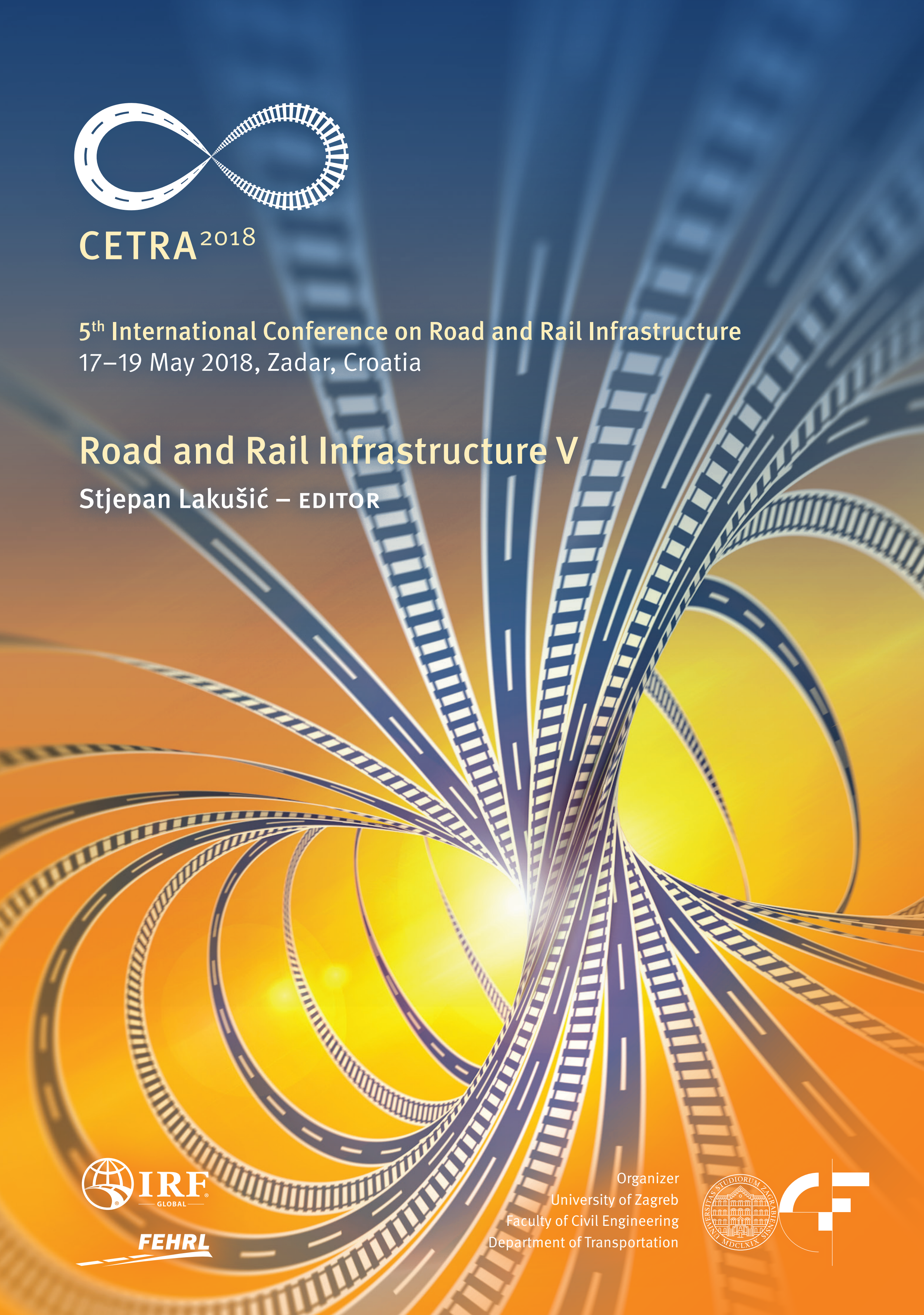

CETRA2018

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

IRF GLOBAL

FEHRL

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

CETRA^{2018}
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

TITLE
Road and Rail Infrastructure V, Proceedings of the Conference CETRA 2018

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

ISBN
978-953-8168-25-3

DOI
10.5592/CO/CETRA.2018

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
“Tiskara Zelina”, May 2018

COPIES
500

Zagreb, May 2018.

