Development of Bridge Management System Using Three-Dimensional Models

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Abstract

It is necessary to manage various data in order for maintaining bridge structures appropriately. However, in the drawing that has recorded conditions and repairs on the bridge structures up to now, the following problems exist. The first problem is that the extend elevations in the drawing is only a schematic illustration without dimensions. The second is that the drawing is not shared in both repair and inspection. The third is that the drawing management cannot be performed in chronological order.

Therefore, the authors developed three-dimensional bridge models such as girder structure (single T girder, single I girder, box girder and single plate girder etc.), ramen viaduct and substructure (abutment, pier etc.) . Also, those can easily make the 2D drawings (extended elevations) for management of the inspections and repairs. And the authors added a function that can manage the cycle of maintenance cycle such as plan, inspection and repair. And the authors added a function that can manage the cycle of maintenance cycle such as plan, inspection and repair. The validity of this system was confirmed by comparing with the conventional method.

1. Introduction

Three-dimensional CAD (Computer aided design) system has been generally used in the manufacturing industries such as the aviation and automobile industry. Additionally, the technology to integrate design, analysis, and manufacturing has been developed by utilization of 3D CAD. It is called CIM (Computer Integrated Manufacturing). Recently, the standardization and the preparation of guidelines have been advanced to substitute 3D models for 2D drawings. Designing and manufacturing by 3D CAD contribute greatly to the improvement of quality and productivity.

On the other hand, in the practical business of the construction industry, the active utilization of 3D CAD for designing is not common practice yet. Construction design generally uses 2D drawing such as plan, cross section and side elevation.

Since CALS/EC (Continuous Acquisition and Life-cycle Support /Electronic Commerce) master plan was decided in 1996 in Japan, the action plan has been updated repeatedly to promote it. In a series of flows about CALS/EC, BPR (Business Process Re-engineering) used by ICT (Information and Communication Technology) has been promoted, too. Concretely, it has promoted the close cooperation that information is exchanged and shared smoothly between related persons by using 3D-CAD. As a result, it is expected to get quality assurance, productivity improvement and cost reductions.

There has recently appeared a trend to introduce another CIM (Construction Information Modeling) noticed as an evolution of CALS/EC in the construction industry. This CIM refers to the concept of BIM (Building Information Modeling) in the field of architecture. CIM is a construction management method using 3D structure models. Especially, it can keep spatial or location information in addition to shape information as 3D models. Moreover, it allows us to manage attributes such as specifications, performance, quantity and cost. We can expect to improvement of the construction process that relates the planning, the investigation of solutions, the design, the estimation, the construction and the maintenance using CIM.

As projects become more and more complex, the authors think the need for 3D data will increase for the construction industry in the future.

2. Purpose of this study

In Japan, a lot of structures were built in the period of high economic growth. These structures have been used for 30 to 50 years since the completion of construction. Therefor, most of the structures have reached their expected service life since 2010 (Table1). Under the circumstances, appropriate and efficient maintenance is going to be an important theme for the social infrastructure in Japan. Because the functional reliability was less likely to be spoiled as for the maintenance of structures promptly, the post-incident management to deal after the damage occurred has been performed. However, the fatal accidents will very probably occur because there are many old structures having exceeded their service life. In such post-incident management, the possibility that accidents will occur in the future becomes high. There is a danger that safety will be spoiled greatly, as a result.

Table 1. Structure in service over 50 years (Percentage)

Structure / year	2010	2020	2030
Road bridge	8%	26%	53%
River management facilities (sluice etc.)	23%	37%	60%
Sewerage pipe	2%	7%	19%
Harbor quay	5%	25%	53%

Data; Ministry of Land, Infrastructure, Transport and Tourism in Japan

The early detection of damage to be repaired would be important for managing these damages appropriately. In other words, it is necessary to extend the life span of structure by the preventive maintenance management. For that purpose, it is necessary to accumulate various data and continue updating data so that it always becomes the latest one, too.

However, there are three characteristic issues as follow.

1. We have to record a lot of maintenance data.
2. Many engineers are involved with the maintenance.
3. The maintenance period of structure is extremely long.

These issues cannot be ignored with regard to maintenance. Moreover, in order to promote preventive maintenance management smoothly, there are some problems related to the above-mentioned issues. About 1, the association between information is unidentified because of huge data. It is also a problem that there are many kinds of data format. About 2, the judgment to information has a difference according to an engineer's skill and situation. About 3, the loss of information has occurred because of the long maintenance period. And the process of judgment tends to become unknown.

