Software Tools and Solutions to Design Concrete Pavements

WCPA 2017 Annual Concrete Pavement Workshop
February 15 – 17, 2017

Eric Ferrebee
Technical Services Engineer
American Concrete Pavement Association
Design Method Basis

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

\[
\epsilon = \frac{\sigma}{E} \quad \Delta L = \alpha \cdot \Delta T \cdot L_o
\]

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

\[
\text{Cracking} = \text{loads} + \text{environment} + \text{material}
\]
U.S. JPCP Roadway Design Methods

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

AASHTO 93
ソフトウェアとしてもACPA WinPAS

ACPA StreetPave

325 & 330
AASHTO 93 / WinPAS
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

\[
\log(ESAL) = Z_R \cdot s_o + 7.35 \cdot \log(D + 1) - 0.06 + \frac{\Delta PSI}{4.5 - 1.5} \cdot \frac{1.624 \times 10^7}{(D + 1)^{8.46}}
\]

**What do designers focus on?**

- Standard Normal Deviate
- Overall Standard Deviation
- Thickness
- Change in Serviceability
- Standard Normal Deviate
- Overall Standard Deviation
- Thickness
- Change in Serviceability

**Factors:**

- Standard Normal Deviate
- Overall Standard Deviation
- Thickness
- Change in Serviceability

**Equations:**

- **Load Transfer**
  \[ S_c' \cdot C_d \cdot (D^{0.75} - 1.132) \]

- **Modulus of Rupture**
  \[ 215.63 \cdot J \cdot \left[ D^{0.75} - \frac{18.42}{(E_c / k)^{0.25}} \right] \]

- **Modulus of Elasticity**
  \[ \Delta PSI \]

- **Drainage Coefficient**
  \[ (D + 1)^{8.46} \]

- **Terminal Serviceability**
  \[ 4.5 - 1.5 \]

- **Traffic**
  \[ 1.624 \times 10^7 \]
WinPAS Makes it Easy!
WinPAS Makes it Easy!

Concrete Pavement Design/Analysis Inputs

- Concrete Thickness: 8 inches
- Total Rigid ESALs: 7,982,600
- Reliability: 80%
- Overall Standard Deviation: 0.35
- Flexural Strength: 650.0 psi
- Modulus of Elasticity: 4,000,000 psi
- Load Transfer Coefficient: 2.7
- Modulus of Subgrade Reaction: 200.0 psf
- Drainage Coefficient: 1.00
- Initial Serviceability: 4.20
- Terminal Serviceability: 2.00

Concrete Pavement Design/Analysis

Total Rigid ESALs: 7,982,600
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

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**PERCENT SURVIVING WITH PSI ABOVE 2.5**

- **Concrete**
- **Asphalt**

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2017 WCPA Annual Concrete Pavement Workshop

Wisconsin Concrete Pavement Association

February 16, 2017
Note on Inference Space of ‘93

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.

Data Limits (AASHO Road Test)

Projection A

Projection B

Projection C

Current Designs > 100 million

1.1mil

AXLE LOAD REPETITIONS

PAVEMENT THICKNESS

Wisconsin Concrete Pavement Association

February 16, 2017
Don’t Just Take My Word…

“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!
MEPDG / DARWin-ME / AASHTOWare Pavement ME
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.

Mechanistic Calculation of Responses + Empirical Tie to Ground = Pavement Performance Prediction
AASHTO 93 vs. ME

- **Design:** Wide range of structural and rehabilitation designs
- **Traffic:** 50+ million load reps
- **Climate:** All climates over 20-50 years
- **Materials:** New and diverse materials

AASHTO 93

AASHTO Pavement ME

- Limited structural sections
- 1.1 million load reps
- 1 climate/2 years
- 1 set of materials
The fatigue damage calculation is a simple process of summing damage from each damage increment, except that a numerical integration scheme is used to accurately determine the effects of traffic. The fatigue damage at the critical damage location caused by an axle load placed at any random distance away from the pavement edge (point \( i \)) is given by the following:

\[
FD_i = P(COV_i) \cdot FD_i
\]

The probability of coverage is determined assuming normal distribution:

\[
NORMDIST = \frac{1}{\sqrt{\pi}SD_{OFF}} e^{\frac{-(x-\mu)^2}{2\sigma^2}} \quad (3.4.12)
\]

\( x \) = normal distribution density function.

