• How well does it work?
  ▪ See plot at right from Caltrans for statewide survey:
  ▪ No = method specification
  ▪ Yes = QC/QA measurement of air-voids and disincentives
Compaction/Density/Air Voids: Laboratory Bulk (Test Maximum) Density

- California Tests 304 & 308
- **Standard Specifications for Public Works Construction**: 302-5.6.2
- % air voids correlates directly to pavement life
- No direct correlation to air voids
- SSPWC: 95% minimum = 8.8% air voids (for lab air voids of 4%)
- Refer to MS-22, Figure 10.9: 96% = 8% air voids
Compaction/Density/Air Voids:

Theoretical Maximum ("Rice") Density (TMD)

- California Test 309/AASHTO T 209, Method A/ASTM D2041

- **Caltrans Standard Specifications**: 39-2.01A(4)(h)(vi), 39-2.01A(4)(i)(ii), 39-2.01C(15)

- **Standard Specifications for Public Works Construction**: Included in Change No. 301SM (2024 edition) currently in approval process

- % air voids correlates directly to pavement life

- % TMD correlates directly to air voids, e.g. 96% = 4% air voids

- Caltrans Standard Specifications: 91% -97% (should be 92% minimum)
Temperature Control for AC/HMA Compaction

• Asphalt compaction is about getting roller passes at correct mixture temperature
  ▪ Temperature, temperature, temperature
• Multi-Cool software predicts available compaction time
  ▪ Free download on CCPIC website
  ▪ Also available on National Asphalt Pavement Association website
• Multi-Cool results have been validated by UCPRC/Caltrans research
The Effect of Temperature:
Fall Sunny Paving Day – 2-inch overlay

- Compaction time when ambient temperature is 55°F: 26 minutes
The Effect of Temperature: Fall Sunny Paving Day – 1.5-inch overlay

- Compact time when ambient temperature is 55°F: 16 minutes
- Same overlay on a sunny summer day (85°F): 32 minutes
Longitudinal Cracking due to Poor Joint Compaction

- Longitudinal cracks out of wheel path, or in wheel path but straight and often showing raveling and cracking
- Poor compaction major contributor
- Visible after rainfall
- Wedge joint construction helps with compaction
- Do not put longitudinal joints in wheel paths
Effect of Asphalt Compaction on Asphalt Surfaced Pavement Distresses

- **Distresses:**
  - Fatigue cracking
    - top down
    - bottom up
    - reflective
  - Rutting
  - Block cracking
  - Raveling
  - Low-temperature “thermal” cracking
  - Moisture damage

- *Good compaction helps with ALL of these!*
Getting Good Asphalt Compaction

- **Maximum lift thickness**
  - About 3 to 4 inches
- **Maximum size aggregate in gradation**
  - Not more than 1/3 lift thickness
- **Use pneumatic tired rollers for the passes between vibratory steel and later static steel**
- **Material Transfer Vehicles (MTV) remix the material before depositing in the paving machine. Remixing prevents segregation and results in a more uniform mixture temperature, both of which facilitate compaction when placing**
Getting Good Asphalt Compaction

• Use a **quantitative** (not method) **specification** to measure compaction.

• Specify in terms of **in-place bulk density and theoretical maximum density** (TMD), not laboratory test maximum density (LTMD).

• Use cores or nuclear gauges **correlated** for the specific mix/project (California Test 375/AASHTO T209) by construction of a test strip.

• Apply and enforce **payment reductions** if the specified density is not achieved.

• **General Rule:** 1% increase in constructed air voids = 10% reduction in fatigue life.
Asphalt Compaction: Common Questions

- Won’t this increase the bid cost for my asphalt?
- Isn’t the cost of managing this specification high?
- Won’t coring damage my new pavement?
- What can I do to help my contractors meet and exceed the specification and further increase the life of my overlays?

- Yes, but not significantly. The additional expense will be recovered by the lower life cycle cost.
- No.
- Cores are only needed from the test strip to correlate the nuclear gauge. If the compaction meets specifications, no further coring will be necessary.
- Require QC testing. Discuss at a pre-paving meeting.
Benefits of Good Compaction

• Reduced/Retarded Pavement Distress/Aging:
  ▪ Longer cracking life (fatigue and age-related)
  ▪ Less rutting in the pavement structural section
  ▪ Less permeability, water damage
  ▪ Slower aging, less raveling

• Cost-Effectiveness:
  ▪ Little or no increase in construction cost
  ▪ Reduced Life Cycle cost
Life Cycle Cost Analysis

Asphalt Compaction
Life Cycle Cost Analysis (LCCA)

- Net Present Value = the total of costs over the analysis period, including discount rate.
- Equivalent Uniform Annual Cost = spread NPV over time, with discount.
- $ (Agency Costs)
- $ (User Costs)
CCPIC LCCA Excel Tool

- Excel tool to calculate Net Present Value, Salvage Value and Equivalent Uniform Annual Cost
- Can compare 3 scenarios side by side
- Can choose and edit the list and sequence of treatments
LCCA: Effect of Asphalt Compaction

Compaction effect, continuous rehab strategy (1 lane mile)

- 6% AV Good compaction: $426,086
- 9% AV Usual practice: $468,291
- 12% AV Bad compaction: $584,559
LCCA and LCA example: 8% vs 12% air-voids

• Assumptions:
  ▪ Rural county road pulverize HMA, compact, 4 in. HMA
  ▪ $26/sy
  ▪ 12% air-voids = 12 year life
  ▪ 8% air-voids = 18 year life

• Net present cost* over 50 year period:
  ▪ 12% air-voids = $4.36 million
  ▪ 8% air-voids = $3.09 million = 29% less cost

• Greenhouse gas emissions are 34% less

*2% discount rate
Bonding of Layers
Tack coats between asphalt layers: Effects of bonding and no bonding

- Asphalt layers are well bonded:
  - All layers resist bonding together
- Asphalt layers **not** well bonded:
  - Each layer bending by itself
- Lack of bonding can cut fatigue life in half
Delamination/Debonding Between Layers

- Lack of bonding reduces overlay fatigue life by about 50%, even if no shoving
- Due to insufficient tack coat application
- Surface must be dry, clean, free of dust and residual millings
- Place between lifts, even if underlying lift is still hot
- Specify by residual amount
- Track-resistant materials available
- Spray pavers available
Proper tack coat application results in the pavement layers acting as a composite section. Analogous to glue used in structural laminated beam. Uniform application over the pavement surface, not streaked. Ensure spray bar is pressurized and discharge cones overlap at least twice. Encourage proper application by making a separate Bid Item.
Resources

References and Links
References/Links

- City and County Pavement Improvement Center (CCPIC):
  www.ucprc.ucdavis.edu/ccpic

- CCPIC: “Writing and Enforcing Specs for Asphalt Compaction”:

- CCPIC: “Asphalt Concrete Model Specification Language”:
Summary of Technical Resources

CCPIC website: www.ucprc.ucdavis.edu/ccpic
References

• Standard Specifications, 2018, Caltrans:

• Standard Specifications for Public Works Construction, 2021 Edition:
References

  - [www.asphaltinstitute.org](http://www.asphaltinstitute.org)

- *Tack Coat Guidelines,* Caltrans:
FHWA Sustainable Pavements Task Group

- Covers everything about pavement and sustainability
  - Cost
  - Environment
  - (they usually go together)
- Tech briefs and webinars

Questions?

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- Shadi Saadeh: Shadi.Saadeh@csulb.edu
- Ashraf Rahim:arahim@calpoly.edu