Under such circumstances, this study focuses on the railway structures. Most of railway structures were built earlier than other infrastructure in Japan. Railway structures have reached their expected life a long time ago. Therefore, there are many old structures that exceeded the service life in the railway structures. Particularly the railway bridge has passed for an average of 60 years after completion, while the road bridge has passed for an average of 30 years (Figure 1).

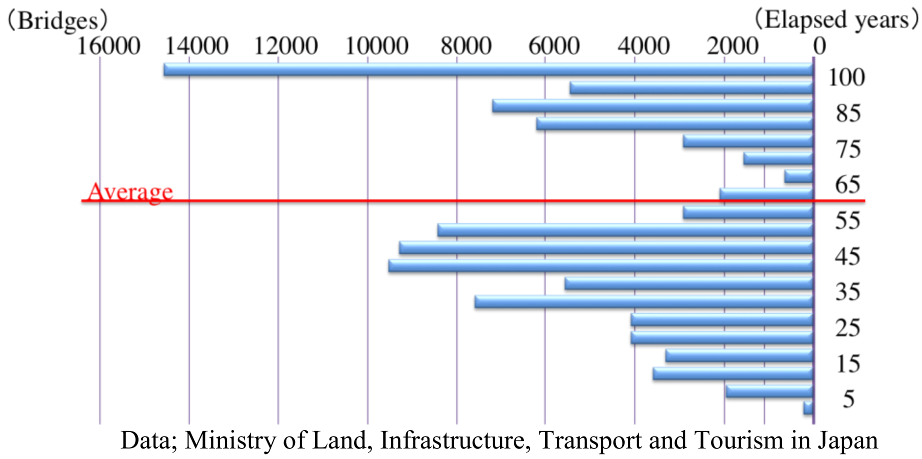


Fig. 1. Built period of railway bridges

Thus, the maintenance of the railway bridges is the problem which we are now confronted with. The purpose of this study is to extend the life of structures by developing a system which improves the inspection process and systematizes maintenance management.

3. Method of this study

In the usual maintenance management in West Japan Railway, inspection and repair carried out by referring to 2D drawings (the extended elevations). This method of inspection requires skillful engineers.

Moreover, various people are participating in the practical maintenance cycle. In that case, it is difficult to share complete information using only on the 2D information compiled by different people. There is a risk of carrying through an inappropriate maintenance action because it is difficult to insure a common understanding of the information only through 2d drawings. These problems are even more likely to happen when an inspection has to be extended or stated again in the worst case scenarios. In order to perform a suitable maintenance, it becomes more and more important to share the knowledge about both inspection and repair between the people involved.

So, the authors thought that it would be more effective to use 3D data to input and share the information visually. 3D models have been used so far for the briefing session to residents, the landscape simulation, the simulation of construction process, and so on (Yamano and Yoshikawa, 2003; Tadehara et al., 2005; Kinoshita et al., 2006). However, they are used only as a tool of visual expression and are not used as a tool for maintenance management. On the other hand, the register-based system has mainly been used in maintenance management (Takinami et al., 2011). So, the authors developed the maintenance management system for bridges by using 3D models in this study.

4. Bridges maintenance management system

The system can create 3D model of a standard bridge by using parameters as the first step. And, it can modify the sizes of 3D model by using detailed dimensions acquired from existing drawings and stereographic photos. As a result, 3D model is transformed into the more realistic model. It can generate accurate 2D diagrams (extended elevations) based on 3D models, too. Consequently, this system can integrate and manage the photos and data (area, length, position, etc.) for inspection and repair. Figure 2 shows the outline of the system flow. Each detail will be described later.

