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Digital Bridge Construction System Using CIM, ICT and AI

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Abstract:

The spread of new coronavirus has led to the widespread use of remote work and remote inspections, and the construction industry is rapidly becoming more digitalized. The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has decided to bring forward the adoption of BIM/CIM, the core of digitalization, from the originally planned FY 2025 to FY 2023. JFE Engineering is also working on the development of various ICT technologies to improve the productivity of construction sites. This paper outlines the digital bridge construction system that JFE Engineering currently develops, which links BIM/CIM, ICT, and AI technologies.

1. Introduction

The construction industry is confronting increasingly serious labor shortages as a result of Japan's declining birthrate and aging population, and productivity improvement has become an urgent issue in the industry as whole. To solve this labor shortage problem, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has promoted the i-Construction initiative to improve productivity at construction worksites since 2016. The aim of this program is to improve productivity in the total construction production system by introducing ICT and BIM/CIM (Building information Modeling & Management/Construction Information Modeling & Management) in all work processes from surveying to design, construction, inspection, and maintenance.

The environment surrounding society has also changed in the past several years, as seen in the progress of AI, IoT and other digital technologies and changes in workstyles due to the widespread use of remote work during the novel coronavirus pandemic. In April 2020, MLIT decided that "in principle, BIM/CIM is to be applied to all public works projects, with the exception of small-scale construction, by 2023." Under this plan, application in principle by the former target year of FY 2025 will be brought forward by 2 years. Use of BIM/CIM, ICT and other digital technologies is advancing rapidly at construction sites, and the industry as a whole is grappling with DX (digital transformation).

The difficulty of DX in the construction industry lies in the application of digital technologies to actual worksites, which are subject to numerous uncertainties and other indeterminate factors. For example, it is difficult to automate construction work by utilizing robots and AI because the types of construction are diverse, since the ordered products are never the same, and construction work is affected by weather, climate and dust. To meet these challenges, which are specific to the construction industry, MLIT launched the "Project on the introduction and use of innovative technologies to dramatically improve productivity at construction sites, solicited from the public by the government" in 2018 in order to promote solutions through cooperation with other types of industries, and is supporting the development of innovative technologies by cross-industrial cooperation.

JFE Engineering adopted, in principle, a policy of incorporating BIM/CIM (hereinafter referred to as CIM: Construction information Modeling & Management) in its own bridge construction projects since FY 2020, in advance of the government policy and moves by other companies in the industry, and has strengthened its implementation system by improvement of software and hardware, education of engineers and col-

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laboration with others outside the company. JFE has also participated in 4 consecutive periods of the above-mentioned "Project on the introduction and use of innovative technologies," and has developed various technologies using AI, ICT and robotics technologies and conducted experimental studies at actual construction sites. Moreover, the company is also promoting implementation of the developed digital technologies as a "Digital Bridge Construction System" by data linkage with CIM models.

This paper first presents an overview of Digital Bridge Construction System in JFE Engineering, and then describes the results of verification of system accuracy and productivity improvement and issues for future work as results of the various experimental studies conducted at actual bridge construction sites.

2. Establishment of Digital Bridge Construction System

Even if CIM models as well as ICT and AI are used independently, the effect will be limited. To maximize the effect of these technologies, it is necessary to demonstrate a synergistic effect by interlinkage as a total system.

JFE Engineering is proceeding with implementation of a "Digital Bridge Construction System" that will improve productivity in bridge construction by linking various ICT and AI technologies around a core CIM model. The concept of the system is shown in **Fig. 1**. Data linkage between the individual technologies and the CIM model is achieved via a cloud system. The control values used in surveying and construction management are acquired from the CIM model, and the surveying results and finished work quality control values are stored, tied to the CIM model, with the aim of improving construction supervision and inspection productivity.

Enhancement and improvement of the functions of the Digital Bridge Construction System have been carried out while conducting experimental studies at bridge construction sites. Among the technologies incorporated in this system, the following chapter will present brief explanations of three: AI-based automatic rebar arrangement inspection system, concrete barrier surveying robot, and AR (augmented reality) system, and describe the contents of the experimental studies carried out at actual bridge construction sites.

