PavementDesigner.org – A New Design Tool for Local Roads, Parking Lots & Industrial Pavements

Webinar
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• Industry Team Partners
  • Wayne Adaska, P.E.
    • Portland Cement Association
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    • National Ready Mix Concrete Association

• Additional Support
  • Jim Mack, P.E. & Feng Mu, PhD, P.E.
    • CEMEX
  • Randy Riley, P.E. & Jim Powell, P.E.
    • ACPA State/Chapter Associations
Need and Relevance – Addressing Demand

- High price point and learning curve for AASHTOWares’s Pavement ME

- Non-DOT agency audience seeking affordable easy-to-understand design tools for pavement solutions, especially where traffic levels are low to moderate

- Consultants have similar needs and value quick-access design tools, providing quick answers
Need and Relevance – Addressing Demand

• Professors often favor simple-to-implement solutions; no complicated or expensive licensing terms or lab setup

• Students looking for technology to assist with course work

• Non-engineers seeking a simple method for designing pavements, parking lots, industrial facilities, etc.
Need and Relevance – Countering PaveXpress and I-PAVE Issues

- I-PAVE underrepresents foundation support
- PaveXpress claims to follow AASHTO design methods but results show otherwise...

Conservative thickness results for PCC lead to first-cost competitive disadvantages

For details, see: Ferrebee, E. (Oct. 2015). I-PAVE and PaveXpress: Equitable Pavement Design?  
http://www.acpa.org/position-papers/
Need and Relevance – Unify Industry Design Tools

• Many existing design programs:
  • ACPA StreetPave 12: Structural Design Software for Street and Road Concrete Pavement
  • ACPA AirPave 11: Structural Design Software for Airport Concrete Pavement
  • ACPA WinPAS 12: Structural Design of Concrete Pavement by AASHTO 1993 Method
  • ACPA BCOA: Bonded Concrete Overlay on Asphalt Thickness Design Calculator
  • NRMCA Concrete Pavement Analyst (CPA): Concrete Pavement Design for Parking Lots
  • PCA RCCPave: Structural Design of Roller-Compacted Concrete for Industrial Pavements
  • PCA PCAPave: Structural Design of Concrete Pavement

• Can be challenging for designers to determine best choice and get consistent results and recommendations across products

• Contributes to negative perception that cement-based pavement solutions are difficult to design compared to asphalt pavements
Bringing Online the Best of the Best Available Design Tools

Design Guidance
Substructure Sensitivity
Asphalt Design Evaluation
Overview and Background

• ACPA, NRMCA, and PCA partnership, with a contribution from the RCC Council to develop a website application to design cement-based solutions for:
  • Streets and Local Roads
  • Parking Lots
  • Intermodal/Industrial Facilities

• Design guidance and tools for:
  • Jointed-Plain Concrete Pavements
  • Continuously Reinforce Concrete Pavement
  • Concrete Overlays
  • Composite Pavements
  • Roller Compacted Concrete
  • Cement Modified Soils
  • Cement-Treated Base
  • Full-Depth Reclamation
Bringing Online the Best of the Best Available Design Tools
Polling Question #2

Next up: A Brief History of Pavement Design for Roads
Design Method Basis

- **Mechanistic** – Purely scientific and based on measured, defendable scientific rules and laws

\[ \varepsilon = \frac{\sigma}{E} \quad \Delta L = \alpha \Delta T \times L_o \]

- **Empirical** – Based on observations or experimentation and requires a lot of tests to connect all the relationships

*Cracking = loads + environment + material*
U.S. JPCP Roadway Design Methods

AASHTOWare Pavement ME
(previously known as DARWin-ME and MEPDG)

AASHTO 93
/software as ACPA WinPAS

ACPA StreetPave

325 & 330
AASHTO GUIDE FOR
Design of Pavement Structures

AASHTO, Guide for
Design of Pavement Structures
1993

Published by the
American Association of State Highway
and Transportation Officials

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AASHTO 93 / WinPAS

acpa.org/winpas

PavementDesigner.org
AASHO Road Test (1958-1960)

- Wholly empirical
- Included 368 concrete and 468 asphalt sections | focus was highway pavement
Necessary Thickness was Guessed!

