Introduction of i-Bridge for a Prestressed Concrete Bridge
— Natsui Viaduct —

PC 橋における i-Bridge の導入
— 夏井高架橋 —


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Synopsis
The Natsui Viaduct Construction Project on National Route 45 located in Kuji City, Iwate Prefecture, includes the construction of a 497-m-long 7-span continuous prestressed concrete (PC) rigid frame box girder bridge on the Sanriku Coast Expressway (**Figs. 1** and **2**) as one of the road rehabilitation projects after the Great East Japan Earthquake. The bridge was constructed with a standard box girder cross section using the cantilever erection method with form travellers. In this method, the bridge is constructed by repeatedly performing a cyclic construction process, including management of work operations and setup for inspection of the construction work, which includes formwork assembly, reinforcing bar and prestressing steel cable assembly, and concrete placement. To reduce the burden on site-staff in construction management operations and to save labor, information and communication technology (ICT) was utilized, which is useful in each process of the cantilevered construction.

Fig. 1 Natsui Viaduct

Structural Data
Structure: 7-span continuous rigid frame bridge
Bridge Length: 497.0 m
Span: 49.7 m + 5@79.0 m + 49.7 m
Width: 11.330 – 16.052 m
Owner: Ministry of Land, Infrastructure, Transport and Tourism
Designer: Fukken Gijyutsu Consultants Co., Ltd.
Contractor: Sumitomo Mitsui Construction Co., Ltd., Abe Nikko Kogyo Co., Ltd., Nippon PS Co., Ltd. JV
Construction Period: Apr. 2016 – Sep. 2018
Location: Iwate Prefecture, Japan

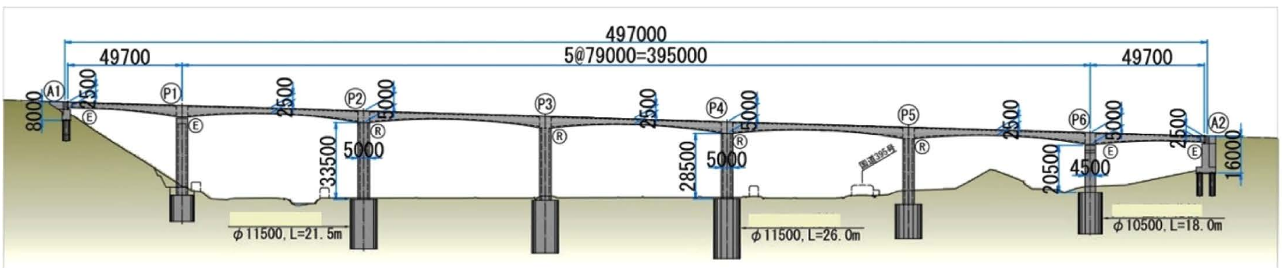

Fig. 2 General view of the Natsui Viaduct

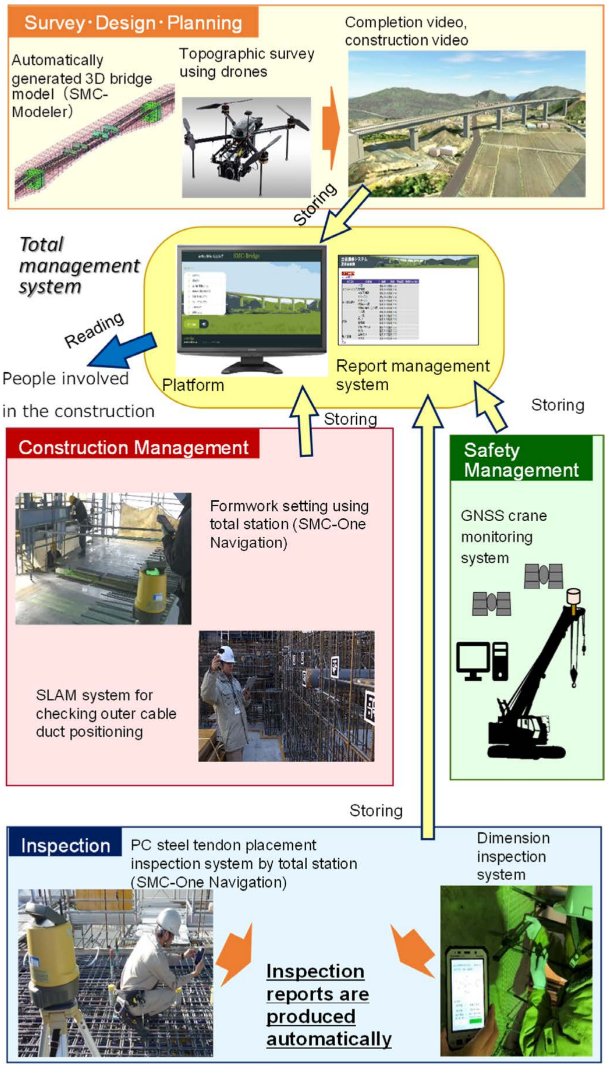

Fig. 3 General Overview of the ICT adopted on the bridge project

1. About i-Bridge

Japan's Ministry of Land, Infrastructure, Transport and Tourism (MLIT) aims to increase construction site productivity by 20% by 2025 through "i-Construction", an initiative promoting the use of ICT in all areas of the construction production process—surveys, design, construction, inspection, maintenance, and renovation. For the bridge sector, MLIT is also working on the "i-Bridge", an initiative to improve safety and productivity using ICT across all processes, surveys, design, construction, inspection, and maintenance.