Although all care was taken to ensure the integrity and quality of the publication and the information herein, no responsibility is assumed by the publisher, the editor and authors for any damages to property or persons as a result of operation or use of this publication or use the information’s, instructions or ideas contained in the material herein.
The papers published in the Proceedings express the opinion of the authors, who also are responsible for their content. Reproduction or transmission of full papers is allowed only with written permission of the Publisher. Short parts may be reproduced only with proper quotation of the source.

Proceedings of the
5th International Conference on Road and Rail Infrastructures – CETRA 2018
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

CETRA^{2018}
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

ORGANISATION

CHAIRMEN

Prof. **Stjepan Lakušić**, University of Zagreb, Faculty of Civil Engineering
Prof. emer. **Željko Korlaet**, University of Zagreb, Faculty of Civil Engineering

ORGANIZING COMMITTEE

Prof. **Stjepan Lakušić**
Prof. emer. **Željko Korlaet**
Prof. **Vesna Dragčević**
Prof. **Tatjana Rukavina**
Assist. Prof. **Ivica Stančerić**
Assist. Prof. **Maja Ahac**
Assist. Prof. **Saša Ahac**
Assist. Prof. **Ivo Haladin**
Assist. Prof. **Josipa Domitrović**
Tamara Džambas
Viktorija Grgić
Šime Bezina
Katarina Vranešić
Željko Stepan
Prof. **Rudolf Eger**
Prof. **Kenneth Gavin**
Prof. **Janusz Madejski**
Prof. **Nencho Nenov**
Prof. **Andrei Petriaev**
Prof. **Otto Plašek**
Assist. Prof. **Andreas Schoebel**
Prof. **Adam Szeląg**
Brendan Halleman

INTERNATIONAL ACADEMIC SCIENTIFIC COMMITTEE

Stjepan Lakušić, University of Zagreb, president
Borna Abramović, University of Zagreb
Maja Ahac, University of Zagreb
Saša Ahac, University of Zagreb
Darko Babić, University of Zagreb
Danijela Barić, University of Zagreb
Davor Brčić, University of Zagreb
Domagoj Damjanović, University of Zagreb
Sanja Dimter, J. J. Strossmayer University of Osijek
Aleksandra Deluka Tibljaš, University of Rijeka
Josipa Domitrović, University of Zagreb
Vesna Dragčević, University of Zagreb
Rudolf Eger, RheinMain Univ. of App. Sciences, Wiesbaden
Adelino Ferreira, University of Coimbra
Makoto Fujiu, Kanazawa University
Laszlo Gaspar, Széchenyi István University in Győr
Kenneth Gavin, Delft University of Technology
Nenad Gucunski, Rutgers University
Ivo Haladin, University of Zagreb
Staša Jovanović, University of Novi Sad
Lajos Kisgyörgy, Budapest Univ. of Tech. and Economics
Anastasia Konon, St. Petersburg State Transport Univ.
Željko Korlaet, University of Zagreb
Meho Saša Kovačević, University of Zagreb
Zoran Krakutovski, Ss. Cyril and Methodius Univ. in Skopje
Dirk Lauwers, Ghent University
Janusz Madejski, Silesian University of Technology
Goran Mladenović, University of Belgrade
Tomislav Josip Mlinarić, University of Zagreb
Nencho Nenov, University of Transport in Sofia
Mladen Nikšić, University of Zagreb
Andrei Petriaev, St. Petersburg State Transport University
Otto Plašek, Brno University of Technology
Mauricio Pradena, University of Concepcion
Carmen Racanel, Tech. Univ. of Civil Eng. Bucharest
Tatjana Rukavina, University of Zagreb
Andreas Schoebel, Vienna University of Technology
Ivica Stančerić, University of Zagreb
Adam Szeląg, Warsaw University of Technology
Marjan Tušar, National Institute of Chemistry, Ljubljana
Audrius Vaitkus, Vilnius Gediminas Technical University
Andrei Zaitsev, Russian University of transport, Moscow