Subgrade = Clay Soil
Sections Loaded for 2 Yrs | 1.1 Mil Reps

Max Single Axle

Max Tandem Axle
1986-93 JPCP AASHTO 93 Equation

\[ \log(ESAL) = Z_R \cdot S_o + 7.35 \cdot \log(D + 1) - 0.06 + (4.22 - 0.32 \cdot p_t) \cdot \log \left( \frac{\frac{\Delta PSI}{4.5 - 1.5}}{1 + \frac{1.624 \cdot 10^7}{(D + 1)^{8.46}}} \right) \]

**WHAT DO DESIGNERS FOCUS ON?**

- Standard Normal Deviate
- Overall Standard Deviation
- Thickness
- Change in Serviceability
- Terminal Serviceability
- Modulus of Rupture
- Drainage Coefficient
- Load Transfer
- Modulus of Elasticity
- Modulus of Subgrade Reaction
WinPAS Makes it Easy!
WinPAS Makes it Easy!
Performance Estimated Subjectively

- **Present Serviceability Index (PSI)**
  - 4.0 – 5.0 = Very Good
  - 3.0 – 4.0 = Good
  - 2.0 – 3.0 = Fair
  - 1.0 – 2.0 = Poor
  - 0.0 – 1.0 = Very Poor

- “Failure” at the Road Test considered @ 1.5

- Typical U.S. state agency terminal serviceability in practice = 2.5
The experimental design at the AASHO Road Test included a wide range of loads as previously discussed (Section 1.4.1); however, the applied loads were limited to a maximum of 1.114,000 axle applications for those sections which survived the full trafficking period. Thus, the maximum number of 18-kip equivalent single axle loads (ESAL’s) applied to any test section was approximately one million. However, by applying the concept of equivalent loads to test sections subjected to only 30-kip single axle loads, for example, it is possible to extend the findings to $8 \times 10^6$ ESAL’s. Use of any design ESAL’s above $8 \times 10^6$ requires extrapolation beyond the equations developed from the Road Test results. Such extrapolations have, how-
Current design traffic is far beyond AASHO road test limits.
“The current design guide and its predecessors were largely based on design equations empirically derived from the observations AASHTO’s predecessor made during road performance tests completed in 1959-60. Several transportation experts have criticized the empirical data thus derived as outdated and inadequate for today’s highway system. In addition, a March 1994 DOT Office of Inspector General report concluded that the design guide was outdated and that pavement design information it relied on could not be supported and validated with systematic comparisons to actual experience or research.”

...this is why Pavement ME exists!
Pavement ME Design

- Not “perfect” & not intended to be a “final” product
- Complex and relatively costly
- For highways and NOT street, road, parking lot, etc.
JPCP Calibration – **BIG INF. SPACE!**

![Map of JPCP Calibration Sections](image-url)
AASHTO 93 vs. ME

Wide range of structural and rehabilitation designs

Limited structural sections

50+ million load reps

1 climate/2 years

1.1 million load reps

All climates over 20-50 years

1 set of materials

New and diverse materials
Sounds Easy Enough, Right?

\[
Fault_m = \sum_{i=1}^{m} \Delta Fault_i
\]

\[
\Delta Fault_i = C_{34} \cdot (FAULTMAX_{i-1} - Fault_{i-1})^2 \cdot DE_i
\]

\[
FAULTMAX_i = FAULTMAX_0 + C_7 \cdot \sum_{j=1}^{m} DE_j \cdot \log(1 + C_5 \cdot 5.0^{EROD}) \cdot C_6
\]

\[
FAULTMAX_0 = C_{12} \cdot \delta_{\text{curing}} \left[ \log(1 + C_5 \cdot 5.0^{EROD}) \cdot \log \left( \frac{P_{250} \cdot \text{WetDays}}{p_s} \right) \right] \cdot C_6
\]

\[
\sigma_0 = \frac{E_{\text{PCC}} \Delta \varepsilon_{101}}{2(1 - \mu_{\text{PCC}})}
\]