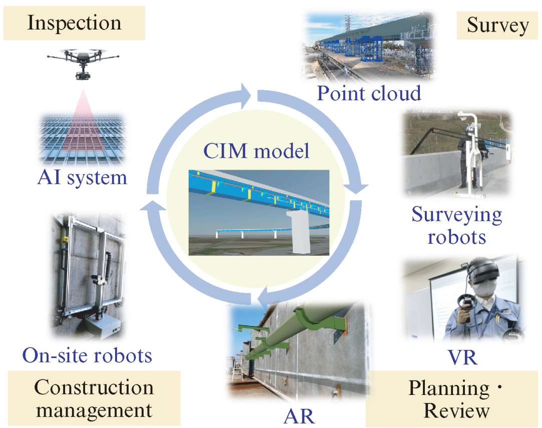

Fig. 1 Digital Bridge Construction System

3. Experimental Studies of Systems

3.1 Advanced Rebar Arrangement Inspection System for Concrete Structures Using AI-Based Image Recognition Technology

3.1.1 Overview of technology

Conventionally, rebar arrangement inspections of reinforced concrete structures during bridge construction were performed by measuring the spacing between the individual rebars with a tape measure and checking the number of rebars by visual inspection. This work was extremely labor-intensive, since the results measured by multiple workers were recorded by handwriting in a finished work quality report and then transcribed to a personal computer. This work was also susceptible to human error in the transcription process.

In the Civil Engineering Construction Management Standards and Standard Values[1)], the standard for rebar spacing in floor slabs specifies sampling inspection premised on manual surveying. The standard value for an error in the design value is within ±20 mm, and the surveying standard is 3 points (both ends and center) per span. All rebars in the bridge transverse direction must be measured, and rebars orthogonal to the bridge axial direction are to be measured in a range of 2 m for each processed shape. Because this is a sampling inspection, no inspection records were kept for points other than the surveying points, but this was also a problem from the viewpoint of quality control.

To solve this problem, JFE Engineering developed an AI-based automatic rebar arrangement inspection system[2)]. **Figure 2** shows an overview of the technology. The newly-developed AI-based rebar arrangement inspection system automatically performs inspections of the rebar arrangement based on images acquired with a digital camera, which are taken using a UAV (drone) or a surveying vehicle. The core of the AI algorithm is object detection based on deep learning, in which the arrangement of the rebars is recognized by learning the features of the intersection points where rebars intersect. Color-coded display of the error in the rebar spacing is also possible by tying the results of

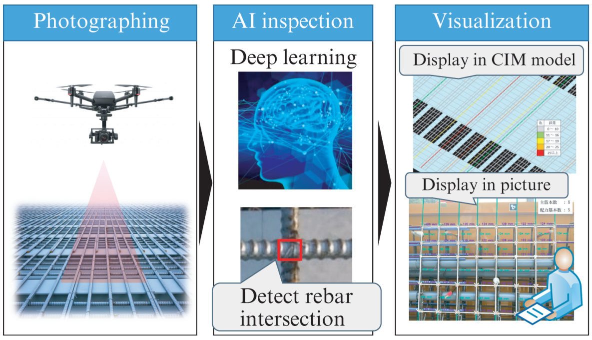

Fig. 2 Overview of AI-based inspection system for rebars

inspections by this system to the CIM model as attribute information, and the results of surveying of the rebar spacing and the number of rebars can also be displayed automatically on the photo screen.

3.1.2 On-site experimental study

An on-site experimental study was carried out during construction of the superstructure of the Shionosawagawa Bridge (Minobu Town, Minamikoma-gun, Yamanashi Prefecture) of the Chubu Odan Expressway. The target structure was a steel-concrete composite slab "River Deck" manufactured by JFE Engineering. The rebar arrangement was photographed and measured using a drone at the construction site after completion of the floor slab. **Figure 3** shows a general view of the target bridge after construction of the floor slab and a schematic diagram of the composite floor slab.

