EVALUATION OF ASPHALT PAVEMENT CRACK SEALING PERFORMANCE USING IMAGE PROCESSING TECHNIQUE

Hyoungkwan Kim
Assistant Professor, Department of Civil Engineering
Yonsei University
Shinchondong 134 Seoul, Korea 120-749
E-mail: hyoungkwan@yonsei.ac.kr

Hamid Soleymani
Assistant Professor, Department of Civil and Environmental Engineering at the University of Alberta
Edmonton, Alberta, Canada T6G 2W2
E-mail: hsoleymani@ualberta.ca

Seung Heon Han
Associate Professor, Department of Civil Engineering
Yonsei University
Shinchondong 134 Seoul, Korea 120-749
E-mail: shh6018@yonsei.ac.kr

Hana Nam
Master student, Department of Civil Engineering
Yonsei University
Shinchondong 134 Seoul, Korea 120-749
E-mail: hellohana@yonsei.ac.kr

Abstract: Crack sealing is a routine and necessary operation of pavement maintenance. Manual observation of road surfaces has been the most common method for evaluating road surface cracks around the world. However it is difficult to objectively and accurately assess the road cracks based on human visual perception. The ultimate objective of this study is to evaluate crack sealing performance on highways, in order to choose the best crack sealing practice in an automated manner. As a preliminary step, this paper discusses how to define crack sealing performance and propose a research methodology to quantify the level of road surface distress using video image processing.

Keywords: crack sealing, image processing, pavement.

1. INTRODUCTION

Pavement crack sealing is a routine and necessary operation of pavement maintenance. This operation cost is approximately US$ 260 million every year in the USA and Canada. The crack sealing with appropriately selected material and procedure can significantly improve the serviceability and lifespan of pavement infrastructure. However, it is difficult to understand which crack sealing practice should be used as the best pavement preservation method. To the end, the main objective of this study is to evaluate the performance of crack sealing on highways. This paper proposes an image processing-based system to evaluate the crack sealing performances. This paper also addresses the important issue of how to define crack sealing performance and present a conceptual design of an image processing-based system to quantify crack sealing performance.

2. CRACK EVALUATION

2.1 Crack Mode

One of the most important aspects of this study is what criteria need to used to measure the crack sealing performance. Although there have been some efforts to describe distresses (loss or failure) in the sealed cracks, no standardized method has been adopted to quantitatively evaluate the status of the sealed cracks.

Generally, the failure modes in sealed cracks can fall into the four categories: adhesive loss, cohesive loss, pull-outs, and secondary crack:

· Adhesive loss refers to the gap between the sealant material and the adjoining pavement edge. This failure can occur when there is insufficient bonding between the two heterogeneous materials (Figure 1).
· Cohesive loss refers to the fractures within the sealant material. It is generally a result of the internal stress caused by pavement expansion and contraction.
· Pull-outs refer to a complete removal of the sealant material in the particular portion of the sealed crack. This failure generally occurs by the combined effect of adhesive and cohesive loss (Figure 1).
· Secondary crack refers to the crack that has occurred as the continuation from the existing crack (Carter et al. 2005).

Each one of the above failure mode could also be divided into its sub-categories based on the severity of distresses. Other failure modes or distress descriptions that have been used include weathering, overband wear, tracking, stone intrusion, edge deterioration, crazing, pattering, etc. While these terms are useful in describing the particular nature of the failure, their implications are subjective and overlapping with other terms. For the accurate evaluation of the crack sealing performance, it is essential to have a well thought-out definition of the loss or failure of sealed cracks.

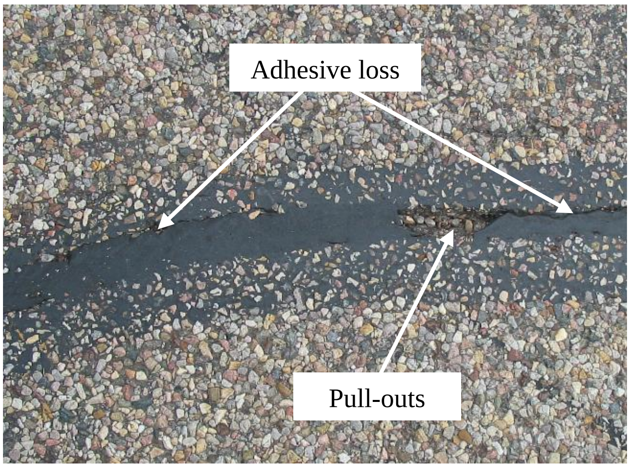


Figure 1. Sealed cracks showing two modes of failures: adhesive loss and pull-out