\[
IRI = IRI_1 + C_1 \cdot CRK + C_2 \cdot SPALL + C_3 \cdot TFAULT + C_4 \cdot SF
\]

\[
SCF = -1400 + 350 \cdot AIR\% \cdot (0.5 + \text{PREFORM}) + 3.4 \cdot f'c \cdot 0.4 - 0.2 \cdot (FTCYC \cdot AGE) + 43 \cdot h_{\text{PCC}} - 536 \cdot WC_{\text{Ratio}}
\]

\[
cw = \max \left( L \left( \varepsilon_{zh} + \alpha_{\text{PCC}} \Delta T_{\zeta} - \frac{C_3 f'c}{E_{\text{PCC}}} \right) \cdot 1000 \cdot CC, 0.001 \right)
\]
OUTPUTS, OUTPUTS, OUTPUTS!!!
U.S. Roadway Length (lane miles)

AASHTO tools are being developed for these owners...

City, county, and other local engineers need to decide what to use locally because Pavement ME will not trickle down due to its cost and complexity!

Source: HM-10, 2012 FHWA Highway Statistics
Figure 7. FE model of tridem axle edge loading.
PavementDesigner for Roadways

- Roots date back to the 1960s PCA Method
- Tailored for streets and roads
- Failure modes are cracking and faulting
Traffic Loads Generate Stresses

- Equivalent stress at the slab edge:

\[
\sigma_{eq} = \frac{6 \times M_e}{h_c^2} \times f_1 \times f_2 \times f_3 \times f_4
\]

- \( M_e \): equivalent moment, psi; different for single, tandem, and tridem axles, with and without edge support - func on radius of relative stiffness, which depends on concrete modulus, Poisson’s ratio, and thickness and the k-value
- \( h_c \): pavement thickness, in.
- \( f_1 \): adjustment for the effect of axle loads and contact area
- \( f_2 \): adjustment for a slab with no concrete shoulder
- \( f_3 \): adjustment to account for the effect of truck (wheel) placement at the slab edge
- \( f_4 \): adjustment to account for approximately 23.5% increase in concrete strength with age after the 28th day and reduction of one coefficient of variation (COV) to account for materials variability
Limit Stress Ratio to Allow Design Reps

- PavementDesigner (SR) = Stress / Concrete Strength
- PavementDesigner makes slab thicker to limit stress ratio low enough to achieve the design traffic repetitions

Inference space normalized to SR
A Conservative Approach!

- PavementDesigner fatigue calculation should be conservative relative to ME Design because:
  - **Size Effects** – Slabs have a greater fatigue capacity than beams
  - **Support** – The beam test has a k-value for support of 0 psi/in.
Faulting Design in PavementDesigner

- If dowels used, faulting mitigated & fails by cracks
- No faulting data collected at the AASHO road test so model developed in 1980s using field performance data from WI, MN, ND, GA, and CA
- Similar to cracking models, the pavement is made thicker, as necessary, until faulting model predicts that the pavement will not fail by faulting during the design life
- PD’s weak point
## Traffic Spectrum + Counts

<table>
<thead>
<tr>
<th>Axle Load (kip)</th>
<th>Single Axles</th>
<th>Axles/1,000 Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>0.63</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>1.78</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>3.52</td>
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<tr>
<td>24</td>
<td>4.16</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>9.69</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>41.82</td>
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</tr>
<tr>
<td>18</td>
<td>68.27</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>57.07</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Axle Load (kip)</th>
<th>Tandem Axles</th>
<th>Axles/1,000 Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td>56</td>
<td>1.07</td>
<td></td>
</tr>
<tr>
<td>52</td>
<td>1.79</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>3.03</td>
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</tr>
<tr>
<td>44</td>
<td>3.52</td>
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<tr>
<td>40</td>
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<td>36</td>
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<tr>
<td>28</td>
<td>95.79</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>71.16</td>
<td></td>
</tr>
</tbody>
</table>

- Total trucks in design lane over the design life... calculated from trucks/day (2-way), traffic growth rate (%/yr), design life (yrs), directional distribution (%), and design lane distribution (%).
U.S. Agencies Quickly Changing

- Summary of State Agency practice in 2005:
  - At the end of 2013, 41 state agencies had performed ME Design calibration and implementation efforts, indicating a relatively quick shift from AASHTO 93.

