Approach to use of robotic technologies in periodic inspection of steel bridges

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Anticipation for robotic technologies in steel bridge inspection

Gifu University's SIP implementation project includes activities aimed at incorporating robotic technologies in periodic inspection of the Kakamigahara Bridge, which has a length of 594m and is managed by the city of Kakamigahara. As part of these activities, operational proposals have been made for the introduction of new technologies such as inspection robots for use in inspection of concrete bridges, including the development of related standards,[1] clarification of performance requirements,[2] evaluation of technologies,[2] and combinations of technologies.

Meanwhile, steel bridges have a more complex cross-sectional shape than concrete bridges because they use many truss structures and arch structures, and this means that inspection work using bridge inspection vehicles and the like is less efficient. Therefore, it is necessary to promote bridge inspection using robotic technologies for steel bridges as well, and standards must be developed on the basis of challenges encountered in steel bridge inspection.

We will discuss the approach for expanding the scope of application of the standards and requirements that have been proposed for concrete bridges in activities thus far to include steel bridges.

Challenges in periodic inspection of steel bridges

In steel bridges, the members of thin-walled structures have a large surface area requiring inspection, and there are also many complex frame structures. In the inspection of truss bridges and arch bridges, the bucket of an inspection vehicle needs to be inserted between complicated frame structures in a careful operation, as shown in Fig. 1 and Fig. 2. This significantly lowers the efficiency of inspection work, and restrictions due to the shape of the bucket make it impossible to bring it up close to some portions. Therefore, although there is widespread interest in using bridge inspection robots to conduct inspection for the sake of efficient and accurate implementation of bridge inspection work, broader application of bridge inspection robots is considered to involve a great deal of difficulty at the present time.

Fig. 1 Inspection of a trussed Langer bottom-road bridge[4]

Fig. 2 Inspection of an arch deck bridge[4]

We will describe the required performance of robotic technologies for use in periodic inspection of steel bridges managed by local governments, based on findings from application of the proposed guidelines for concrete bridges[1] to the Kakamigahara Bridge.

Inspection functions at wide and narrow fields of view

Degradation of anticorrosive function, a change that is typically seen in steel bridges, requires information gathering over a relatively wide range. Meanwhile, local corrosion, which has a major impact on integrity evaluation, requires information gathering in a relatively narrow field of view; that is, information must be gathered at a level where it is possible to judge whether to perform measurement for reductions in plate thickness.

Inspection in places with inadequate brightness

Many coatings, which come in a variety of colors, are used on steel bridges, and a great deal of inspection work is performed in situations with inadequate brightness in the case of steel bridges with dark coatings, compared to concrete bridges.

Crack detection accuracy

Cracks in steel materials originate at welds, and when a crack involves cracking of a coating at an early stage, it is sometimes detected as a change involving rust staining. The standard of concrete cracks about 0.2 mm in width could be introduced as an accuracy requirement for detection of cracked coatings during periodic inspection of bridges, although further discussion is necessary.

Detection of loosened and missing bolts

In steel bridges, it is necessary to detect when bolts that connect members are loose or missing. An inspection engineer can detect loosened bolts by hammer sounding, but accurate hammer sounding of bolt heads and nuts by robotic means is difficult based on the current state of the technology, and it is considered more realistic to use alternate means, such as detecting gaps due to loosening of bolts or cracked coatings where a bolt head or nut contacts the steel plate.

Crack detection accuracy in reinforced concrete floor slabs of steel bridges

The accuracy of crack detection in concrete floor slabs of steel bridges is an issue. As long as the condition of the bridge is equivalent to at least soundness category II, it is sufficient to be able to detect wide-ranging unidirectional or bidirectional cracks without free lime (cracks up to about 0.2 mm in width).

Close-up access in narrow spaces

Many types of structures in steel bridges involve constraints on the directions in which they can be accessed by inspection robots from the horizontal or vertical direction, etc., and this means that accurate operation within a narrow range is necessary. An inspection robot equipped with a rotating spherical shell,[5] like the one shown in Fig. 3, performed very well in providing close-up access to narrow spaces during a field test performed by the authors on a steel bridge (Chidori Bridge in Gifu-shi). Other types of robots also perform very well in providing close-up access to narrow spaces by making use of the characteristics of steel bridges, including an inspection robot that moves omnidirectionally under a girder under control by the length of a hanging wire,[5] an inspection robot equipped with a mechanism that moves it while adhering to steel by magnetic attraction,[6] and an inspection robot that moves while suspended from the lower flange of a steel plate girder bridge.[6] It is anticipated that these types of robots will be utilized in steel bridge inspection.

