AN IMPLEMENTABLE FRAMEWORK FOR STANDARDIZING NATIONAL PAVEMENT CRACK MEASURES

Yichang (James) Tsai
School of Civil and Environmental Engineering
Georgia Institute of Technology
790 Atlantic Drive NW,
Atlanta, GA, 30332-0355

Chenglong Jiang
School of Civil and Environmental Engineering
Georgia Institute of Technology
790 Atlantic Drive NW,
Atlanta, GA, 30332-0355

Submission Date: 8/26/2014
Word Count: 2,925
Tables and Figures: 9
Total: 2,925 + 6 × 250 = 4,425
ABSTRACT

National consistent pavement performance measures are essential for MAP-21. Cracks, as the most common type of pavement distresses and an important symptom of potential pavement failure, are a major component of many transportation agencies’ pavement performance measures. However, due to the significant diversity among the state DOTs’ pavement distress protocols, it remains a challenge to establish consistent, nationwide crack measures. State DOTs have, over decades, invested major resources to collect and maintain their legacy data for pavement management and are not willing to change their distress protocols. This paper presents an implementable framework to address this issue using a multi-scale crack analysis concept based on Crack Fundamental Element (CFE). The framework aims to systematically provide physical and topological crack properties using three scales: fundamental crack properties, aggregated crack properties, and CFE cluster geometrical properties. These crack properties are independent from state DOT’s protocols, so they can be measured consistently and are flexible enough to transform into the Federal LTPP pavement distress manual and states’ legacy protocols through rules and modeling. An actual pavement segment on State Route 236 in Georgia is used to demonstrate the compatibility between the proposed framework and the Georgia DOT COPACES manual; the experimental tests show that these proposed crack measures can be transformed into existing crack definitions with over 90 percent accuracy as compared to human established ground truth. The proposed framework will establish a crucial foundation towards national standardized pavement performance measures.
Cracking is one of the most common types of pavement distresses. It is usually caused by constant overloading, asphalt aging, environmental impact, and improper structural design, etc. Progressive cracking can weaken pavement because it allows water into the base and accelerates the pavement deterioration. The proper treatment of pavement cracks is important for cost-effective pavement maintenance. Crack evaluation is a necessary component in most pavement surface condition surveys and is required by Federal Highway Administration (FHWA) through the Highway Performance Monitoring System (HPMS) (1). To fulfill the need of MAP-21, the AASHTO standing committee on performance management also suggests using pavement crack data as part of the pavement performance measures (2). Many state agencies, including the Georgia Department of Transportation (GDOT), the Texas Department of Transportation (TxDOT), etc., have invested major resources in their pavement condition survey to enhance their decision-making capabilities.

Traditionally, the collection of pavement crack data is done by visual and manual inspection in the field. Due to the significant diversity among Federal and state DOTs’ pavement distress protocols, it remains a challenge to establish consistent, nationwide crack measures for this manual crack data collection process. On one hand, most state DOTs have been collecting and maintaining their legacy data over decades and are not willing to change their own distress protocols. On the other hand, collecting crack data following both a DOT’s legacy protocol and a separate national standard requires extra resources, which is not optimal given the current and projected budgetary constraints.

In recent years, automatic crack data collection and evaluation has been gaining attention among transportation agencies and researchers. Sensing techniques on pavement data collection have been evolving dramatically over the past two decades, from real-time digital imaging (3) with the assistance of artificial lighting (4), to stereo vision photogrammetric systems (5) and 3-D line laser imaging (6). The automatic pavement surface data collection with the emerging sensing techniques has started to supplement and gradually replace the manual process with better data quality, safety, and productivity.

In the meantime, diverse approaches to automatic crack analysis, including detection and classification, have also been studied. However, the crack properties explored in most literature are still preliminary; however, the real-world crack protocols from transportation agencies use a much more complicated crack definition involving human identification of complex crack patterns, which hasn’t been comprehensively modeled in previous studies (7). For example, different crack types and severity levels may share similar crack orientations and amounts. Numerous large-scale studies (8-11) have shown that current automatic crack classification and quantification survey results don’t necessarily reproduce the manual survey results.

In order to represent the real-world complex crack patterns, Tsai et al. (7) proposed the multi-scale Crack Fundamental Element (CFE) model to provide rich and systematic crack properties for crack classification. The objective of this paper is to extend the previous study by proposing an implementable framework for standardizing national pavement crack measures that utilizes the data derived from the emerging sensing technology and characterizes pavement surface cracks in a systematic and comprehensive manner. This paper is organized as follows: this section introduces the background and research objective. The second section uses GDOT’s distress protocol as
an example to demonstrate the complexity of crack definitions in a real-world protocol. The third section presents the proposed framework for standardizing crack measures. The fourth section demonstrates the compatibility of the proposed framework and existing legacy protocols from transportation agencies. The last section concludes the paper and recommends future research.