<table>
<thead>
<tr>
<th>Design Method</th>
<th>Used</th>
<th>Percent of Responding Agencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASHTO 72/86/93</td>
<td>85%</td>
<td>AR, AZ, DE, FL, ID, IN, IA, KS, MD, MI, NV, NC, OH, OK, SC, SD, TN, UT, VA, WA, WV, WI, WY</td>
</tr>
<tr>
<td>AASHTO MEPDG</td>
<td>4%</td>
<td>MO</td>
</tr>
<tr>
<td>PCA Method</td>
<td>11%</td>
<td>HI, IN, IA</td>
</tr>
<tr>
<td>State-Developed</td>
<td>7%</td>
<td>IL, MT</td>
</tr>
</tbody>
</table>

AASHTO Pavement ME National Users Group Meetings Technical Report - 2016

Figure 4. Implementation status by state—concrete pavements and/or overlays.
AASHTO tools are being developed for these owners…

City, county, and other local engineers need to decide what to use locally because Pavement ME will not trickle down due to its cost and complexity!

Source: HM-10, 2012 FHWA Highway Statistics
StreetPave Accepted in MN

MINNESOTA DEPARTMENT OF TRANSPORTATION
State Aid Division
Technical Memorandum No. 12-SA-03
October 09, 2012

To: County Engineers
City Engineers
MNDOT District State Aid Engineers

From: [Name]

Subject: State Aid for Local Transportation (SALT)
Use of ACAPA StreetPave Software for Design of Concrete Pavements for Cities and Counties

Expiration: This Technical Memorandum will remain in effect until October 09, 2017, unless superseded prior to this date, or the information provided in this Technical Memorandum is incorporated into the State Aid Manual.

Implementation: This Technical Memorandum, which allows the use of the American Concrete Paving Association’s (ACAPA) StreetPave software for assisted concrete pavement design as an alternative to the MnDOT Roadway Design software, is effective immediately. In deciding which software program to use, several factors, including those mentioned in the Technical Memorandum, shall be considered by the Engineer. City, county and consultant engineers working on State Aid and Federal-aid concrete pavement projects are allowed to use the ACAPA StreetPave software only if the Department has approved the use of the ACAPA StreetPave software for the project.

Introduction: In an effort to use elements of new technology and design methods, State Aid for Local Transportation (SALT) has recently completed a comparison of the ACAPA StreetPave concrete pavement design software and the MnDOT Roadway Design concrete pavement design software (previously the only concrete pavement design software approved for State Aid and Federal-aid projects).
And Its Use is Growing!

- Also “approved” in VA and many other state, city, and county engineers are using it in the U.S.
- StreetPave used in design tables in:
  - ACI 325 and 330 documents
  - Dr. Norb Delatte’s textbook *Concrete Pavement Design, Construction, and Performance*
- Internationally, used in Australia, Portugal, Mexico, Uruguay, Argentina, Chile, etc.
Polling Question #3

Next up: Full Depth Concrete Streets Demo
And then: RCC and CRCP Background and Composites
What About RCC Design?
RCC Design Methodologies

- Section 5 – Structural Design of RCC Pavements
  - Heavy-Duty Industrial Pavements
  - Mixed Vehicle Traffic
RCC Design Methodologies

- Heavy-Duty Industrial Pavements
  - RCC-Pave
  - PCA-Pave
RCC Design Methodologies

- Mixed Vehicle Traffic
  - ACI 330-08 Guide for Design of Concrete Parking Lots
  - ACI 325.12R-02 Guide for Design of Jointed Concrete Pavements for Streets and Local Roads
- StreetPave
- WinPAS
Fracture Properties of Roller-Compacted Concrete with Virgin and Recycled Aggregates
Eric C. Ferrabees, Alexander S. Brand, Abbas S. Kachwaha, Jeffery R. Roedler, Daniel J. Gancarz, and James E. Pfarr

