Concrete Pavement Design Proposal:

Example Street Design
Your Town, State

Project Location/Length/Limits

Project Owner
Public Works Department
100 1st Street
Town, State 00000-0000
(123) 456-7890

Civil Engineer
Civil Engineer, Inc.
200 2nd Street, Suite 200
Town, State 00000-0000
(987) 654-3210

Geotechnical Engineer
Geotechnical Engineer, Inc.
300 3rd Street
Town, State 00000-0000
(800) 123-4567
Disclaimer

The information contained herein is provided for use by professional personnel who are competent to evaluate the significance and limitations of the information provided and who will accept total responsibility for the application of this information. The project Engineer of Record shall be responsible for the review and acceptance of the design recommendations. The recommendations reflect the judgment of the National Ready Mixed Concrete Association (NRMCA) and NRMCA believes the recommendations are accurate. However, NRMCA makes no representations or warranties concerning the fitness of this information for any particular application or installation and DISCLAIMS any and all RESPONSIBILITY and LIABILITY for the accuracy of and the application of the information provided to the full extent of the law.
January 1, 2012

Mr. John Smith, P.E.
Civil Engineer, Inc.
200 2nd Street, Suite 200
Town, State 00000-0000

RE: Concrete Pavement Design Proposal
    Example Street Design
    Your Town, State

Mr. Smith:

The National Ready Mixed Concrete Association (NRMCA) is pleased to provide this concrete pavement design proposal for the subject project. Specific information used to develop this alternative design was gathered from the Geotechnical Engineering Report (Project No. 1000-12-001) dated December 1, 2011.

This proposal demonstrates that based upon a Life-Cycle Cost Analysis (LCCA) the concrete pavement provides the lowest cost to the owner over the life of the pavement. Please contact us if you desire further assistance regarding this project.

Sincerely,

National Ready Mixed Concrete Association

Brian M. Killingsworth, P.E.
Senior Director, Pavement Structures
Concrete Pavement Design Proposal
Example Street Design
Your Town, State

Summary

Project Description

Approximately 1 mile of roadway will be constructed in a new subdivision in Your Town, State. The subdivision is being platted and developed by New Development, LLC and includes 150 lots situated on primarily residential streets.

Subgrade Foundation Soils

Primarily consists of CH fine-grained soils with a California Bearing Ratio of approximately 2.0. For both pavement types the subgrade should be prepared in accordance with Section 3.1 Subgrade Preparation from the NRMCA Guide Specification for Materials and Construction of Jointed Unreinforced Concrete Pavement for Streets and Local Roads.

Traffic Conditions

Residential collector with approximately 20 trucks per day (two-way, all lanes) with no growth anticipated over the 20 design period.

Asphalt Surfaced Pavement Recommendation (from Geotechnical Report)

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMAC Surface Course</td>
<td>DOT HMA-9.5mm</td>
<td>1.5 inches</td>
</tr>
<tr>
<td>HMAC Base Course</td>
<td>DOT HMA-25.0mm</td>
<td>2.0 inches</td>
</tr>
<tr>
<td>Aggregate Subbase</td>
<td>DOT STONE BASE</td>
<td>12.0 inches</td>
</tr>
</tbody>
</table>

Proposed Concrete Surfaced Pavement Recommendation (from NRMCA Analysis)

<table>
<thead>
<tr>
<th>Material</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed Portland Cement Concrete Thickness</td>
<td>5.0 inches (1” Nom. Max., 4,000 psi, 5% Air Content)</td>
</tr>
<tr>
<td>Aggregate Base</td>
<td>Not Required</td>
</tr>
<tr>
<td>Maximum Transverse Joint Spacing</td>
<td>10.0 feet</td>
</tr>
<tr>
<td>Maximum Longitudinal Joint Spacing</td>
<td>12.0 feet</td>
</tr>
<tr>
<td>Concrete Curb and Gutter</td>
<td>Required</td>
</tr>
<tr>
<td>Dowel Bars</td>
<td>Not Required</td>
</tr>
</tbody>
</table>

Life-Cycle Cost Analysis (LCCA)

Net present cost over 30 year life-cycle period:

Concrete Pavement $502,404
Asphalt Pavement $634,429
Detailed Report

Project Description

Approximately 1 mile of roadway will be constructed in a new subdivision in Your Town, State. The subdivision is being platted and developed by New Development, LLC and includes 150 lots situated on primarily residential streets. Design approval and oversight is provided by the County Department of Development Services Division. Changes in grade on the order of 5 feet or less are anticipated.

Subgrade Pavement Foundation Soils

Soils encountered in the upper 10 feet of the borings drilled for the geotechnical engineering report include fine-grained soils of soft to very stiff fat clay (CH) and elastic silt (MH) with varying amounts of sand and gravel. Uncorrected SPT N-values for these soils ranged from 3 blows per foot (bpf) to 7 bpf, with an average of 5 bpf. Engineering properties of the encountered soils were measured and reported in the geotechnical engineering report as shown in the table below.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Liquid Limit</th>
<th>Plasticity Index</th>
<th>Max. Dry Density (pcf)</th>
<th>Opt. Moisture (%)</th>
<th>CBR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – 4</td>
<td>58 – 79</td>
<td>33 – 51</td>
<td>88.2 – 101.7</td>
<td>19.2 – 31.4</td>
<td>2.0 – 2.8</td>
</tr>
</tbody>
</table>

Asphalt Surfaced Pavement Recommendation (from Geotechnical Report)

To determine the required design Structural Number (SN) value for the recommended flexible pavement, the geotechnical engineer utilized a software program entitled AASHTOWare DARWin Pavement Design and Analysis System, which is published by the American Association of State Highway and Transportation Officials (AASHTO) and is based on the 1993 edition of the AASHTO Guide for the Design of Pavement Structures.

The following inputs were used to determine the required SN and resulting pavement cross section:

- Design Period: 20 years
- Roadbed Soil Resilient Modulus: 3,500 psi
- Serviceability Indices (initial/terminal): 4.0/2.0
- Overall Standard Deviation: 0.49
- Reliability: 75%
- Average Daily Truck Traffic: 20 trucks per day

Based on the inputs used above and the assumptions regarding traffic, the required structural number ($SN_{reqd}$) is 2.69. The recommended asphalt surfaced pavement cross section as detailed in the geotechnical report is as follows:

<table>
<thead>
<tr>
<th>Pavement Layer</th>
<th>Material Specification</th>
<th>Thickness (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMAC Surface Course</td>
<td>DOT HMA-9.5mm</td>
<td>1.5</td>
</tr>
<tr>
<td>HMAC Base Course</td>
<td>DOT HMA-25.0mm</td>
<td>2.0</td>
</tr>
<tr>
<td>Aggregate Subbase</td>
<td>DOT STONE BASE</td>
<td>12.0</td>
</tr>
</tbody>
</table>

Note 1: Prime coat is to be placed on the aggregate subbase and tack coat is to be placed between asphalt concrete layers.
If the assumed structural coefficient for HMAC surface and base layers is 0.42 for the HMA surface, 0.38 for the HMA Base, and 0.11 for the aggregate stone base the design above provides a structural number (SN_{actual}) of 2.71 which exceeds the SN_{reqd} of 2.69. It is assumed that the subgrade will be prepared in accordance with Section 3.1 Subgrade Preparation from the NRMCA Guide Specification for Materials and Construction of Jointed Unreinforced Concrete Pavement for Streets and Local Roads (see attached Guide Specification) since it was not explicitly stated in the geotechnical report.

**Proposed Concrete Surfaced Pavement Recommendation (from NRMCA Analysis)**

As per the DOT Pavement Design Guide for Subdivision and Secondary Roads acceptable pavement designs for rigid pavement include PCA, ACPA, and AASHTO. For the purposes of this proposal the ACPA StreetPave v1.3 pavement design software has been used to determine an acceptable concrete pavement cross section.

Based on the StreetPave v1.3 software the following inputs were used to determine the required concrete pavement thickness:

<table>
<thead>
<tr>
<th>Design Period</th>
<th>20 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadbed Soil Resilient Modulus</td>
<td>3,000 psi</td>
</tr>
<tr>
<td>Percent of Concrete Slabs Cracked at End of Design Life</td>
<td>25%</td>
</tr>
<tr>
<td>Terminal Serviceability</td>
<td>2.0</td>
</tr>
<tr>
<td>Minimum 28-Day Compressive Strength</td>
<td>4,000 psi</td>
</tr>
<tr>
<td>28-Day Flexural Strength (MR)</td>
<td>600 psi</td>
</tr>
<tr>
<td>Modulus of Elasticity (E)</td>
<td>4,000,000 psi</td>
</tr>
<tr>
<td>Traffic Category</td>
<td>Residential</td>
</tr>
<tr>
<td>Average Daily Truck Traffic</td>
<td>20 trucks per day</td>
</tr>
</tbody>
</table>

The recommended pavement cross section as determined by StreetPave v1.3 and construction details are as follows (see attached StreetPave program output for further details):

- Proposed Portland Cement Concrete Thickness: 5.0 inches
- Aggregate Base: Not Required
- Maximum Transverse Joint Spacing: 10.0 feet
- Maximum Longitudinal Joint Spacing: 12.0 feet
- Concrete Curb and Gutter: Required
- Dowel Bars: Not Required
- Subgrade Preparation: NRMCA Guide Specification Section 3.1

**Suggested Concrete Pavement Details**

A proper jointing plan is integral to the overall long-term performance of the concrete pavement. In particular, proper jointing through intersections and a functional transition joint between existing

---

1 Concrete should conform to ACI 301 (1” Nom. Max., 4,000 psi, 5% Air Content) placed in accordance with NRMCA Guide Specification for Materials and Construction of Jointed Unreinforced Concrete Pavement for Streets and Local Roads

2 May be integral or placed independently.
asphalt pavement and the new concrete are important for good performance. Intersection and other joint details should be in accordance with American Concrete Pavement Association (ACPA) publication TB019P entitled Concrete Intersections: A Guide for Design and Construction. Additional jointing information may be found in American Concrete Institute publication ACI 325.12R-02 entitled Guide for Design of Jointed Concrete Pavements for Streets and Local Roads.

The following transverse joint detail is recommended for the proposed pavement cross section:

![Transverse Joint Detail](image)

If the full width of pavement is paved together, longitudinal joints shall be sawcut to a minimum depth of 1/4 the concrete slab thickness and sealed with no tie bars required. If each pavement lane is paved independently, the pavement lanes may be tied with 24 inch long 5/8 inch diameter Grade 60 deformed steel bars placed on 30 inch centers. Local experience may indicate that tie bars are not required with the confinement provided by the curb and gutter.

The suggested curb detail is the standard DOT curb design and is shown below. Curbs and gutters may be formed monolithically with the pavement at the same thickness or may be poured independently. If placed independently, the curb and gutter should be tied to the pavement to reduce separation.

![Curb Detail](image)

**Suggested Materials and Construction Specification**

NRMCA has developed a reference specification entitled Guide Specification for Materials and Construction of Jointed Unreinforced Concrete Pavement for Streets and Local Roads (see attached) for use by owners and their design consultants to define material and construction requirements, criteria, and expectations of material suppliers and construction contractors. This guide specification may be used for materials and construction control on this project; however, prior to use, the guide specification should be thoroughly reviewed by the Project Engineer of Record for applicability to the specific project and local conditions. It is intended that the language contained within the guide
specification will be modified, as necessary, to fit within the project contractual conditions and local preferences and that the referenced test methods will be modified accordingly.

**Maintenance and Rehabilitation of Concrete Pavements**

The pavement design assumes that approximately 25% of the slabs at the end of the design life will have a transverse crack across the entire pavement width. This is a typical design scenario and generally these cracks do not require significant maintenance other than sealing which may be at the discretion of the maintenance engineer. Due to the expansive nature of the subgrade it is assumed that some longitudinal cracks may develop over time which will require partial depth repair. In addition, it is assumed that due to the expansive subgrade some slabs will move sufficiently to cause faulting at some of the transverse joints which will require diamond grinding of the joints to restore smoothness. Maintenance and concrete pavement restoration techniques can be found in ACPA publication *Concrete Paving Technology: The Concrete Pavement Restoration Guide – Procedures for Preserving Concrete Pavements*.

**Life-Cycle Cost Analysis (LCCA)**

As per the Federal Highway Administration, LCCA is an analysis technique that builds on the well-founded principles of economic analysis to evaluate the over-all-long-term economic efficiency between competing alternative investment options. It does not address equity issues. It incorporates initial and discounted future agency, user, and other relevant costs over the life of alternative investments. It attempts to identify the best value (the lowest long-term cost that satisfies the performance objective being sought) for investment expenditures.

For comparison purposes the StreetPave v1.3 LCCA module was utilized to provide an assessment of the proposed concrete pavement alternative relative to the asphalt pavement design over a 30 year life cycle analysis period. The initial costs as well as the maintenance and rehabilitation costs were considered in the analysis and typical maintenance and rehabilitation schedules were assigned for each pavement type. A 30 to 50 year analysis period is typical for life cycle cost analysis (which is different from the 20 year analysis period for thickness design) and is used to reflect long-term cost differences between alternatives. FHWA typically recommends a 30 to 35 year life cycle analysis period.

The cost information used in the LCCA comes from multiple sources and includes average national data from RSMeans, DOT historical data, and a national pavement rehabilitation study conducted by the Texas Transportation Institute. The maintenance schedules indicate that partial depth repairs for concrete pavement will be conducted at years 12 and 30 and diamond grinding will occur at year 20. For the asphalt surfaced pavement crack sealing is to occur at years 2, 8, and 20 while sealing will occur at years 10 and 15. A mill and overlay will be required at year 30.