CETRA2018 17–19 May 2018, Zadar, Croatia
5th International Conference on Road and Rail Infrastructure

A STUDY ON IMAGE DIAGNOSTIC TECHNOLOGY FOR BRIDGE INSPECTION USING ULTRA HIGH RESOLUTION CAMERA

Takahiro Minami[1], Makoto Fujiu[2], Junichi Takayama[3], Shinya Suda[4], Shuya Okumura[4]
[1] *Kanazawa University, Department of Environmental Design, Japan*
[2] *Kanazawa University, Department of Environmental Design, Japan*
[3] *Kanazawa University, Department of Environmental Design, Japan*
[4] *WorldLink & Company SkyLink Japan, Japan*

Abstract

In Japan, there are now approximately 730,000 road bridges, 2.0 m or longer. In 2013, about 18 % of these bridges had been in service for more than 50 years, which is considered the normal service life of a bridge, and it is predicted that in 10 years, about 43 % of them will have reached this age. Moreover, deformation by deterioration of the bridge structure has appeared in those parts that have undergone emergency repairs, which are underwater or are exposed to harsh local environments. Under such circumstances, in Japan, the Ministry of Land, Infrastructure, Transport, and Tourism has, since 2014, mandated regular close visual inspections of bridges once every 5 years and adopted a policy of extending the service lifetime of bridges. That means replacing corrective with preventive maintenance in order to prolong the service life of existing bridges. However, in order to carry out close visual inspection, it is necessary to install a scaffold or use bridge inspection vehicle, which are costly and laborious. It is difficult for local government facing a shortage of financial resources and human resources to carry out the current inspection continuously. Therefore, in this research, we propose image diagnostic technology using super high resolution camera to inspect an enormous number of bridges considering efficiently and continuously. By using image of 100 million pixels, we developed an inspection environment that is almost the same as an actual visual inspection. Some inspection workers diagnosed crack of concrete bridge pier in the inspection environment, and the usability of image diagnostic technology as inspection tool was verified

Keywords: bridge inspection, super-high-resolution camera, crack detection, UAV

1 Introduction

In Japan, there are about 730,000 bridges with a length of 2 m or longer, and many of these were built during a period of high economic growth. Bridges that were built during the period of high economic growth or later age together, and, the ratio of aged bridges (50 years or older) was about 18 % in March 2013. This is expected to rapidly increase to about 43 % in 10 years, and 67 % in 20 years [1]. Parts that were repaired during emergencies and bridges placed in harsh environments age notably. About 2,300 bridges managed by local public organizations had their traffic regulated in 2015. This increased by 2.4 times in the seven years after 2008 [2]. It is an urgent issue to strategically manage and update infrastructures that are aging together.

DOI: https://doi.org/10.5592/CO/CETRA.2018.828

Under these circumstances, there is a shift from breakdown maintenance that attempts countermeasures after major damage occurs, to preventive maintenance that extends the healthy lifespan of bridges by taking countermeasures while the damage is mild. To take preventive countermeasures, bridges must be inspected and diagnosed routinely, and the health condition of bridges must be well understood. In 2014, with a comprehensive standard stipulated by the federal government, the close visual inspection of all bridges by road maintenance staff was required every five years. By performing routine inspections, the most up-to-date status should be understood, and information necessary to determine the necessity of measures is acquired, thus making preventive maintenance management possible.

The authors used the results from routine inspections to statistically analyze factors (environmental and structural conditions) that influence deterioration, and proposed a method to prioritize the repair of bridges [3]. There are also studies toward building a deterioration prediction model from the results of routine inspections [4–6]. By accumulating the results of routine inspections, maintenance management plans can be created effectively.

