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Development and practical application of a bridge maintenance management system using 3D models

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Summary

For adequate maintenance of bridge structures, it is important not only to accumulate data in a maintenance cycle but also to update and edit the data to the latest data as necessary. This paper introduces a system we have developed to identify the positions and shapes of deteriorations from photographs by generating 3D models, and to grasp their exact quantities and manage the data chronologically. It also describes how we are provisionally starting to use the system for bridge maintenance management on the Hokuriku Shinkansen railway line prior to practical application.

1. Introduction

Bridge structures must undergo periodic inspections and repairs as needed to ensure that they perform as required throughout their designed working life. However, the average age of railway bridge structures in Japan is now about 60 years 1). Furthermore, there is a growing shortage of skilled engineers for railway maintenance as the average age of workers is growing younger. We therefore need to transform the existing system to a new management system of preventive maintenance in which actions such as monitoring and repairs are performed before the structures become seriously damaged, thus dispersing the times of repairing and updating the structures. We must establish a framework for efficient, high-quality maintenance with limited resources. To achieve this, it is essential to accumulate and manage a variety of information gathered during inspection, planning and construction of bridge structures.

In the existing maintenance management, base maps for maintenance management are developed by plotting deteriorations and repairs on the extended elevations that represent on a plane the components of a bridge which is a three-dimensional structure, and are used for calculating the extent of deterioration and so forth. However, the more complicated structures become, the more time and work are required for generating extended elevations and calculating quantities. Furthermore, since in this method the visually identified deteriorations are transferred to extended elevations, the positions and sizes of such deteriorations are not precisely controlled. Also, in some cases the extended elevations are generated in different formats for inspections and repairs, which were performed using separate extended elevations. This situation has hindered the precise management of chronological data. With this background, the West Japan Railway Company has developed a system to build a sustainable maintenance cycle for bridge structures (Fig. 1), using 3D models as base maps for sharing and managing information, while also making the services more efficient and advanced. Moreover, for the practical maintenance management of bridges on the Hokuriku Shinkansen railway line, the Company has extended the system to handle structures to prevent snow damage as well as complicated bridges, developed practical functions for operation and management, and started trial use of the system. The management operations in this trial use are also introduced below.

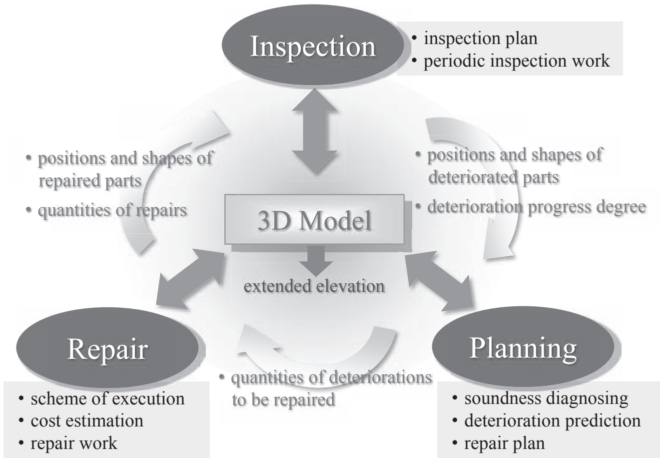

Fig.1 A sustainable maintenance cycle expected to be built using this system.

2. Overview of the System

One of the advantages of using 3D models as base maps is that the data of a three-dimensional structure can be managed in accordance with the precise coordinate information in a 3D space. We therefore developed the system with three functions for: 1) generating a precise 3D model; 2) placing a photograph onto a 3D space and identifying the positions and shapes of deteriorations and repairs; and 3) grasping the precise quantities of deteriorations and repairs and managing them chronologically in accordance with the coordinate information.

3. Generation of 3D models of bridges

Template models of representative types of structures are registered in the database of this system, which has a function for generating a 3D model semiautomatically by referring to the property drawing showing the dimensional information of each component. Upon choosing a structure type, its template model is retrieved (Fig. 2). Then, by entering the dimensions of each component as needed, an accurate 3D model of the bridge will be generated (Fig. 3).