Based upon the LCCA, the net present cost for the two pavement designs over 30 years is as follows:

- **Concrete Pavement** $502,404
- **Asphalt Pavement** $634,429

The following graph demonstrates the total agency cost over the 30 year period. See the attached output from the StreetPave program for further details.
Concrete Sustainability

As transportation professionals and owners/operators continue to look for ways to lessen the environmental impact of streets, roads, and highways the use of concrete as been proven over time to achieve these goals. Attached is a publication produced by NRMCA entitled CSR03 - Sustainability of Concrete Pavements that demonstrates the many ways that the use of concrete can achieve the important goals of lowering environmental impacts of pavements.
Report for Concrete Pavement Design

Project Name: Example Subdivision
Route: Local Streets
Location: Your County
Project Description: Phase 3
Owner/Agency: Local Development Board
Design Engineer: Brian M. Killingsworth, P.E.

Recommended Concrete Pavement Design

Thickness 5 in
Joint Spacing 10 ft
Dowel Bars Dowel bars not chosen and not recommended.

Effect of Rounding on Thickness

<table>
<thead>
<tr>
<th>Rounded-Up Concrete Thickness</th>
<th>Rounded-Up Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>59 years @ 75% reliability</td>
<td>5.00 in</td>
</tr>
<tr>
<td>91.1% reliability for 20-year design</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rounded-Down Concrete Thickness</th>
<th>Rounded-Down Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 years @ 75% reliability</td>
<td>4.50 in</td>
</tr>
<tr>
<td>66.4% reliability for 20-year design</td>
<td></td>
</tr>
</tbody>
</table>

Inputs

Design Life 20 years

Reliability

Specified Reliability = 75%
Allowable Percent Cracked Slabs at End of Design Life = 25%

Traffic

Traffic Category: Residential
Total Number of Lanes 2
Direction Distribution 50
Design Lane Distribution 100
ADTT 20 per day (average daily truck traffic, two-way, all lanes)
Truck Traffic Growth 0% per year
Support Conditions

Subgrade:

Resilient Modulus of the Subgrade 3000 psi

Subbase:

Top Layer = Not Selected
  Modulus = 0 psi
  Thickness = 0 in

Layer 2 = Not Selected
  Modulus = 0 psi
  Thickness = 0 in

Layer 3 = Not Selected
  Modulus = 0 psi
  Thickness = 0 in

Composite Modulus of Subgrade Reaction (K-value):
  k = 155 psi/in

Concrete Properties

Flexural Strength (Modulus of Rupture, MR) = 600 psi

Modulus of Elasticity = 4000000 psi

Modulus of Elasticity (E) = 6750 x MR

Design Features

Load Transfer Devices (Dowel Bars) Needed? No
  Diameter = N/A

Edge Support? Yes
  (widened lane, tied concrete shoulder, or curb & gutter)
Fatigue & Erosion Calculations

<table>
<thead>
<tr>
<th>Traffic Category: Residential</th>
<th>Fatigue Analysis</th>
<th>Erosion Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axle Load, kips</td>
<td>Stress Ratio</td>
<td>Allowable Repetitions</td>
</tr>
<tr>
<td>22</td>
<td>0.861</td>
<td>245</td>
</tr>
<tr>
<td>20</td>
<td>0.787</td>
<td>823</td>
</tr>
<tr>
<td>18</td>
<td>0.713</td>
<td>4298</td>
</tr>
<tr>
<td>16</td>
<td>0.638</td>
<td>44321</td>
</tr>
<tr>
<td>14</td>
<td>0.563</td>
<td>1384453</td>
</tr>
<tr>
<td>12</td>
<td>0.487</td>
<td>297784261</td>
</tr>
<tr>
<td>10</td>
<td>0.41</td>
<td>unlimited</td>
</tr>
<tr>
<td>8</td>
<td>0.333</td>
<td>unlimited</td>
</tr>
<tr>
<td>6</td>
<td>0.254</td>
<td>unlimited</td>
</tr>
<tr>
<td>4</td>
<td>0.173</td>
<td>unlimited</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single Axles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>0.597</td>
<td>243983</td>
</tr>
<tr>
<td>32</td>
<td>0.534</td>
<td>7763001</td>
</tr>
<tr>
<td>28</td>
<td>0.471</td>
<td>unlimited</td>
</tr>
<tr>
<td>24</td>
<td>0.408</td>
<td>unlimited</td>
</tr>
<tr>
<td>20</td>
<td>0.344</td>
<td>unlimited</td>
</tr>
<tr>
<td>16</td>
<td>0.279</td>
<td>unlimited</td>
</tr>
<tr>
<td>12</td>
<td>0.213</td>
<td>unlimited</td>
</tr>
<tr>
<td>8</td>
<td>0.145</td>
<td>unlimited</td>
</tr>
<tr>
<td>4</td>
<td>0.076</td>
<td>unlimited</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>unlimited</td>
</tr>
<tr>
<td>Tandem Axles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>52</td>
<td>0.572</td>
<td>837937</td>
</tr>
<tr>
<td>46</td>
<td>0.51</td>
<td>44872902</td>
</tr>
<tr>
<td>40</td>
<td>0.447</td>
<td>unlimited</td>
</tr>
<tr>
<td>34</td>
<td>0.384</td>
<td>unlimited</td>
</tr>
<tr>
<td>28</td>
<td>0.32</td>
<td>unlimited</td>
</tr>
<tr>
<td>22</td>
<td>0.255</td>
<td>unlimited</td>
</tr>
<tr>
<td>16</td>
<td>0.189</td>
<td>unlimited</td>
</tr>
<tr>
<td>10</td>
<td>0.121</td>
<td>unlimited</td>
</tr>
<tr>
<td>4</td>
<td>0.051</td>
<td>unlimited</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>unlimited</td>
</tr>
<tr>
<td>Tridem Axles</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Total Fatigue Used: 99.7 Total Erosion Used: 11
Report for Asphalt Pavement Design

Project Name: Example Subdivision
Route: Local Streets
Location: Your County
Project Description: Phase 3
Owner/Agency: Local Development Board
Design Engineer: Brian M. Killingsworth, P.E.

Recommended Concrete Pavement Design

Asphalt Thickness 5.84 in

Cross-Section
StreetPave
Pavement Design & Analysis Software
American Concrete Pavement Association

Inputs

Design Life: 20 years
Traffic Category: Residential
Total Number of Lanes: 2
Direction Distribution: 50%
Design Lane Distribution: 100%
ADTT: 20 per day (average daily truck traffic, two-way, all lanes)
Truck Traffic Growth: 0% per year

ESALs = 37,543

<table>
<thead>
<tr>
<th>Axle Load, kips</th>
<th>Axles per 1000 Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Axles</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>0.96</td>
</tr>
<tr>
<td>20</td>
<td>4.23</td>
</tr>
<tr>
<td>18</td>
<td>15.81</td>
</tr>
<tr>
<td>16</td>
<td>38.02</td>
</tr>
<tr>
<td>14</td>
<td>56.11</td>
</tr>
<tr>
<td>12</td>
<td>124</td>
</tr>
<tr>
<td>10</td>
<td>204.96</td>
</tr>
<tr>
<td>8</td>
<td>483.1</td>
</tr>
<tr>
<td>6</td>
<td>732.28</td>
</tr>
<tr>
<td>4</td>
<td>1693.31</td>
</tr>
<tr>
<td>Tandem Axles</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>4.19</td>
</tr>
<tr>
<td>32</td>
<td>69.59</td>
</tr>
<tr>
<td>28</td>
<td>68.48</td>
</tr>
<tr>
<td>24</td>
<td>39.18</td>
</tr>
<tr>
<td>20</td>
<td>57.1</td>
</tr>
<tr>
<td>16</td>
<td>75.02</td>
</tr>
<tr>
<td>12</td>
<td>139.3</td>
</tr>
<tr>
<td>8</td>
<td>85.59</td>
</tr>
<tr>
<td>4</td>
<td>31.9</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tridem Axles</td>
<td></td>
</tr>
<tr>
<td>52</td>
<td>0</td>
</tr>
<tr>
<td>46</td>
<td>0</td>
</tr>
<tr>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>34</td>
<td>0</td>
</tr>
<tr>
<td>28</td>
<td>0</td>
</tr>
<tr>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Support Conditions

Subgrade:

Resilient Modulus of the Subgrade

\[
M_{RSG \ [\text{user-entered}]} = 3000 \text{ psi} \quad M_{RSG \ [\text{design}]} = 2231.08 \text{ psi}
\]

\[
M_{RSG \ [\text{design}]} = M_{RSG \ [\text{user-entered}]} \times (1 - ZR \times COV)
\]

Where:
- ZR = standard normal variate, calculated from user-entered reliability (R)
- COV = coefficient of variation typical of the project type and soils for the project

Coefficient of Variation = 38%

Subbase: 12 inch Granular Base

Reliability

Specified Reliability = 75%
StreetPave
Pavement Design & Analysis Software
American Concrete Pavement Association

Life Cycle Cost Analysis

Project Name: Example Subdivision
Route: Local Streets
Location: Your County
Project Description: Phase 3
Owner/Agency: Local Development Board
Design Engineer: Brian M. Killingsworth, P.E.

Initial Cost

Concrete Pavement Details

<table>
<thead>
<tr>
<th>Project Length</th>
<th>Number of Lanes</th>
<th>Lane Width</th>
<th>Design Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 miles</td>
<td>2</td>
<td>15 feet</td>
<td>5.0 in.</td>
</tr>
</tbody>
</table>

*StreetPave Recommended Value

Aggregate Base Thickness: Top Layer = Not Selected

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 in.</td>
</tr>
<tr>
<td>2</td>
<td>0 in.</td>
</tr>
<tr>
<td>3</td>
<td>0 in.</td>
</tr>
</tbody>
</table>

Composite Aggregate Base Density: 120 lb/ft³

Cost Inputs

Concrete Pavement (material): $140.00 / yd³
Concrete Placement (cure, saw, seal): $5.00 / yd²
Aggregate Base: $12.00 / ton

Calculated Initial Cost for Concrete = $430,222
Calculated Initial Cost for Aggregate Base = $0

Total Initial Cost for Concrete Pavement Design = $430,222

Engineer: Brian M. Killingsworth, P.E.
**Asphalt Pavement Details**

Project Length: 1 miles  
Number of Lanes: 2  
Lane Width: 15 feet  
Design Thickness 5.84 in. *StreetPave Recommended Value  
Surface Coarse Thickness: 0 in.  
Remaining Base Thickness: 5.84 in.  
Aggregate Base Thickness: 12 inch Granular Base  
Surface Course Density: 145 lb/ft³  
Base Density: 140 lb/ft³  
Aggregate Base Density: 120 lb/ft³  

**Cost Inputs**  
Asphalt Surface Course: $70.00 / ton  
Asphalt Base: $68.00 / ton  
Aggregate Base: $12.00 / ton  

Calculated Initial Cost for Asphalt Surface Course = $0  
Calculated Initial Cost for Asphalt Base = $366,939  
Calculated Initial Cost for Aggregate Base = $114,048  

Total Initial Cost for Asphalt Pavement = $480,987
## Maintenance Costs

### Concrete Cost Inputs

Concrete Annual Maintenance: $0.00 / yd²  
Joint Sealant: $0 / lf  
Full-Depth Repairs: $90.00 / yd²  
Partial-Depth Repairs: $125.00 / yd²  
Diamond Grinding: $2.25 / yd²  

### Concrete Maintenance Schedule with Associated Costs

<table>
<thead>
<tr>
<th>Year</th>
<th>Item</th>
<th>Available Quantity</th>
<th>Amount</th>
<th>Units</th>
<th>Present Value Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Partial-depth repairs</td>
<td>2.5</td>
<td></td>
<td></td>
<td>$41,865</td>
</tr>
<tr>
<td>20</td>
<td>Diamond grinding</td>
<td>10</td>
<td></td>
<td></td>
<td>$2,513</td>
</tr>
<tr>
<td>30</td>
<td>Partial-depth repairs</td>
<td>2.5</td>
<td></td>
<td></td>
<td>$27,803</td>
</tr>
</tbody>
</table>

### Asphalt Cost Inputs

Asphalt Annual Maintenance: $0.15 / yd²  
Crack Sealing: $1.25 / lf  
Milling: $2.50 / yd³  
Chip Seal: $1.50 / yd²  
Seal Coat: $3.25 / yd²  

### Asphalt Maintenance Schedule with Associated Costs

<table>
<thead>
<tr>
<th>Year</th>
<th>Item</th>
<th>Amount</th>
<th>Units</th>
<th>Present Value Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Rout &amp; seal cracks</td>
<td>300</td>
<td>lf</td>
<td>$358</td>
</tr>
<tr>
<td>8</td>
<td>Rout &amp; seal cracks</td>
<td>900</td>
<td>lf</td>
<td>$938</td>
</tr>
<tr>
<td>10</td>
<td>Seal coat</td>
<td>17600</td>
<td>yd²</td>
<td>$21,030</td>
</tr>
<tr>
<td>15</td>
<td>Chip seal</td>
<td>17600</td>
<td>yd²</td>
<td>$40,669</td>
</tr>
<tr>
<td>20</td>
<td>Rout &amp; seal cracks</td>
<td>600</td>
<td>lf</td>
<td>$476</td>
</tr>
<tr>
<td>30</td>
<td>Mill &amp; Asphalt Overlay</td>
<td>2</td>
<td>in</td>
<td>$89,971</td>
</tr>
</tbody>
</table>
Cumulative Costs (includes initial costs and present value maintenance costs)