3.1.3 Results of experimental study

The accuracy of rebar spacing surveying was verified by comparing the error of the actual measured values and the values measured by the AI system (**Fig. 4**). The average absolute value of error was 3.7 mm, and the average considering the signs of errors was -2.5 mm, which is well within the error of less than 5 mm that had been considered the target accuracy for practical use.

There was deviation in the tendency of the error, in that comparatively large error of 10 mm or more occurred in some parts. This was particularly remarkable at locations where the rebar arrangement became irregular, for example around lap splices between the rebars. This is thought to be caused by a lack of learning data for lap slices and a tendency to erroneously recognize lap splices as adjacent rebars in the inference of the rebar arrangement because rebar intersections are detected in close proximity at lap splices. Therefore, in addition to continuing to increase the number of learning data, we are also working to improve the system as a whole.

Figure 5 shows the results of a comparison of a rebar arrangement inspection by conventional manual work and the productivity improvement effect of inspection by the rebar arrangement AI system. Although the AI technique includes additional time for transfer of the data from the drone to the cloud and the time required for data analysis, the surveying time was shortened significantly, resulting in a 65% labor saving.

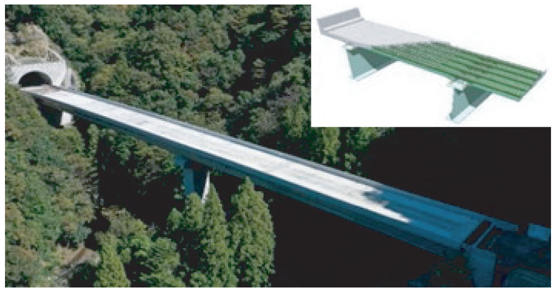

Fig. 3 Target bridge and schematic diagram of composite slab

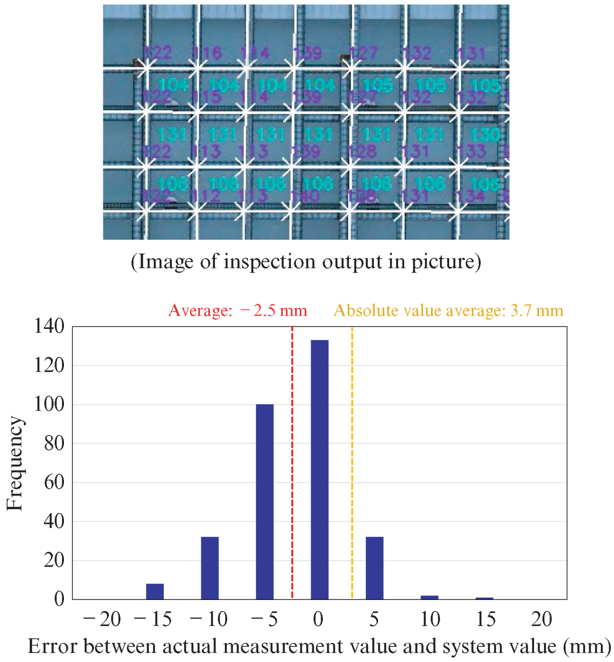

Fig. 4 Measurement accuracy of rebar spacing

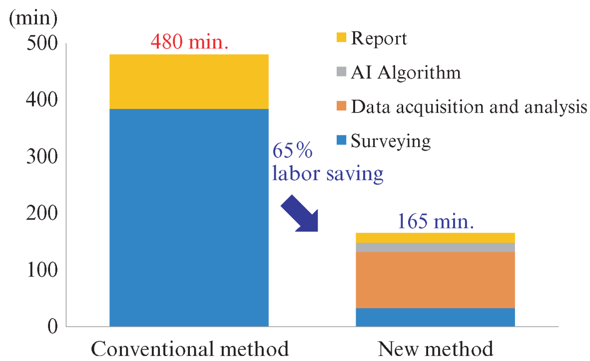

Fig. 5 Effect of productivity improvement

3.2 Development of a Robot for Measuring the Form of Concrete Barrier

3.2.1 Overview of technology

In the conventional method of construction supervision of concrete structures, including bridge construction, the finished work quality was measured by multiple workers using tape measures and other surveying devices, and cracks in the concrete were investigated by visual inspection. Based on the surveying and investigation results, the workers prepared a finished work quality report by manual work using a personal computer, etc., but this was unproductive, heavily labor-intensive work.