\( \mu \) = wheel location – distance from pavement edge (or outside of the paint stripe for widened slab) to the outer edge of outermost wheel, in.
INPUTS, INPUTS, INPUTS!!!!
### Vehicle Class Distribution and Growth

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Distribution (%)</th>
<th>Growth Rate (%)</th>
<th>Growth Function</th>
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<td>Class 12</td>
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### Monthly Adjustment

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<th>Class 6</th>
<th>Class 7</th>
<th>Class 8</th>
<th>Class 9</th>
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### Axles Per Truck

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<th>Vehicle Class</th>
<th>Single</th>
<th>Tandem</th>
<th>Tandem</th>
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<tr>
<td>Class 9</td>
<td>1.93</td>
<td>1.32</td>
<td>1.32</td>
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</tbody>
</table>
OUTPUTS, OUTPUTS, OUTPUTS!!!
U.S. Roadway Length (lane miles)

- Federal, 3%
- State Agency, 19%
- County, 44%
- Town, 32%
- Other, 1%

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
Some Agencies Trying to Simplify

Note the inputs that have been deemed worth varying...

...designers have a new idea of “what matters”!
Figure 7. FE model of tridem axle edge loading (lane with tied concrete shoulder)
ACPA StreetPave

- Roots date back to the 1960s PCA Method
- Tailored for streets and roads
- Failure modes are cracking and faulting
## Traffic Spectrum + Counts

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

<table>
<thead>
<tr>
<th>Tandem Axles</th>
<th>Axle Load (kip)</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>
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<tr>
<td>52</td>
<td>1.79</td>
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<td>48</td>
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<td>44</td>
<td>3.52</td>
<td></td>
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<tr>
<td>40</td>
<td>20.31</td>
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<td>36</td>
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<td>32</td>
<td>109.54</td>
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<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 (%)
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

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

Inference space normalized to SR
A Conservative Approach!

StreetPave 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 StreetPave

- 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
- StreetPave’s weak point
StreetPave | Project Details

Project Information

Project Name: StreetPave Example
Route: Kane St
Location: Anywhere, USA
Owner / Agency: The City
Design Engineer: Rodden, P.E.

Project Description:
This is just an example to illustrate the key features of StreetPave

Software Use:

- Design a new jointed plain concrete pavement
- Determine a comparable new asphalt pavement thickness?
- Conduct a life cycle cost analysis (LCCA)?
StreetPave | Traffic Details

Traffic Category / Load Spectrum

Typical Traffic Spectrums
- Residential
- Collector
- Minor Arterial
- Major Arterial

ACI 330 Traffic Spectrums
- Category A
- Category B
- Category C
- Category D

Traffic Category Over the Pavement Design Life

Trucks per Day (two-way, at time of construction) 240
Traffic Growth Rate 2% per year
Design Life 30 years
Directional Distribution 50%
Design Lane Distribution 100%

Average Trucks per Day in Design Lane over the Design Life 162
Total Trucks in Design Lane over the Design Life 1,778,099

Traffic Category
- Major Arterial
- Single Axles
- Tandem Axles
- Tridem Axles

Axle Load, Kips
- Axles / 1000 trucks

- Single Axles
  - 34
  - 32
  - 30
  - 28
  - 26
  - 24
  - 22
  - 20
  - 18
  - 16
- Tandem Axles
  - 60
  - 56
  - 52
  - 48
  - 44
  - 40
  - 36
  - 32
  - 28
  - 24
- Tridem Axles
  - 78
  - 72
  - 66
  - 60
  - 54
  - 48
  - 42
  - 36
  - 30
  - 24
StreetPave | Design Details | General

General Design Inputs

Terminal Serviceability 2

Reliability 85%

Resilient Modulus of the Subgrade

- Convert CBR or R-value to MRSG: 4,118 psi
- Input a known MRSG: 4,118 psi
StreetPave | Design Results

**CONCRETE PAVEMENT DESIGN**

Rigid ESALs = 1,331,869
Composite Modulus of Subgrade Reaction (Static k-Value) = 100 psi/in.