<table>
<thead>
<tr>
<th>Year</th>
<th>Concrete</th>
<th>Asphalt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$430,222</td>
<td>$480,987</td>
</tr>
<tr>
<td>2</td>
<td>$430,222</td>
<td>$481,345</td>
</tr>
<tr>
<td>3</td>
<td>$430,222</td>
<td>$481,345</td>
</tr>
<tr>
<td>4</td>
<td>$430,222</td>
<td>$481,345</td>
</tr>
<tr>
<td>5</td>
<td>$430,222</td>
<td>$481,345</td>
</tr>
<tr>
<td>6</td>
<td>$430,222</td>
<td>$481,345</td>
</tr>
<tr>
<td>7</td>
<td>$430,222</td>
<td>$481,345</td>
</tr>
<tr>
<td>8</td>
<td>$430,222</td>
<td>$482,283</td>
</tr>
<tr>
<td>9</td>
<td>$430,222</td>
<td>$482,283</td>
</tr>
<tr>
<td>10</td>
<td>$430,222</td>
<td>$503,313</td>
</tr>
<tr>
<td>11</td>
<td>$430,222</td>
<td>$503,313</td>
</tr>
<tr>
<td>12</td>
<td>$472,088</td>
<td>$503,313</td>
</tr>
<tr>
<td>13</td>
<td>$472,088</td>
<td>$503,313</td>
</tr>
<tr>
<td>14</td>
<td>$472,088</td>
<td>$503,313</td>
</tr>
<tr>
<td>15</td>
<td>$472,088</td>
<td>$543,982</td>
</tr>
<tr>
<td>16</td>
<td>$472,088</td>
<td>$543,982</td>
</tr>
<tr>
<td>17</td>
<td>$472,088</td>
<td>$543,982</td>
</tr>
<tr>
<td>18</td>
<td>$472,088</td>
<td>$543,982</td>
</tr>
<tr>
<td>19</td>
<td>$472,088</td>
<td>$543,982</td>
</tr>
<tr>
<td>20</td>
<td>$474,601</td>
<td>$544,458</td>
</tr>
<tr>
<td>21</td>
<td>$474,601</td>
<td>$544,458</td>
</tr>
<tr>
<td>22</td>
<td>$474,601</td>
<td>$544,458</td>
</tr>
<tr>
<td>23</td>
<td>$474,601</td>
<td>$544,458</td>
</tr>
<tr>
<td>24</td>
<td>$474,601</td>
<td>$544,458</td>
</tr>
<tr>
<td>25</td>
<td>$474,601</td>
<td>$544,458</td>
</tr>
<tr>
<td>26</td>
<td>$474,601</td>
<td>$544,458</td>
</tr>
<tr>
<td>27</td>
<td>$474,601</td>
<td>$544,458</td>
</tr>
<tr>
<td>28</td>
<td>$474,601</td>
<td>$544,458</td>
</tr>
<tr>
<td>29</td>
<td>$474,601</td>
<td>$544,458</td>
</tr>
<tr>
<td>30</td>
<td>$502,404</td>
<td>$634,429</td>
</tr>
</tbody>
</table>
Guide Specification for Materials and Construction of Jointed Unreinforced Concrete Pavement for Streets and Local Roads

February 2012
Disclaimer

The information contained herein is provided for use by professional personnel who are competent to evaluate the significance and limitations of the information provided and who will accept total responsibility for the application of this information. The project Engineer of Record is responsible for the review and acceptance of the materials and construction specifications. The recommended specification requirements, criteria, and language herein reflect the professional knowledge and experience of the National Ready Mixed Concrete Association (NRMCA). However, NRMCA makes no representations or warranties concerning the fitness of this information for any particular application or installation and DISCLAIMS any and all RESPONSIBILITY and LIABILITY for the accuracy of and the application of the information provided to the full extent of the law.
Introduction

The following specification has been developed for use by owners and their design consultants to define material and construction requirements, criteria, and expectations of material suppliers and construction contractors. The definitions, test methods, and quality requirements are considered current state of the practice for the industry at the time of publication. This document is a recommended guide specification and has not been developed through a consensus process typical of industry standards that can be referenced. It should not be incorporated by reference in project specifications or contract documents.

Jointed unreinforced streets and local roads may be designed using various methods; however, NRMCA recommends using the American Concrete Institute (ACI) procedure 325.12R-02 Guide for the Design of Jointed Concrete Pavements for Street and Local Roads (www.concrete.org) or the American Concrete Pavement Association’s StreetPave Software (http://www.acpa.org) both of which specifically address the unique loading conditions inherent to streets and local roads and provide optimized concrete pavement thicknesses for city, municipal, county, and state roadways.
Notes to Specifier

1. Prior to use on a project, this guide specification should be thoroughly reviewed by the Project Engineer of Record for applicability to the specific project and local conditions. It is intended that the language contained herein will be modified, as necessary, to fit within the project contractual conditions and local preferences and that the referenced test methods will be modified accordingly.

2. All references to NRMCA on the cover page and in the main document header should be removed prior to incorporation into the final project specifications by the Engineer of Record or their representative.

3. The specification includes hidden text throughout which provides guidance to the specifier regarding the applicability or use of a section/subsection. Hidden text may be shown or hidden with the use of the Show/Hide button to see notes about optional language and what should be removed from the specification if it is not applicable. Hidden text is indicated as blue text. The hidden text should not be shown in the final project specification. The Show/Hide button in Microsoft Word is highlighted below. Print options can suppress printing of hidden text.

4. There are several locations where the engineer of record needs to input information specific to the project for which this specification is being issued. Without modifying these locations, this specification is incomplete. Locations identified as <bold text> indicate required information to be completed by the specifier. Locations identified as [bold text] generally indicate choices between one or more options to be selected by the specifier. The specifier is responsible for removing or inserting these for the final project specification. The engineer can also add other clauses as is typical for local practice and standard of care.

5. NRMCA requests feedback regarding this guide specification in terms of clarity of the language, constructability, and specification criteria/parameters. Feedback may be emailed to Publications@nrmca.org. Please include the specification title, revision number, and section/subsection number pertinent to your comment(s).
SECTION 32 13 13.51 – CONCRETE PAVEMENT FOR STREET AND LOCAL ROAD APPLICATIONS

PART 1 - GENERAL.................................................................................................................. 2
  1.0 PROJECT IDENTIFICATION ......................................................................................... 2
  1.1 RELATED DOCUMENTS ............................................................................................. 2
  1.2 SUMMARY .................................................................................................................... 2
  1.3 DEFINITIONS ............................................................................................................... 2
  1.4 REFERENCED STANDARDS AND MANUALS ............................................................... 4
  1.5 SUBMITTALS ............................................................................................................... 6
  1.6 QUALITY CONTROL PLAN ......................................................................................... 7
  1.7 QUALITY ASSURANCE ............................................................................................... 8
  1.8 EQUIPMENT ............................................................................................................... 9
  1.9 DELIVERY, STORAGE, AND HANDLING ................................................................. 10

PART 2 - PRODUCTS ............................................................................................................ 10
  2.1 CONCRETE MATERIALS ............................................................................................. 10
  2.2 STEEL REINFORCEMENT ......................................................................................... 10
  2.3 ADMIXTURES ............................................................................................................. 11
  2.4 FIBER REINFORCEMENT ......................................................................................... 11
  2.5 CURING MATERIALS ................................................................................................ 11
  2.6 JOINT AND SEALANT MATERIALS ............................................................................ 11
  2.7 CONCRETE MIXTURES .............................................................................................. 12

PART 3 - EXECUTION .......................................................................................................... 13
  3.1 SUBGRADE PREPARATION ........................................................................................... 13
  3.2 SURFACE FIXTURES .................................................................................................. 13
  3.3 FORMWORK .............................................................................................................. 13
  3.4 STEEL REINFORCEMENT ......................................................................................... 14
  3.5 CONCRETE PLACEMENT ............................................................................................ 14
  3.6 CONCRETE PROTECTION AND CURING ................................................................. 18
  3.7 JOINTS ...................................................................................................................... 19
  3.8 JOINT FILLING .......................................................................................................... 20
  3.9 OPENING TO TRAFFIC .............................................................................................. 20
  3.10 TOLERANCES .......................................................................................................... 21
  3.11 FIELD QUALITY CONTROL ..................................................................................... 21
  3.12 FIELD QUALITY ACCEPTANCE .............................................................................. 23
  3.13 MEASUREMENT AND PAYMENT ............................................................................. 25

APPENDIX A – PERTINENT NRMCA CONCRETE IN PRACTICE (CIP) SERIES REFERENCES ........................................................... 26
PART 1 - GENERAL

1.0 PROJECT IDENTIFICATION

A. This specification is to be used for concrete pavement materials and construction associated with <insert project name and location>.

1.1 RELATED DOCUMENTS

A. Drawings and general provisions of the Contract, including General and Supplementary Conditions, apply to this Section.

1.2 SUMMARY

A. This Section covers the requirements for the construction of unreinforced concrete pavements, with or without subbases, and may also include attached or integral curbs.

B. Related Sections may include the following:

1. Division 03 Section “Concrete Slip Forming” for pavement construction.
2. Division 03 Section “Concrete Reinforcing” for dowel and tie bars.
3. Division 03 Section “Concrete Curing” for concrete pavement and curb curing.
4. Division 31 Section “Base Courses” for subgrade soil stabilization and subbases.
5. Division 32 Section “Curbs, Gutters, Sidewalks, and Driveways” for attached curbs, gutters, and intersecting driveways.

1.3 DEFINITIONS

A. Accepted: determined to be satisfactory to the engineer.

B. Cementitious Materials: Portland cement alone or in combination with one or more of the following: blended hydraulic cement, fly ash and other pozzolans, slag cement, and silica fume; subject to compliance with requirements.

C. Cold Weather: a period when for more than three successive days the average daily outdoor temperature drops below 40°F (5°C). The average daily temperature is the average of the highest and lowest temperature during the period from midnight to midnight. When temperatures above 50°F (10°C) occur during more than half of any 24 h duration, the period shall no longer be regarded as cold weather.

D. Construction Joint: a joint constructed from two separate placements where the first has undergone final setting before the next placement.
E. **Contraction Joint:** formed, sawed, or tooled groove in a concrete structure to create a weakened plane and regulate the location of cracking resulting from the dimensional change of different parts of the structure.

F. **Contractor:** the person, firm, or entity under contract for construction of the Work.

G. **Contract Documents:** a set of documents supplied by Owner to Contractor as the basis for construction; these documents contain contract forms, contract conditions, specifications, drawings, addenda, and contract changes.

H. **Dowel Bars:** steel pins, commonly plain round steel bars that extend into adjoining portions of a concrete construction, as at a joint in a pavement slab, to transfer shear loads.

I. **Engineer:** the engineer or engineering firm issuing Contract Documents or administering Work under the contract documents, or both.

J. **Exposure Conditions:**
   1. **Negligible:** absence of exposure to freezing and thawing or to deicing agents.
   2. **Moderate:** exposure to a climate where the concrete will not be in a saturated condition when exposed to freezing and will not be exposed to deicing agents or other aggressive chemicals.
   3. **Severe:** exposure to deicing chemicals or other aggressive agents or where the concrete can become saturated by continual contact with moisture or free water before freezing.

K. **Free Edge:** the edge of pavement abutting an isolation joint or the edge of the pavement against which no concrete is placed.

L. **High-Early-Strength Concrete:** concrete that, through the use of additional cement, high-early-strength cement, or admixtures, has accelerated early-age strength development.

M. **Hot Weather:** any combination of the following conditions that tend to impair the quality of freshly mixed or hardened concrete by accelerating the rate of moisture loss and rate of cement hydration, or otherwise resulting in detrimental results.
   1. high ambient temperature above 90°F (32°C);
   2. high concrete temperature;
   3. low relative humidity;
   4. wind velocity; and
   5. solar radiation.

N. **Isolation Joint:** a separation between adjoining parts of a concrete structure, usually a vertical plane, at a designed location such as to interfere least with performance of the structure, yet such as to allow relative movement in three directions and avoid formation of cracks elsewhere in the concrete and through which all or part of the bonded reinforcement is interrupted.

O. **Owner:** the corporation, association, partnership, individual, public body, or authority for whom the work is constructed.

P. **Panel:** an individual concrete slab bordered by joints or slab edges.
Q. Project Drawings: graphic presentation of project requirements.

R. Project Specifications: the written document that details requirements for Work in accordance with service parameters and other specific criteria.

S. Subbase (also called base): a layer in the pavement system between the subgrade and the concrete pavement.

T. Subgrade: the soil prepared and compacted to support the pavement system.

U. Tie Bar: a reinforcing bar, commonly a deformed steel bar intended to transmit tension, compression, or shear through a construction joint.

V. Tolerances: the permitted deviation from a specified dimension, location, or quantity. Plus (+) tolerance increases the amount or dimension to which it applies or raises a level alignment. Minus (-) tolerance decreases the amount or dimension to which it applies or lowers a level alignment. A non-signed tolerance means + or -. Where only one signed tolerance is specified (+ or -), there is no limit in the other direction.

W. Unreinforced Concrete Pavement: concrete pavement that does not contain distributed deformed steel reinforcing bars or welded wire fabric. Pavement may include dowel bars at the joints (construction and possibly contraction joints) and tie bars in some locations.

X. Water/Cementitious Ratio (w/cm): the ratio of the mass of water, exclusive only of that absorbed by the aggregates, to the mass of cementitious material (hydraulic) in concrete, stated as a decimal.

Y. Work: the entire construction or separately identifiable parts thereof required to be furnished under the Contract Documents.

1.4 REFERENCED STANDARDS AND MANUALS

A. All standards and manuals referenced herein shall be the latest versions or editions. Check with the reference organization for latest published version and utilize this version on the project.