However, among local public organizations, there are some that have insufficient manpower relative to the number of bridges to manage, as well as insufficient funding for maintenance. Thus, these organizations are unable to perform routine close visual inspections. In a questionnaire on mandating local public organizations to perform close visual inspections every five years [7], insufficient funding and manpower were noted as problems with inspection tasks. Specific problems included “notably less staff and consulting technicians relative to number of bridges to be managed” and “high inspection cost preventing from funding for repair.” In particular, in small municipalities (cities, wards, towns, and villages), there are not many civil engineers involved with bridge maintenance work, and the inspection costs that can be spent on each bridge are much lower compared to large-scale municipalities such as prefectures. Therefore, municipalities such as cities, towns, and villages have difficulty conducting continuous preventive maintenance owing to insufficient funding and manpower.

With these issues in mind, we propose a new inspection method to replace the current close visual inspection. The current close visual inspection requires visual inspection of members under the beam, which is difficult to access. Thus, scaffolding is built, or aerial work vehicles and bridge inspection vehicles are used. However, building scaffolding has issues with cost and efficiency, and aerial work vehicles and bridge inspection vehicles are extremely expensive, even if rented. As it is accompanied by traffic control, it causes economic loss. In this study, to develop an alternative method to the current close visual inspection, we examined the practical potential of bridge inspections using images captured with a super-high-resolution camera.

2 Previous studies and importance of present study

There are many studies on the imaging potential and diagnostic potential for damage to develop a remote imaging system to replace close visual inspections.

In recent years, there have been studies that use machine learning or AI in the maintenance management of bridges. For example, HG Melhem et al. [8] attempted to predict the remaining service period of bridges using deep learning. They saw that the prediction precision was low at 41.8 %. The reason is that teaching data used in deep learning is incomplete, and the precision of the deterioration model is low.

ChristianKoch et al. [9] summarized studies on the deterioration of infrastructures using methods such as deep learning, neuro-fuzzy theory, and support vector machines. Young-Jin Cha et al. [10] proposed a method to automatically classify the degree of damage using deep learning. However, the method gave only laboratory results, and the deterioration of concrete used outdoors could not be accurately classified owing to the impact of shadows, dirt, etc. Furthermore, Chen, P.-H et al. [11–12] built an evaluation method for damage to concrete structures and bridges using neuro-fuzzy theory and a support vector machine. The results showed that although damages to concrete and steel can be classified, damage needs to be evaluated. On the other hand, C. Koch, S. Paal et al. [13] proposed a more efficient method to inspect massive numbers of concrete structures by using image analysis and 3D modeling technology. The results showed that 3D modeling of a concrete structure notably improves the detection speed of damage.

As shown, there are many studies on the classification, detection, and automatic detection of deterioration and damage. However, there has not been a proposal for a method to identify cracks in piers from a single high-resolution image while verifying the potential of routine bridge inspections using images taken with an ultra-high-resolution camera.

In this study, we used images of an entire pier with 100 million pixels taken with a super-high-resolution camera, and created an inspection environment similar to that of on-site close visual inspections by human inspectors. By having people with experience in bridge inspection performing inspections and diagnostic experiments with the images, we verified the diagnostic potential of cracks in concrete based on images. We utilized image recognition technology to prepare AI that identifies cracks, and proposed a method that delineates locations with cracks based on the entire image of a pier.

The super-high-resolution camera (Phase One) used in this study is able to centrally understand parts that exhibit even minor damage, based on a single image of a pier, by utilizing a scaling function. The brightness, saturation, and contrast of the captured images can be freely adjusted. Thus, this method can photograph areas under beams where light does not enter easily and photography is usually difficult. In addition, the camera itself is relatively easy to use and can be mounted on a UAV. Thus, the limitations on the users and imaging locations are minor.