<table>
<thead>
<tr>
<th></th>
<th>Min. Required Thickness</th>
<th>Design Thickness</th>
<th>Max Joint Spacing</th>
<th>Failure Controlled By</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doweled</td>
<td>7.80</td>
<td>8.00</td>
<td>15</td>
<td>Cracking</td>
</tr>
<tr>
<td>Undoweled</td>
<td>7.80</td>
<td>8.00</td>
<td>15</td>
<td>Cracking</td>
</tr>
</tbody>
</table>

*Because the doweled thickness is less than 8 in. and cracking is the predicted cause of failure, dowel bars typically would not be recommended for the design details you provided.*
### StreetPave | Design Report

#### Traffic Category: Major Arterial

<table>
<thead>
<tr>
<th>Axle Load, kips</th>
<th>Axles per 1000 Trucks</th>
<th>Expected Repetitions</th>
<th>Stress Ratio</th>
<th>Allowable Repetitions</th>
<th>Fatigue Consumed</th>
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</thead>
<tbody>
<tr>
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<tr>
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<td>57.07</td>
<td>101476</td>
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#### Tandem Axles

<table>
<thead>
<tr>
<th>Axle Load, kips</th>
<th>Axles per 1000 Trucks</th>
<th>Expected Repetitions</th>
<th>Stress Ratio</th>
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**Total Fatigue Used %:** 98.53
StreetPave | Design Results

CONCRETE PAVEMENT DESIGN

Rigid ESALs = 1,331,869
Composite Modulus of Subgrade Reaction (Static k-Value) = 100 psi/in.

Min. Required Thickness | Design Thickness | Max Joint Spacing | Failure Controlled By

- Doweled: 7.80 in. | 8.00 in. | 15 ft | Cracking
- Undoweled: 7.80 in. | 8.00 in. | 15 ft | Cracking

*Because the doweled thickness is less than 8 in. and cracking is the predicted cause of failure, dowel bars typically would not be recommended for the design details you provided.
Sensitivity Analysis – PCC Strength

Effect of Flexural Strength on Thickness

- Thickness, in.
- Modulus of Rupture (Flexural Strength), psi

The graph shows the relationship between the thickness of concrete pavement and the modulus of rupture (flexural strength) in pounds per square inch (psi). As the flexural strength increases, the thickness decreases, indicating a direct correlation between the two variables.
Sensitivity Analysis – Design Life

Effect of Design Life on Thickness

![Graph showing the relationship between Design Life and Thickness.](image-url)
Comparison of Results and U.S. Trends
Top 10 ME Design Most Sensitive

1. Concrete Flexural Strength at 28-Days
2. Concrete Thickness
3. Surface Shortwave Absorptivity (SSA)
4. Joint Spacing
5. Concrete Modulus of Elasticity at 28-Days
6. Design Lane Width with a 14 ft (4.3 m) Widened Slab
7. Edge Support via Widened Slab
8. Concrete Thermal Conductivity
9. Concrete Coefficient of Thermal Expansion (CTE)
10. Concrete Unit Weight

Red = only ME Design input... the **VALUE** of the software!
Blue + Bold = common for all
Doweled JPCP Thickness Comparison

remember AASHTO 93 limit?
Flexural Strength Sensitivity

Required Thickness (in.) vs. Concrete Flexural Strength (psi)

- AASHTO 93 (ACPA WinPAS)
- AASHTOWare Pavement ME @ ORD
- AASHTOWare Pavement ME @ PHX
- ACPA StreetPave

Wisconsin Concrete Pavement Association
February 16, 2017
Modulus of Elasticity Sensitivity

... in reality, need to change strength too...
Thickness Reduction w/ Edge Support

- AASHTO 93 (ACPA WinPAS)
- AASHTOWare Pavement ME @ ORD
- AASHTOWare Pavement ME @ PHX
- ACPA StreetPave

Design Lane ESALs

- 0
- 10,000,000
- 20,000,000
- 30,000,000
- 40,000,000
- 50,000,000

Thickness Reduction w/ Edge Support (in.)