4. Photograph management

Photographs taken in the field provide useful information as records of deterioration and other problems. When managing the photographs, it is important to correctly record the shooting directions and positions. It is sometimes difficult to recognize the precise location of a deteriorated and/or repaired part of a structure by referring to a conventional photograph ledger. Therefore, we built a system that enables the positional relationship between a structure and its photograph to be visually grasped by precisely placing a photograph onto a 3D space in this system. Specifically, the approximate position and direction of an individual photograph are input on a schematic diagram of the structure using a tablet computer when taking photographs, so that these may be given to the photograph by drawing an arrow (Fig. 4). Such photographs can then be placed onto a 3D space as follows. First, choose a photograph to be registered. The photograph can be placed preliminarily onto a 3D space by referring to the positional information obtained when photographing (Fig. 5). Then enter four or more component edges or other characteristic points that correspond between the 3D model and the photograph. The shooting position, direction, and angle of the photograph in a 3D space will then be precisely corrected (Fig. 6), where it is possible to project the photograph to the 3D model exactly by calibrating the camera lens distortion.

5. Deterioration and repair management

Structure maintenance management requires periodic inspections. If aging such as corrosion or degradation appears to have progressed compared with the previous inspection result, causing the performance to fall below the requirements, the structure should be repaired as planned in consideration of cost-effectiveness. Maintenance work can be continuously carried out by repeating this cycle. In order to perform efficient and high-quality maintenance with limited resources, it is important to improve the accuracy of determining the positions and quantities of deterioration and repaired parts and managing the chronological data. Therefore, this system includes a function for measuring the positions and shapes of deteriorations and repaired parts using photographs (Fig. 7). Since the shooting position, direction, and angle of the photograph placed onto a 3D space are found, the line-of-sight vector in a 3D space, which is represented by the point "p" on the photograph, will be uniquely determined. The XYZ coordinates of the geometric shapes that represent the deteriorations and repairs can be calculated by calculating the point "P" on the plane of that line-of-sight vector's intersection with the 3D model. If the shapes of the deteriorated and repaired parts are drawn on the photograph, the calculations enable the results to be accurately represented by the 3D model, from which numerical parameters such as lengths and sizes can be automatically calculated (Fig. 8). Moreover, it is possible to track the records of progress of deterioration over time and repairs because the geometric shapes of individual deteriorated and repaired parts are consolidated in a database with a unique ID and attribute information (Fig. 9).

Conversely, the extended elevations representing structures in two-dimensional drawings have been used as management drawings for recording the positions of individual deteriorations and repairs in structure maintenance management operations. In the 3D models generated in this system, dimensions are shown for each component. Therefore, extended elevations can be automatically output, though this is possible only for standard types of structures. Furthermore, since the positions and shapes of the deteriorated and repaired parts reflected in 3D models as well as those of the 3D models can also be represented in extended elevations, it is also possible to output the results by using the extended elevations as the base maps as they have been (Fig. 10).

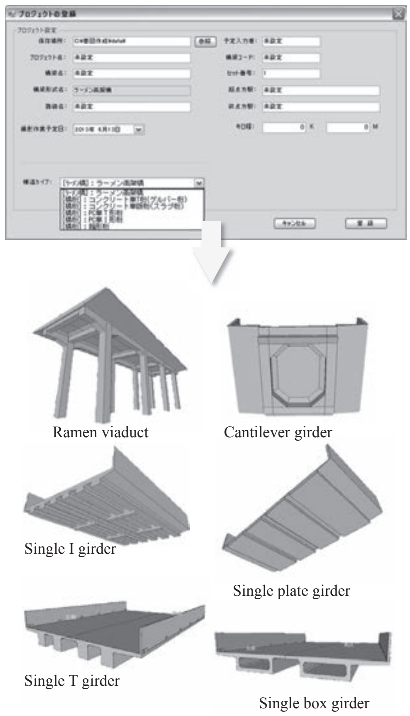

Fig.2 Selecting template models registered in the database.