3 Photography experiment using super-high-resolution camera

In this study, we used a Phase One Industrial iXU-RS 1000 aerial camera. The iXU-RS 1000 aerial camera is a super-high-resolution camera with a dynamic range of 84 db or higher, pixel size of 4.6 microns, photosensitivity/ISO of 50–6400, and maximum shutter speed of 1/1,600 s. It is able to take photographs of 100 megapixels (11,608 × 8,708). Photographic image data captured with this super-high-resolution camera use about 600 MB per photo and can be browsed using specialized software (Capture ONE). Brightness, saturation, and contrast can be adjusted as needed. The size of the super-high-resolution camera is 97.4 × 93 × 170.5 mm, with a weight of 930 g. Thus, it is quite mobile and can be mounted on a UAV, so it can be used to take photos of bridges that are difficult to approach by bridge inspection vehicles and boats

The target bridge was a double-span steel-welded bridge with I-beams (noncomposite) having a length of 41.30 m and total width of 4.70 m in Hakui City, Ishikawa Prefecture. The analysis target member was a T-shaped pier (RC). It was built in 1967 and was inspected in November 2016. The target member pier was evaluated as a classification of II, and cracks, water leakage, and stagnant water were confirmed. Since the condition under the road was a river, traffic was restricted during the routine inspection in 2016, and a bridge inspection vehicle was used.

Photographs were taken on Friday, October 27, 2017, for 2 h and 30 min between 12:30 and 15:00. All members (superstructure, substructure, and bearings) of the target bridge were photographed from all four cardinal directions. To take overall photographs and side views of the bridge, we mounted the super-high-resolution camera on a UAV and took photographs from three directions: upstream, downstream, and directly above. Since this was just after a flood, the scaffolding was not in good condition. Thus, instead of a tripod, we set up a table and placed the super-high-resolution camera on the table. Photographs were taken by changing the angle. We took 182 photographs to cover all members of the target bridge of this study.

4 Diagnostic experiment using image with 100 million pixels

4.1 Construction of diagnostic experimental environment

Using a 52-inch 4K-resolution monitor and designated software (Capture ONE), we created a setting where the entire image of the pier, captured with the super-high-resolution camera, can be observed. Brightness, saturation, and contrast can be adjusted, and one can smoothly zoom in and out of the image. In this study, we used A0 paper with the entire pier printed as the media to record the diagnostic results of cracks.

4.2 Detection of cracks with an image

In the diagnostic experimental environment, two staff with civil engineering degrees but without inspection experience visually detected cracks in the image of the entire pier. To detect cracks, we repeatedly zoomed in and out of the entire image of the pier on the PC, and visually confirmed that cracks were noted on the A0 paper with the photograph of the entire pier using red lines. In this study, we focused only on the cracks and did not record the widths of the cracks. In Chapter 4, it was shown that the detection of cracks with a width of 0.1 mm is possible; thus, we detected all cracks with a width of 0.1 mm or more.

4.3 Diagnostic experiment by experienced bridge inspector

We performed a diagnostic experiment to determine if experienced inspectors can identify cracks in the image. The experienced bridge inspectors were Mr. A (Hakui City staff) and Mr. B (Ph.D. in engineering, technician in construction department/steel structures and concrete, concrete diagnostician); the inspectors zoomed in and out of the photograph of the pier on a PC. Cracks that could be visually confirmed were noted on the A0 paper with the entire image of the pier printed using red lines. Figure 1 show the diagnosis based on the image.
We interviewed the diagnosticians about the diagnostic potential of the images. Their opinions were that they were able to detect cracks in a similar manner as a close visual inspection. If we can incorporate this method in an actual inspection, there is further utility in that the inspection cost can be reduced, and diagnostic results can become more objective. However, there are some results that are difficult to identify regarding whether they are marks from construction formwork or cracks, and there is damage that is difficult to diagnose with images alone. If we can keep the record on a PC, or if a mesh can be displayed, the task will run more smoothly. These are the remaining issues for the diagnostic experimental environment.