- 0
- 0.5
- 1
- 1.5
- 2
- 2.5
- 3
- 3.5
- 4

Thickness Reduction w/ Edge Support (mm)

- 0
- 25
- 50
- 75
- 100
- 50
- 75
- 100
Reliability Sensitivity

Graph showing the relationship between required thickness in millimeters and reliability percentage for different pavement modeling software and methods. The graph includes data points and lines for AASHTO 93 (ACPA WinPAS), AASHTOWare Pavement ME @ ORD, AASHTOWare Pavement ME @ PHX, and ACPA StreetPave.
k-value Sensitivity

Very few designed for < 100 psi/in. (27 MPa/m)?
U.S. Agencies Quickly Changing

Summary of State Agency practice in 2005:

<table>
<thead>
<tr>
<th>Design Method Used</th>
<th>Percent of Responding Agencies</th>
<th>State Agency</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>

At the end of 2013, 41 state agencies had performed ME Design calibration and implementation efforts, indicating a relatively quick shift from AASHTO 93.
U.S. Roadway Length (lane miles)

- Federal, 3%
- State Agency, 19%
- County, 44%
- Town, 32%
- Other, 1%

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
   MnDOT District Materials Engineers
   FHWA

From: Julie Sklafman, P.E.
      State Aid Engineer

Subject: State Aid for Local Transportation (SALT)
Use of ACWA 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 Pavement
Association's (ACWA) StreetPave software for jointed concrete pavement design as an
alternative to the MnDOT RigifPave software, is effective immediately. In deciding which
software program to use, several factors, including those mentioned in this Technical
Memorandum, shall be reconsidered by the Engineer. City, county and consultant engineers
working on State Aid and Federal-aid concrete pavement projects are allowed to use the ACWA
StreetPave software program as an alternative to the MnDOT RigifPave software program.
However, concrete pavement projects within Trunk Highway right-of-way must continue to
implement the MnDOT RigifPave design software.

StreetPave Equivalent Stiffness Design and the Life Cycle Cost Module are not approved by
SALT.

Introduction
In an effort to stay abreast of new technology and design methods, State Aid for Local
Transportation (SALT) has recently completed a comparison of the ACWA StreetPave concrete
pavement design software and the MnDOT RigifPave concrete pavement design software
(previously the only concrete pavement design software approved for State Aid and Federal-aid
projects).

http://www.dot.state.mn.us/stateaid/admin/memos/12-sa-03.pdf
http://www.dot.state.mn.us/research/documents/201210.pdf

Wisconsin Concrete Pavement Association
February 16, 2017
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.
Other Thickness Design Tools
Pervious Concrete Thickness Design
Reasons for ACPA’s PerviousPave

- Several hydrological design methods exist
- No universal structural design method before PerviousPave
  - some used Westergaard solutions
  - some suggested to use StreetPave – recommended in at least two widely-circulated resources/journals

Delatte’s TRB 2007 Paper:

“The author investigated adaptation of ACPA StreetPave software…”
From StreetPave to PerviousPave

Key changes:

- Exclusion of erosion
- Different design variables:
  - maximum strength and correlation to modulus
  - no dowel bars
  - traffic distribution defaults
  - allowable subgrades/subbases
- Inclusion of hydrological design
- acpa.org/PerviousPave
Aircraft Loading

- One aircraft wheel load can easily exceed the total gross weight of many vehicles, including semi-tractor trailers
  - Aircraft wheel loads are approaching 65,000 lb (29,500 kg) and tire pressures exceed 200 psi (1.4 MPa)
ACPA’s AirPave

- **AirPave** is based on calculated pavement responses (mechanics – independent of climate)
- Developed as an update to PCA’s AIRPORT, originally developed by Bob Packard
- Design is strictly mechanistic and limit stress ratio; no faulting / IRI
- acpa.org/AirPave
- Now it is more of an analysis tool…
Tri-Services (Army, Air Force, Navy)