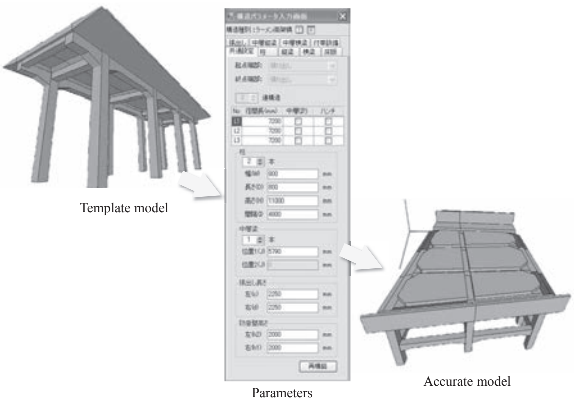

Fig.3 Generating an accurate 3D model by entering the length of each component.

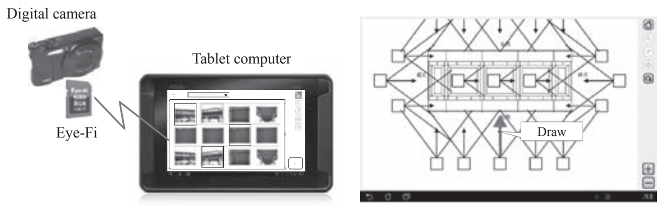

Fig.4 Giving direction and position of photographing using tablet computer.

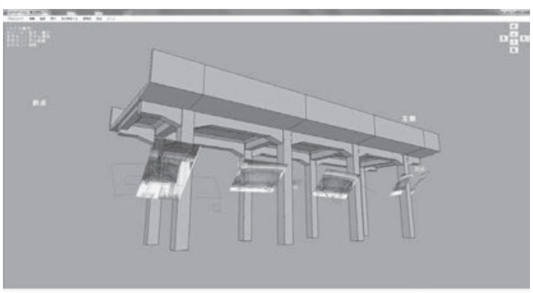

Fig.5 Preliminary placement of photographs onto 3D space.

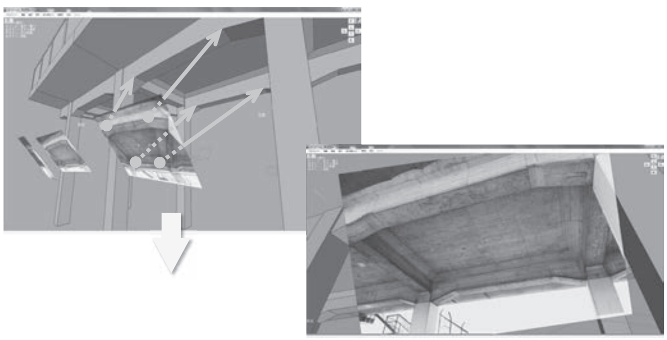

Fig.6 Overlaying a photograph onto a 3D model by entering characteristic points between a photograph and a 3D model.

6. Work project management for practical use

This system is expected to enable more efficient and advanced management than the conventional management method. A field trial with a view to practical use was started at the normal general inspection on the Hokuriku Shinkansen railway line, which was inaugurated in March 2015.

The bridges of the Hokuriku Shinkansen include snow storage type structures to protect against snow damage in view of the regional characteristics. The types of structure are wide-ranging because of the long construction period. Accordingly, the components for modeling were selected mainly from among the major components of bridges in view of the importance of management. The structure type used for a large quantity of bridges was incorporated as a template model in this system. Moreover, a 3D model of this type was experimentally produced in the optimal way according to the quantity and structural complexity, using generic 3D CAD software (Fig. 11).

Furthermore, the West Japan Railway Company constructed a BRidge Analysis and Maintenance System (BRAMS) to support integrated management of the equipment specifications and inspection and repair data of bridges in 2002 and has been using the system since then 2). Therefore, the current maintenance management system has a function to obtain the planning information and related files of inspections and constructions downloaded from the BRAMS, and then to upload the results of recording and accumulation with this system for consolidation back into the BRAMS. Thus, the system is designed to be operated mutually linked with the BRAMS and incorporated into the existing management systems.