2. Introduction of i-Bridge

With the goal of implementing i-Bridge on the Natsui Viaduct, a comprehensive assessment of the cost effectiveness, implementation process, feasibility of system development, and future potential of ICT was carried out to determine which technologies to be implemented in each construction phase, such as design verification, construction planning, site construction, and inspection. **Fig. 3** shows a general overview of the ICT used in the bridge project.

3. Overview of Adopted ICT

(1) Survey Technologies

1) Topographic Survey Using Drones

At the beginning of construction work, a topographic survey using drones to obtain 3D mapping data was conducted to confirm that the site terrain was consistent with that specified in the design drawings. The results made it possible to plan precisely for the construction yard, and they were also used effectively in land lease negotiations.

(2) Design and Construction Planning Technologies

1) Automatically Generated 3D Bridge Model

During design verification, a 3D model of the main girders was created using SMC-Modeler, a 3D model drawing system for bridges that makes it easy to accurately model prestressed concrete bridge configurations (**Fig. 4**).

2) Check for 3D Model Member Obstruction

Using a feature added to the drawing system, it was verified that there were no obstructions between the prestressing steel cables and the other materials, and that there were no construction problems due to the placement on the drawings.

3) Completion and Construction Videos

3D images of the bridge under construction and after completion were created by superimposing accurate topographical data of the vicinity of the construction site obtained by drone surveys on the 3D model of the bridge. The model was used to produce a reduced scale model of the completed bridge using a 3D printer and videos showing the bridge under construction and after completion. Several video renderings of the completed bridge were produced, including an aerial view and a running vehicle simulation. These were useful for explaining project details to stakeholders and local residents. The video rendering of the construction stage was produced by breaking down the complex bridge construction procedure into several steps of cantilever erection method, and used to verify the procedure and review the construction work with people involved in the construction (**Fig. 5**).

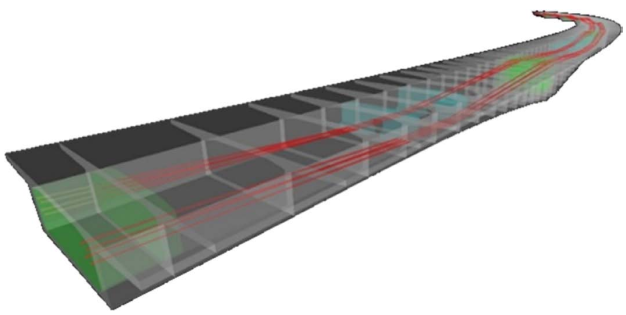

Fig. 4 3D model

Fig. 5 Image of the construction stage

Fig. 6 Formwork setting by TS

(3) Site Construction Technologies

1) Formwork Setting and Bridge Deck Elevation Surveying

In general, the formwork adjustment of cantilever block requires several people to conduct a survey using levels and transits, and fix the formwork in correct position. The automated surveying system composed of an auto-tracking total station (TS) and a special mobile application was developed and used to facilitate labor-saving for the formwork adjustment. This system together with the SMC-One Navigation system enable one person to perform everything from surveying to preparing the survey report achieving labor-saving and acceleration of onsite construction works for onsite staff. To use the system, design coordinates, deflection allowance, and other data are preloaded into the application as design values. The TS uses these data for control to sight survey points and display discrepancies between the design and survey points onscreen in real time. The measured survey data are stored wirelessly in the cloud and can be readily output as survey report data using software. Using the same technologies as in the automated surveying system, an application for surveying bridge deck elevation was also developed, which made it possible to prepare survey record files only by one onsite staff and achieve more-efficient and more productive management tasks (**Fig. 6**).

2) SLAM System for Checking External Cable Duct Positioning

External cables are essential members made of high-performance prestressing steel, and if for some reason their deviator ducts were to be misaligned during construction, then there would be a risk of serious damage to the main girder concrete due to insufficient prestressing. Therefore, reliable checks of the positions of the deviator ducts before concrete placement are important. In this project, a system that uses SLAM (Simultaneous Localization and Mapping) technology to quickly locate the position of the external cable's deviator duct in real time was tested and its effectiveness evaluated. SLAM is a technology for creating a map of the surrounding environment in 3D while simultaneously estimating its own location. The system involves taking a video while looking at the image on camera using a mobile device. The positioning error of a deviator duct with respect to the design coordinates can be obtained on the spot by taking a video of the deviator duct. Furthermore, augmented reality allows marking the location of the design coordinates of the deviator duct on the screen, which is useful for confirming the approximate location of the deviator duct. In this accuracy verification, the horizontal and vertical errors were confirmed to be less than ±10 mm, which is sufficient to confirm that there are no significant positional deviations.

