Efficiency promotion and sophistication of periodic bridge inspection by robotic technology with drastically reduced time of traffic restriction

Keitetsu ROKUGO

Professor Emeritus, Dept. of Civil Engineering, Gifu University

Hideaki HATANO

Project Professor, Center for Infrastructure Asset Management Technology and Research, Gifu University

Adoption of RT for periodic bridge inspection

Periodic inspection of bridges by visual observation from a close distance once every five years has been mandated since July 2014. Introduction of robotic technology (RT), including drones, for periodic inspection is expected to bring about the effects given below but has yet to be fully implemented.

- Shorten the time of traffic restriction for inspection
- Enhance safety of inspection work
- Accumulate detailed inspection data
- Reduce the cost

The Gifu University Project for Regional Implementation of SIP (Gifu Univ. SIP)[1] has been undertaking activities focusing on the adoption of RT, including drones, for periodic inspection of Kakamigahara Bridge managed by Kakamigahara City, which is scheduled for fiscal 2018. This article is an excerpt from Reference[2].

Difficulty in periodic inspection of Kakamigahara Bridge

Kakamigahara Bridge with a bridge area of 11,200 m^2 shown in Fig. 1 is a prestressed concrete continuous 10-span fin-back bridge 594 m in length over Kiso River. The superstructure of this bridge completed in 2013 is of a semicylindrical box girder structure, with a height of approximately 10 m from the water surface. The elliptical piers have no hammerhead. The standard vehicle lane width is 7.5 m, with 3-m wide lanes for cyclists and pedestrians on both the upstream and downstream sides, which are locally widened to 5 m near Piers P5 and P7.

Inspection of the undersurface of Kakamigahara Bridge is impossible even with a large bridge inspection vehicle widely used for general bridges, as shown in Fig. 2, due to the wide sidewalk and the fin-back members constructed between each sidewalk and vehicle lane. The P2-P9 spans 420 m in length above the river are particularly difficult to inspect from the underside, as they require inspection with an ultralarge bridge inspection vehicle with a sidewalk-overbridging capacity of around 5 m, suspended scaffolding, or ropework, which would incur heavy costs.

Problems and efforts for solutions

Table 1 shows problems arising when RT is employed, regarding standards, RT, and cost. This table also includes the key points of the efforts by the Gifu Univ. SIP.

Fig. 1 Kakamigahara Bridge

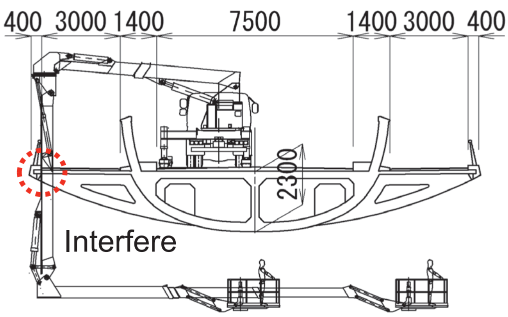


Fig. 2 Inspection with a general large bridge inspection vehicle

Conformity to standards

When introducing RT into periodic inspection of bridges under the management of municipalities, it is important that the technology conform to the Guideline for Periodic Road Bridge Inspection[3]. Also, technical specifications are necessary to serve as a basis for placing an order for bridge inspection involving RT.

Gifu Univ. SIP organized the Assessment Committee for Applicability of New Bridge Inspection Techniques (July 2017 – March 2018), which formulated and published Recommendations for Bridge Inspection Incorporating Robotic technology (draft) – for Local Municipalities (hereafter the Draft Recommendations)[1,4].

Gifu Univ. SIP also proposed a two-step method for periodic inspection of Kakamigahara Bridge. This method consists of RT-supported preliminary research in accordance with the Draft Recommendations and visual inspection of the entire bridge from a close distance using an ultralarge bridge inspection vehicle (Fig. 3).