1. AASHTO M182: Standard Specification for Burlap Cloth Made from Jute or Kenaf and Cotton Mats
2. ACI 301: Specifications for Structural Concrete
4. ACI 308.1: Standard Specification for Curing Concrete
5. ACI CP-1: Technical Workbook for ACI Certification of Concrete Field Testing Technician-Grade 1
7. ASTM A615/A615M: Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
8. ASTM A775/A775M: Standard Specification for Epoxy-Coated Steel Reinforcing Bars
9. ASTM WK34874: New Specification for Epoxy-Coated Steel Dowels for Concrete Pavement
10. ASTM A820/A820M: Standard Specification for Steel Fibers for Fiber-Reinforced Concrete
11. ASTM C31/C31M: Standard Practice for Making and Curing Concrete Test Specimens in the Field
12. ASTM C33: Standard Specification for Concrete Aggregates
14. ASTM C42/C42M: Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
17. ASTM C138/C138M: Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
18. ASTM C143/C143M: Standard Test Method for Slump of Hydraulic-Cement Concrete
21. ASTM C172/C172 M: Standard Practice for Sampling Freshly Mixed Concrete
22. ASTM C173/C173M Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
23. ASTM C231/C231M: Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
25. ASTM C309: Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete
27. ASTM C566: Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying
29. ASTM C618: Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
30. ASTM C989: Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars
31. ASTM C1017/C1017M: Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete
32. ASTM C1064/C1064M: Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete
33. ASTM C1074: Standard Practice for Estimating Concrete Strength by the Maturity Method
34. ASTM C1077: Standard Practice for Agencies Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Testing Agency Evaluation
35. ASTM C1116/C1116M: Standard Specification for Fiber-Reinforced Concrete
37. ASTM C1240: Standard Specification for Silica Fume Used in Cementitious Mixtures
41. ASTM C1602/C1602M: Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete
42. ASTM D698: Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3))
43. ASTM D994/D994M: Standard Specification for Preformed Expansion Joint Filler for Concrete (Bituminous Type)
44. ASTM D1751: Standard Specification for Preformed Expansion Joint Filler for Concrete Paving and Structural Construction (Nonextruding and Resilient Bituminous Types)
45. ASTM D1752: Standard Specification for Preformed Sponge Rubber Cork and Recycled PVC Expansion Joint Fillers for Concrete Paving and Structural Construction
46. ASTM D2628: Standard Specification for Preformed Polychloroprene Elastomeric Joint Seals for Concrete Pavements
47. ASTM D3406: Standard Specification for Joint Sealant, Hot-Applied, Elastomeric-Type, for Portland Cement Concrete Pavements
50. ASTM E329: Standard Specification for Agencies Engaged in Construction Inspection, Testing, or Special Inspection
51. ASTM E548: Standard Guide for Proficiency Testing by Interlaboratory Comparisons
52. ASTM E950/E950M: Standard Test Method for Measuring the Longitudinal Profile of Traveled Surfaces with an Accelerometer Established Inertial Profiling Reference
53. ASTM E1980: Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces
55. NRMCA QC 3 – Checklist for Certification of Ready Mixed Concrete Production Facilities, NRMCA, www.nrmca.org

1.5 SUBMITTALS

A. LEED Submittals:

1. **Design Mixtures for Innovation and Design Process Credit 1.1:**
   a. For each concrete mixture containing fly ash or slag cement as a replacement for portland cement or other portland cement replacements and for equivalent concrete mixtures that do not contain portland cement replacements.
   b. For each concrete plant delivering concrete for the work, indicate the level of NRMCA Sustainable Concrete Plant Certification (Bronze, Silver, Gold or Platinum).

2. **Product Data for Materials and Resources Credit 4.1 [or Credit MR 4.2]:** For products having recycled content, documentation indicating percentages by weight of postconsumer and preconsumer recycled content.
   a. Include statement indicating costs (selling price of concrete) for each product having recycled content.

3. **Product Data for Materials and Resources Credit 5.1 [or Credit 5.2]:** For products using regional materials, documentation indicating percentages by weight that are extracted, processed, and manufactured within 500 miles (805 km) of the project site.
4. **Heat Island Effect: Non-Roof for Sustainable Site Credit 7.1**: For products (cement and aggregate combined), evidentiary documentation that the Solar Reflectance Index (SRI) is at least 29 calculated using ASTM E1980. For standard grey concrete or concrete using white cement, no testing is required because they are deemed to comply with SRI 29 or greater in LEED.

B. **Design Mixtures**: For each concrete mixture proposed for the Work. Submit changes to design mixtures when characteristics of materials, project conditions, weather, test results, or other circumstances warrant adjustments. Only submit adjustments that involve changes in material sources or when the quantity of cementitious materials and aggregates vary by more than ±5% of that in the design mixtures or admixture quantities exceed the manufacturers recommended range

1. Indicate on delivery tickets of delivered batches of concrete amounts of mixing water withheld for addition at Project site.

C. **Dowel and Tie Bar Steel Reinforcement Drawings**: Drawings that detail placement. Include bar sizes, lengths, material, grade, and supports for concrete reinforcement.

D. **Qualification Data**: For each plant supplying, vehicle transporting, installer, laboratory, and technician involved in testing concrete for paving, submit documentation that the appropriate certifications have been obtained and are currently valid.

E. **Material Certificates**: For each of the following, signed by manufacturers:

1. Cementitious materials.
2. Admixtures.
3. Steel reinforcement and accessories.
4. Fiber reinforcement.
5. Curing compounds.

F. **Quality control plan as described in Section 1.6 and field quality-acceptance inspection and testing reports as described in Section 3.12.**

1.6 **QUALITY CONTROL PLAN**

A. **Quality Control Plan**: Prepare a plan addressing the elements that affect the quality of the pavement. Submit this plan at least **[14] or [insert number of days]** days prior to commencement of concrete paving. The Quality Control plan should also address the conduct of acceptance testing. The plan should address at a minimum the following:

1. Introduction with Project Description and Key Contact Information
2. Organizational Chart Delineating the Flow of Responsibility
3. Duties and Responsibilities of Project Personnel
4. Pre-Paving Meeting Agenda
5. Inspections and Submittals

---

1 See NRMCA Concrete In Practice (CIP) Series 32 – Concrete Pre-Construction Conference for Recommended Pre-Paving Agenda Items (http://www.nrmca.org/aboutconcrete/cips/default.asp)
6. Process Control Testing Plan and Submittals
7. Contractor Acceptance Testing Plan and Submittals
8. Deficiencies Reporting
9. Conflict Resolution
10. Defective Pavement Repair
11. Changes To The QC Plan During Work
12. Supporting Information as Needed

1.7 QUALITY ASSURANCE

A. Installer Qualifications: A qualified installer who employs on project personnel qualified as ACI-certified Concrete Flatwork Technician and a supervisor who is an ACI-certified Concrete Flatwork Finisher.

B. Manufacturer Qualifications: A firm experienced in manufacturing ready-mixed concrete products and that complies with ASTM C94/C94M requirements for production facilities and equipment.

1. Manufacturer’s production facilities and delivery vehicles certified according to NRMCA’s “Certification of Ready Mixed Concrete Production Facilities” <optional: and “Sustainable Concrete Plant Certification Bronze level or higher.”>

2. Personnel responsible for quality control/quality assurance of concrete, certified as NRMCA Concrete Technologist Level 2 or equivalent certification required by state highway agency in the jurisdiction of the Work.

C. Testing Agency Qualifications: An independent agency, complying with the requirements of ASTM C1077 and ASTM E329 for quality assurance testing indicated, as documented according to ASTM E548, or similar and acceptable to the Engineer.

1. Personnel conducting field tests shall be qualified as ACI Concrete Field Testing Technician, Grade 1, according to ACI CP-1 or an equivalent certification program. Equivalent certification programs shall include a component that evaluates performance of the test methods.

2. Personnel performing laboratory tests shall be ACI-certified Concrete Strength Testing Technician or Concrete Laboratory Testing Technician - Level I. Testing Agency laboratory supervisor shall be an ACI-certified Concrete Laboratory Testing Technician - Level II.

D. Source Limitations: Use the same source of cementitious materials, aggregates, chemical admixtures and other ingredients for concrete mixtures for the duration of the project, unless otherwise permitted.

E. Concrete Mixture Design: A qualified laboratory shall perform material evaluation tests and design concrete mixtures. The qualified laboratory can be the concrete supplier’s laboratory facility or an independent testing agency either of which shall be accredited for testing concrete mixtures and aggregates by the AASHTO Accreditation Program (AAP) or similar as accepted by the Engineer.
1.8 EQUIPMENT

A. Paving Equipment: Furnish the paving and finishing equipment applicable to the type of construction in this Work, as follows:

1. Slipform Machines: If slipforming, furnish machines capable of spreading, consolidating, screeding, and finishing the freshly placed concrete in one pass to provide a dense and homogeneous pavement requiring minimal hand finishing. Equip the paving machine with the following:

   a. Automatic controls to control line and grade from either or both sides of the machine, or from averaging-skis that reference the grade.
   b. Vibrators to consolidate the concrete for the full width and depth of the strip of pavement being placed.
   c. A positive interlock system to stop all vibration and tamping elements when forward motion of the machine stops.

2. Self-Propelled Form-Riding Machines: Where used, furnish mechanical, self-propelled spreading and finishing machines capable of consolidating and finishing the concrete with minimal hand finishing. Do not use machines that displace the fixed side forms. Furnish internal immersed tube or multiple spud vibrators. Attach vibrators to the spreader or finishing machine, or attach them on a separate carriage that precedes the finishing machine.

3. Manual Fixed-Form Paving Machines: Where needed, furnish spreading and finishing machines capable of consolidating and finishing concrete up to 8 in. (200 mm) thick.

B. Vibrators: Operate the vibrators at frequencies within 5,000 - 8,000 vibrations/minute. Furnish a surface pan vibrator as an alternate to immersed tube or multiple spud vibrators for consolidation of 8 in. (200 mm) or thinner concrete slabs. Operate the surface pan vibrator at a frequency no less than 3,500 vibrations/minute. For construction of irregular areas, use handheld vibrators. Operate the vibrator at a frequency in the range recommended by the manufacturer for the vibrator's head diameter.

C. Concrete Saws: Furnish concrete saws that are capable of sawing new concrete for crack control on all concrete pavements included in the Work. Equip all saws with blade guards and guides or devices to control alignment and depth.

D. Forms: When used, furnish straight, steel forms with a height equal to the nominal pavement thickness at the edge. For curved edges with radii less than 100 ft. (30 m), furnish flexible or curved forms. Conform to the following:

   1. Use straight forms that are 10 ft. (3 m) minimum in length.
   2. Use forms with a maximum top face deviation of 1/8 in. in 10 ft. (3 mm in 3 m).
   3. Use forms with a maximum inside face deviation of 1/4 in. in 10 ft. (6 mm in 3 m).
   4. Equip each form with devices to adequately secure the form to the subbase or subgrade, and to withstand operation of the paving equipment and pressure of the concrete.
   5. Equip each form with devices to tightly join and lock each end to abutting form sections.
E. Joint Sealing: Furnish joint sealing equipment, if required, according to the sealant manufacturer’s recommendations for the sealant specified in the Plans.

F. Finishing Tools: Furnish aluminum, magnesium or wooden hand finishing tools.

1.9 DELIVERY, STORAGE, AND HANDLING

A. Dowel and Tie Bar Steel Reinforcement: Deliver, store, and handle steel reinforcement to prevent bending and damage. Avoid damaging coatings, if used, on steel reinforcement.

PART 2 - PRODUCTS

2.1 CONCRETE MATERIALS

A. Comply with ASTM C94/C94M and the following requirements.

1. Cement: Conforms to ASTM C150, C595 or C1157.

2. Supplementary Cementitious Materials (SCMs):
   a. Fly ash conforming to ASTM C618.
   b. Slag cement conforming to ASTM C989.
   c. Silica fume conforming to ASTM C1240.

3. Water: Conforms to ASTM C1602/C1602M. Provide documentation required by ASTM C1602/C1602M when non-potable water is proposed for use.


2.2 STEEL REINFORCEMENT

A. Dowel and Tie Reinforcing Bars: When used, dowel and tie bars shall comply with the sizes and grades as shown on the plans. If dowel and tie bar material requirements are not shown on plans, comply with ASTM A615, Grade 60 (Grade 420) and:

1. Dowel bars shall be plain bars cut true to length with ends square and free of burrs.
2. Epoxy-Coated Joint Dowel Bars shall comply with ASTM A775/A775M2 epoxy coated.
3. Plate Dowels shall be manufactured from hot rolled steel plate meeting ASTM A36.
4. Tie bars shall be deformed bars.

B. Bar Supports: Dowel bar chairs or other devices for spacing, supporting, and fastening reinforcing bars in place. Manufacture bar supports from steel wire, plastic, or precast concrete according to CRSI’s “Manual of Standard Practice,” of greater compressive strength than concrete.

---

2 ASTM Committee A01.05 is currently developing a revised specification for epoxy coated dowel bars entitled ASTM WK34874: New Specification for Epoxy-Coated Steel Dowels for Concrete Pavement to supplement or replace ASTM A775. Until such time as the new ASTM specification is complete ASTM A775 is acceptable.
2.3 ADMIXTURES

A. Air-Entraining Admixture: Conform with ASTM C260/C260M.

B. Chemical Admixtures: The following admixtures are permitted. Do not use calcium chloride or admixtures containing calcium chloride.

1. Water-Reducing Admixture: ASTM C494/C494M, Type A.
2. Retarding Admixture: ASTM C494/C494M, Type B.
3. Water-Reducing and Retarding Admixture: ASTM C494/C494M, Type D.
4. High-Range, Water-Reducing Admixture: ASTM C494/C494M, Type F.
5. High-Range, Water-Reducing and Retarding Admixture: ASTM C494/C494M, Type G.
6. Special Performance Admixture: ASTM C494/C494M, Type S.
7. Plasticizing Admixture for flowing concrete: ASTM C1017/C1017M, Type I.
8. Plasticizing and Retarding Admixture for flowing concrete: ASTM C1017/C1017M, Type II.

2.4 FIBER REINFORCEMENT

A. Carbon-Steel Fiber: Comply with ASTM A820, deformed, with a minimum of <Insert dimension> long, and an aspect ratio of <Insert ratio>.

B. Synthetic Fiber: Utilize [Monofilament] or [fibrillated] polypropylene fibers engineered and designed for use in concrete pavement, complying with ASTM C1116/C1116M, Type III, <Insert dimensions> long.

2.5 CURING MATERIALS

A. Liquid Membrane-Forming Compounds: Utilize a Membrane-Forming Curing Compound complying with ASTM C309, Type 2, Class A consisting of a waterborne, monomolecular film forming, manufactured for application to fresh concrete.