In construction supervision of concrete rigid protective fences (hereinafter, "concrete barriers") in construction of the bridge superstructure, much labor is required in finished work quality surveying and crack inspections. Based on the above-mentioned Civil Engineering Construction Management Standards and Standard Values, finished work quality surveying of concrete barriers must be performed at 3 locations on one side of the barrier in each span, and crack inspection was required along the entire length of the barrier. Finished work quality surveying was carried out by multiple personnel using tape measures and levels, but the reproducibility of the measured values was a problem. As additional issues, considerable labor was required in crack inspections, as it was necessary to check both sides (front and back) of the concrete barrier, and there were also process-related problems, as the work could not proceed to the next process until the inspection was completed.

To solve these problems, JFE Engineering developed a surveying robot (hereinafter, "concrete barrier surveying robot") which can simultaneously carry out finished work quality surveying and crack inspections of concrete. Photos of the robot are shown in **Fig. 6**.

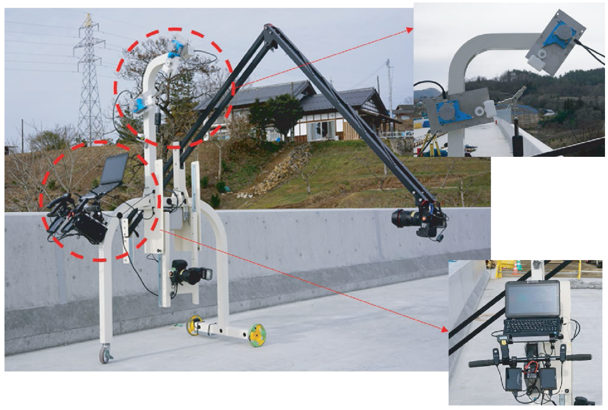

Fig. 6 Surveying robot for concrete barrier

Using the developed robot, finished work quality surveying can be performed by one worker on the bridge, and the finished work quality report can be prepared automatically. As the actual surveying method, the concrete barrier surveying robot acquires the relative coordinates at each point on the concrete barrier from the drawn-out length of wires by two wire encoders mounted on the robot, and then obtains the finished work values of the concrete barrier width and height by numerical calculation.

One aim of the concrete crack inspection system was to make it possible to conduct inspections efficiently and without scaffolding. Specifically, use of the system for crack detection utilizing image recognition AI technology[3)] achieved a system which is capable of simultaneously photographing the front and back sides of a concrete barrier. An experimental study was carried out at an actual bridge using the developed concrete barrier surveying robot, and confirmed that the system has an excellent construction supervision function.

3.2.2 On-site experimental study

The experimental study was carried out at the site of the Furukawa Bridge superstructure construction (Date City, Fukushima Prefecture). Based on the Civil Engineering Construction Management Standards and Standard Values and the condition of construction at the site, the range of the experimental study was set as finished work quality surveying at 9 points and crack measurement over a length of 257.2 m. The study was conducted by a flow which consisted of sequential surveying at each finished work quality surveying point while continuously capturing images of the concrete barrier. **Figure 7** shows the surveying points.

3.2.3 Results of experimental study

Figure 8 shows the results of a comparison of the finished work quality values surveyed by the concrete barrier surveying robot and the surveying values by the conventional technique. In comparison with the conventional technique, surveying was possible with an average error of within 3 mm, confirming suitable accuracy for use in finished work quality surveying.

In some surveying values, there were points where the error exceeding 5 mm. Since these are values at surveying points where the coordinates of the back side of the concrete barrier were calculated by spin compensation from an angle of the finished work quality of the barrier surface, this type of error is thought to have occurred because the values depend on the finished surface of the barrier. We are currently working on the improvement of the system to solve this problem.