3) GNSS Crane Monitoring System

Using the previously discussed 3D model, a system that monitors the position of a crane boom using the Global Navigation Satellite System (GNSS) was adopted to prevent the boom from intruding into the space of the national highway during crane work in the neighboring construction yard. The system sounds an alarm if the GNSS antenna mounted at the end of the boom approaches or enters a preset restricted area. The relative positions of the boom and the restricted area can be checked instantly in 3D virtual space using special software on a computer in the office (**Fig. 7**). This system allowed the construction in this project to be carried out safely.

(4) Inspection Technologies

1) PC Tendon Placement Inspection

To inspect the PC tendon profile, a level string stretched at the top of deck slab surface to be cast and a scale are used to visually measure the length of drop from the string to the sheathing duct and rebar supporting

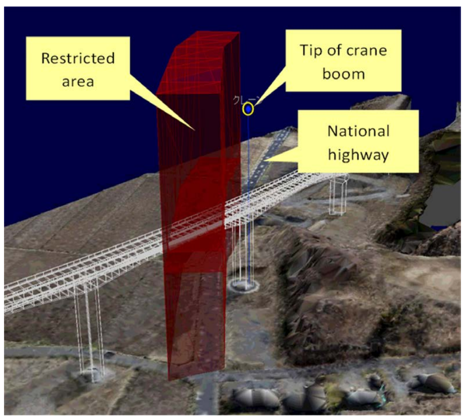

Fig. 7 GNSS crane monitoring system

the duct, and these results are recorded manually. This inspection procedure takes time and effort because of the routine work of setting level strings, measuring, and recording, and there is a risk of reading errors during visual measurement. In this project, measurements were taken by the previously described SMC-One Navigation to achieve labor-saving and improve measurement accuracy. After recognizing positions of survey marks on the top of the existing deck slab and the fixed formwork using a TS, the system with a special application was used to automatically calculate the length of the expected drop from the top surface of deck slab to be cast and display the results instantly after measuring positions of sheathing ducts and rebars. Measurement data are transmitted wirelessly to the cloud and reports are prepared automatically. Calibration conducted beforehand showed no measurement errors, therefore the system was used during the joint inspection with the client (**Fig. 8**).

2) Finished Work Inspection

In general, inspecting finished concrete work involves measuring cross-sectional dimensions using a scale or tape measure and then recording the results manually. In this project, wireless communication between a large digital caliper and a mobile device was developed and introduced to upload measurement data with a single tap and prepare reports automatically. Although the system requires the same amount of time as before for the inspection itself, it saves time and effort of manually recording and inputting data. It also was proven to be useful tool during site inspections with the client.

(5) Total Management System for Centralized Management

1) Platform

Because various ICT approaches involving a wide range of data were introduced in this project to manage the construction, a system was created to centrally manage data collection for all systems on a common platform and share it with all concerned parties. The platform was built on the web with a user interface that is visually simple and intuitive (**Fig. 9**). Users of the platform are given either administrator permission allowing to record, edit and read or viewer permission allowing to read only; the former permission is for site staff, while the latter is intended for people involved in the construction, including the client. The left side of the main screen displays a menu of the ICT used onsite to show all the technologies at a glance. Information

Fig. 8 PC steel tendon placement inspection

Fig. 9 Screen of platform

such as system descriptions and manuals or input and output data can then be easily downloaded and read by choosing a suitable menu item.

2) Report Management System

The platform menu includes a report management system that stores inspection records and other reports classified by location and work item. All the report data can be recorded and viewed from anywhere via the web, and the latest data can always be shared with concerned parties. The management work productivity was increased by using this system through automated direct storage and simultaneous automated output of report data from the inspections of PC tendon placement and finished work discussed above.

4. Conclusion

The approach to increase construction site productivity using ICT becomes more necessary. The development of systems and technologies in this project were able to remain results in the limited construction period. The authors hope that efforts in this project will be helpful in the future development of i-Bridge.

概　要

国道45号夏井高架橋工事は，岩手県久慈市に位置し，震災復興道路の一環として整備される三陸沿岸道路の橋長497m の PRC7径間連続ラーメン箱桁橋の建設工事である。本橋は標準的な箱桁断面を有しており，移動作業車を用いた張出し架設で施工される。張出し架設では，型枠組立，鉄筋・PC 鋼材組立，コンクリート打設などの施工管理や検査の段取り作業をサイクル施工の中で繰り返し行う。このため，張出し架設の各施工段階により有効な ICT を導入することにより i-Bridge に取り組み，現場職員が行う施工管理業務の負担軽減と，省力化を図った。