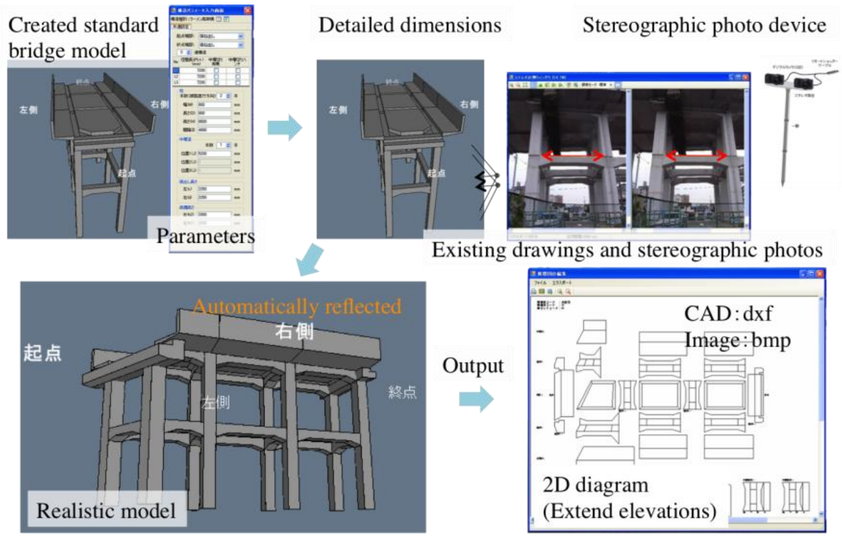
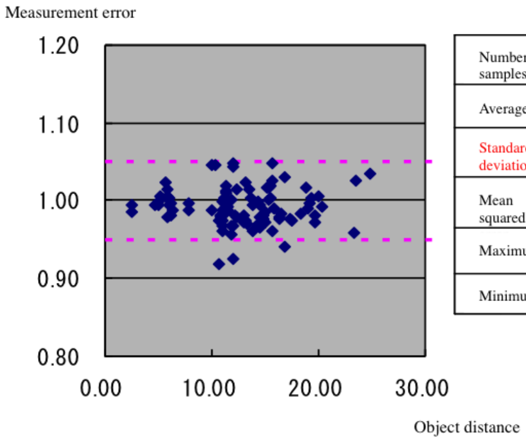


Fig. 2. Outline of system flow

5. Stereographic photo measurement device

If the engineers can approach structures closer, they can manually measure structures by using measuring tapes etc. In case of huge structures, it is often difficult to approach and measure them. In this case, the engineers have to measure in the remote and non-contact way. It is effective to measure with the non-contact methods like the total station and the terrestrial laser. These methods provide us extremely high accuracy. However, those measurement devices cannot be installed when the coordinates of their positions are not calculated correctly. Also, the observation and measurement data from multiple viewpoints are required, and it is the problem that analyzing these data takes long time. In maintenance management, it is important how to finish quickly the on-site works and how to simplify them. Then, it is enough as maintenance management that the nearly correct position can just be grasped for inspection and repair; therefore high precision measurement of a millimeter and a centimeter order is not essential. Based on the above-mentioned point, the authors developed the stereographic photo measurement device. This device aimed at less than 5% of measurement accuracy to the size of the measured structure. Furthermore, portability and operability were emphasized for on-site use. First of all, the baseline length, the object distance, the camera angle, and the measurement dimensions were set as parameters. Next, the authors performed a simulation like the dimension error of measurement size. The authors finally decided the performance of a camera and the baseline length.

They verified the measurement accuracy with an apparatus, and the results are shown in Figure 3 . Plotting points in Figure 3 shows the measurement dimensions (LO) divided by actual dimensions (L).



Number of samples	105
Average	0.992
Standard deviation	0.023
Mean squared	0.992
Maximum	1.048
Minimum	0.918

Fig. 3. Measurement results

The standard deviation was 2.3% to less than 5% of target accuracy. The authors' experimental results show that measurement accuracy is secured clearly. This device does not need the measurement from the close distance in on-site work. The engineers have only to take photos from the distant place to structures in on-site work. And the weight of the device is less than 1.5 kg; therefore there are few burdens in the engineers' photo work. Even if there is a point which has forgotten to be measured, it is not necessary to return to the site and measure it again because the photos taken before can be used again. Both work efficiency and safety improvement were provided by development of this device.

6. Construction of 3D models

It is required to create 3D models for the maintenance management by this system. At first, the initial rough bridge model is generated by selecting the type of structure from the list of prepared standard structure models. After that, a complex and more precise bridges model can be generated by entering parameters for each part of the structure by using the previously mentioned stereographic photo measurement device (Figure 4). This system can be generated the various types of structure such as girder structure (single T girder, single I girder, box girder and single plate girder etc.), ramen viaduct and substructure (abutment, pier etc.) (Figure 5).