2.2 Review of Crack Evaluation Technique

Manual observation of road surfaces has been the most common method for evaluating road surface cracks around the world. Inspectors walk on the roadways to visually understand and record where cracks exist, what types of cracks they are, and how severe they are. However, for many reasons, it is difficult to objectively and accurately assess the road cracks based on human visual perception. First, there are not enough inspection personnel who can be deployed to cover the vast area of road surfaces. Second, even the most experienced and best trained inspectors tend to produce significantly different opinions on the same road surface cracks. In many cases, the same road surface could be evaluated differently even by the same inspector if there exists some time interval between the observations. Third, the human evaluation of road surface crack is an extremely time-consuming process. Last but not least, the human inspectors are generally exposed to high-speed traffic, raising the important concern of human safety.

Video image processing is an alternative method to collect the crack data to address the disadvantages of the visual inspection (Haas et al. 2001; Lee and Lee 2004; Feng et al. 2005; Offrell et al. 2005). A vehicle is typically equipped with one ore more video cameras to capture the image of road surfaces. Once images are obtained, they can be stored in an analog device such as video cassette or a digital computer hard disk drive and processed later to indicate the locations and types of the cracks. Previous research demonstrated that the video image processing can classify road cracks into such categories as longitudinal crack, transverse crack, alligator crack, and block crack.

Although video image processing provides ample two-dimensional crack data in the form of image, it cannot capture crack depth information. Sometimes this additional information (crack depth) gives an important clue as to how severe the crack is, so there have been several attempts to use other techniques such as laser sensing to measure three-dimensional crack data (Haas and Hendrickson 1991; Offrell et al. 2005). However, the current laser technique can scan only limited area of road surface, making it hard to produce accurate characterization of road surface cracks.

The aforementioned attempts have all been contributory to the evolution of crack evaluation techniques. Video image processing, in particular, has obtained the most attention as the major technique for automating crack evaluation process. However, their application has been limited only to the identification of crack locations and types. This paper proposes to use image processing not just to identify the location and type of cracks but also to quantify the level of distress of sealed cracks.

3. PROPOSED METHODOLOGY

In this section, a research methodology is presented. The main technology that is suggested in this paper is image processing technique. Considerable effort will be made to evaluate the feasibility of video image processing for its ability to accurately quantify the distress level of sealed cracks. To our knowledge, this is the first to propose the video image processing to evaluate the distress level of sealed cracks. To ensure the successful completion of this proposed research, visual inspection is also proposed in parallel with image processing for evaluating the crack sealing performance.

3.1 STEP1: Develop a Practical and Intuitive Definition of Crack Sealing Performance

The crack sealing performance could be defined as the failure level of the sealing on a length basis. For example, in the case of evaluating adhesive loss, the length of the adhesive failure can be compared to the total crack length, producing a certain percentage figure indicating how severe the adhesive loss is (Figure 2). In the same manner, the severity of cohesive loss or pull-outs can be quantified. The three failure modes (adhesive loss, cohesive loss, and pull-outs) could also be added up to produce their combined length, which can be compared to the total crack length, in order to produce a comprehensive distress definition of sealed cracks. Alternatively, an area based definition can be used for evaluating the crack sealing performance as long as the area of failure and the area of sealed cracks are accurately measured.

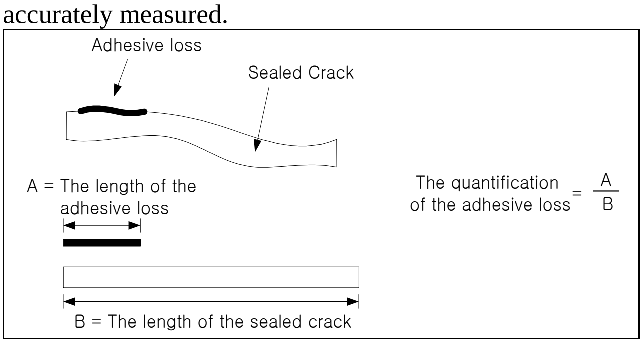


Figure 2. An example of the quantification of adhesive loss

3.2 STEP2: An Alternative Method for Crack Sealing Evaluation

The objective of this step is to develop an alternative method for a rapid assessment of crack sealing performance. Traditionally, the distress of road surfaces has been evaluated by human visual inspection. However, the visual inspection is time-consuming and subject to human errors because any field inspector can have his/her own qualitative criteria. We propose video image processing as a promising approach for evaluating crack sealing performance. Image analysis can be automated, configured to work in a continuous data acquisition and analysis mode. Furthermore, a two dimensional imaging technique (as opposed to three dimensional sensing techniques such as laser sensing) will provide the best balance between speed, accuracy, and cost for this application.