B. Absorptive Cover: If used, comply with AASHTO M182, Class 2, burlap cloth made from jute or kenaf, weighing approximately 9 oz/yd² (305 g/m²) when dry.

C. Moisture-Retaining Cover: If used, comply with ASTM C171, polyethylene film or white burlap-polyethylene sheet.

2.6 JOINT AND SEALANT MATERIALS

A. Isolation Joint Materials: When used, comply with ASTM D994/D994M, D1751, or D1752, or as shown on plans.

B. Joint Sealing Materials: When used, comply with the following:

1. Hot-Poured Elastomeric Type; ASTM D3406
2. Silicone Rubber Type (cold applied); ASTM D5893/D5893M
3. Single-Component Elastomeric Type (preformed); ASTM D2628
CONCRETE MIXTURES

A. Mixture Design: Prepare design mixtures for each type and strength of concrete required, proportioned on the basis of field test records or laboratory trial mixtures according to ACI 301. Use a qualified laboratory in accordance with Section 1.7.E for preparing and reporting proposed mixture designs when proposed mixtures are based on laboratory trial mixtures.

1. Supplementary Cementitious Materials (SCMs): For concrete that will be in a Severe Exposure Condition, limit percentage of supplementary cementitious materials, by weight of total cementitious materials, to a maximum quantity as follows:

   b. Slag Cement: 50 percent.
   c. Silica Fume: 10 percent.

2. Strength: Specified compressive strength shall be 4,000 psi (28 MPa) at 28 days, unless otherwise specified.

3. Total Air Content: Comply with Table 1, unless otherwise specified. The tolerance for air content shall be ±1.5%.

4. Aggregates: Nominal maximum aggregate size shall not exceed 1/3 of the specified pavement thickness.

   a. When required by the Engineer, provide results of aggregate tests for alkali silica reactivity in accordance with ASTM C1260.
   b. When ASTM C1260 expansion at 14 days measured on each source of aggregate exceeds 0.10%, provide test results with the aggregate and proposed combination of cementitious materials with an expansion that is less than or equal to 0.10% at 14 days, in accordance with ASTM C1567.

5. Slump: For pavements placed other than by using slipform equipment, nominal slump shall be 4 in. (100 mm), unless otherwise permitted. For pavements placed using slipform equipment the maximum slump shall be 2 in. (50 mm), unless otherwise permitted. Tolerance for slump stated in ASTM C94/C94M shall apply.

B. Submit documentation for mixture proportions of concrete mixtures proposed for use in accordance with ACI 301 and Section 1.5.B herein.

Table 1. Required Total Air Content1.

<table>
<thead>
<tr>
<th>Nominal Maximum Aggregate Size, in. (mm)</th>
<th>Total Air Content, %2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Negligible Exposure</td>
</tr>
<tr>
<td>3/8 (9.5)</td>
<td>6.0</td>
</tr>
<tr>
<td>1/2 (12.5)</td>
<td>5.5</td>
</tr>
<tr>
<td>3/4 (19.0)</td>
<td>5.0</td>
</tr>
<tr>
<td>1 (25.0)</td>
<td>4.5</td>
</tr>
<tr>
<td>1-1/2 (37.5)</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Note 1: Measured in accordance with ASTM C173 or C231.
Note 2: Air content tolerance ±1.5%.
Note 3: Non-air entrained concrete, unless the concrete supplier chooses to entrain air in concrete mixtures.
PART 3 - EXECUTION

3.1 SUBGRADE PREPARATION

A. Prepare subgrade as required by the plans. If not specified on the plans or related specification, compact to a minimum depth of 6 in. of subgrade to a minimum of 95% of the maximum dry density as determined by ASTM D698 and within ± 2% of the optimum moisture content and compact entire depth of subbase, if used, to a minimum of 98% of the maximum dry density as determined by ASTM D698 and within ± 2% of the optimum moisture content.

B. Construct subgrade/subbase to ensure that the required pavement thickness is obtained in all locations.

C. Re-grade and re-compact subgrade/subbase disturbed by concrete delivery vehicles or other construction equipment to the requirements of Section 3.1.A.

D. Do not use sand or loose material to obtain final subgrade or subbase elevation.

E. At the time of concrete paving the subgrade or subbase, if used, density and moisture shall be in the condition described in section 3.1.A.

3.2 SURFACE FIXTURES

A. Adjust manhole frames and other fixtures within area to be paved to conform to finished surface. Comply with plans for manhole adjustments and water fixture adjustments.

B. Clean outside of fixture to depth of pavement before concrete placement.

C. Construct boxouts if necessary for later adjustment of fixtures. Comply with plans for the size and shape of the boxout.

3.3 FORMWORK

A. Construct formwork so concrete pavement is of size, shape, alignment, elevation, and position indicated and so that the pavement is within the tolerance limits of Section 3.10 Tolerances.

B. Construct forms tight enough to prevent loss of concrete mortar.

C. Fabricate forms for easy removal without hammering or prying against concrete surfaces.

D. Clean forms and adjacent surfaces to receive concrete. Remove debris from forms just before placing concrete.

E. Retighten forms and bracing before placing concrete, as required, to prevent mortar leaks and maintain proper alignment.

F. Coat contact surfaces of forms with form-release agent, according to manufacturer's written instructions, before placing reinforcement, if used.
G. The edge of previously placed concrete may be used as a form. Do not apply form release agent to previously placed concrete, unless prevention of bond between the new and the old concrete is desired.

H. Formwork may be removed after cumulatively curing at not less than 50°F (10°C) for 24 hours after placing concrete, if concrete is hard enough to not be damaged by form-removal operations and curing and protection operations are maintained.

I. Clean and repair surfaces of forms to be reused in the Work. Damaged forms will not be acceptable. Apply new form-release agent.

J. When forms are reused, clean surfaces, remove fins and laitance, and tighten to close joints. Align and secure joints to avoid offsets.

3.4 STEEL REINFORCEMENT

A. Comply with CRSI’s “Manual of Standard Practice” for placing reinforcement.

B. Clean dowel and tie bar reinforcement of loose rust and mill scale, earth, ice, and other foreign materials.

C. Place joint reinforcement at locations indicated on project drawings. Align dowels exactly centered over the joint line.

D. Anchor dowel baskets securely into the subgrade. For paving lane widths greater than 12 ft (3.66 m), install a minimum of 4 stakes on the leave side of both basket legs.

E. Do not place bent dowel baskets. Do not leave bent dowel baskets in place.

F. At time of paving, make sure all dowels are parallel to the center line of the roadway, parallel to the base, baskets are properly pinned, and the center of each basket (i.e., the joint location) is clearly marked.

G. Place and align to meet the requirements of Section 3.10, Tolerances.

H. For epoxy-coated dowel bar reinforcement, if used, repair cut and damaged epoxy coatings with epoxy repair coating according to ASTM D3963/D3963M.

3.5 CONCRETE PLACEMENT

A. Measure, batch, mix, and deliver concrete according to ASTM C94/C94M, and ASTM C1116/C1116M when fibers are used, and furnish batch ticket information required by these specifications.

B. Before placing concrete, verify that installation of formwork, reinforcement, and embedded items is complete and that required inspections have been performed.

C. When placing and finishing fixed-form concrete pavement, comply with the following steps:

1. Deposit concrete directly from the transporting equipment onto the subgrade or subbase.
2. Do not place concrete on frozen subgrade or subbase.
3. Other methods of conveying the concrete may be used when specified or permitted by the Engineer.
4. Deposit concrete between the forms to a uniform height.
5. Consolidate concrete to remove voids and air pockets. Do not move concrete horizontally with a vibrator.
6. Strike off concrete between forms using a form riding paving machine, vibrating screed, or laser screed. Other strikeoff devices may be used, such as a highway straightedge or scraping straightedge, when approved by the Engineer.
7. Immediately after strikeoff and before bleed water appears on the surface, level concrete with a bullfloat.
8. Do not use steel trowels or power finishing equipment, unless otherwise specified or permitted.
9. Finish the pavement to the elevations, cross slope, and thickness specified in the project drawings and meet the requirements of Section 3.10, Tolerances.

D. When placing and finishing slipform concrete pavement, comply with the following steps:

1. Deposit and finish concrete in conformance with Section 3.5.C.
2. The slipform paver shall be operated with adherence to continuous forward movement as possible, and as such, all delivery and spreading of concrete shall be coordinated so as to provide uniform progress without stopping and starting the machine. Coordination with the concrete supplier is especially important to achieve the desired result.
3. Adjust the vibrator frequency for varying paver speeds and turn off vibrators when the paver stops.
4. When the slipform paver is to ride on the edge of a new concrete pavement, the concrete strengths of the riding surface shall be greater than 2,000 psi (14 MPa), determined by testing field cured specimens in accordance with ASTM C31 or maturity methods.
5. String lines or other means for setting grade should be checked frequently.

E. Edging:

1. Edge top surface edges to a radius of 1/8 in. (3 mm).
2. Do not tool edges if the joint is to be widened to provide a reservoir for joint sealant.

F. Final Surface Texture:\^ Complete final texturing as soon as possible after finishing, but before the concrete has attained its initial set.

1. Artificial Turf Drag:
   a. Drag artificial turf longitudinally along the concrete pavement surface after finishing. The turf shall be mounted on a work bridge or a moveable support system capable of varying the area of turf in contact with the pavement.
   b. The turf drag shall be a single piece of artificial turf of sufficient length to span the full width of the pavement being placed. The turf shall have a means to adjust the height and/or length so as to always maintain a minimum of 4 ft (1.2 m) longitudinal length of turf in contact with the concrete being placed. Where construction operations necessitate and with the approval of the Engineer, the length and width of the turf may be varied to accommodate specific applications.

\^ See hidden text for important note regarding projects where pavement/tire noise reduction is important.
c. The turf used shall be an artificial grass type having a molded polyethylene pile face. The pile shall contain blades that are curled and/or fibrillated. The pile shall not contain straight, smooth monofilament blades. The pile shall include blade lengths of 0.6 to 1.3 in. (15 to 33 mm). The turf shall have a minimum weight of 60 oz/yd² (2,035 g/m²). The backing shall be a strong, durable material not subject to rot, and shall be adequately bonded to withstand use as specified.

d. Turf dragging operations should be delayed if there is excessive bleed water.

e. Prevent the turf from getting plugged with grout or dragging larger aggregates or foreign materials by cleaning or replacing as necessary.

f. Measures should be taken to ensure a surface of uniform appearance that is free from deep striations.

g. Turf should be thoroughly cleaned or replaced at the end of each day's use. Damaged or worn turf should be repaired and/or replaced.

h. When surface corrections for pavement smoothness are made in the hardened concrete, no additional texturing is required.

2. Broom Finish:

a. Broom concrete surface with a steel or fiber broom to produce corrugations between 1/16 and 1/8 in. (2 and 3 mm) deep.

b. Broom perpendicular to nearest edge of pavement. Broom all areas of a panel in the same direction.

c. Use the same type and manufacture of broom for all paved surfaces to provide a consistent appearance.

3. Longitudinal Tining:

a. Drag Pretxture: Pretecture the surface of the newly placed pavement in accordance with Section 3.F.1.

b. Tining:

1) Place longitudinally tined grooves in the surface of the pavement while the concrete is plastic. The tining shall be done with a mechanical device such as a wire comb. The comb shall have a single row of tines that each has a nominal width of 5/64 to 1/8 in. (2 to 3 mm). The nominal spacing of the tines shall be 3/4 ± 1/8 in. (19 ± 3 mm) center-to-center. The nominal depth of tined groove in the plastic concrete shall be 1/8 ± 1/32 in. (3 ± 0.8 mm).

2) Longitudinal tining shall be accomplished by equipment with automated horizontal and vertical controls to ensure straight, uniform depth tined grooves. The texture geometry shall be the same as imparted throughout the length of the tining comb.

3) A 2 to 3 in. (51 to 76 mm) wide strip of pavement surface shall be protected from tining for the length of and centered about longitudinal joints.

4) The tining operation shall be done at such time and manner that the desired surface texture will be achieved while minimizing displacement of the larger aggregate particles and before the surface permanently sets.

5) Where abutting pavement is to be placed, the tining shall extend as close to the edge as possible without damaging the edge. If abutting pavement is not to be placed, the 6 in. (152 mm) area nearest the edge or 1 ft (305 mm) from the face of the curb shall not be tined.
6) Hand-operated tining equipment that produces an equivalent texture may be used only on small or irregularly shaped areas. Tines should be thoroughly cleaned at the end of each day’s use, and damaged or worn tines replaced.

7) When surface corrections for pavement smoothness are made in the hardened concrete, no additional texturing is required.

4. **Transverse Tining:**

   a. **Drag Pretexture:** Pretexthe the surface of the newly placed pavement in accordance with Section 3.F.1.

   b. **Tining:**

   1) Place transversely tined grooves in the surface of a pavement while the concrete is plastic. The tining shall be done with a mechanical device such as a wire comb. The comb shall have a single row of tines that each has a nominal width of 5/64 to 1/8 in. (2 to 3 mm). The nominal spacing of the tines shall be 3/4 ± 1/8 in. (19 ± 3 mm) center-to-center. The nominal depth of tined groove in the plastic concrete shall be 1/8 ± 1/32 in. (3 ± 0.8 mm).

   2) Transverse tining shall be accomplished by equipment with automated horizontal and vertical controls to ensure straight, uniform depth tined grooves. The texture geometry shall be uniformly imparted throughout the length of the tining comb and between successive passes of the tining comb. Successive passes of the tining comb shall be overlapped the minimum necessary to attain a continuously textured surface.

   3) The tining operation shall be done at such time and manner that the desired surface texture will be achieved while minimizing displacement of the larger aggregate particles and before the surface permanently sets.

   4) Where abutting pavement is to be placed, the tining shall extend as close to the edge as possible without damaging the edge. If abutting pavement is not to be placed, the 6 in. (152 mm) area nearest the edge or 1 ft (305 mm) from the face of the curb shall not be tined.