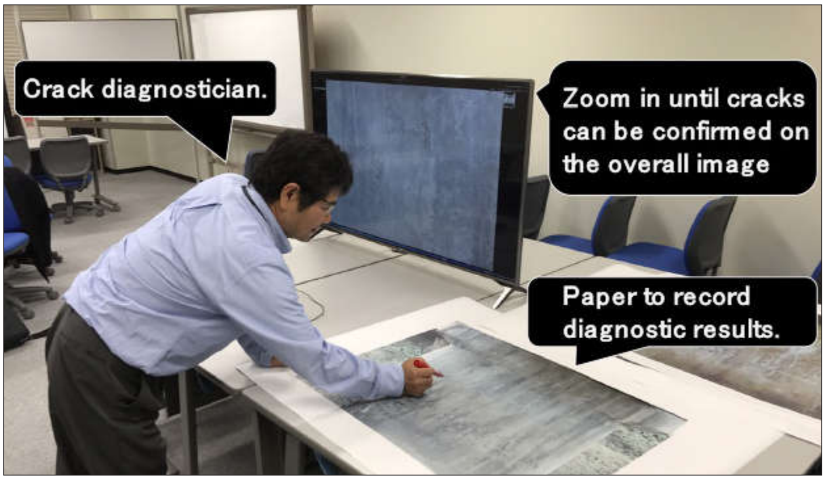

Figure 1 Diagnosing with image

5 Analysis of diagnostic potential using images captured with high-resolution camera

Participants without experience in bridge inspection diagnosed cracks using the image, and recorded the detection results of the cracks on the print of the entire pier (Figure 2 and Figure 3). Although there were some differences between the diagnosticians' results, anything that could be confirmed as a crack was comprehensively detected from the image. Next, the experienced bridge inspectors diagnosed cracks from the image and recorded the detection results of cracks on the print of the entire pier (Figure 4 and Figure 5).

Figure 2 Diagnostic results of cracks by staff inexperienced in bridge inspection

Figure 3 Diagnostic results of cracks by staff inexperienced in bridge inspection

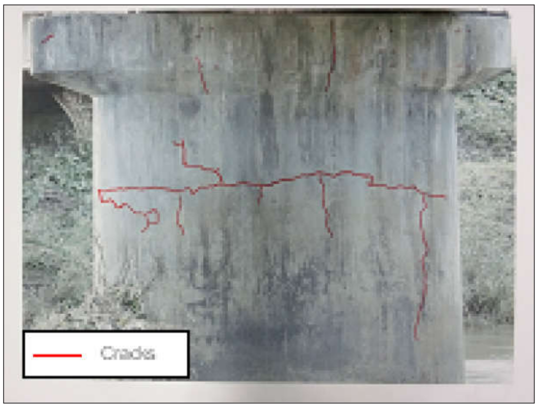

Figure 4 Diagnostic results of cracks by experienced bridge inspection

Figure 5 Diagnostic results of cracks by experienced bridge inspection

Each detection result detected the lateral crack at the center of the pier. The detected positions of the cracks were mostly the same. However, depending on the diagnostician, the detection results had slight differences. The reason for this was the participants' experience with bridge inspection. Compared to experienced bridge inspectors, inexperienced staff had a poorer ability to identify cracks, joints, and marks from formwork. Alternatively, these inexperienced staff might not even recognize the presence of joints and marks from formwork. Therefore, they could misidentify other items as cracks. Experienced bridge inspectors already know the likely sites for cracks, which allows them to find damage with more ease and to miss very few cracks.

6 Summary and future challenges

In this study, we performed photography experiments using a high-resolution camera on a real bridge. The brightness, saturation, and contrast of photographs captured with the super-high-resolution camera can be adjusted, and members under the beam that are usually difficult to be imaged with a digital camera or inspected by the naked eye can be photographed. Since this camera can be mounted on a UAV, it can photograph the side of a bridge, which is usually difficult to do. Since the mounted camera has high resolution, the distance between the UAV and the bridge can be secured. Since safety, the disadvantage of UAV imaging, can be secured with a high-resolution camera, this indicates the good compatibility of a high-resolution camera and a UAV.