Figure 9 shows an example of crack detection by the

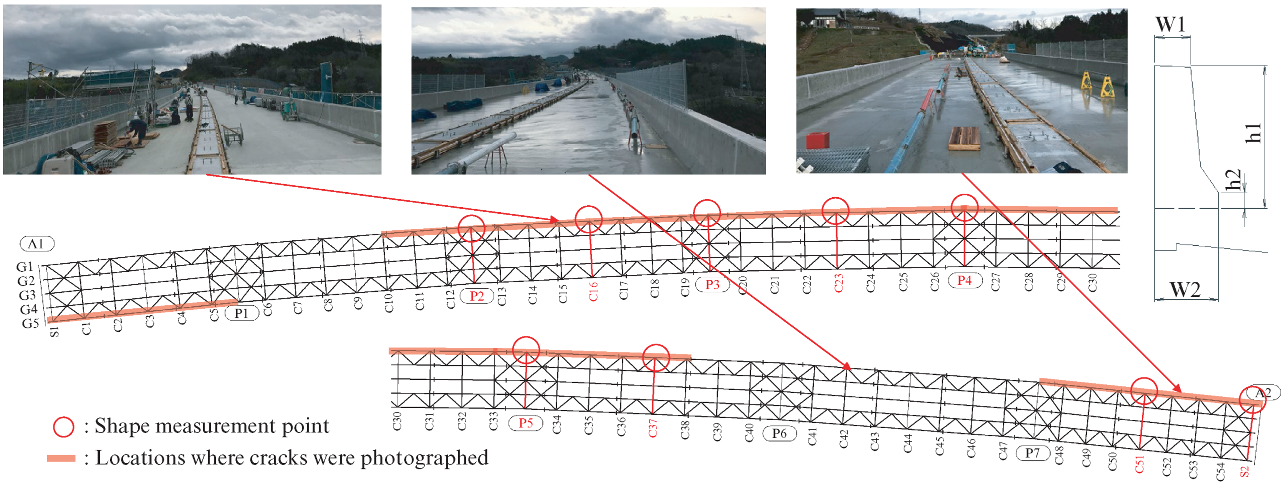

Fig. 7 Surveying points

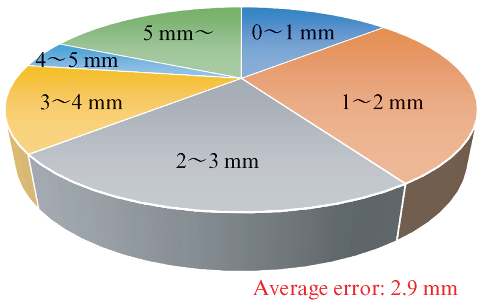

Fig. 8 Error comparison result between conventional method and new method

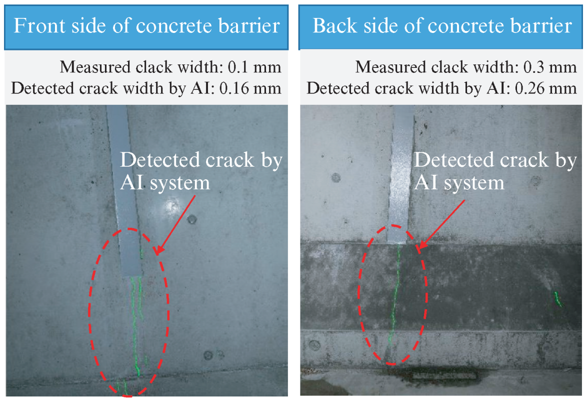

Fig. 9 Example of crack detection result by AI

system from images captured by the concrete barrier surveying robot. Cracks were detected on both the front and back sides, as indicated by the green line in the areas shown by the red circles in the figure, confirming that those cracks can be detected with the same width and at the same location as in visual inspections. Regarding the number of detected points, a crack with a width of 0.2 mm or larger was detected at one point by both AI and visual inspection, but the AI system detected a slightly smaller number of comparatively small cracks with a width of less than 0.2 mm detected, as cracks were detected at 10 points by AI and at 12 points by visual inspection. It is thought that detection accuracy for cracks smaller than 0.2 mm can be improved by increasing the number of learning data and improving the photography method.