   5) Hand-operated tining equipment that produces an equivalent texture may be used only on small or irregularly shaped areas.

   6) Tines should be thoroughly cleaned at the end of each day’s use, and damaged or worn tines replaced.

   7) When surface corrections for pavement smoothness are made in the hardened concrete, no additional texturing is required.

G. **Cold-Weather Placement:** Comply with ACI 306.1 and as follows. Protect concrete work from physical damage or reduced strength that could be caused by frost, initial freezing, freezing and thawing cycles, or low temperatures.

   1. Concrete temperature as delivered and temperature of placed concrete shall be maintained within the temperature range required by ACI 301.

   2. Do not use frozen materials or materials containing ice or snow. Do not place concrete on frozen subgrade or on subgrade containing frozen materials.

   3. Do not use calcium chloride, salt, or other materials containing antifreeze agents or chemical accelerators, unless otherwise specified or permitted.

H. **Hot-Weather Placement:** Comply with ACI 301 and as follows:
1. Maintain concrete temperature below 95°F (35°C) at time of placement. Chilled mixing water or ice may be used to control temperature. Quantity of ice used shall be included in the total amount of mixing water. Using liquid nitrogen to cool concrete is Contractor’s option.

2. Fog-spray forms, steel reinforcement, and subgrade just before placing concrete. Keep subgrade uniformly moist without standing water, soft spots, or dry areas.

3.6 CONCRETE PROTECTION AND CURING

A. Protect the concrete from damage due to rain. Have available, near the site of the work, materials for protection of the edges and surface of the concrete. Should any damage result, the Engineer will suspend operations until corrective action is taken and may require removal and replacement of the rain-damaged concrete.

B. Protect freshly placed concrete from premature drying and excessive cold or hot temperatures. Comply with ACI 306.1 for cold-weather protection and ACI 301 for hot-weather protection during curing.

C. Apply curing compound immediately after final surface texture has been obtained and water sheen has disappeared.

D. Apply membrane-forming curing compound to all exposed surfaces at a maximum coverage rate of 180 ft²/gal. (5 m²/L).

E. When using liquid membrane-forming compounds, if the evaporation rate during paving operations does not exceed 0.1 lb/ft²/hr (0.49 kg/m²/hr), then only 1 coat of membrane curing compound at an individual application rate not to exceed 180 ft²/gal. (5 m²/L) is permissible. Do not allow the concrete surface to dry before applying the curing compound. Remove any standing pools of bleed water that may be present on the surface before applying the curing compound. Apply the first coat within 10 min. after completing texturing operations. If applicable, apply the second coat within 30 min. after completing texturing operations.

F. Maintain and promptly repair damage to curing materials on exposed surfaces of concrete pavement continuously for at least 3 curing days, or until the pavement is open to the traveling public, whichever occurs first. A curing day is defined as a 24-hr. period when either the temperature taken in the shade away from artificial heat is above 50°F (10°C) for at least 19 hr. or when the surface temperature of the concrete is maintained above 40°F (5°C) for 24 hr. Curing begins when the concrete curing system has been applied. Stop concrete paving if curing compound is not being applied promptly and maintained adequately.

G. Apply curing compound to pavement edges after forms, if used, have been removed.

H. Alternative curing methods may be used in accordance with this specification or with ACI 308.1 when acceptable to the Engineer.

---

4 Unless an alternate technique is approved by the Engineer, evaporation rate shall be evaluated using the Menzel nomograph or its underlying equations. For more information, refer to the Guide to Curing Concrete, ACI 308R-01, ACI International, http://www.concrete.org.
3.7 JOINTS

A. Construct joints at the locations, depths, and with dimensions indicated on the project drawings or accepted drawings submitted by the contractor.

B. If jointing requirements are not indicated on the project drawings, the contractor shall submit drawings describing proposed jointing in accordance with the requirements of 3.7.B.1 through 3.7.B.9. The contractor shall not proceed with work until the jointing requirements are accepted by the Engineer.

1. Indicate locations of contraction joints, construction joints, and isolation joints. Spacing between contraction joints shall conform to Table 2, unless otherwise permitted.
2. The larger dimension of a panel shall not exceed 125% of the smaller dimension.
3. The minimum angle between two intersecting joints shall be 80 degrees, unless otherwise specified or permitted.
4. Joints shall intersect pavement free edges at 90-degree angles and shall extend straight for a minimum of 1-1/2 ft (0.5 m) from the pavement edge, where possible.
5. Align joints of adjacent panels.
6. Align joints in integral curbs with joints in pavement.
7. Ensure joint depth and width dimensions are as specified.
8. Minimum contraction joint depth, using a conventional saw, hand tools, or inserts, shall be 1/4 of the pavement thickness. Minimum joint width for saw cutting is 1/8 in. (3 mm). When using an early-entry dry-cut saw, the depth of the cut shall be at least 1 in. (25 mm).
9. Use isolation joints only where pavement abuts buildings, foundations, existing pavements, manholes, and other fixed objects.

C. Construct contraction joints by one of the following methods:

1. Tool contraction joints in fresh concrete after the concrete has set sufficiently to maintain the formed joint to the specified depth and width.
2. Insert plastic strips vertically into the fresh concrete. Depress strips into pavement until flush with surface.
3. Saw-cut concrete after concrete has hardened sufficiently to prevent aggregate being dislodged and soon enough to control pavement cracking. Discontinue sawing joint if a crack precedes the saw-cut. Resume sawing at the next joint location.

D. Extend isolation joints through the full depth of the pavement. Fill the entire isolation joint with isolation joint material, unless otherwise required by project drawings or by accepted jointing drawings submitted by the contractor (see Section 2.6 for material requirements).

Table 2. Spacing Between Contraction Joints.

<table>
<thead>
<tr>
<th>Pavement Thickness, in. (mm)</th>
<th>Maximum Spacing, ft. (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-1/2 (90)</td>
<td>8-1/2 (2.5)</td>
</tr>
<tr>
<td>4, 4-1/2 (100, 110)</td>
<td>10 (3)</td>
</tr>
<tr>
<td>5, 5-1/2 (125, 140)</td>
<td>12-1/2 (4)</td>
</tr>
<tr>
<td>6 or greater (150 or greater)</td>
<td>15 (4.5)</td>
</tr>
</tbody>
</table>
3.8 JOINT FILLING

A. Prepare, clean, and install joint filler according to manufacturer's written instructions.

B. Unless otherwise allowed by the Engineer, before any portion of the pavement is opened to the Contractor's equipment or to general traffic, clean and seal joints that require sealing. Remove dirt, debris, saw cuttings, curing compounds, and sealers from joints; leave contact faces of joint clean and dry.

C. Hot-Poured Liquid Sealants:

1. Place joint sealer when the pavement and surrounding air temperature are 40°F (5°C) or higher.
2. Where specified, backer rods shall be installed to provide proper shape factor.
3. Use an indirect heating kettle with an agitator to prevent localized overheating. Discard overheated material.
4. Use insulated hoses. Fit the application wand with a recirculation line to prevent the temperature of the sealant in the hose from dropping below application temperature.
5. Make sure that the top of the sealant is 1/8 to 1/4 in. (3 to 6 mm) below the pavement surface.
6. Clean any spilled or overfilled joint sealant from the concrete surface.

D. Cold-Poured Silicone Sealants:

1. Place joint sealer when the pavement and surrounding air temperature are 40°F (5°C) or higher.
2. Where specified, backer rods shall be installed to provide proper shape factor.
3. Use joint primer provided by the manufacturer to ensure a good bond between the sealant and the joint reservoir face.
4. Tool non-self-leveling sealants before the material cures.
5. Clean any spilled or overfilled joint sealant from the concrete surface.

E. Preformed Compression Sealers:

1. Check joint width for compatibility.
2. Make sure the joint width doesn’t vary, especially at points where the saw reenters the joint.
3. Clean and dry the saw cut reservoir before sealing the joint. Seal joints only when the joint surfaces appear dry.
4. Follow the manufacturer’s recommendation for sealant sizing and installation.
5. Make sure the sealant is lubricated, straight, vertical, and undamaged before installation.
6. Make sure that the installation device does not stretch the sealant.

3.9 OPENING TO TRAFFIC

A. Do not open the pavement to vehicular traffic until the in-place compressive strength is at least 3,000 psi (21 MPa), or 75% of the specified strength, or until the pavement is accepted by the Engineer for opening to traffic. In-place strength shall be determined using field cured cylinders in accordance with ASTM C31/C31M or maturity methods in accordance with ASTM C1074.
3.10 TOLERANCES

A. Construct pavement to comply with the following tolerances:

1. Elevation: 3/4 in. (19 mm)
2. Thickness: +3/8 in., -1/4 in. (+10 mm, -6 mm)

B. Joint reinforcement:

1. Tie bars: alignment of tie bar end relative to line perpendicular to edge of pavement: 1/2 in./ft (13 mm/305 mm) of tie bars

C. Dowels:

1. Lateral alignment and spacing: 1 in. (25 mm)
2. Vertical alignment: 1/4 in. (6 mm)
3. Alignment of dowel bar end relative to line perpendicular to edge of pavement: 1/4 in./ft (6 mm/305 mm) of dowel

D. Joint Spacing (see Table 2)

1. Contraction joint depth: +1/4 in. (6 mm), -0 in.
2. Joint width: +1/8 in. (3 mm), -0 in.

3.11 FIELD QUALITY CONTROL

A. Contractor shall perform quality control testing and prepare statistical process control charts (control charts) according to the Quality Control Plan described in Section 1.6 and the following requirements:

1. Aggregates:

   a. Grading: ASTM C136; On the combined grading for each concrete mixture at a minimum of every \[1,000 \text{ yd}^3 (765 \text{ m}^3)\] or [insert volume], but not less than one test for each day’s pour of each concrete mixture determine:

      1) Coarseness and Workability Factors,
      2) 0.45 Power Curve, and
      3) Percent Retained on Individual Sieves.

   b. Aggregate Moisture: ASTM C566; On the individual stockpiles utilized for each concrete mixture utilized at a minimum of every \[500 \text{ yd}^3 (382 \text{ m}^3)\] or [insert volume], but not less than one test for each day’s pour of each concrete mixture determine aggregate moisture content.

---

5 Background information related to QC testing and statistical process control charts may be found in the CPTech Center Report entitled Testing Guide for Implementing Concrete Paving Quality Control Procedures dated March 2008 at http://www.cptechcenter.org/publications/mco/testing_guide.pdf
Concrete Mixtures: test one composite sample at a minimum of every \([500 \text{ yd}^3 (382 \text{ m}^3)]\) or [insert volume], but not less than one test for each day’s pour of each concrete mixture.

a. Slump and Loss of Workability: ASTM C143/C143M
b. Air Content: ASTM C231/C231M (normal weight concrete)
c. Density: ASTM C138/C138M

<Optional: if maturity methods are used for early opening to traffic> Strength-Maturity Relationship (see Section 3.9 Opening to Traffic): ASTM C1074

B. Statistical Process Control Charts:

1. Prepare control charts for the following test results obtained from Section 3.11.A.
   a. Coarseness Factor
   b. Workability Factor
   c. Combined % Retained on Individual Sieves
   d. Aggregate Moisture
   e. Slump
   f. Air Content
   g. Density

2. Control charts shall be developed using the following components:
   a. The average of test results plotted as the centerline.
   b. Test data plotted continuously over time with each result representing a single test point.
   c. Upper and lower limits, plotted at 3 times the standard deviation (3s) of the test data.

3. The initial standard deviation for each test parameter shall be developed based upon historical data from the concrete producer and revised as project specific data is obtained. A minimum of 10 project samples shall be used to determine the revised standard deviations. If historical information is unavailable, the following values may be used to calculate one standard deviation (1s) until sufficient data is available.
   a. Coarseness Factor = 0.052 * Target Value
   b. Workability Factor = 0.020 * Target Value
   c. Combined % Retained on Individual Sieves (3/8” & larger), % = 0.147 * Target Value
   d. Combined % Retained on Individual Sieves (#4 & #8), % = 0.112 * Target Value
   e. Combined % Retained on Individual Sieves (#16, #30, #50 & #100), % = 0.061 * Target Value
   f. Combined % Retained on Individual Sieves (#200), % = 0.170 * Target Value
   g. Aggregate Moisture = 0.043 * Target Value
   h. Slump = 0.231 * Target Value
   i. Air Content = 0.0.097 * Target Value
   j. Density = 0.007 * Target Value

4. Investigate process control instability when one of the following occurs:
a. One test result is outside of the 3s limits.
b. Five consecutive test results are all increasing or decreasing.
c. Five consecutive test results are on the same side of the average value.
d. Ten consecutive test results are alternating up and down.

3.12 FIELD QUALITY ACCEPTANCE

A. Testing and Inspecting: Contractor shall engage a qualified testing and inspecting agency meeting the requirements of Section 1.7.C to perform tests and inspections and to submit reports for acceptance in accordance with Section 1.5.F.

B. Inspections: Prior to commencement of portions of the work, the inspection agency shall provide verification that the following items meet the specification requirements:

1. Subgrade and/or subbase density and elevation.
2. Steel tie and dowel bar reinforcement placement, if used.
3. Use of required design mixture.
4. Concrete placement, including conveying and depositing.
5. Curing procedures.
6. Concrete strength before removal of forms, if used.

C. Concrete Tests: Testing of composite samples of fresh concrete obtained according to ASTM C172/C172M shall be performed according to the following requirements:

1. Preliminary Samples/Tests: Preliminary samples to measure slump and air content and to make necessary adjustments to mixtures to achieve specified requirements are permitted in accordance with ASTM C94/C94M.

2. Testing Frequency: Obtain at least one random composite sample for each \([150 \text{ yd}^3 (115 \text{ m}^3)]\) or [insert volume] or fraction thereof of each concrete mixture placed each day.

   a. When frequency of testing will provide fewer than five compressive-strength tests for each concrete mixture, testing shall be conducted from at least five randomly selected batches or from each batch if fewer than five are used.