- **PCASE** = Pavement-Transportation Computer Assisted Structural Engineering
- US Army Corps of Engineers product
- [https://transportation](https://transportation)
FAARFIELD

- FAA standard for airfield pavement design
- Rigid pavement design based on 3D finite element analyses
- [http://www.faa.gov/airports/engineering/design_so](http://www.faa.gov/airports/engineering/design_so)
EverFE

- 3D user-friendly FEA software
- Based on calculated pavement responses (mechanics — independent of climate)
- Focus is ???
- Design is strictly mechanistic
- http://www.civil.umaine.edu/everfe/
Short Joint Spacing
Joint Spacing Impacts Cracking

- 20 ft (6.10 m)
- 18 ft (5.49 m)
- 17 ft (5.18 m)
- 15 ft (4.57 m)

Traffic, million ESALs

Percent slab cracking

0% 10% 20% 30% 40% 50% 60% 70% 80%
OptiPave’s Goal is to Optimize Joint Spacing

Typical Design
- Slab Size = 12’ x 15’ = 3.7 m x 4.6 m
- Max Top Stress = 363 psi (2.5 Mpa)
- Thickness = 10 in. (250 mm)

OptiPave Design
- Slab Size = 6’ x 6’ = 1.8 m x 1.8 m
- Max Top Stress = 363 psi (2.5 Mpa)
- Thickness = 6.3 in. (160 mm)
But Thickness Design Is Only One Piece of the Puzzle!
There’s an ACPA App for That!

- Agency Practices Explorer
- Airfield Steel Calculator
- Area and Volume Calculator
- Bonded Concrete Overlay on Asphalt (BCOA) Calculator
- Compression Seal Joint Width Calculator
- Concrete Mixture Proportioner
- Concrete Temperature Calculator
- Dowel Bar Alignment Calculator
- Evaporation Rate Calculator
- Friberg Group Dowel Analyzer
- Friberg Single Dowel Analyzer
- Gradation Analyzer
- Green Streets Calculator
- Highway Specs for Airfields Lookup
- Joint Movement Estimator
- Joint Noise Estimator
- k-Value Calculator
- Maturity Calculator
- Maximum Joint Spacing Calculator
- M-E Tie Bar Designer
- National Concrete Overlay Explorer
- Online Glossary
- Online Thickness Designer
- Radius of Relative Stiffness Calculator
- Rate of Delivery Calculator
- Relative Cost Estimator
- Staking Interval Calculator
- Strength Analyzer
- Strength Converter
- Subgrade Resilient Modulus Calculator
- Taper Length Calculator
- Total ESAL Calculator
- Units Converter
- Westergaard Stress & Deflection Solver
- … working on more!
Description

by inputting sieve size analysis (gradation) information for up to three coarse aggregates and two fine aggregates, and the relative percent of each aggregate to be used in the mixture, this web applet allows you to view plots of the percent passing, percent retained, workability chart, ASTM C333 curve, and 0.45 power curve for the combined aggregate gradation.

Terms of Use

The user accepts ALL responsibility for decisions made as a result of the use of this design tool. American Concrete Pavement Association, its Officers, Board of Directors and Staff are absolved of any responsibility for any decisions made as a result of your use. Use of this design tool implies acceptance of the terms of use.

Percent Blend

<table>
<thead>
<tr>
<th></th>
<th>Stone 1</th>
<th>Stone 2</th>
<th>Stone 3</th>
<th>Sand 1</th>
<th>Sand 2</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>70%</td>
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<td>0%</td>
<td>30%</td>
<td>6%</td>
<td></td>
<td>100%</td>
</tr>
</tbody>
</table>

*Combined must total 100% before a calculation can be run.