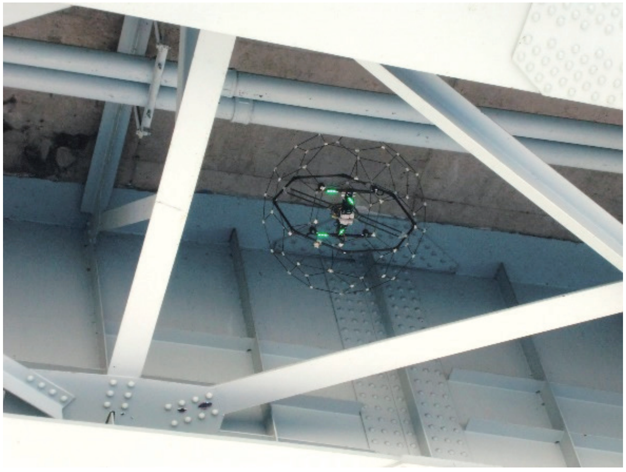

Fig. 3 Inspection robot equipped with a rotating spherical shell

Efficient imaging of deterioration in narrow spaces

In steel bridges having many narrow spaces, it is necessary to capture images in multiple directions while positioned close-up to a narrow space, and to reduce the amount of time needed to get in and out of such spaces. For example, images could be captured using a high-resolution 360° camera. Fig. 4 shows an example of a robot operating in a narrow space on a concrete bridge; this is a bridge inspection robot equipped with a 360° camera that we tried out on the Kakamigahara Bridge. An image captured by this robot is shown in Fig. 5. This camera-based method was fully capable of detecting cracks about 0.2 mm in thickness on the web surface on the left side.

Fig. 4 Drone equipped with a 360° camera

Fig. 5 Image obtained by a 360° camera

More efficient inspection work on members above the road

When using a drone robot to inspect a bottom-road bridge, as shown in Fig. 1, it is possible to inspect the underside of the bridge without any traffic restrictions; however, the bridge needs to be closed to traffic when inspecting the members above the road. There is presently a need to devise ways to avoid lengthy closure to traffic. To reduce the amount of time that a bridge is closed to traffic, it is necessary to take steps to accomplish inspection work more efficiently, such as operating multiple robots simultaneously.

Example of performance requirements for inspection of steel bridges (draft)

Based on the matters discussed above, the performance requirements according to the bridge inspection manual of Gifu Prefecture[3)] are as shown in Table 1. Steel bridges involve very different performance requirements from concrete bridges with regard to close-up access to narrow spaces, depending on bridge type; so these requirements are classified by the type of bridge concerned. This table is presented as a set of initial values for future use when considering standards, based on the authors' activities with the use of bridge inspection robotic technologies on concrete bridges.

Table 1 Example of performance requirements for information obtained by robotic technologies (steel bridges)

Content requirements			Verification method
Bridge types	Steel girder and box girder (deck bridges)	The inspection mechanism can freely pass through spaces of about 1m × 2m in a vertical direction.	Verified by field testing on actual bridges or model bridge facilities, organized by committees, etc. including persons having relevant knowledge and experience.
	Deck bridges	The inspection mechanism can freely pass through spaces of about 3m × 5m in a horizontal or vertical direction in a truss bridge, etc.	
	Bottom-road bridges	The inspection mechanism can freely pass through spaces of about 3m × 5m in a horizontal or vertical direction in a truss bridge, etc., and the length of time of traffic closure during bridge surface inspection can be minimized.	
Detection of deterioration	Presence and type of deterioration	Capable of detecting and categorizing deterioration (corrosion, cracked coating, loosened or missing bolts and rivets, fracture, degraded anti-corrosive function, deformed or damaged steel plates).	Comparison with deterioration diagrams prepared on the basis of close-up visual inspection, confirming that it shows generally the same location, scope, etc. of deterioration.
	Location	Capable of detecting deteriorated spots and relative positions with other members.	
	Extent	Capable of determining whether deterioration is localized or widespread.	
	Direction, etc.	Capable of detecting the directions of cracks, fractures, deformation, etc.	
	Route of moisture intrusion	Capable of detecting the route of moisture intrusion and the origin with regard to corrosion and degradation of anticorrosive function.	
Measurement of deterioration	Dimensions	Capable of detecting steel plate deformation and damage with an error of less than 1 cm.	The measurement results of deterioration and accuracy verification indicators are generally within the permissible error limits shown at left.
		Capable of measuring the dimensions of deterioration with an error of less than 5 cm.	
	Displacement	Capable of measuring girder expansion gaps and displacement of supports with an error of less than 10 mm.	

Combinations of robotic technologies

Based on utilization in field testing at Kakamigahara Bridge and in actual bridge inspection work, it is essential to select and combine robotic technologies according to the portions to be inspected and the types of inspection work. It is desirable to compile field test results performed throughout Japan and prepare documentation including the correspondence of robotic technologies to different portions for inspection.

Formats for use of robotic technologies to support inspection

The following are conceivable formats for the use of robotic technologies in support of bridge inspection.

(1) Using robotic technologies for preliminary surveys to improve the efficiency of overall close-up visual inspection work (the current proposed guidelines[1)]).

(2) Using robotic technologies for screening to select those portions where close-up visual inspection work will be performed.

(3) Using robotic technologies in place of close-up visual inspection on bridges classified as soundness category I based on close-up visual inspection in the previous fiscal year.

Formats (2) and (3) are thought to be desirable future steps in terms of improving efficiency and reducing costs in bridge inspection work.

[References]
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