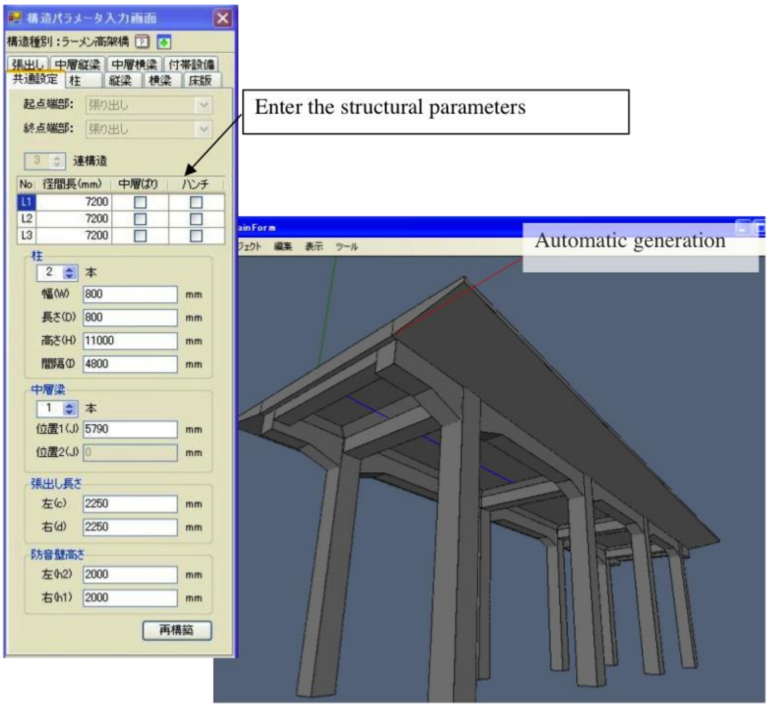


Fig. 4. Construction of 3D model

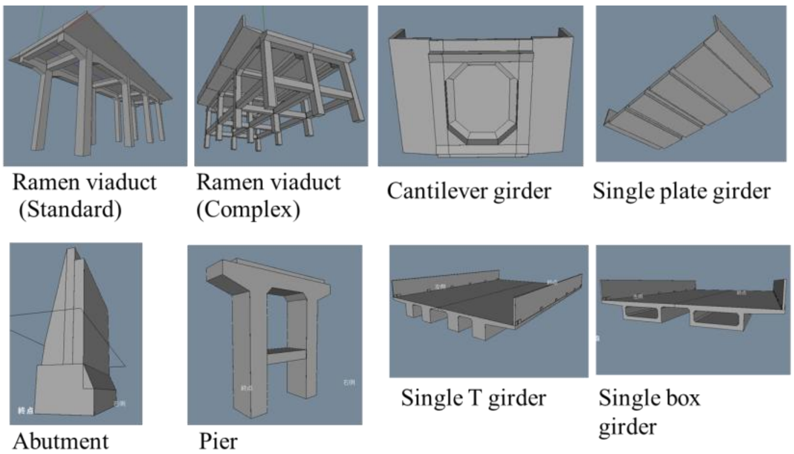


Fig. 5. Types of structure

7. Photo management

In maintenance management, the engineers have to manage both diagrams and photos taken on site. Photo management is complicated because of the enormous amount of pictures documenting every inspection. As a result, it is difficult to search effectively in past photos. Also, it is difficult to understand from where the photos were taken exactly. In maintenance management, it is important to manage the appropriate positions of photos. In order to solve these problems, this photo management system is created so that it is easy to grasp visually the position from which the picture was taken in relation to the bridge. More specifically, it has a function enabling to place the photo data in 3D space by dragging and dropping (Figure 6).

Furthermore, it is possible to place precisely these images in 3D space because 3D models and photos can be matched using characteristic points such as the corners of structure parts. This system can precisely place the captured image on 3D model by removing distortion of a lens (Figure 7 ; Figure 8). This system can precisely place the captured image on 3D model by removing distortion of a lens. Even if the photos are taken by different engineers or taken on different days, this system can easily match the photos with 3D model. That is to say, the system can manage the photos very effectively (Figure 9).