Percent Passing (Gradation)

<table>
<thead>
<tr>
<th>Size</th>
<th>Stone 1</th>
<th>Stone 2</th>
<th>Stone 3</th>
<th>Sand 1</th>
<th>Sand 2</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0%</td>
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</tr>
<tr>
<td>1.5 in.</td>
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<td>0%</td>
<td>0%</td>
<td>100%</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>1 in.</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
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<td>0%</td>
<td>100%</td>
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<td>100%</td>
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<tr>
<td>1/8 in.</td>
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<td>0%</td>
<td>100%</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>3/16 in.</td>
<td>13%</td>
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<td>0%</td>
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<tr>
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<td>0%</td>
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<td>100%</td>
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<tr>
<td>1/2 in.</td>
<td>3%</td>
<td>0%</td>
<td>0%</td>
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<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>100%</td>
</tr>
</tbody>
</table>
MAX JOINT SPACING

CONCRETE PAVEMENT STRUCTURE DETAILS

Concrete Pavement Thickness (in.): 8.00
Layer Immediately Below Concrete Surface Course: Unstabilized (Granular) Subbase

Calculate  Save Inputs

JOINT SPACING RECOMMENDATION

Maximum Joint Spacing: 15 ft

Note: The ratio of transverse joint spacing to longitudinal joint spacing should not exceed 1.5
// MECHANISTIC-EMPIRICAL TIE BAR DESIGNER //

LOCATION DETAILS
State: Illinois
Location: Chicago

CONCRETE MATERIAL DETAILS
Cement Type: Type I
Cementitious Materials Content (lb/yd³): 550.0
Coefficient of Thermal Expansion (10⁶/°F): 5.50

CONCRETE PAVEMENT STRUCTURE DETAILS
Concrete Pavement Thickness (in.): 8.00
Lane Configuration: Two Tied 12-ft Lanes
Subbase Type/Thickness: Unstabilized (Granular) Subbase - 6 in.

CONSTRUCTION DETAILS
Month of Construction: May
Curing Procedure: Curing Compound

CALCULATED DESIGN
OPTION 1:
- Total Free Strain: 650 (Rounded up from 626.63)
- Tie Bar Size: #5
- Tie Bar Spacing*: 45
- Tie Bar Length: 24
- Steel Grade: 40

THE LONGITUDINAL JOINT IN THIS DESIGN CONTAINS 0.082 IN.² OF STEEL PER FOOT. THIS VALUE MAY BE USED TO DETERMINE EQUIVALENT DESIGNS FOR ALTERNATE TIE BAR SIZES.
Welcome to ACPA's Concrete Pavement Wiki

This is WikiPave

WikiPave™ is a free concrete pavement, encyclopedic resource, featuring technical and general information about concrete pavements, as well as information about the American Concrete Pavement Association, its allied Chapter/States, technology partners, and other allied organizations.

This resource is provided to you courtesy of ACPA National, ACPA-affiliated chapters and state paving associations, and ACPA members. Content editing is reserved for ACPA members. Contact Eric Fermebee for access.

A Brief Introduction to Concrete Pavements

Concrete pavements utilize cement to create a rigid surface which can be used for numerous applications. The most common applications are highways, streets, roadways, airports, industrial sites, and parking facilities. Due to the concrete’s rigidity, concrete pavements distribute applied loads over a wide influence area.

The most common types of concrete pavement are jointed plain concrete pavement (JPCP), jointed reinforced concrete pavement (JRCP), and continuously reinforced concrete pavement (CRCP). The main difference that distinguishes between these three systems is the jointing system used to control crack development and transfer load.

Additionally, previous concrete pavement and roller-compacted concrete (RCC) pavement have been gaining popularity in recent years. These two types of concrete pavement utilize optimized mixes and construction methods to achieve different properties than the three more traditional types of concrete pavement. These typically behave as an undressed jointed plain concrete pavements which rely on aggregate interlock and subgrade support to transfer the load between slabs.