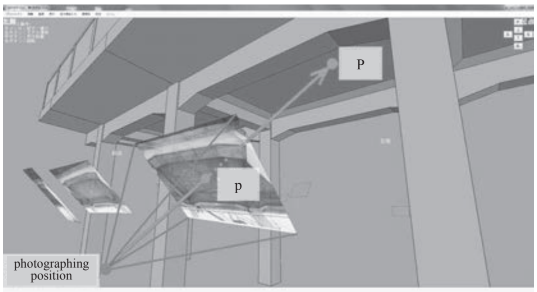

Fig.7 A specific point on a photograph projected onto 3D model.

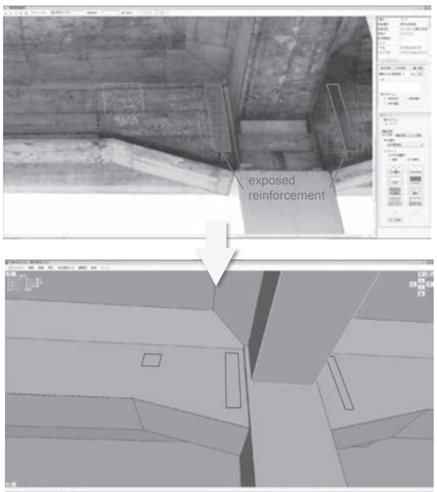

Fig.8 Drawing shapes of deteriorated parts on photograph and automatically presenting them on 3D model.

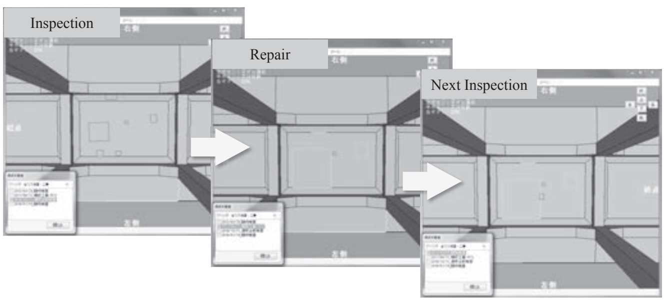

Fig.9 Tracking changes in an individual deteriorated part by referring to geometric shape and unique ID. Outlines of deteriorated and repaired parts are shown by red and blue lines, respectively.

7. Conclusion

Application of this system using 3D models as base maps improves the quality and efficiency of managing photographs and grasping the quantities of deteriorated and repaired parts, which used to require much time and cumbersome labor, and enables shared and integrated management of a variety of information, thus enabling a sustainable cycle of preventive maintenance. The system also enables intuitive management by using 3D models instead of extended elevations. Thus, the system is expected to be highly effective for bridges with complicated structures due to snow damage countermeasures like those of the Hokuriku Shinkansen railway line. We plan to evaluate the performance of this system through experimental use in the inspection operations for the Hokuriku Shinkansen, make improvements as needed, and fully introduce the system in the future. Among the functions of this system, it is still necessary to improve the work efficiency of placing a photograph onto a 3D space and identifying deteriorated and repaired parts. To solve these issues, we will continue our studies based on the latest technological trends.

References

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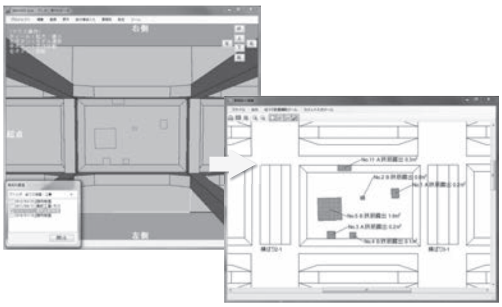

Fig.10 Automatic generation of an extended elevation on which deteriorated parts are drawn using a 3D model.

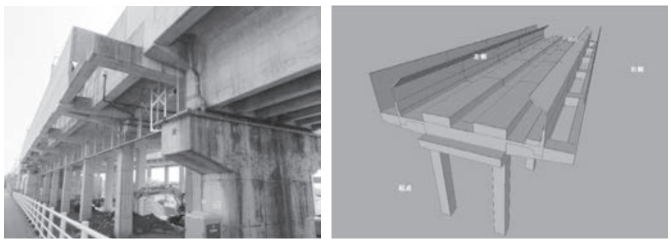

Fig.11 3D model of a snow damage countermeasure structure.