CRACK EVALUATION ON GEORGIA ASPHALT PAVEMENT

The Pavement Condition Evaluation System (PACES) \(^{(12)}\) is designed for conducting the annual pavement surface condition survey in Georgia. A total of ten types of distresses have been identified, including load cracking, block/transverse cracking, reflection cracking, edge distress, rutting, raveling, bleeding/flushing, corrugation/pushing, patches and potholes, and loss of section. Both the presence of these distresses and their corresponding severity levels must be measured in a field survey. Load cracking and block/transverse cracking are the two most common distresses in Georgia.

Load cracking is caused by repeated heavy loads and always occurs in the wheel paths. Figure 1 shows the illustrations of four different severity levels of load cracking. Severity Level 1 usually starts as a single longitudinal crack in the wheelpath, as shown in Figure 1(a). Severity Level 2 has a single or double longitudinal crack with a number of short transverse cracks intersecting, as shown Figure 1(b). The crack width in this severity level is larger than Severity Level 1 cracks. Severity Level 3 shows an increasing number of longitudinal and transverse cracks in the wheelpath. This level of cracking is marked by a definite, extensive pattern of small polygons, which are formed by the intersection of these cracks, as shown in Figure 1(c). Severity Level 4 has the definite “alligator hide” pattern but has deteriorated to the point that the small polygons are beginning to pop out, as shown in Figure 1(d).
Unlike load cracking, block/transverse cracking (B/T cracking) is caused by weathering of the pavement or shrinkage of cement-treated base materials. B/T cracking is not load related and, therefore, is usually distributed uniformly throughout the roadway. Figure 2 shows illustrations of three different severity levels of B/T cracking. Severity Level 1 is made up of transverse, longitudinal, or a combination of both types of cracks, but the block pattern has not developed yet, as shown in Figure 2(a). Severity Level 2 has a definite block pattern, as shown Figure 2(b), and Severity Level 3 has a very large number of small blocks, as shown in Figure 2(c). It needs to be noted that for both Severity Level 2 and Severity Level 3, some of the cracks may meander into the wheelpaths for short distances but are still considered as B/T cracking.
Based on the definitions of load cracking and B/T cracking, the evaluation of these cracks involves the identification of the changing and complex crack patterns for different severity levels. It is challenging to rely on preliminary crack characteristics, such as crack orientation and crack amount, to differentiate them, especially when multiple crack types and severity levels appear on the same image.

**PROPOSED FRAMEWORK FOR STANDARDIZING CRACK MEASURES**

Crack pattern, together with other crack characteristics, is crucial for differentiating crack types and severity levels in transportation agencies’ pavement survey practices. Tsai, et al. (7) defines a Crack Fundamental Element (CFE) by clustering a group of cracks with a bounding box based on the cracks’ spatial proximity to better present their topological patterns. It starts from groups of pixels which form an approximately linear structure as the initial CFEs, and gradually clusters into higher scales. This multi-scale CFE model not only topologically represents crack patterns, but also provides rich crack properties at three different scales (fundamental crack properties, aggregated crack properties, and CFE cluster geometrical properties), which can be used as standardized crack measures for different transportation agencies. Figure 3 shows the concept of sensor-based multi-scale crack analysis using the CFE model.
Figure 4 demonstrates the three scales of crack properties in a more intuitive way. Fundamental crack properties focus on each crack segment and describe the fundamental and physical properties of cracks; aggregated crack properties focus more on crack patterns inside the clustered CFE and represent how cracks interact with each other, include crack intersection, crack piece, and crack network; clustered CFE geometrical properties treat each CFE as a whole and describe its overall properties. From the bottom, the model represents more on the physical characteristics of pavement cracks; from the top, it tends to mimic the pavement engineers’ manual evaluation procedure in the field (from the macro to the micro levels of observation). When experienced pavement engineers conduct a condition survey, they do not usually measure the crack width and depth first; instead, they first identify a group of cracks that should be clustered together; then, they look at the crack pattern inside the cluster and, finally, they measure the physical and fundamental crack properties if necessary. By clearly defining three scales of crack representation, this approach can better incorporate both physical crack properties and the logic of human judgment. Figure 4 also illustrates the idea of abstracting real-world crack characteristics into consistent crack properties and transforming these properties into specific distress protocols (load cracking defined in GDOT’s COPACES protocol as an example). The focuses of the entire framework are consistency and flexibility: the multi-scale crack representation is completely based on the physical crack characteristics on the pavements, and is independent from different distress protocols, while the extracted crack properties are fully compatible with existing legacy protocols (the different severity levels of load cracking shown as an example).
FIGURE 4 Illustration of abstracting crack properties from the data and transforming them into specific distress protocol