Featured Pages

Must-See Pages:
- Joint Layout
- Utility Cuts
- RCC Materials Selection
- Concrete Pavement Thickness Design
- ACPA Chairman
- Joint Sealing

Featured Topics
- Concrete Pavement Joints
- Joint Layout
- Joint Mechanics
- Pavement Utility Cuts
- Pothole Pavements
- Maternity Testing

Featured Article: Colored Crosswalks

The use of decorative concrete has increased dramatically in the last few years, especially for urban streetscape programs intended to revitalize downtown areas in small- and medium-sized towns and cities. A common location for decorative (stamped and/or colored) concrete in roadway pavements is at crosswalks. The colored concrete can help serve as a pavement marking if the standard white stripes identifying the crosswalk wear off. The colored crosswalk still alerts pedestrians and motorists of the crossing, making for safer pedestrian/vehicle intersections.

To view the rest of this page, click here.

Featured Picture: Dowels Baskets in Wheel Path

Dowel baskets can be placed for paving using baskets before paving begins or using a dowel bar inserter as paving is taking place. In this photo dowel have been placed with baskets and have been placed only in the wheel paths. This can result in cost savings by eliminating dowels without impacting long-term performance. Dowel bars are used to transfer the load at the joints from one slab to the next and are an important part of the joint mechanics of jointed plain concrete pavement (JPCP).
Joints

There are numerous types of joints utilized in concrete pavements and all of them serve a specific purpose. All joints are designed in some way or another to help the pavement achieve its desired life. Jointed plain concrete pavement (JPCP) is most representative of how a pavement contains joints, but as concrete pavement types, including jointed reinforced concrete (JRCP) and continuously reinforced concrete pavement (CRCP), use joints for a number of reasons. This page talks about the whole purpose of joints and history of joints as well as their proper design and construction.

The primary focus of this page is to create pavements. While much of the information is applicable to airports pavements, there are some significant differences that are featured in the asphalt paving page.

Why Joint Concrete Pavements? [edit]

The first reason for paving concrete pavements is to create concrete slabs. This happens under a few different mechanisms. Drying shrinkage is the result of water being lost by evaporation, which is also called the loss of water between the time of placing of concrete and when the pavement is complete. Chemical shrinkage occurs because the products of the cement hydration (cement) occupy less volume than the reactants (cement and water in addition to aggregates). Shrinkage can occur at any time but usually occurs on an issue if pavements are not subject to restraint. In the concrete is free to shrink, as a result, it is restrained by the moisture at a moisture source, and then shrinkage sets at no cause any distress. However, shrinkage from the subgrade or pavement structure reduces to the shrinkage forces, which in turn results in pavement distress. Shrinkage propagates over time, and the internal stresses build up eventually reaching the surface strength of the concrete and the pavement will begin to crack. Without joints, the concrete will naturally begin to crack at about 40-50 kg/mm² to relieve the internal normal forces. As shrinkage continues to progress, cracking will continue at an interval of 15-20 mg/mm². This interval will occur not only transversely but longitudinally as well because the restraint forces vary along different sections. This cracking can occur completely due to shrinkage, without any load being applied.

To control the cracking, concrete pavements can be placed at an interval less than what the concrete would crack naturally. This cuts the pavement into slabs or panels that are small enough that the internal stresses are restrained and restrain or level cracks cracking in sections. The joints can be used to create slabs about 1.8-2.4 m thick, which is typically around 6-8 ft. The timing of the joint cuts is important as it can influence many results in cracking and setting. It is always recommended to use a jointing machine to ensure a clean cut and proper placement.

![Shrinkage Crack Progression](image)

Shrinkage Crack Progression

While controlling cracking due to shrinkage is the primary reason why jointed concrete pavements, there are a number of other reasons. One such reason is that joints allow drainage of the pavement into construction joints or linear materials. This can be through longitudinal joints that occur at the edges of a highway or through transverse joints that occur at the same location as the edges of lines, if they often help distribute load for materials. However, distribution lines is not one of the reasons to joint pavements. It can be beneficial to place longitudinal joints in the center of lanes if it eliminates the need for the driver when nearing a lane or as a safety measure.

Another reason for jointed concrete pavements is to accommodate traffic movement. Isolation joints provide for a concrete pavement to expand and contract without pushing up against adjacent structures. The expansion and contraction of concrete occurs in cycles as weather fluctuates with humidity and temperature.