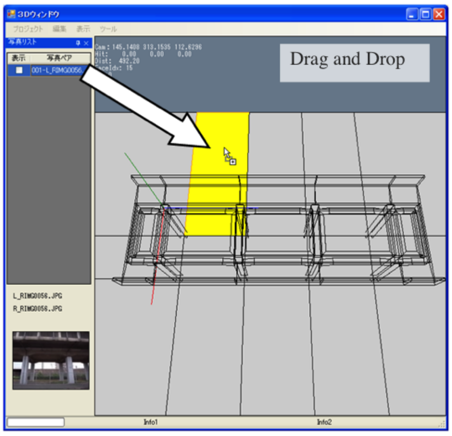


Fig. 6. Placed photo in 3D space

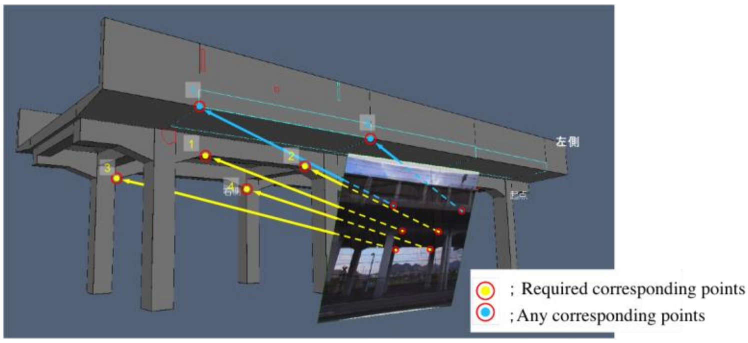


Fig. 7. Precisely placed photo (1)

Fig. 8. Precisely placed photo (2)

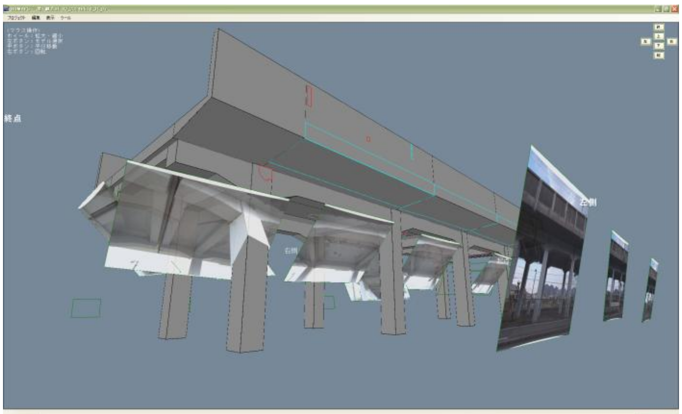


Fig. 9. Effective photo management

8. Inspection and repair management system

It is important for maintenance management to grasp aging such as corrosion or deterioration of structures, and it needs to settle on the most cost-effective repair plan. For that purpose, it is necessary to easily grasp the contents of inspection and repair in chronological order. We must exactly evaluate structural soundness to grasp the point that must deal with precedence. So, the location and quantity about inspection and repair have to be recorded exactly. Conventionally, the history of repairs, corrosion and deterioration is managed with 2D drawing.

Not only is it difficult to grasp the actual bridge structure based on 2D drawings. But, with the conventional method, it is also difficult to follow the aging of the structure because of the inaccuracy of the record. The accuracy of the record`s diagram is limited by the accuracy of the schematic diagram. Also, it is not easy to measure a position and quantity correctly and simply by the conventional method. For example, the engineers have to approach the damaged points to inspect and measure by the aerial vehicle. However, because there are many preparations in this method, the workload becomes large. Furthermore, there is a safety problem because the measurement is carried out in a high place. There is an alternative inspection method using a camera with a zoom lens, but it lacks the accuracy about the location and quantity to measure. Those measurement results have to be copied on the 2D drawing by hand; therefore the accuracy of the diagram will be about the same as the schematic diagrams.

In this system, the method of using the photograph arranged in 3D space mentioned in the preceding chapter is adopted as the measuring method. This system makes it possible to record the exact position of damages and repairs. This system makes it possible to trace the records of damages and repairs on the photo. If the 3D model and the photos are associated, those records are reflected accurately on the 3D models in this system (Figure 9).

The associated photos are overlapped accurately on 3D space. Since they are matched on the real coordinate system of 3D model, it becomes possible to measure a position, shape and quantity (length and area) correctly. In addition, this system can track the progress of each damage and repair by giving an ID.

Fig. 10. Tracing of records of damages and repairs on the photo

9. Output of 2D diagrams (extended elevations)

There are so many various and complicated types of bridge structures that producing drawings in the conventional method has become a burden for the engineers. As a result, reaching a sufficient accuracy has become a problem. This system can automatically output 2D diagrams from the bridge model as generated by entering each parts' parameters of the structure. Therefore, no matter how complicated the structures are, this system can output diagrams quickly and exactly (Figure 11). Also, the actual size of damage and repair points located in the 3D models, the system can output exact location, shape and quantity. Moreover, this system can output each progress of damage and repair (Figure 12). This system can also output panorama images to help the understand (Figure 13).