We propose a prototype analyzer of crack sealing performance, using off-the-shelf hardware and customized software. The prototype apparatus may incorporate five to six video cameras (machine vision type CCD (Charge Coupled Device) cameras) to secure the required resolution. Using the prototype assembly, a series of preliminary field experiments is proposed to discover avenues for improvement. This should be an iterative process in which results are used to modify and refine the prototype analyzer of crack sealing performance to achieve the desired system performance.

3.3 STEP3: Collect the Data of Crack Sealing Performance

Test sites where old sealed cracks exist are proposed to be inspected using two different methods: visual inspection and video image processing. By correlating the result from the visual inspection with that of the video image processing, we can ensure that the analysis from the video image processing are consistent with the realities of infrastructure management. This approach is expected to enable accurate and quantitative analyses of the crack sealing performances, as well as comprehensive documentation of the cracks in image format.

3.4 STEP4: Analyze the Crack Sealing Data

The data collected in Step 3 are then analyzed in this step. Various parameters, such as a range of sealant products, rout profiles, pavement structures, and climatic conditions, and seasonal conditions, should be carefully evaluated to identify their impact on the crack sealing performance. It is also be interesting to see how the evaluated crack sealing performance affects the International Roughness Index (IRI).

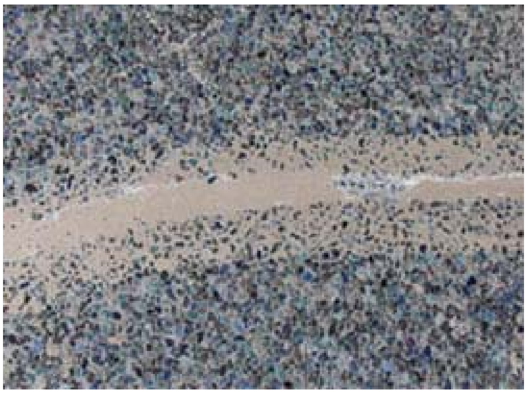
4. CASE STUDY

In 1994, several crack sealing practices were performed on roadways in Alberta, in particular, Highway 63:00 (north of highway 28 to south of Newbrook, kilometre 13.000 to kilometre 18.000) was chosen as the main "research" site for the long term evaluation of crack sealing performance. Eight crack sealant products (Hydrotech 6160, Husky 1611, Elsro 1191, Koch 9030, Bakor 590-13A, Crafco 522, Beram 195, and Super-Flex 100) were used with two different rout profiles (wide profile (40 x 10 mm) and narrow profile (19 x 19 mm)) Also two different compressed airs (hot-compressed-air and cold-compressed -air) were used to blow the crack to remove small debris before the sealant was poured into the crack. All the cracks on the test site were recorded along with their sealing materials and construction methods. This site is a good example of where the proposed methodology can be applied to.

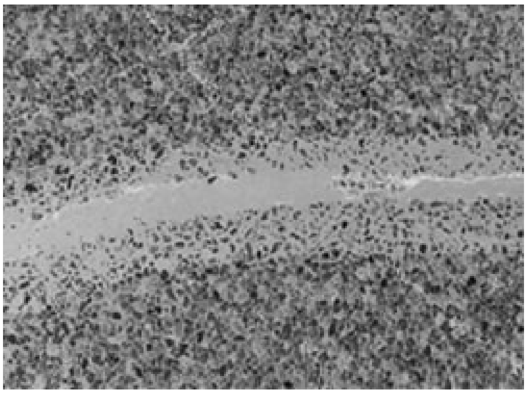
Figure 3 shows an example process for identifying the distress of a sealed crack. Figure 3 (a) is the original image that shows adhesive loss and pull-outs type failures.