Since Kakamigahara Bridge is a special bridge (fin-back bridge) with wide sidewalks, it requires 10 days to inspect the bridge using an ultralarge bridge inspection vehicle, of which only one of its kind is available in Japan. However, by conducting RT-supported preliminary research, the time requiring the large vehicle can be reduced to 4 days. This reduces the congestion due to the closing of one lane by 6 days. This can be

Table 1 Problems associated with introduction of RT into periodic inspection of bridges and Gifu Univ. SIP's efforts

	Problem	Key points of Gifu Univ. SIP's efforts
Standards	No standard is available to serve as a basis for introducing RT	Formulated the Recommendations for Bridge Inspection Incorporating RT (Draft) – for Local Municipalities[1, 4]
	Inspection methods should conform to Guideline for Periodic Road Bridge Inspection	Proposed preliminary research by RT prior to visual inspection from a close distance based on the inspection guideline
RT	Performance requirements for RT is unclear	Required that the technology is capable of providing information for judging if the soundness grade of each member is Grade II or higher with respect to Guideline for Periodic Road Bridge Inspection (Table 2)
	Assessment of technology is insufficient	Assessed the performance of RT by field testing at Kakamigahara Bridge (Table 3)
	No single RT can inspect all segments	Proposed combinations of multiple robotic techniques (Figs. 3 and 4)
Cost	The possibility of inspection cost reduction is not obvious	Proposed to change RT-supported preliminary research to screening survey and utilize AI

Table 2 Requirements for information obtained through RT

		Requirements	Verification
Detection of damage	Presence and type	Damage can be detected and classified.	Pictures and sketches of damage are provided to confirm the requirements in the left column. The locations, ranges and directions of damage shown in the provided pictures and sketches are roughly in agreement with those in the damage chart prepared by visual inspection from a short distance.
	Location	Damage can be detected in a manner to allow sketching of damaged portions in relation to other members.	
	Size	The overall image can be obtained to judge whether the damage is localized or extensive.	
	Direction and pattern	The direction (horizontal, vertical, diagonal, longitudinal or transverse to reinforcement, etc.) and pattern (map cracking, etc.) of damage can be detected.	
	Water penetration paths	The source and path of water ingress can be detected regarding damage involving water, such as water leakage and free lime.	
Measurement of damage	Size	Crack width: The crack width of 0.2 mm or more can be measured with an error margin of 0.0 to + 0.1 mm.	The measurement results of damage described in the damage chart prepared by visual inspection from a short distance or artificially created accuracy verification marks are roughly within the tolerances shown in the left column.
		Crack length, peeling, rebar exposure, leakage, etc.: The size can be measured with an error margin of 5 cm. (Length: L = XX cm, Area: A = XX cm × XX cm)	
	Displacement	The displacements of expansion gaps and bearings can be measured with an error margin of 10 mm.	

※ The following performance is required so that there can be no omission of cracks with a width of 0.3 mm or more.
For a crack width of 0.2 mm, it is acceptable to output a measurement result of 0.3 mm (0.2 mm + error 0.1 mm) to be on the safe side.
For a crack width of 0.3 mm, it is not acceptable to output a measurement result of 0.2 mm (0.3 mm – error 0.1 mm) on the dangerous side.

done without incurring additional cost, if the cost of RT can be covered by the reduced cost for the inspection vehicle.

Performance and operation method of RT

It is difficult to clearly define the performance required of RT for bridge inspection, since RT has scarcely been introduced to periodic inspection of bridges so far. The above-mentioned Draft Recommendations require that the technology be capable of providing information for judging if the soundness grade of each member is Grade II or higher with respect to the Guideline for Periodic Road Bridge Inspection. Gifu Univ. SIP specified the performance requirements for the information to be acquired as Table 2 by inventorying the data necessary for inspection engineers to judge the soundness of each member of the bridge and data that the RT should provide. Table 3 gives the key results of the performance of RT confirmed by field testing. Note that the measurement performance was selected referring to Gifu Prefecture's Bridge Inspection Manual[5] and tolerances were specified also taking account of the results of field tests.

Table 3 reveals that it is currently difficult to inspect all segments by one single robotic technique within the range of the techniques considered. As shown in Figs. 3 and 4, Gifu Univ. SIP intends to combine multiple techniques making the most of their features.

Future development

Gifu Univ. SIP is undertaking the projects given below with the aim of introducing RT in periodic inspection of Kakamigahara Bridge (first inspection in fiscal 2018).