Roller-compacted concrete (RCC) has been primarily applied to dams (1) but over the years has been used for pavements in intermodal facilities, storage areas, and municipal and industrial roads (2) with design procedures available for industrial pavements (3) and roadways (4). The first experimentally proven pavement was constructed in 1955 by the United States Army Corps of Engineers (5). With more attention and emphasis being given to sustainable pavement practices in recent years, RCC has seen more interest because of its lower cement content, high-density pavement, lower environmental impact, and potential for crack repair when using the RCC fatigue curve. The RCC fatigue curve is used to determine the fatigue life of a pavement structure based on the number of load applications and the magnitude of the load. This provides a practical method for predicting the fatigue life of a pavement structure, which is critical for ensuring the durability and longevity of the pavement.

The fracture properties of RCC have been studied extensively. The fracture properties of RCC are influenced by several factors, including the aggregate type, the cement content, the water-cement ratio, and the compaction method. The fracture properties of RCC are important for determining the durability and longevity of the pavement structure. The fracture properties of RCC are also important for predicting the performance of the pavement structure under service conditions.

The fracture properties of RCC can be characterized using several fracture toughness tests, such as the fracture energy, the fracture toughness, and the fracture strength. The fracture energy is the energy required to propagate a crack in a material, and it is a measure of the material's resistance to fracture. The fracture toughness is the critical stress intensity factor, and it is a measure of the material's resistance to fracture. The fracture strength is the maximum stress that a material can withstand without fracturing.

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CRCP Design with Pavement Designer

- PavementDesigner recommends using AASHTOWare’s Pavement ME

- Can use PavementDesigner to get an estimated design with AASHTO 93
Composite Pavements with PavementDesigner

- Composite Pavement Module accounts for cement altered structure layers
  - Full Depth Reclamation
  - Cement Treated Bases
  - Cement Modified Soils
  - Etc.
- Designed with JPCP, RCC, or Asphalt surface layer
Composite Pavements with PavementDesigner

- **Asphalt Surfaces**
  - PCA-Pave Methodology
  - Linear Elastic

- **Concrete Surfaces**
  - StreetPave
  - Accounts for additional substructure stiffness with higher k-value
Pavement Categories:

- **Flexible (Asphalt)**
  - Low Stress, High Strain

- **Rigid (Concrete)**
  - High Stress, Low Strain

- **Composite (Asphalt over Concrete)**
  - Behaves mostly like Rigid

- **Semi-Rigid (Asphalt over CTB) (NEW!)**
  - Between Flexible and Rigid
Based on the assumption that pavement can be modeled as a multi-layered elastic structure.
Mechanistic Empirical Pavement Design for pavements with Soil Cement layers

\[ N_f = \left( \frac{\beta c_4}{\sigma_t/\text{MR}} \right)^{\beta c_3 \cdot 20} \]

**PCA Exponential**

\[ \log N_f = \frac{(0.972\beta c_1 - \left( \frac{\sigma_t}{\text{MR}} \right)}{0.0825 \cdot \beta c_2} \]

**NCHRP  ME PDG**

![Graph showing stress ratio against number of repetitions to fatigue cracking](image-url)
Optimizing Design of Support Layers

“Real” Design Example
Actual Savings of CTB vs. Aggregate Base + Lime Mod. Soil

- TxDOT US 290, Bryan District
  - Traditional vs. “Fast Track*” design
  - Using TxDOT “FPS” program (similar, by Scullion)

2” Asphalt Surface
6” Asphalt Base
4.5” Graded Agg.
8” Lime Mod. Soil
Compacted Subg.
$70/sq yd

2” Asphalt Surface
4” Asphalt Base
10.5” CTB
Compacted Subg.
$64/sq yd

Asphalt + Agg. Base + Lime Mod. Soil
Asphalt + CTB (“Fast Track”)
Next up: Composites Demo
And then: Overlays
What About Overlay Design?

- **PavementDesigner Overlay Design Procedure**
  - Utilizes StreetPave with modification to account for existing surface layer’s condition and thickness

- **Links out to the BCOA-ME**
  - Best method available
  - Incorporates ACPA BCOA and 6x6x6 designs
Increasing in Use!
Guide to All Things Overlays!