3. Slump: ASTM C143/C143M; one test at point of placement for each composite sample when compressive strength specimens are made, but not less than one test for each day's pour of each concrete mixture.

4. Air Content: ASTM C231/C231M, pressure method, for normal-weight concrete; one test for each composite sample, but not less than one test for each day's pour of each concrete mixture.

5. Density: ASTM C138/C138M; one test for each composite sample when strength specimens are made.

6. Concrete Temperature: ASTM C1064/C1064M; one test hourly when air temperature is 40°F (5°C) and below and when 80°F (27°C) and above, and one test for each composite sample when strength specimens are made.
Concrete Pavement for Street and Local Road Applications

7. **Compression Test Specimens:** ASTM C31/C31M; two sets of two standard-cured cylinder specimens for each composite sample. Specimen sizes of 6 x 12 in. (150 x 300 mm) or 4 x 8 in. (100 x 200 mm) are permitted.

8. **Compressive-Strength Tests:** ASTM C39/C39M; test one set of two standard-cured specimens at 7 days and one set of two specimens at 28 days. A compressive-strength test result shall be the average compressive strength from a set of two specimens obtained from same composite sample and tested at age indicated.

   a. Strength of each concrete mixture is satisfactory if every average of any three consecutive compressive-strength test results equals or exceeds specified compressive strength and no compressive-strength test result falls below specified compressive strength by more than 500 psi (3.5 MPa).

D. **Smoothness:** Determine smoothness based upon one of the following methods.

   1. **Straightedge:** For pavements with a speed limit of 40 mph (64 kph) or below, use a 10 ft (3 m) metal straightedge to measure the locations marked by the Engineer. A minimum of one test location per 500 feet (152 m) in each travel lane that will carry traffic will be marked. Where there is more than 1/4 in. in 10 ft (6 mm in 3 m), between any two contacts of the straightedge with the surface, the surface requires correction. Following correction, retest the area to verify compliance with this section. Pavement surfaces that have been purposely warped to meet fixtures (manholes, drainage inlets, catch basins, etc.), existing curb and gutter, or cross- and side-road connections are exempt from this straightedge requirement.

   2. **Inertial Profiler:** For pavements with a speed limit greater than 40 mph (64 kph), perform tests in each travel lane that will carry traffic using an inertial profiler in conformance with ASTM E950/E950M. Coordinate with and obtain authorization from the Engineer before starting testing. Perform tests on the finished surface of the completed project or at the completion of a major stage of construction as approved by the Engineer. Perform tests within 7 days after receiving authorization.

   The Engineer may require testing to be performed at times of off-peak traffic flow. Operate the inertial profiler in a manner that does not unduly disrupt traffic flow as determined by the Engineer. When using a lightweight inertial profiler to measure a surface that is open to traffic, use a moving traffic control plan in accordance with the MUTCD and the plans.

   IRI values will be calculated for 0.1 mi. (0.1 km) sections using the average of both wheel paths. The maximum allowable IRI for any 0.1 mi. (.1 km) section will be 70 in./mi (1,184 mm/km). For each 0.1 mi. (0.1 km) section measured to be over 70 in./mi (1,184 mm/km) but not exceeding 80 in./mi. (1,262 mm/km) [$250] or [insert $ value] will be deducted from the payment for this item. For each 0.1 mi. (0.1 km) section measured to be over 80 in./mi (1,262 mm/km) but not exceeding 90 in./mi. (1,429 mm/km) [$500] or [insert $ value] will be deducted from the payment for this item. Use diamond grinding or other approved work methods to correct any 0.1 mi (0.1 km) section with an average IRI over 90 in./mi (1,429 mm/km). Correct the deficient section to an IRI of 70 in./mi (1,184 mm/km) or less. After making corrections, reprofile the pavement section to verify that corrections have produced the required improvements.
E. Reporting: Test results shall be reported in writing to Engineer within 48 hours of testing. Reports shall contain project identification information, date of concrete placement, name of concrete testing and inspecting agency, and location of concrete batch in Work.

F. Additional Tests: Testing and inspecting agency shall make additional tests of concrete when test results indicate that slump, air entrainment, compressive strengths, or other requirements have not been met, as directed by Engineer. Testing and inspecting agency may conduct tests to determine adequacy of concrete by cored cylinders complying with ASTM C42/C42M or by other methods as directed by Engineer.

G. Additional testing and inspecting, at Contractor's expense, will be performed to determine compliance of replaced or additional work with specified requirements.

H. Correct deficiencies in the Work that test reports and inspections indicate does not comply with this specification and/or the Contract Documents.

3.13 MEASUREMENT AND PAYMENT

A. Measurement: Measurement will be in square yards (square meters) for each different thickness of concrete pavement. The area of manholes, intakes, or other fixtures in the pavement will not be deducted from the measured pavement area. When the curb is integral with the pavement, the width for pavement square yards will be measured from back of curb to back of curb.

B. Payment: Payment will be at the unit price per square yard (square meters) for each thickness of concrete pavement. Unit price includes, but is not limited to, final trimming of subgrade or subbase, integral curb, bars and reinforcement, joints and sealing, surface curing and pavement protection, safety fencing, concrete for rigid headers, box outs for fixtures, and pavement smoothness testing.

END OF SECTION 32 13 13.51
APPENDIX A – Pertinent NRMCA Concrete In Practice (CIP) Series References

The following NRMCA documents may be used for further guidance on topics related to this specification and concrete pavement construction. The requirements, criteria, or language in the above guide specification should supersede if there are any discrepancies between the specification and the CIP documents. The CIP documents are provided for reference only to the specification writer and should not be included in the project specification either directly or through reference.

<table>
<thead>
<tr>
<th>Concrete In Practice Series Title</th>
<th>CIP #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joints in Concrete Slabs on Grade</td>
<td>CIP 6</td>
</tr>
<tr>
<td>Discrepancies in Yield</td>
<td>CIP 8</td>
</tr>
<tr>
<td>Low Concrete Cylinder Strength</td>
<td>CIP 9</td>
</tr>
<tr>
<td>Strength of In-Place Concrete</td>
<td>CIP 10</td>
</tr>
<tr>
<td>Curing In-Place Concrete</td>
<td>CIP 11</td>
</tr>
<tr>
<td>Hot Weather Concreting</td>
<td>CIP 12</td>
</tr>
<tr>
<td>Chemical Admixtures for Concrete</td>
<td>CIP 15</td>
</tr>
<tr>
<td>Flexural Strength of Concrete</td>
<td>CIP 16</td>
</tr>
<tr>
<td>Synthetic Fibers for Concrete</td>
<td>CIP 24</td>
</tr>
<tr>
<td>Jobsite Addition of Water</td>
<td>CIP 26</td>
</tr>
<tr>
<td>Cold Weather Concreting</td>
<td>CIP 27</td>
</tr>
<tr>
<td>Concrete Slab Moisture</td>
<td>CIP 28</td>
</tr>
<tr>
<td>Supplementary Cementitious Materials</td>
<td>CIP 30</td>
</tr>
<tr>
<td>Ordering Ready Mixed Concrete</td>
<td>CIP 31</td>
</tr>
<tr>
<td>Concrete Pre-Construction Conference</td>
<td>CIP 32</td>
</tr>
<tr>
<td>Making Concrete Cylinders in the Field</td>
<td>CIP 34</td>
</tr>
<tr>
<td>Testing Compressive Strength of Concrete</td>
<td>CIP 35</td>
</tr>
<tr>
<td>Concrete Maturity</td>
<td>CIP 39</td>
</tr>
<tr>
<td>Acceptance Testing of Concrete</td>
<td>CIP 41</td>
</tr>
</tbody>
</table>
The Sustainability of Concrete Pavements

By Lionel Lemay, P.E., S.E., LEED AP, Senior VP, Sustainable Development, NRMCA
Erin Ashley, Ph.D., LEED AP, Senior Director, Sustainable Construction, NRMCA

Our economy depends on transportation infrastructure. We drive to work and school on roads each day. Most of our food, clothing and consumer products are delivered in trucks that travel our interstate highway system. Businesses rely on roads and runways to transport materials and parts needed to manufacture the products we use every day. Families rely on these same roads and runways to visit friends and family or to take vacations. And, when we reach our destinations, we rely on driveways and parking areas to park our cars and trucks. We even rely on sidewalks to get us where we’re going.

Our transportation infrastructure connects our communities. Without it, we would not be a productive society. However, this interconnecting network of roads, runways, parking areas and sidewalks does have an impact on our environment. The same cars, trucks and airplanes that support our economy also use energy, emit greenhouse gases and other air emissions, and can place a significant toll on surrounding ecosystems. The construction process, including material manufacturing, can also place a burden on the environment. Therefore, when we build new transportation infrastructure or repair and maintain existing infrastructure, it makes sense to use design strategies and building materials that minimize environmental impact.

What Makes a Pavement Sustainable?
Pavements should have a long service life and require little maintenance. They should minimize energy consumption and greenhouse gas emissions. They should be resource efficient by using local materials and incorporating recycled products. One way to accomplish these objectives is to use concrete pavements. Concrete pavements can be used to build new or replace existing sidewalks, driveways, parking lots, local streets and roads, highways and runways. Concrete pavements can be designed economically to carry light loading, such as pedestrians and passenger vehicles, all the way up to the heaviest trucks and airplanes. Concrete can also be used to repair deteriorated asphalt pavement with a product called whitetopping or concrete overlay. Other products such as pervious concrete, that allows rainwater to pass through it, can help reduce and treat stormwater.

When evaluating environmental impacts, it is important to look at the entire life cycle of a product or project. Looking at one phase of the life cycle, such as material extraction,
manufacturing or construction, and ignoring the operation or use phase may not result in the most efficient design. This paper explores how concrete pavements can improve our transportation infrastructure and minimize environmental impacts throughout all phases of a pavement’s life cycle, including material extraction, manufacturing, construction, use (operations and maintenance) and recycling/reuse/disposal.

**Durability**
Excessive wear and tear on vehicles is directly related to the quality of roads. According to the Federal Highway Administration (FHWA), for federally funded highways, including the national highway system and other arterials and collectors eligible for federal funding, the vehicle miles travelled on pavements with good ride quality was only 47% in 2006.

In addition, congestion continues to increase and clog America’s roadways, costing taxpayers billions of dollars and billions of wasted hours. According to FHWA, the estimated percentage of travel occurring under congested conditions rose from 24.9% to 28.7% from 1997 to 2005. The average length of time motorists spend in congested conditions increased from 5.9 hours per day in 1997 to 6.4 hours per day in 2005.1

Americans spend more than 4.2 billion hours per year stuck in traffic, costing $78.2 billion per year in wasted time and fuel. Thirty-two percent of America’s major roads are in poor or mediocre condition. Driving on roads in need of repair costs American motorists $67 billion annually in extra vehicle repair and operating costs, which amounts to over $324 per motorist. The problem continues to rise as vehicle travel on America’s highways increased by 39% from 1990 to 2008, while new road mileage increased by only four percent.2

Providing durable, long lasting roadways that require little maintenance can reduce the wear and tear on our cars and trucks and decrease the congestion on our roadways. Concrete pavements are durable and as a result they generally have longer service lives than asphalt pavements. There are many examples of concrete pavements with service lives of 50 years or longer.3 Concrete pavements do not require rehabilitation or reconstruction as often as asphalt pavements and as a result the life cycle cost of concrete pavements are lower and losses in productivity as a result of lane closers are reduced.

**Lower Embodied Energy**
The embodied energy of a material refers to the energy needed to extract, process and refine it for its intended use. Thus, a correlation exists between the number and type of processing steps and the embodied energy of a material. For example, the fewer and simpler the extraction, processing and refining steps involved in a material’s production, the lower its embodied energy.

The embodied energy of a pavement is the total energy required to extract materials from the ground, process these materials, produce the pavement, provide maintenance over the specified time period, and recycle or demolish the roadway at the end of its specified life.

The Athena Institute studied the embodied energy and global warming potential of concrete and asphalt roads over a 50-year life cycle. The study concluded that for a high volume highway, the asphalt pavement alternative required three times more energy than its concrete pavement counterpart from a life cycle perspective. For a high volume roadway, asphalt generated global warming potential of 738 t/km (1,309 tons/mi) of CO₂ equivalents compared to 674 t/km (1,196 tons/mi) of CO₂ equivalent for concrete. The study did not take into account

---

1 Figure 2. Our transportation infrastructure, including roads, runways, parking lots and sidewalks, connects our communities and sustains our vibrant economy.
addition fuel savings or energy savings from lighting as described later in this paper that would further reduce the embodied energy and CO₂ equivalents associated with concrete pavements.

**Fuel Savings**

Several research studies have shown that driving on concrete pavements uses less fuel and as a result, lowers carbon emissions and other associated emissions when compared to asphalt pavements. Although the reasons are not completely understood, the theory is that because concrete pavements are considerably stiffer than asphalt pavements they deflect less when subjected to vehicle loading. This means that a car or truck traveling on a more flexible pavement absorbs part of the vehicle energy that would otherwise be available to propel the vehicle forward, thus requiring more fuel.

The studies have shown that trucks demonstrate fuel savings when driven on concrete highway pavements versus asphalt highway pavements. Fuel consumption for cars is not influenced by pavement type for highways presumably because cars are lighter in weight and the deflections are such that they do not affect fuel consumption significantly. However, one study shows that cars traveling on city streets do demonstrate lower fuel consumption on concrete pavements compared to asphalt pavements. It is assumed that because the pavement cross sections are thinner for concrete streets that deflections caused by passenger vehicles are large enough that they do affect fuel consumption.

Zaniewski conducted one of the earliest fuel consumption studies commissioned by FHWA in 1982. In this study, fuel consumption data was collected for different vehicle types, pavement designs, pavement conditions, and pavement grades and curvatures. Twelve highway sections were tested, some concrete and some asphalt. Vehicles were driven at different speeds ranging from 16 to 112 km/h (10 to 70 mph) and fuel consumption was accurately measured while other variables, including pavement roughness, remained constant.

