About the National CP Tech Center

The mission of the National Concrete Pavement Technology Center is to unite key transportation stakeholders around the central goal of advancing concrete pavement technology through research, tech transfer, and technology implementation.

Disclaimer Notice

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the sponsors.

The sponsors assume no liability for the contents or use of the information contained in this document. This report does not constitute a standard, specification, or regulation.

The sponsors do not endorse products or manufacturers. Trademarks or manufacturers' names appear in this report only because they are considered essential to the objective of the document.

Iowa State University Non-Discrimination Statement

Iowa State University does not discriminate on the basis of race, color, age, religion, national origin, sexual orientation, gender identity, genetic information, sex, marital status, disability, or status as a U.S. veteran. Inquiries can be directed to the Director of Equal Opportunity and Compliance, 3280 Beardshear Hall, (515) 294-7612.

Iowa Department of Transportation Statements

Federal and state laws prohibit employment and/or public accommodation discrimination on the basis of age, color, creed, disability, gender identity, national origin, pregnancy, race, religion, sex, sexual orientation or veteran's status. If you believe you have been discriminated against, please contact the Iowa Civil Rights Commission at 800-457-4416 or the Iowa Department of Transportation affirmative action officer. If you need accommodations because of a disability to access the Iowa Department of Transportation's services, contact the agency's affirmative action officer at 800-262-0003.

The preparation of this report was financed in part through funds provided by the Iowa Department of Transportation through its “Second Revised Agreement for the Management of Research Conducted by Iowa State University for the Iowa Department of Transportation” and its amendments.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Iowa Department of Transportation or the U.S. Department of Transportation Federal Highway Administration.
# Technical Report Documentation Page

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>TPF 5(205)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparison of Setting Time Measured Using Ultrasonic Wave Propagation With Saw-Cutting Times on Pavements in Iowa</td>
<td>January 2014</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Peter Taylor and Xuhao Wang</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>9. Performing Organization Name and Address</th>
<th>10. Work Unit No. (TRAIS)</th>
<th>11. Contract or Grant No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Concrete Pavement Technology Center</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iowa State University</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2711 South Loop Drive, Suite 4700</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ames, IA 50010-8664</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Federal Highway Administration and Pooled Fund Partners</td>
<td>Technical Report</td>
<td>TPF-5(205)</td>
</tr>
<tr>
<td>U.S. Department of Transportation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1200 New Jersey Avenue SE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Washington, DC 20590</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>15. Supplementary Notes</th>
<th>16. Abstract</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visit <a href="http://www.cptechcenter.org">www.cptechcenter.org</a> for color pdfs of this and other research reports.</td>
<td>Concrete setting behavior strongly influences scheduling of construction operations, such as surfacing, trowelling, jointing, and saw-cutting. To conduct pavement sawing activities effectively, it is useful for contractors to know when a concrete mixture is going to reach initial set, or when the sawing window will open. Monitoring the set time of a fresh mixture also provides a tool to assess the uniformity between material and concrete batches. The aim of this project was to confirm that initial set could be measured using an ultrasonic pulse velocity (UPV) approach, and to assess whether there was a relationship between initial set and sawing time for pavement concrete in the field. Eight construction sites were visited in Iowa over a single summer/fall period. At each site, initial set was determined using a p-wave propagation technique with a commercial device. It was also determined on mortar samples in accordance with ASTM C 403. Calorimetric data were collected using a commercial semi-adiabatic device on some of the sites. The data collected to date revealed the following: • UPV approaches appear to be able to report initial set times • Early entry sawing time can be predicted for the range of mixtures tested here</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>17. Key Words</th>
<th>18. Distribution Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>concrete mixtures—initial set—pavement saw-cutting—ultrasonic pulse velocity</td>
<td>No restrictions.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Unclassified.</td>
<td>Unclassified.</td>
<td>22</td>
<td>NA</td>
</tr>
</tbody>
</table>
COMPARISON OF SETTING TIME MEASURED USING ULTRASONIC WAVE PROPAGATION WITH SAW-CUTTING TIMES ON PAVEMENTS IN IOWA

Technical Report
January 2014

Principal Investigator
Peter Taylor, Associate Director
National Concrete Pavement Technology Center, Iowa State University

Research Assistant
Xuhao Wang

Authors
Peter Taylor and Xuhao Wang

Sponsored by
FHWA Pooled Fund Study TPF-5(205): Colorado, Iowa (lead state), Kansas, Michigan, Missouri, New York, Oklahoma, Texas, Wisconsin