Joints can also provide load transfer through placed dowels, because joints can be covered over the location of the dowels. The dowels can be placed with embeds on grade or with a dowel bar inserter (DBI). Such load transfer is not provided over a crack because cracks occur at unplanned locations. If a pavement is not jointed, then placing where the dowels need to be placed becomes difficult. To restore load transfer over a crack, dowel bars can be retrofitted into the pavement if aggregate interlock will provide enough load transfer. This process is known as dowel bar insertion (DBI).

A Brief History of Jointing [edit]

The earliest concrete pavements were typically built in 6-8 ft. wide and were about 6 in. thick. There was no such thing as a structural design, and the main purpose was to try to solve some of the durability problems and in areas where it was arbitrarily chosen. The 6-8 ft. spacing of the slabs was not a design consideration but rather a limitation of mill capacity. This was the birth of construction joints or tie-in joints created by joints between these slabs. As the speed of vehicle increased, the roughness of these joints began to be more apparent. Additionally, to increase productivity and minimize costs, larger slabs with cracks, acting as construction joints, permit load transfer through aggregate interlock became more popular. Utilizing construction joints and promoting load transfer through aggregate interlock began to see some of the smoothness issues.

Issues with the load transfer provided through aggregate interlock occurred as cracks began to open. To combat this, steel was added to help restrict the slabs and hold the cracks together. This was the birth of JRCP around 1913. The amount of steel in JRCP is typically between 0.5% and 0.25% by cross sectional area and is calculated based on aggregate size (slab). The surface of the slab is a great place for structural joints to occur, but it is a great place to use reinforcement, which is also applied to large slabs and intermediate cracks, serving as construction joints, occurring every 15-20 ft.

The attempts to place a transfer crack at the JRCP were difficult to maintain. This led to the beginning of JRCP shortly after 1913. For JRCP, the construction joints were spaced at intervals less than the 15-20 ft. the pavement would naturally crack. This led to joints that were straight lines, similar to construction joints, and the crack would precipitate from the bottom of the saw cut was not. This would still allow for aggregate interlock across the joints. Early JRCP did not utilize any steel for reinforcement or load transfer and construction joints were still placed at a 15-20 ft. interval due to paving limitations.

To obtain adequate load transfer at the construction joints of JRCP and JRP, joint bars were newly added around 1917. This also helped eliminate other joint distresses that were being seen. Later it became common practice to double the intermediate construction joints as well.

Due to the poor performance of the dowelled JRP, more detail was added to create CRCP around 1935. The amount of load increased from 0.6 to 0.75% by cross sectional area up to 4-6 0.9% steel by cross sectional area. The increase in the amount actually increased the restraint forces applied to the concrete which resulted in shorter crack spacings of 2-6 ft. However, the additional detail did not stop cracks from continuing to promote load transfer through aggregate interlock.

Design Challenge JRCP JRCP CRCP

| Transverse Joint Spacing | 12-22 ft. | 22-100+ ft. | N/A |
| Transverse Crack Spacing | N/A | 11-20 ft. | 2.6 ft |
| Shrinkage Accommodated by | Joints | Cracking | Joints |
| Reinforcement | No | 0.06-0.25% | 0.06-0.25% |
| Expansion Joints Used | No | As needed | Monthly |
| The beam used in longitudinal joints | Vert. | Vert. | Vert. |
| Dowel Bars (To inhibit Transverse Joints) | Opt. | N/A | N/A |
Looking to the Future…

A Unified Pavement Design Software
Bringing Online the Best Design Tools
Unified Design Map
A One Stop Shop…

Select Project Type

PARKING

STREET

INDUSTRIAL
For Concrete Pavement Design
Coming Late 2017!
Key Features

- Free, attractive, easily accessible and easy-to-use design application
- Users can save and share their projects
- Tools to guide and educate users
- Printable and shareable output reports
- CAD Library
- Direction to design experts
Thank you.

Questions? FEEDBACK!

Check Out WikiPave.org
ACPA’s Concrete Pavement Encyclopedia

Eric Ferrebee
Technical Services Engineer
American Concrete Pavement Association
eferrebee@acpa.org | 847.423.8709