As the productivity improvement effect, it was possible to reduce the work time in construction supervision by about 50%, as shown in **Fig. 10**. A labor-saving effect was also confirmed, as surveying work which had conventionally been performed by multiple persons can now be done by one person.

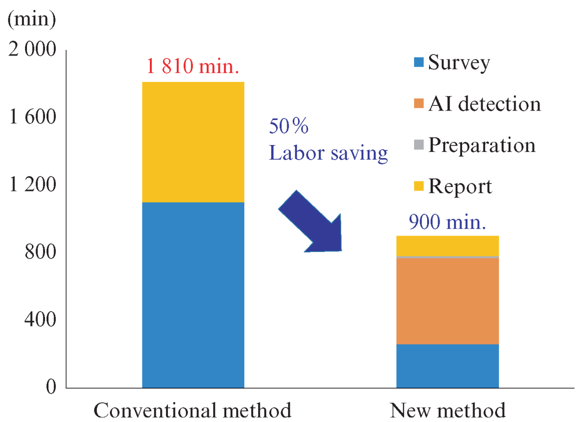

Fig. 10 Productivity improvement effect

3.3 Confirmation of Installation Position of Steel Bridge Accessories on Members with Main Girder by Augmented Reality (AR)

3.3.1 Overview of technology

In addition to the main structure, various types of accessories are also attached to bridges; these include fittings for drainage, scaffoldings, inspection decks and the like. In the conventional method for checking the installation positions of these accessories, surveying was performed by multiple personnel using tape measures at each surveying point to check whether the dimensions of the actual structure matched those shown in drawings. However, the conventional method involved various problems, including the fact that work by multiple workers was required in the actual surveying and recording work, the reading locations in the drawings and surveying points were easily mistaken, and there was a heightened risk of labor accidents such as falling from high places when checking blocks in high locations.

JFE Engineering solved these problems by developing a method for confirming the installation positions of accessories by superimposing the CIM model on the manufactured member by augmented reality (AR), in which digital information is superimposed on real space, as illustrated in **Fig. 11**. Use of this technique to check the installation positions of accessories improves productivity by making it possible to perform the work with a smaller number of workers and time compared to the conventional technique, and also contributes to improved safety by reducing work in high places.

3.3.2 On-site experimental study

The experimental study was conducted at the Yamato Gose Road Kashihara Takada Interchange D Ramp Bridge, Etc. Superstructure Project (Kashihara City, Nara Prefecture) using a main girder after fabrication. The target accessory in the study was only a drainage fitting installed on the body of the main girder, and the installation position was confirmed in a total of 5 blocks.

As advance preparation, coordinates were arranged so it would be possible to align the positions of the CIM model created in the design stage and the actual structure. AutoCAD (Autodesk) was used in the modeling, and the model was converted to an FBX file, which is a file format supported by the system.

Markers for use in positioning were installed on the target structure at points corresponding to the model, as shown in **Fig. 12**. Two markers were installed on the web surface near the ends of the main girder block and were used to determine the bridge axial direction in AR projection. The system can also support any desired marker image if the data are stored in the system in advance. Therefore, after the two markers were installed, the markers were read with a tablet terminal, and the CIM model was projected on the tablet screen using the marker positions as reference points. Finally, the position of the installed fitting was confirmed by superimposing the model.