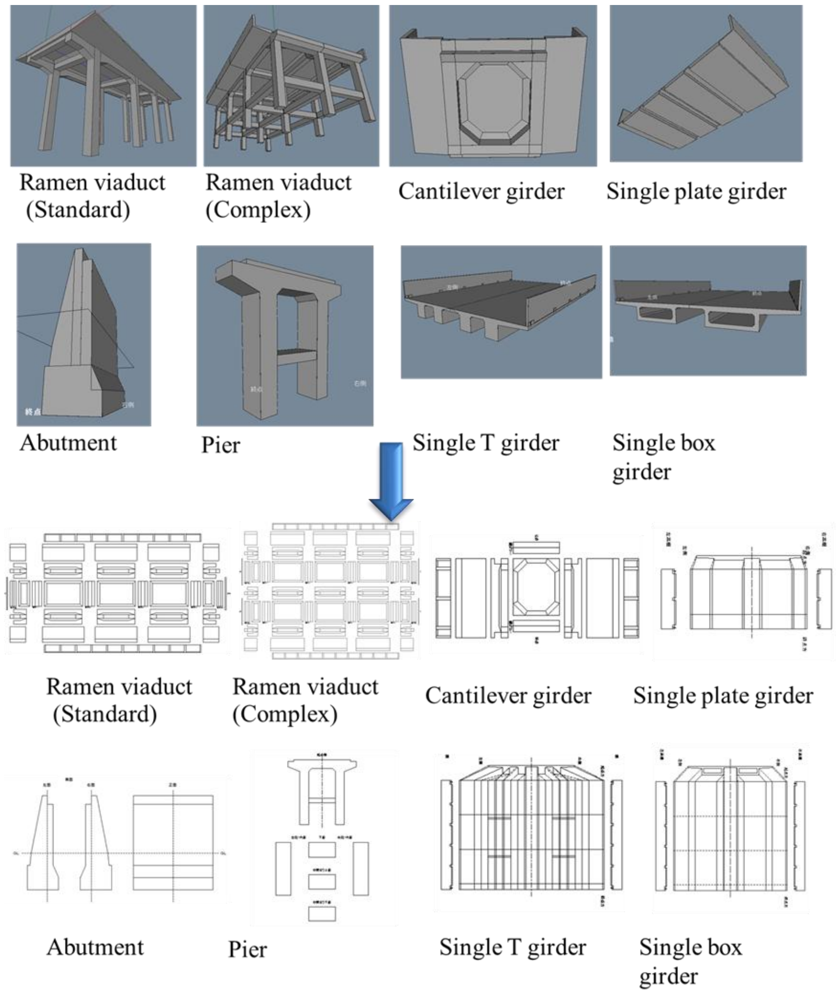


Fig. 11. Responding to complicated structure

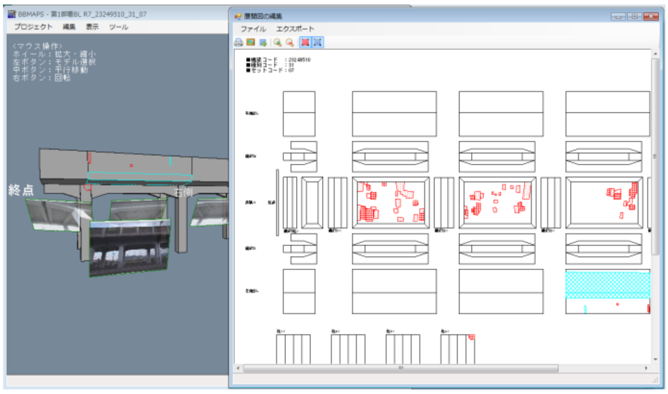


Fig. 12. Accurate management of location, shape and quantity

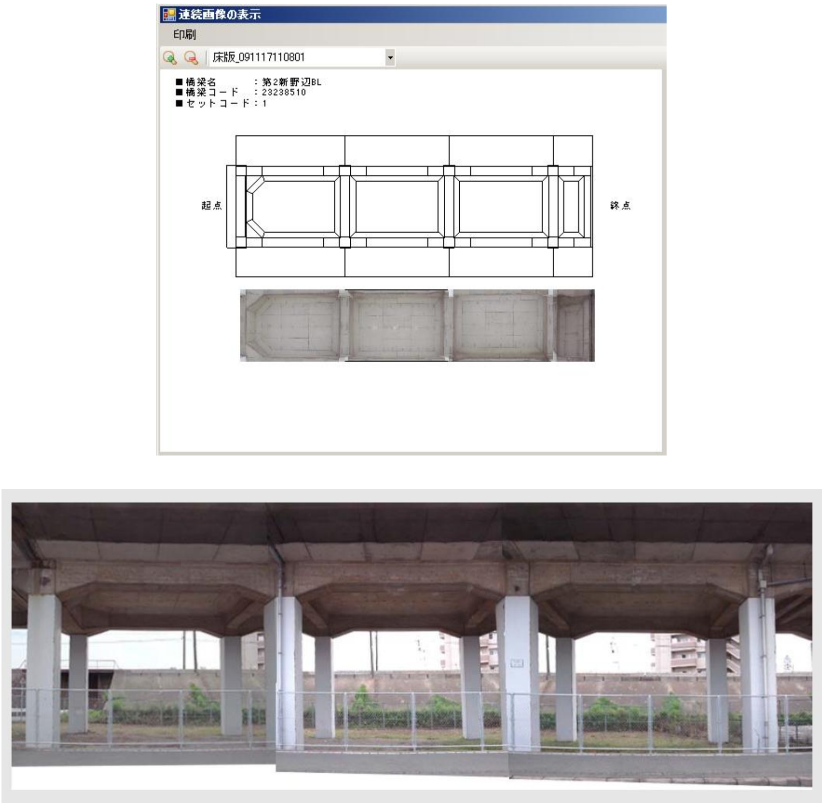


Fig. 13. Output of connected images

10. System verifications

The authors verified the validity of this system by comparing it with the conventional method. First of all, they verified and compared the number of engineers and working hours. They measured both indoor and outdoor working hours using this system and the conventional method (Figure 14). From our comparison, they found out engineers' working hours could be greatly reduced. The inspection's process time can be shortened to one forth. Moreover, the repair's process time can be shortened to one tenth.