The test results indicate that fuel consumption for trucks, ranging from 2-axle pickup trucks to 4-axle semi-trailer trucks, at speeds greater than 32 km/h (20 mph), was lower for concrete highway pavements then for asphalt highway pavements. The difference in fuel consumption was as much as 0.85 km/l (2 mpg). The semi-trailer truck in this study had fuel consumption of approximately 1.91 km/l (4.5 mpg) on asphalt pavement and 2.33 km/l (5.5 mpg) on concrete pavement, meaning the average savings was approximately 20% for semi-trailer trucks.

Another comprehensive study of fuel consumption was conducted by the National Research Council of Canada with reports published in 2002 and 2006. Semi-trailer trucks were driven on highway pavements in Ontario and Quebec.

<table>
<thead>
<tr>
<th>% Fuel Savings</th>
<th>Fuel Saved (l)</th>
<th>Fuel Savings ($)</th>
<th>CO₂ Equiv. (t)</th>
<th>NOₓ (kg)</th>
<th>SO₂ (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8 minimum</td>
<td>550.4</td>
<td>$440.32</td>
<td>1.5</td>
<td>17.17</td>
<td>2.17</td>
</tr>
<tr>
<td>3.85 average</td>
<td>2,648.8</td>
<td>$2119.04</td>
<td>7.31</td>
<td>82.68</td>
<td>10.45</td>
</tr>
<tr>
<td>6.9 maximum</td>
<td>4,747.2</td>
<td>$3797.76</td>
<td>13.09</td>
<td>148.18</td>
<td>18.73</td>
</tr>
</tbody>
</table>

Table 1. Annual potential fuel savings, cost savings and reduction in CO₂, NOₓ, SO₂ if a semi-trailer operated a total of 160,000 km/year (99,419 mi/year). It is assumed the semi-trailer truck has a fuel consumption of 2.33 km/l (5.47 g/mi) and an average cost of diesel fuel of $0.80 per liter ($3.02 per gallon).
comparing fuel consumption for asphalt and concrete pavements. Variables studied in the analysis included pavement roughness, load, speed, season, temperature, grade and wind. Onboard state-of-the-art real time computerized data collection equipment was used in the semi-tractor trailer unit to collect and calculate instantaneous fuel flow while traveling over the different pavements.

The semi-trailer data was analyzed using a multivariate linear regression analysis tool to determine the potential savings and the statistical significance of the results. The results of the 2002 study showed statistically significant fuel savings for trucks operating on concrete pavements over asphalt pavements ranging from:

- 4.1% to 4.9% savings on concrete pavement at 100 km/h (62 mph)
- 5.4% to 6.9% savings on concrete pavement at 60 km/h (37 mph)

The results of the 2006 study shows statistically significant fuel savings for trucks traveling on concrete pavements over asphalt pavements ranging from:

- 0.8% to 1.8% savings on concrete pavement at 100 km/h (62 mph)
- 1.3% to 3.9% savings on concrete pavement at 60 km/h (37 mph)

Based on these studies, Table 1 shows the annual potential fuel savings, cost savings and reduction in \( CO_2 \), \( NO_\text{x} \), \( SO_\text{2} \) if a semi-trailer truck operated a total of 160,000 km/year (99,419 mi/year). It is assumed the semi-trailer truck has a fuel consumption of 2.33 km/l (5.47 g/mi) and an average cost of diesel fuel of $0.80 per liter ($3.02 per gallon).6,7

The University of Texas at Arlington investigated the differences that might exist in fuel consumption and \( CO_2 \) emissions when operating an automobile on asphalt street pavements versus concrete street pavements under city driving conditions. Two pairs of street sections, one asphalt and one concrete, with similar gradients and roughness were selected for fuel consumption comparisons.

The study concludes that driving on concrete pavements reduced fuel consumption by 3% to 17%, resulting in significant cost savings, fuel savings and reduction in \( CO_2 \) emissions. For example, if the annual vehicle miles travelled in the Dallas-Fort Worth region in Texas took place at a constant speed of 50 km/h (30 mph) on concrete pavements similar to those in the study, the annual fuel savings would be 670 million liters (177 million gallons) and the annual \( CO_2 \) reduction would be 620,000 tonnes (680,000 tons).8

**Reduced Lighting Requirements**

Darkness increases the potential for accidents. The fatality rate is approximately three times greater during the nighttime than during the daytime, when adjusted for vehicle traffic volumes. Therefore, in busy traffic areas, it makes sense to add artificial lighting to reduce accidents. However, lighting is expensive to install, maintain and operate. In a 1986 paper by Stark, the initial cost of purchasing and installing light fixtures for a typical roadway can range from $54,370 to $96,313 per kilometer ($87,500 to $155,000 per mile.) This is based on an estimated cost per light fixture of approximately $4,000. The Stark report also estimates the cost to operated roadway lighting to range between $1,367 and $2,485 per kilometer ($2,200 and $4,000 per mile) per year for energy and between $1,616 and $2,858 per kilometer ($2,600 and $4,600 per mile) per year for maintenance. All dollar figures have been adjusted for inflation.

Concrete pavements can reduce the initial costs, maintenance costs and energy demand for lighting since concrete is more reflective than darker pavements. Fewer lighting fixtures, or lower wattage fixtures, are needed to provide the same illumination on a roadway built with concrete. Stark demonstrated that a concrete roadway would use 31% less

![Figure 3. Reflectance of concrete pavements (left) are higher than asphalt pavement (right) resulting in safer pavements and reduced energy consumption.](image)
energy and associated greenhouse gas emissions as a result of using fewer lighting fixtures and could reduce initial cost and maintenance costs by similar amounts.9

**Reduced Urban Heat Islands**
Research at Lawrence Berkeley National Laboratory shows that the consistent use of light-colored pavements along with strategic landscaping and light colored roofing, can help reduce urban heat islands. An urban heat island is a metropolitan area which is significantly warmer than its surrounding rural area because of roofs and pavements that are baked by the sun and warm air. In many large cities, temperatures in residential zones can rise by as much as 1.7 °C (3 °F) and in downtown areas by as much as 3.9 °C (7 °F), primarily because of dark-colored roofing and pavements. The increased temperatures can cause discomfort, hike air-conditioning bills and accelerate the formation of smog. Cities in all climate zones, such as Los Angeles, Chicago, Washington and Atlanta, along with many other U. S. cities are subject to the urban heat island effect.

Counter intuitively, using light colored roofing and pavements can also benefit cities in the north. For example, in New York City, the length of the day in December is half that of a day in June. Also, the sun is so low in the sky that it shines on only half the roof or pavement area in December versus June. In addition, New York experiences three times more cloudy days in the winter than in the summer. When you multiply these three factors (1/2 x 1/2 x 1/3 = 1/12) the potential for horizontal surfaces to absorb the sun’s energy is only 1/12 in December as in June. This means that because so little sun ever reaches roofs and pavements in the winter months the benefits of lowering temperatures in the summer far outweighs raising temperatures in the winter.10

**Stormwater Management**
Pervious concrete is a performance-engineered concrete with a 15-30% void system that allows rainwater to percolate through it. When pervious concrete is used for parking areas, streets, plazas and walkways it minimizes stormwater runoff to surrounding streams and lakes and allows for natural filtration to recharge local groundwater supplies.

Pervious pavement is especially compelling as a leading edge green building technology and is recognized by the U.S. Environmental Protection Agency (EPA) as a recommended Best Management Practice (BMP) for stormwater management that supports the principles of Low Impact Development (LID).
Pervious concrete has been documented as eliminating stormwater runoff and improving water quality.

In addition to the stormwater management benefits of pervious concrete, it can also act to reduce the heat island effect by absorbing less heat from solar radiation than darker pavements. The relatively open pore structure and the light color of pervious concrete stores less heat, therefore, helping to lower heat island effects in urban areas. Kevern, et al, have shown that pervious concrete stores less energy, therefore less heat, when exposed to sun over an extended period of time. This heat is not reflected back to the environment resulting in lower external temperatures. Lower external temperatures of the pavement result in a reduction of the heat island effect.\footnote{11}

**Recycling and Reuse**
Concrete incorporates recycled materials in several different ways. The most widely used recycled products in concrete are Supplementary Cementitious Materials (SCMs) such as fly ash, slag cement and silica fume. In 2007, the concrete industry consumed over 26 million tonnes (28.66 million tons) of these industrial byproducts that would otherwise end up in landfills. SCMs are the key to high performance concrete. When combined with cement in concrete they improve durability, strength and constructability. In the case of highways, streets and parking areas, durability is the number one concern. Fly ash, slag and silica fume are used to enhance durability by decreasing permeability and cracking. They help block migration of chloride ions to reinforcing steel, the most common cause of corrosion.

The environmental benefits of using these industrial byproducts in concrete means a reduction in the amount of waste materials sent to landfills, reduced raw materials extracted, reduced energy of production and reduced emissions, including \( \text{CO}_2 \). Fly ash is the byproduct of burning coal in electric power plants. Generally, 15% to 20% of burned coal takes the form of fly ash. At one time, most fly ash was landfilled, but today a significant portion is used in concrete. Blast furnace slag is the byproduct of steel manufacturing. After grinding, the blast furnace slag takes on much higher value as a cementitious material for concrete. Blast furnace slag can be used as a partial replacement for cement to impart added strength and durability to concrete. Silica fume is a byproduct of processing quartz into silicon metals in an electric arc furnace. They are superfine, spherical particles that when combined with cement significantly increases strength and durability of concrete. It is used heavily for bridge and parking decks to produce concretes that are extremely durable.

The greatest opportunity for recycling lies in crushing concrete for various applications after demolition. After decades, or sometimes centuries of use in a building or pavement, concrete can be crushed and reused. The Construction Materials Recycling Association estimates that 127 million tonnes (140 million tons) of concrete are recycled annually. Recycling concrete from demolition can be used for aggregate base for new pavements and some crushed concrete can be recycled as aggregate into new concrete. Recycling old concrete as aggregate protects natural resources by reducing the demand for virgin aggregate materials and eliminates the need to dispose of it into landfills. The same basic equipment used to process virgin aggregates is used to crush, size, clean and stockpile recycled concrete aggregates. Ideal uses include fills and bases, roadways and parking areas, driveways and sidewalks, shoulders, curbs and gutters, landscaping features, foundations and some concrete structures, including pavements.

According to an FHWA study, 38 states recycle concrete as aggregate base and 11 recycle it into new concrete.\footnote{12} In one example, recycled concrete aggregate was used for Interstate 5 Improvements in Anaheim, California. Crushed concrete from

![Figure 6. Recycled industrial byproducts such as fly ash, slag and silica fume (inset) are used to enhance durability of concrete by decreasing permeability and cracking.](image)
the demolition of the existing roadway was stockpiled for reuse as base material for the new roadway. The highway improvement project consumed all 635,029 tonnes (700,000 tons) of recycled concrete generated from the demolition and an additional 90,718 tonnes (100,000 tons) of recycled aggregate was brought in to complete the project. Using the recycled aggregate saved Caltrans approximately $5 million over purchasing and hauling virgin aggregate and disposing of the demolition debris.13

Life Cycle Assessment

Life cycle assessment (LCA) is a technique for assessing impacts associated with a product or process. LCA’s are usually accomplished using complex computer models that take into account every impact throughout all life cycle phases, from cradle to grave, for the product or process being evaluated. For pavements, life cycle phases include material extraction, manufacturing, construction, use (operations and maintenance), and recycling/reuse/disposal. For most pavements, the use phase has the greatest impact on the overall footprint since it includes the impacts of fuel consumption and emissions from cars and trucks, along with the energy and emissions as a result of maintenance, lighting and the urban heat island effect.

The process of conducting an LCA involves compiling an inventory of energy and material inputs and environmental impacts such as emissions to water and air, ozone depletion, global warming, acidification, eutrophication, photochemical smog, human health risks, ecotoxicity, fossil fuel use, land use and water use. The goal of LCA is to compare all the environmental, social, and economic damages to help make informed decisions about how to change the process to reduce impact.

The science of LCA is relatively new and few full LCA’s have been conducted for pavements. The Massachusetts Institute of Technology (MIT), a leader in the field of LCA, has released initial reports of research efforts that will help set a new standard for LCA modeling. Researchers are working to quantify the full cradle to grave life cycle environmental and economic impacts of pavements and buildings. What is setting the MIT research apart from other research is that more effort is being placed on identifying the impacts of operating and maintaining pavements over a 50-year life cycle.

An interim report issued in December 2010 suggests that for high-volume roads (major highways), the use phase can account for as much as 85% of the carbon emissions. Based on previous research on fuel consumption conducted by others, there is a potential for significant fuel savings on concrete pavements over asphalt pavements that could lead to substantially lower life cycle carbon emissions. In addition, varying scheduled maintenance and associated lane closures can reduce CO₂ emissions for concrete pavements over the life cycle of the pavement.

As work continues, MIT will supplement the ongoing environmental LCA work with economic analyses using life-cycle-cost analysis (LCCA). The research will provide the scientific and design community, industry leaders and policymakers with a much clearer understanding of the real life environmental and economic costs of building and paving materials.

Conclusions

Transportation infrastructure connects our communities and is a critical component to a vibrant economic system in the U.S. However, transportation is a large consumer of energy and emitter of greenhouse gases. One way to improve the overall environmental performance of our transportation infrastructure is to use concrete pavements since:

- Concrete pavements are durable and last longer
- Concrete pavements require less maintenance and fewer repairs
- Concrete pavements take less energy to build
- Cars and trucks traveling on concrete pavements consume less fuel
- Concrete pavements need less lighting
- Concrete’s light color helps reduce urban heat islands
- Concrete is made from local and abundant materials
- Concrete uses significant amount of recycled materials
- Concrete is recyclable

All these features of concrete pavements help reduce energy consumption, greenhouse gas emissions and resource depletion attributed to our transportation infrastructure. For more information on the sustainability of concrete, visit www.nrmca.org/sustainability.
References