Preparation of this report was financed in part through funds provided by the Iowa Department of Transportation through its Research Management Agreement with the Institute for Transportation (InTrans Project 10-374)

A report from
National Concrete Pavement Technology Center
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-8103
Fax: 515-294-0467
www.cptechcenter.org
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>vii</td>
</tr>
<tr>
<td>EXECUTIVE SUMMARY</td>
<td>ix</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>BACKGROUND</td>
<td>1</td>
</tr>
<tr>
<td>WORK CONDUCTED</td>
<td>4</td>
</tr>
<tr>
<td>RESULTS</td>
<td>6</td>
</tr>
<tr>
<td>DISCUSSION</td>
<td>8</td>
</tr>
<tr>
<td>CLOSING</td>
<td>10</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>11</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure 1. Typical UPV data with initial set taken as the time when the velocity starts to rise as marked [15]........................................................................................................................................3
Figure 2. Plots from different measurement techniques for a single mix ........................................4
Figure 3. Test setup with sample and transducers in a wooden frame for stability .........................5
Figure 4. Use of early entry saws ........................................................................................................6
Figure 5. Calorimetric data .................................................................................................................7
Figure 6. Crack at Site 2 ......................................................................................................................8
Figure 7. Comparison of setting and sawing times .............................................................................9
Figure 8. Comparison of setting and average air temperature ............................................................9

LIST OF TABLES

Table 1. Sites where samples were tested ..........................................................................................5
Table 2. Collated test data ...............................................................................................................6
ACKNOWLEDGMENTS

This research was conducted under the Federal Highway Administration (FHWA) Transportation Pooled Fund Study TPF-5(205) with support from the following state departments of transportation (DOTs):

- Colorado
- Iowa (lead state)
- Kansas
- Michigan
- Missouri
- New York
- Oklahoma
- Texas
- Wisconsin

The authors would like to express their gratitude to the Iowa DOT and the other pooled fund state partners for their financial support and technical assistance.

The researchers would also like to acknowledge the agencies and contractors that allowed them to be on their construction sites and to take samples.
EXECUTIVE SUMMARY

Concrete setting behavior strongly influences scheduling of construction operations, such as surfacing, trowelling, jointing, and saw-cutting. To conduct pavement finishing and sawing activities effectively, it is useful for contractors to know when a concrete mixture is going to reach initial set, or when the sawing window will open. Monitoring the set time of a fresh mixture also provides a tool to assess the uniformity between material and concrete batches.

The aim of this project was to confirm that initial set could be measured using an ultrasonic pulse velocity (UPV) approach, and to assess whether there was a relationship between initial set and sawing time for pavement concrete in the field.

Eight construction sites were visited in Iowa over a single summer/fall period. At each site, initial set was determined using a p-wave propagation technique with a commercial device. It was also determined on mortar samples in accordance with ASTM C 403. Calorimetric data were collected using a commercial semi-adiabatic device on some of the sites.

The data collected to date revealed the following:

- UPV approaches appear to be able to report initial set times
- It seems that early entry sawing time can be predicted for the range of mixtures tested here
INTRODUCTION

To conduct finishing and sawing activities of pavements effectively, it is useful for contractors to know when a concrete mixture is going to reach initial set, or when the sawing window will open. Monitoring the set time of a fresh mixture also provides a tool to assess the uniformity between material and concrete batches.

Work has been reported in Australia on the effective use of calorimetry for this purpose. There is, however, concern that temperature is not uniquely tied to setting, and that tests conducted in a semi-adiabatic calorimeter may not represent the environment being experienced by a given slab.

An alternative approach to measuring initial set is to monitor the speed of sound through a concrete sample. Previous work has shown a clear relationship between this parameter and initial set.

The aim of this project was to confirm that initial set could be measured using an ultrasonic pulse velocity (UPV) approach, and to assess whether there was a relationship between initial set and sawing time for pavement concrete in the field.

BACKGROUND

The “correct” time to conduct sawing of a freshly placed concrete slab is often a subjective decision based on the experience of the saw operator. Conventional guidance is normally in the form of inspecting the amount of raveling. A very clean cut is normally indicative of late sawing and, therefore, a high risk of random cracking. Severe raveling is an indicator that sawing should not yet start. Other approaches include scratching the surface with a penknife or standing on the slab and observing footprint depth. There is a need for a more rigorous approach to determining when sawing should start that will reduce errors and disputes.