- First, the complement of the original figure is obtained, as shown in Figure 3 (b). In other words, each pixel value is subtracted from its possible maximum value, and the calculation result replaces the original pixel value. This is to represent the region of distress in a distinguished manner. The failure area is shown in white color.
- Second, for the effective utilization of existing image processing algorithm, the complement color image is changed into a grayscale image, as shown in Figure 3 (c). This transformation is also for efficient computation because grayscale image manipulation requires less computational power than color images requires.
- Third, binary gradient mask is calculated based on the grayscale image (Figure 3 (d)). The binary gradient mask shows lines with high contrast of light intensity of the image. This gradient mask is useful to represent a range of texture content of the image. That is, the sealed crack area with no distress shows a uniform texture which is distinguished from the texture of other regions.
- Fourth, a dilation operation is conducted on the gradient mask image, resulting in Figure 3 (e). This dilation operation is a type morphological operation which relies on a structuring element. The dilation operation has the effect of simplifying the sealed crack region and background region, respectively. In other words, those lines showing gradient information are merged together to create a region with improved consistency.
- Fifth, a hole-filling algorithm is applied. After the dilation operation is executed, there are still noisy holes in the non-crack region of the road surface. These holes are filled by the hole-filling algorithm, as shown in Figure 3 (f).
- Sixth, the original color image (Figure 3 (a)) is binarized into a black and white image (Figure 3 (g)). Based on a threshold value, each pixel value of the original image becomes either 0 or 255.
- Finally, the binary image obtained from the sixth step is compared with the binary image obtained from the fifth step. The two images are complementary to each other. Therefore, the logical "and" operation is used to find the pixel location that has white value in both images. This process produces Figure 3 (h), which displays the failure regions of the sealed cracks.

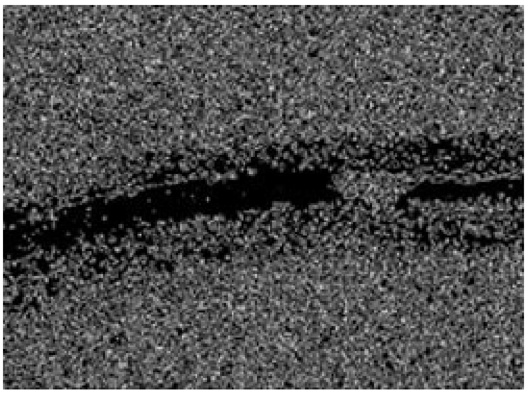
(a) Original figure



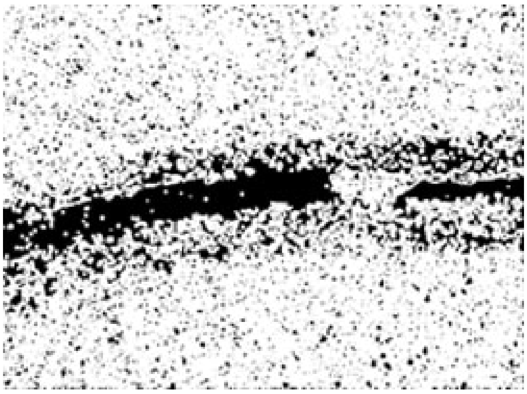
(b) Complement of image



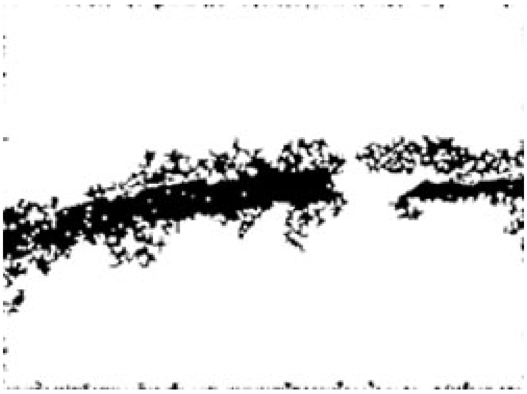
(c) Grayscale image



(d) Binary gradient mask



(e) Dilated gradient mask



(f) Binary image with holes filled

(g) Binary image from the original figure

(h) Final extraction of the distress of a sealed crack

Figure 3. Crack extraction process

The comparison between the failure region of the sealed crack in Figure 1 (a) and the white region in Figure 1 (h) indicates that the proposed method is promising in extracting the distress region of sealed cracks. The proposed method illustrates a preprocessing example of how the failure region of a sealed crack image is extracted. The future works should address the issues of how robust the proposed method is, how to label the identified failure regions, and, most importantly, and how to quantify the level of distress of the failure region.

5. CONCLUSION

Crack sealing is an essential maintenance strategy for pavement infrastructure, especially in North America. Various types of sealing practices have been used. However, it has been difficult to understand which sealing practice produces the best performance in terms of being able to protect road surfaces from water intrusion. It is because evaluation of the sealed cracks is generally done by manual observation, which requires significant amount of time and efforts. This paper proposed an image processing based research plan to evaluate crack sealing performance. Although the proposed method is in its conceptual stage yet, when the method is coupled with high-resolution image capturing devices installed on a vehicle, it has the potential for accurate and quantitative assessment of crack sealing performance.

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