- Overlay types and uses
- Evaluation & selection
- Design guidance
- Miscellaneous design details
- Overlay materials selection
- Work zones under traffic
- Key points for overlay construction
- Accelerated construction
- Specification considerations
- Repairs of overlays

Free download at:
www.cptechcenter.org
Bonded versus Unbonded

- **Unbonded**: Use to restore structural capacity and increase pavement life equivalent to full-depth pavement. Also results in improved surface friction, noise, and rideability.

- **Bonded**: Use to eliminate surface defects; increase structural capacity; and improve surface friction, noise, and rideability.
Additional Inputs for Overlay Design

- For AASHTO 93, StreetPave PavementDesigner, and Pavement ME, they all use their same “core” to calculate overlay thickness, with a few considerations, e.g.,
  - For unbonded designs, essentially assume existing pavement is the same as subbase in new design and that no friction/bond exists right under surface slabs
  - For bonded over concrete, all calculate a required new concrete thickness and adjust to account for the effective existing pavement thickness
  - Bonded over asphalt/composite is a different game!
Overlay Design – Accounting for Existing Surfaces

- **Unbonded Concrete on Asphalt (UCOA)**
  - Treats existing asphalt as a subbase layer

- **Unbonded Concrete on Concrete (UCOC)**
  
  \[
  T_{UCOC} = \sqrt{T_{\text{required}}^2 - T_{\text{effective}}^2} = \\
  \sqrt{T_{\text{required}}^2 - \left(\frac{AF}{\text{cracks}} \times T_{\text{existing}}\right)^2}
  \]

- **Bonded Concrete on Concrete (BCOC)**

  \[
  T_{BCOC} = T_{\text{required}} - T_{\text{effective}} = T_{\text{required}} - \frac{AF}{\text{cracks}} \times AF_{\text{durability}} \times AF_{\text{fatigue}} \times T_{\text{existing}}
  \]
Bonded over Asphalt/Composite

- AASHTO 93: not applicable
- AASHTO ME: SJPCP Module released 2016
- ACPA BCOA and StreetPave: account for bond to asphalt and short slab size, fibers, etc., but supplanted by....
FHWA pooled fund TPF-5(165)
BCOA ME failure modes

- **≤ 4.5 ft**
  - Corner Break
  - Negative $\Delta T$

- **5 to 7 ft**
  - Long. & Diag Crack
  - Positive $\Delta T$

- **10 x 12 ft**
  - 12 x 12 ft
  - 12 x 15 ft
  - Trans. Crack
  - Positive $\Delta T$
Next up: Overlays Demo
And then: Parking Lots
WHAT ABOUT PARKING LOTS?
ACI 330

- ACI 330R-08
- Guide for Concrete Parking lots
- Uses Design Tables
Table 3.1—Subgrade soil types and approximate support values (Portland Cement Association 1984a,b; American Concrete Pavement Association 1982)

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>Support</th>
<th>( k ), psi/lin.</th>
<th>CBR</th>
<th>( R )</th>
<th>SSV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine-grained soils in which silt and clay-size particles predominate</td>
<td>Low</td>
<td>75 to 120</td>
<td>2.5 to 3.5</td>
<td>10 to 22</td>
<td>2.3 to 3.1</td>
</tr>
<tr>
<td>Sands and sand-gravel mixtures with moderate amounts of silt and clay</td>
<td>Medium</td>
<td>130 to 170</td>
<td>4.5 to 7.5</td>
<td>29 to 41</td>
<td>3.5 to 4.9</td>
</tr>
<tr>
<td>Sand and sand-gravel mixtures relatively free of plastic fines</td>
<td>High</td>
<td>180 to 220</td>
<td>8.5 to 12</td>
<td>45 to 52</td>
<td>5.3 to 6.1</td>
</tr>
</tbody>
</table>

\( k \) = California bearing ratio; \( R \) = resistance value; and SSV = soil support value. 1 psi = 0.0069 MPa, and 1 psi/lin. = 0.27 MPa/lin.