Challenges to contractors include the fact that the rate of hydration of a slab is strongly influenced by the temperature of the slab, as well as the chemistry of the cementitious system. Any approach that will help understand the state of concrete hydration will reduce construction (i.e., repair) costs. Likewise, crews will not have to be paid overtime to sit on the site waiting for sawing to start, and can be called in at an appropriate time.

Based on the idea that sawing time can be correlated with initial setting, this work used a UPV device to collect initial setting times at a number of sites and to compare that with the timing at which sawing occurred.

The basic principle behind the method used in this work is that the speed of sound is lower in a fluid than in a solid. The time taken for an impulse to travel through a sample will therefore start to increase when hydration products start to interact with each other, which is coincident with initial set.
Two types of waves are utilized in this type of application: compression (p-waves) that travel through the material, or shear (s-waves) that travel at the interface between the material and its container or air. According to Biot’s theory [1, 2], two types of compression wave are observed with one being fast and the other being slow. The fast wave is observed at all frequency ranges but the slow wave only exists at a high frequency [3].

Studies have also reported that p-waves are less sensitive to difficulties with the sample-transducer contact than s-waves and allow a more accurate determination of the velocity through concrete due to their high signal-to-noise ratio [4]. Both methods have been used to assess the following:

- Setting behavior [5-15]
- Strength development [16-22]
- Formwork pressure development [23]
- Chemical shrinkage [5]

According to Biot, the velocity of sound in a continuous medium is as follows:

\[
\nu = \sqrt{\frac{E(1 - \mu)}{\rho(1 + \mu)(1 - 2\mu)}}
\]

where:
E = dynamic modulus of elasticity
\(\mu\) = Poisson’s ratio
\(\rho\) = density

The velocity of sound can be determined using a device that tracks the time taken for a signal to travel through a sample with a known length.

Previously reported work at Iowa State University (ISU) [15] clearly showed a good relationship between when the speed of sound accelerates in a sample and the initial set time. The work described in this report was to compare setting times measured in the field with sawing times on the same slabs in an attempt to develop a correlation.

Initial set is taken to be when the sound velocity starts to increase (Figure 1).
Correlation between the penetrometer, UPV, and calorimetric approaches is reasonable as observed in a typical set for a single mix shown in Figure 2.
Figure 2. Plots from different measurement techniques for a single mix

WORK CONDUCTED

Eight construction sites were visited in Iowa over a single summer/fall period. At each site, a sample of concrete was obtained at the point of delivery and formed into a 4x8 in. cylinder mold. The mold was placed in a frame that also held two transducers used by a commercial p-wave device. The lower transducer was placed in contact with the bottom of the mold with a gel couplant interlayer. The top transducer was placed on a polyethylene disk floating on the concrete surface, also with the couplant between the transducer and the disk. A frame was used to keep the system stable.

Sound impulses were sent every minute from the top transducer, and the time of flight to the lower was collected and recorded on a laptop computer. During the test, the device was stored in or next to an open vehicle to maintain the test sample at the same temperature that the slab was experiencing (Figure 3). Initial set time was also determined on mortar samples in accordance with ASTM C 403. Calorimetric data were collected using a commercial semi-adiabatic device on some of the sites.

Site staff then reported the time at which that portion of the slab was sawn. They were not given any instructions on when sawing should take place.

Data on mix proportions, weather, setting time, and sawing time were then collated.
Details of the sites visited are shown in Table 1.

Table 1. Sites where samples were tested

<table>
<thead>
<tr>
<th>Site</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>May 24</td>
<td>June 18</td>
<td>Aug. 7</td>
<td>Aug. 19</td>
<td>Aug. 26</td>
<td>Oct. 2</td>
<td>Oct. 15</td>
<td>Oct. 18</td>
</tr>
<tr>
<td>Agency</td>
<td>DOT</td>
<td>County</td>
<td>DOT</td>
<td>DOT</td>
<td>DOT</td>
<td>DOT</td>
<td>City</td>
<td>City</td>
</tr>
<tr>
<td>Cementitious content, pcy</td>
<td>560</td>
<td>561</td>
<td>552</td>
<td>561</td>
<td>552</td>
<td>563</td>
<td>561</td>
<td>571</td>
</tr>
<tr>
<td>Fly ash content, %</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>w/cm</td>
<td>0.40</td>
<td>0.40</td>
<td>0.41</td>
<td>0.40</td>
<td>0.41</td>
<td>0.40</td>
<td>0.41</td>
<td>0.43</td>
</tr>
<tr>
<td>Coarse aggregate type</td>
<td>Lime-stone</td>
<td>Lime-stone</td>
<td>Quartzite</td>
<td>Lime-stone</td>
<td>Lime-stone</td>
<td>Lime-stone</td>
<td>Lime-stone</td>
<td>Lime-stone</td>
</tr>
<tr>
<td>Coarse aggregate size</td>
<td>1½&quot;</td>
<td>1½&quot;</td>
<td>1&quot;</td>
<td>1&quot;</td>
<td>1&quot;</td>
<td>1½&quot;</td>
<td>1&quot;</td>
<td>1&quot;</td>
</tr>
<tr>
<td>Fine aggregate type</td>
<td>River sand</td>
<td>River sand</td>
<td>River sand</td>
<td>River sand</td>
<td>River sand</td>
<td>River sand</td>
<td>River sand</td>
<td>River sand</td>
</tr>
</tbody>
</table>
All of the sites visited used early entry saws (Figure 4).