- Formulate Recommendations for Bridge Inspection Incorporating RT (Draft) - for Local Municipalities
- Present performance requirements for, and assess the performance of, RT
- Provide examples of optimum combinations of robotic techniques

Utilizing RT for bridge inspection will bring about the following advantages:

- Facilitate inspection of bridges with a large cross section such as Kakamigahara Bridge
- Significantly shorten the period of traffic restriction on bridges with a large inspection vehicle (in the case of Kakamigahara, the period of 10 days was reduced to 4 days)

Table 3 Assessment of RT performance

Inspection segments of Kakamigahara Bridge	Assessment of applicability to Kakamigahara bridge	Operation by drone engineer			Operation by inspection engineer	
		Drone with wheels for visual observation and hammering tests	Two-wheeled drone with a camera for bridge inspection	Drone with controllable pitch propellers	Robotic camera indicating crack scale for bridge inspection	Camera system for bridge inspection
Bridge members above water	A: Applicable B: Conditionally applicable C: Inapplicable	B (Using boat)	B (Using boat)	B (Using boat)	A	A
Bottom surface of deck		A (+) (hammering test)	A (-) (Revaluation)	A	A	A
Girder (Side surface)		B (Only upper part)	C (Except for curved surface)	A	A	A
Girder (Bottom surface)		A	A (-) (Revaluation)	A	A	B (Except for center part)
Beam on bearings		C (Unavailable)	C (Unavailable)	A	B (Only side surface)	A
Bracket		B (Only lower surface)	A	A	A	A
Bearing		C (Unavailable)	A	A (-) (Revaluation)	B (Except for space between bearings)	B (Except for space between bearings)
Drainage pipe and metal fitting		A	A	A	A	A
Substructure (Top surface)		C (Unavailable)	A	A (-) (Revaluation)	C (Unavailable)	C (Unavailable)
Substructure (Side surface above water)		C (Unavailable)	A	A	C (Unavailable)	C (Unavailable)

		A2	P9	P8	P7	P6	P5	P4	P3	P2	P1	A1
					W.Z.		W.Z.					
Preliminary survey with RTs	Wide view	Drone										
	Narrow view	Drone/Robotic camera										
	Hammer	Drone with hammer										
Human Visual inspection		Inspection vehicle			Rope access	Inspection vehicle	Rope access	Inspection vehicle				

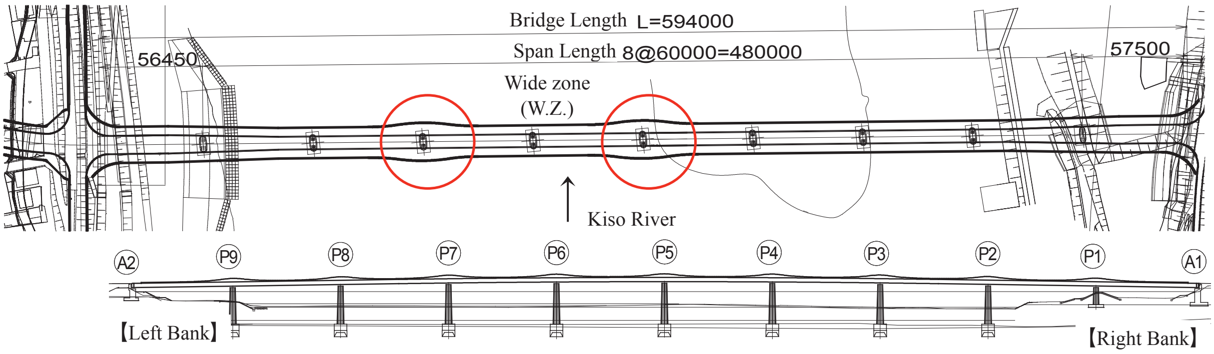


Fig. 3 Combination of robotic techniques

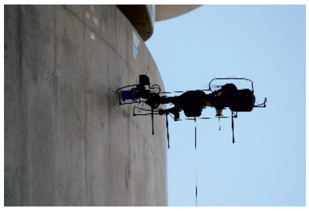
(a) Drone with wheels for visual observation and hammering tests

(b) Two-wheeled drone with camera for bridge inspection

(c) Drone with controllable pitch propellers

(d) Robotic camera indicating crack scale for bridge inspection

(e) Camera system for bridge inspection



(f) Drone with hammering test equipment for bridge inspection

Fig. 4 Robotic techniques for inspection of Kakamigahara Bridge

When revising technical standards, it is hoped that the inspection items and performance requirements will be reviewed from the aspects of evolving technology and adopting new technology, including the improvement of measurement technology using robots, enhancement of the accuracy of acquired data, and sophistication of data processing technology.

[References]
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