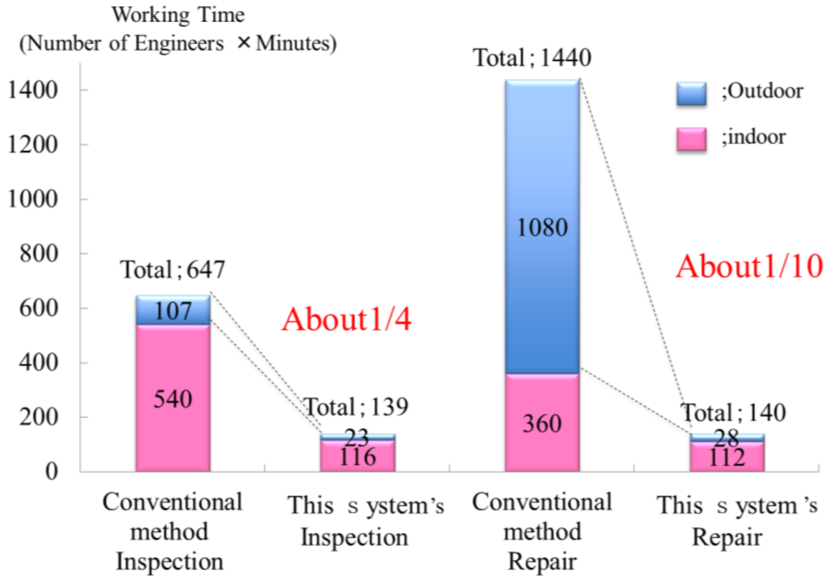


Fig. 14. Result of time verification

Next, they verified the measurement accuracy. Especially in the repair construction, the accuracy of repair dimensions is important because the dimensions of the repair part are related to the cost of construction directly. Then, they extracted each from repair our model and calculated the difference in area between the measures taken following the conventional method and the measuring method of this system. Table 2 and Figure 15 show the result of the comparison. The error in the model's measures follows a normal distribution and the mean value is centered near zero, in other word, measurements are reliable (Figure 15). From such results, this system can therefore be applied to maintenance management.