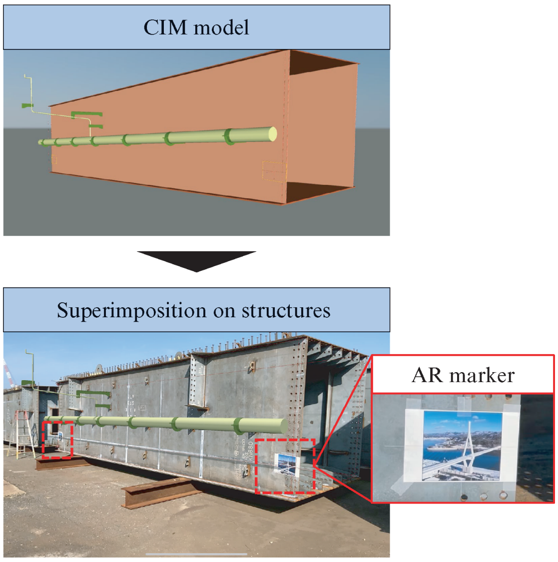

Fig. 11　Projected image of CIM model using AR

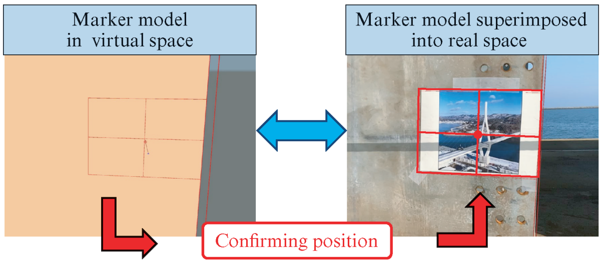

Fig. 12　Image of positioning with markers

3.3.3 Results of experimental study

Figure 13 shows the scene during checking of the installation position of the drainage fitting by superimposing the CIM model on the tablet screen. The position of the drainage fitting can be confirmed visually by displaying the CIM model superimposed on the actual object in this manner. The projection error was on the order to several mm to a few 10 mm over the entire length of the object. The cause of this variation in the projection error is thought to be the cumulative error of the acceleration sensor in the tablet and the LiDAR sensor used to acquire spatial information as the worker moved while holding the tablet. We plan to improve this problem by introducing a system that resets the accumulated error by arranging markers at regular intervals and reading each marker.

The productivity improvement effect of this system is shown in **Fig. 14**. Since a location that had required a working time of 40 minutes per 5 blocks by two workers with the conventional method could be checked in 25 minutes by 1 worker with the AR method, both shortening of working time and a labor-saving effect were confirmed. Although the working time for marking work at marker installation positions occupied a

Fig. 13 Checking scene of installation position of drainage fittings

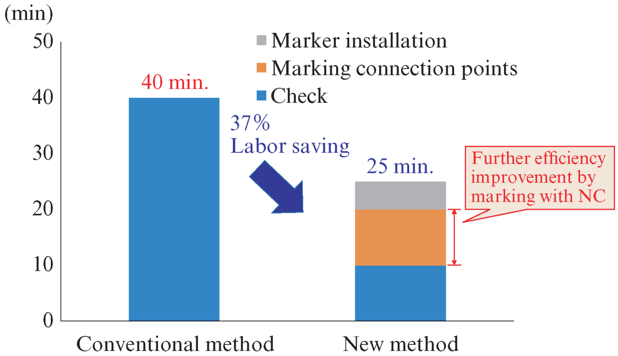

Fig. 14 Productivity improvement effect

large weight in the total working time, a further labor saving is expected to be possible by including this process in the work flow in the shop, for example, by marking the marker installation positions on members in advance with a NC marking machine in the bridge fabrication shop.

4. Conclusion

JFE Engineering is promoting the implementation of a Digital Bridge Construction System utilizing CIM, ICT and AI. As functions of the system, an AI-based automatic rebar arrangement inspection system, a concrete barrier surveying robot and an AR system were developed, and experimental studies were carried out at actual bridge construction sites. In the future, further improvement will be added while applying these technologies in actual construction, and extension of the functions is also planned.

Acknowledgment

Development of the AI-based automatic rebar arrangement inspection system was carried out with the support of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) "Project on the Introduction and Use of Innovative Technologies to Dramatically Improve Productivity at Construction Sites (PRISM)" solicited from the public by the government in 2019 and the supplemental solicitation of 2019. The concrete barrier surveying robot was also selected for support by the same project in 2020. We wish to express our appreciation to all those concerned with the project.

We also wish to thank our partners in these joint development projects, ACES, Inc. (AI-based automatic rebar arrangement inspection system), iXs Co., Ltd. (concrete barrier surveying robot) and Pocket Queries, Inc. (AR System).

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