As a future challenge, the potential of photographing bridges under various environments needs to be verified. For the bridge in this study, flooding rendered the scaffolding unstable, and there was a thick growth of grass, making access under the beam difficult. Existing bridges have diverse structures, crossbeams, and environments, and the difficulty of photographing varies. Therefore, in the future, by performing photography experiments on other real bridges, bridges and members that are difficult to photograph can be understood.

Using the images taken with a high-resolution camera, we performed a diagnostic experiment on the cracks and verified the diagnostic potential of the images. As a result, although there were some crack detection errors between diagnosticians, the detection results of cracks were mostly similar. Interviews with diagnosticians showed that cracks could be detected with a confidence similar to close visual inspection in the field. If this method can be incorporated into actual inspections, inspection costs can be reduced and diagnostic results can be more objective. With such comments, the utility of the bridge diagnosis from images taken with a high-resolution camera was indicated.

In this study, we performed an examination of cracks on a pier. We need to perform an examination of the diagnostic potential for other members and damage, and members and damage that can and cannot be diagnosed with images must be classified.

7 References

[1] White Paper on Land, Infrastructure, Transport and Tourism, 2016 Part II, Chapter 2, Section 2, http://www.mlit.go.jp/hakusyo/mlit/h28/hakusho/h29/pdf/np202000.pdf [as of July 17, 2017]

[2] Ministry of Land, Infrastructure, Transport and Tourism, Current situation of aging and challenges in the measures against aging, http://www.mlit.go.jp/road/sisaku/yobohozen/torikumi.pdf [as of July 17, 2017]

[3] Minami, T., Fujiu, M., Nakayama, S., Takayama, T., Chikata, Y.: Analysis of relationship between soundness of bridges and natural environments using routine bridge inspection data in Ishikawa Prefecture. J Japan Soc Civil Eng 72: 251-260, 2016.

[4] Kaito, K., Kobayashi, K., Aoki, K., Matsuoka, K.: Hierarchical Bayesian estimation of mixed Markov hazard models. J Japan Soc Civil Eng 68:255-271, 2012.

[5] Tsuda, Y., Kaito, K., Yamamoto, K., Kobayashi, K.: Bayesian estimation of Weibull hazard models for deterioration forecasting. J Japan Soc Civil Eng 62: 473-491, 2006.

[6] Kobayashi, K., Kaito, K., Oi, A., Thao, N.D., Kitaura, N.: Estimating composite hidden Markov deterioration models for pavement structure with sample missing. J Japan Soc Civil Eng 71:63-80, 2015.

[7] Japan Society of Next Generation Sensor Technology, Toward utilization of IoT in inspection tasks, A report on inspection task survey for municipal bridges [survey of challenges and needs], http://www.socialinfra.org/p_activity/questionnaire/Bridge_tenken_Digest.pdf [As of July 19, 2017]

[8] Melhem, H.G., Cheng, Y.: Prediction of remaining service life of bridge decks using machine learning. J Comput Civil Eng 17: issue 1, 2013.

[9] Koch, C., Georgieva, K., Kasireddy, V., Akinci, B., Fieguthd, P.: A review on computer vision based defect detection and condition assessment of concrete and asphalt civil infrastructure. Adv Eng Inform 29:196-210, 2015.

[10] Cha, Y.J., Choi, W., Suh, G., Mahmoudkhani, S., Buyukozturk, O.: Autonomous structural visual inspection using region-based deep learning for detecting multiple damage types. Computer-Aided Civil Infrastruct Eng, 2017.

[11] Chen, P.H., Chang, L.M.: Effectiveness of neuro-fuzzy recognition approach in evaluating steel bridge paint conditions. Can J Civil Eng 33:103-108, 2006.

[12] Chen, P.H., Shen, H.K., Lei, C.Y., Chang, L.M.: Support-vector-machine-based method for automated steel bridge rust assessment. Autom Constr 23:9-19, 2012.

[13] Koch, C., Paal, S., Rashidi, A., Zhu, A., Konig, M., Brilakis, I.: Achievements and challenges in machine vision-based inspection of large concrete structures. Adv Struct Eng 17:303-318, 2014.