Table 3.2—Modulus of subgrade reaction \( k^* \)

<table>
<thead>
<tr>
<th>Subgrade ( k ) value, psi/lin.</th>
<th>4 in.</th>
<th>6 in.</th>
<th>9 in.</th>
<th>12 in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granular aggregate subbase</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>65</td>
<td>75</td>
<td>85</td>
<td>110</td>
</tr>
<tr>
<td>100</td>
<td>130</td>
<td>140</td>
<td>160</td>
<td>190</td>
</tr>
<tr>
<td>200</td>
<td>220</td>
<td>230</td>
<td>270</td>
<td>320</td>
</tr>
<tr>
<td>300</td>
<td>320</td>
<td>330</td>
<td>370</td>
<td>430</td>
</tr>
<tr>
<td>Cement-treated subbase</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>170</td>
<td>230</td>
<td>310</td>
<td>390</td>
</tr>
<tr>
<td>100</td>
<td>280</td>
<td>400</td>
<td>520</td>
<td>640</td>
</tr>
<tr>
<td>200</td>
<td>470</td>
<td>640</td>
<td>830</td>
<td></td>
</tr>
<tr>
<td>Other treated subbase</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>85</td>
<td>115</td>
<td>170</td>
<td>215</td>
</tr>
<tr>
<td>100</td>
<td>175</td>
<td>210</td>
<td>270</td>
<td>325</td>
</tr>
<tr>
<td>200</td>
<td>280</td>
<td>315</td>
<td>360</td>
<td>400</td>
</tr>
<tr>
<td>300</td>
<td>350</td>
<td>385</td>
<td>420</td>
<td>490</td>
</tr>
</tbody>
</table>

For subbase applied over different subgrades, psi/lin. (Portland Cement Association 1984a,b, Federal Aviation Administration 1978).

Table 3.4—Twenty-year design thickness recommendations, in. (no dowels)

<table>
<thead>
<tr>
<th>MOR, psi</th>
<th>( k = 500 ) psi/lin. (CBR = 50; ( R ) = 86)</th>
<th>( k = 400 ) psi/lin. (CBR = 38; ( R ) = 80)</th>
<th>( k = 300 ) psi/lin. (CBR = 26; ( R ) = 67)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (ADTT = 1)</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>B (ADTT = 10)</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>C (ADTT = 25)</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>D (ADTT = 300)</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td>E (ADTT = 700)</td>
<td>6.5</td>
<td>6.5</td>
<td>6.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MOR, psi</th>
<th>( k = 200 ) psi/lin. (CBR = 10; ( R ) = 48)</th>
<th>( k = 100 ) psi/lin. (CBR = 3; ( R ) = 18)</th>
<th>( k = 50 ) psi/lin. (CBR = 2; ( R ) = 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (ADTT = 1)</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>B (ADTT = 10)</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>C (ADTT = 25)</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>D (ADTT = 300)</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td>E (ADTT = 700)</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>

\( k \) = modulus of subgrade reaction; \( R \) = California bearing ratio; MOR = modulus of rupture.

Note: 1 in. = 25.4 mm, and 1 psi/lin. = 0.27 MPa/lin.
Parking Lot Design

- ACI 330 Guide based on StreetPave design runs
- StreetPave is another accepted design methodology for Parking Lots
Parking Lot Design with PavementDesigner

- PavementDesigner uses a slightly modified version of StreetPave for the sake of simplicity
  - Allows for various design lives, reliabilities, and percent slabs cracked at the end of the design life
Next up: Parking Lots Demo
And then: Intermodal/Industrial
BUT WHAT ABOUT THESE?
What Designs are Available for Heavy Intermodal/Industrial Vehicles

- ACI 330.2R-17 – Guide for the Design and Construction of Concrete Site Paving for Industrial and Trucking Facilities
  - Uses design tables
  - Lists additional design software:
    - ACPA StreetPave
    - Pavement ME
    - TCPavements / Optipave
    - ACPA AirPave
AirPave Methodology for Heavy Equipment
AirPave Load Distribution

Nose Gear: 5% of Total Weight

Landing Gears: 47.5% of Total Weight
Demo Time
Check it out now at:
preview.pavementdesigner.org

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