Table 2. Result of measurement accuracy verification

Average error	Standard deviation	Remarks
-0.002㎡	0.010㎡	Number of places ; 63places Average cross-sectional area of repair ; 1.612㎡/places (0.11%)

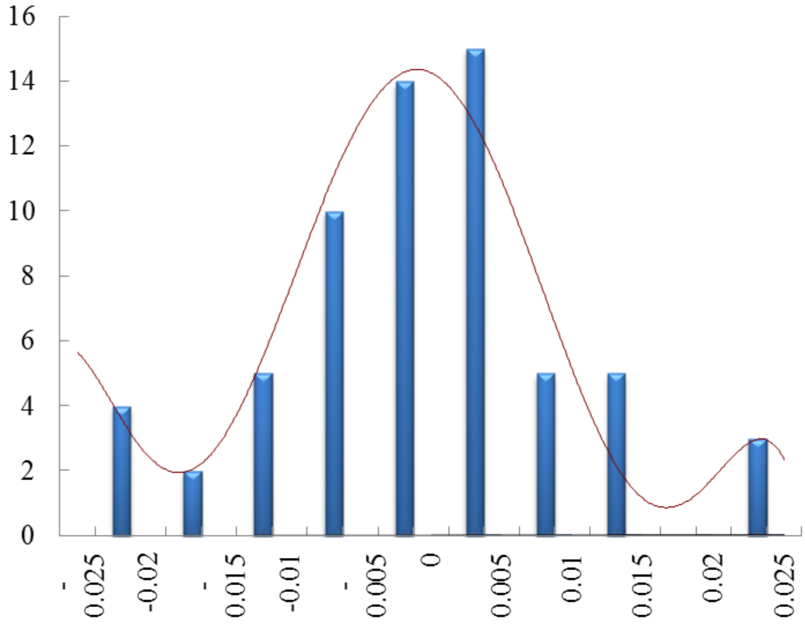


Fig. 15. Result of measurement accuracy verification

11. Conclusions

The following effects are provided by the development of this system. Although making a 2D drawing (extended elevations) has required much time, this system can easily make it only by inputting structure dimensions. Also, once 3D models are made, it is not necessary to make new one afterward.

Until now, generating a 2D drawing (extended elevations) has required a lot of time. However, this system can easily generate it only by inputting the structure dimensions. Also, the conventional data management, such as organizing drawings, photos and keeping damages and repairs information requires a lot of labor. This system can shorten time needed and reduce labor. This way, the authors think that it will lead to cost reduction by providing the tools for s more efficient management.

In conventional 2D drawings (extended elevations), data of the maintenance management are not shared mutually. On the other hand, in this system, various data such as those photos, records of the maintenance, and drawings are shared and unified for management.

This system can record accurate locations and measurements, so it can help manage changes of structures over time.

Therefore, this system is a powerful asset management tool allowing for a comprehensive preventive maintenance program.

This system, if applied properly, will be applicable to the management of structures other than bridges.

It has been confirmed that the burden of maintenance recording on inspection and repair points has been decreased.

On the other hand, in this system, the engineers must manually enter the photo position in 3D space. This operation is a large part of the indoor work (Figure 16). Future development is needed in order to reduce the time required by photo positioning.

As shown in Figure 16, the operation of tracing damages from photos is another major manual operation and also takes up most of the indoor work. To address this problem, a potential solution would be to use image processing to extract automatically the damages and repairs shapes. The authors are needed development in order to automatic extraction of damages and repair. They should continue the technology development about two above-mentioned problems.

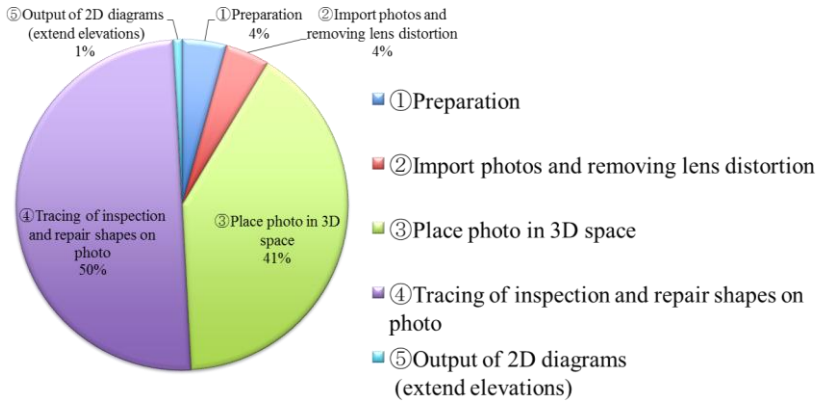


Fig. 16. Proportion of indoor works

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