EXPERIMENTAL TESTS

Overview: from Standardized Crack Measures to State Legacy Protocols

This section uses GDOT’s COPACES protocol to demonstrate the capability of the proposed crack measures to be flexibly transformed into Federal and state DOTs’ existing distress protocols, which is critical to reducing the data collection efforts for both Federal and state needs. This is essentially a crack classification process: instead of classifying cracks using the raw data or detected crack map, this process takes the proposed crack measures as features to construct and calibrate a classifier. Table 1 shows the selected crack measures that have been used in this study to classify load cracking, B/T cracking, and their severity levels.

**TABLE 1 Crack measures used as features for crack classification**

<table>
<thead>
<tr>
<th>Fundamental Crack Properties</th>
<th>Aggregated Crack Properties</th>
<th>CFE Cluster Geometrical Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of longitudinal cracks</td>
<td>Length of total cracks</td>
<td>Length of clustered CFEs</td>
</tr>
<tr>
<td>Length of total cracks</td>
<td>Ratio of longitudinal to total crack length</td>
<td>Width of clustered CFEs</td>
</tr>
<tr>
<td>Ratio of longitudinal to total crack length</td>
<td>Number of initial CFEs</td>
<td></td>
</tr>
<tr>
<td>Number of initial CFEs</td>
<td>Number of continuous crack lines</td>
<td></td>
</tr>
<tr>
<td>Number of continuous crack lines</td>
<td>Average crack width</td>
<td></td>
</tr>
<tr>
<td>Average crack width</td>
<td>Maximum crack width</td>
<td></td>
</tr>
<tr>
<td>Maximum crack width</td>
<td>Number of crack intersect points</td>
<td></td>
</tr>
<tr>
<td>Number of crack intersect points</td>
<td>Area of surface loss</td>
<td></td>
</tr>
<tr>
<td>Area of surface loss</td>
<td>Crack distribution based on orientations</td>
<td></td>
</tr>
<tr>
<td>Crack distribution based on orientations</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Using these features, this study employs an approach that combines machine learning technique and heuristic rules from engineering experiences to transform these crack properties into corresponding crack types and severity levels. In order to demonstrate the performance of the proposed approach, a field validation is conducted on State Route 236 in Atlanta, Georgia. The selected project starts from Milepost 0 to about Milepost 6.8; the pavements in the project have excessive amount of load cracking and B/T cracking. With help from GDOT’s pavement engineers, each pavement image is visually reviewed, and the presence and severity level of load cracking and B/T cracking are manually labeled. The data from each crack type and severity level are randomly separated into two sets: 70% of the data are used for model training and calibration, while 30% are used for testing. The experimental results are presented in the following subsections.

**Experimental Results**

Based on the experimental results, the proposed crack measures provides an accuracy of 92.2% on correctly identifying load cracking and its four severity levels on a test set of 701 images, and an accuracy of 98.1% on correctly identifying B/T cracking and its three severity levels on a test set of 368 images. Some representative cases are shown in the Figure 5.
CONCLUSIONS AND RECOMMENDATIONS

The development of sensing techniques brings the opportunity to establish nationwide, consistent pavement crack measures. This paper proposes an implementable framework for sensor-based standardized crack measures. These crack measures achieve consistency, since the multi-scale crack representation based on a CFE model is completely based on the physical crack characteristics of the pavements and is independent from different distress protocols. They are also fully compatible with state DOTs’ crack definitions and Federal standards. The experimental tests use load cracking and B/T cracking in GDOT’s COPACES protocol as an example and demonstrate how these standardized crack measures can be transformed into various crack definitions in existing protocols. Overall, the proposed framework provides consistent crack measures to fulfill the need of MAP-21 and, also, maintains the legacy of state DOTs’ historical data and pavement management practices; it streamlines the data collection efforts for both Federal and state needs. For future research, more crack definitions in different federal and state distress protocols need to be explored to further revise and enrich the proposed crack measures.

ACKNOWLEDGEMENTS

The work described in this paper was sponsored by the US Department of Transportation RITA program and the Georgia Department of Transportation. The views, opinions, findings and conclusions reflected in this presentation are the responsibility of the authors only and do not represent the official policy or position of the USDOT, RITA, GDOT, or any state or other entity. Special thanks to GDOT Office of Maintenance and Mr. Thomas Mims for reviewing and labeling the collected pavement images.

REFERENCES


(4) Xu, B., Artificial Lighting for the Automated Pavement Distress Rating System. Austin, TX, 2005.


(12) Georgia Department of Transportation - Office of Maintenance, Pavement condition evaluation system (PACES), 2005.