Figure 4. Use of early entry saws

RESULTS

The data collected are shown in Table 2.

Table 2. Collated test data

<table>
<thead>
<tr>
<th>Site</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Air Temperature, °F</td>
<td>63.1</td>
<td>83.5</td>
<td>72.5</td>
<td>80.6</td>
<td>86.9</td>
<td>75.5</td>
<td>48.9</td>
<td>46.2</td>
</tr>
<tr>
<td>Initial set ASTM C 403, min</td>
<td>290</td>
<td>153</td>
<td>285</td>
<td>184</td>
<td>255</td>
<td>209</td>
<td>441</td>
<td>316</td>
</tr>
<tr>
<td>Initial set UPV, min</td>
<td>276</td>
<td>135</td>
<td>270</td>
<td>195</td>
<td>260</td>
<td>220</td>
<td>400</td>
<td>295</td>
</tr>
<tr>
<td>Initial set Calorimetry, min</td>
<td>N/A</td>
<td>N/A</td>
<td>390</td>
<td>180</td>
<td>228</td>
<td>230</td>
<td>300</td>
<td>330</td>
</tr>
<tr>
<td>Sawing time, min</td>
<td>480</td>
<td>330</td>
<td>460</td>
<td>450</td>
<td>455</td>
<td>470</td>
<td>625</td>
<td>1,050</td>
</tr>
<tr>
<td>Comments</td>
<td>Cracked</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sawn next day
Data plots from the calorimetric tests are shown in Figure 5.

![Graph showing temperature over time for different sites]

**Figure 5. Calorimetric data**

One site (Site 2) was observed to have a crack parallel to the saw cut (Figure 6); all others appeared to be satisfactory.
DISCUSSION

There appears to be a good correlation between sawing and setting times, except for Site 8 where the sawing was conducted the following day (Figure 7). The data seems to indicate that once initial set is observed, sawing should begin about 220 minutes later for the sort of mixtures observed here and for early entry sawing.

It is interesting that the trend is a seeming constant amount of time added after initial set rather than a multiplier, despite the range of initial set times. This can be explained by observing the calorimetric plots (Figure 5), which show that once hydration starts, the rate of hydration is similar for all the mixtures.
The reason for the variation in setting times seems to be related to the temperature of the mixture as shown in Figure 8.

It is not known why Site 2 cracked despite the sawing time reported being on the line in Figure 7. It was, however, placed at the highest temperature and it’s possible that, while sawing started on time as reported in this dataset, the saw crew may not have been able to keep up with the rapidly hydrating concrete. On the other hand, Site 8 does not appear to have cracked despite the very late sawing.
It is notable that the only mixture containing the harder quartzite aggregate fell into the same dataset as the limestone mixtures.

While the data presented here are limited to early entry sawing, it is believed that the approach will be equally applicable to conventional sawing methods. All that will be required is that the system be operated as described above to compare actual sawing with initial set on a given construction site. Once a reasonable correlation has been determined, the initial set can then be used to direct sawing operations as long as the mixture does not change significantly. It is planned that further work will be conducted to verify this.

It should be noted that care will be required to ensure that the rate of sawing is similar to the rate of paving. If sawing lags significantly behind the paver because insufficient equipment or staff are available, then the risk of random cracking will increase.

**CLOSING**

The data collected to date indicates the following:

- UPV approaches appear to be able to report initial set times
- It seems that early entry sawing time can be predicted for the range of mixtures tested here

Data needs to be collected for a wider range of mixtures, and for conventional sawing.
REFERENCES


