Development and Verification of Inspection Method for Concrete Surface utilizing Digital Camera

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Abstract –

Currently, road managers are required to maintain and renew road assets that are rapidly aging and damaged. On the other hand, due to the ever-increasing road assets, social problems such as cost reduction and shortage of engineers in maintenance and renewal are occurring. In particular, the "Road Bridge Periodic Inspection Procedure" was formulated in June 2014, and the periodic inspection is based on close-up visual inspection once every five effore, which requires enormous expenses and personnel. Therefore, efficient and economical inspection by applying non-destructive inspection technology is strongly required. For this reason, NEXCO West Japan Group has developed a digital camera inspection system (hereinafter referred to as Auto-CIMA) for the purpose of enhancing the structure inspection and improving efficiency.

Keywords –

Digital camera; Non-destructive inspection; Inspection; Crack;

1 Introduction

Auto-CIMA is a system that acquires high-definition images from digital cameras in order to grasp and inspect the state of concrete structures. Auto-CIMA can automatically paste the high-definition images that have taken and digitally check the surface condition of concrete. In addition, cracks and their widths (widths more than 0.1 mm can be visually confirmed in the image) and lengths can be automatically extracted, and the secular change of cracks can be grasped by accumulated data.

According to the verification from the development to the present, the inspection using Auto-CIMA has a condition that it is inefficient, but it does not require adjustment work or high place work by inspection, so it is economically advantageous. It has also been confirmed that the same inspection results as the close-up visual inspection can be obtained by combining with an inspection method that captures internal damage such as floating or peeling of concrete by infrared inspection.

Currently, we are verifying the applicability of Auto-CIMA as one of the inspection methods for periodical inspection, and it is expected that the efficiency of inspection using Auto-CIMA will be improved in the future. Here, I will report the outline.

2 Auto-CIMA

2.1 Overview of Auto-CIMA

Auto-CIMA is an inspection method that grasps the condition of the concrete surface of a bridge by acquiring high-definition images with a digital camera. The captured high-definition images are automatically pasted together and expanded in a plane, and the surface condition of the concrete can be confirmed on the digital image from the expanded image. Furthermore, cracks and their widths and lengths can be automatically extracted, and secular changes in cracks can be grasped by accumulated data. The Auto-CIMA shooting is aimed at a concrete plane and can shoot up to a distance of 40 m. Under this shooting distance condition, cracks with a width of more than 0.2 mm can be automatically extracted, and cracks with a width of more than 0.1 mm can be confirmed visually with a digital image. Table 1 shows the targets and specifications of Auto-CIMA.

Table 1. Targets and specifications of Auto-CIMA

target
Hollow slab bridge
Box-girder bridge
Abutment
Pier

specification
Shooting distance:2m～40m
Shooting angle:Within 45°
Shooting renge:Horizontal Within ±45°
Vertical Within ±30°

2.2 Features of Auto-CIMA

①Automatic shooting

Auto CIMA can photograph concrete planes by automatically operating a digital camera with an electric pan head shown in Fig. 1 on a PC. The shooting range for one shot is ±45° on the long side and ±30° on the short side, and the dimensions differ depending on the shooting distance. The shooting plan (shooting angle of view and direction) shown in Figure 2 is automatically set by setting the shooting range and shooting accuracy (0.5mm/pixel in NEXCO West Japan) on the PC. This eliminates erroneous measurement during shooting as much as possible.

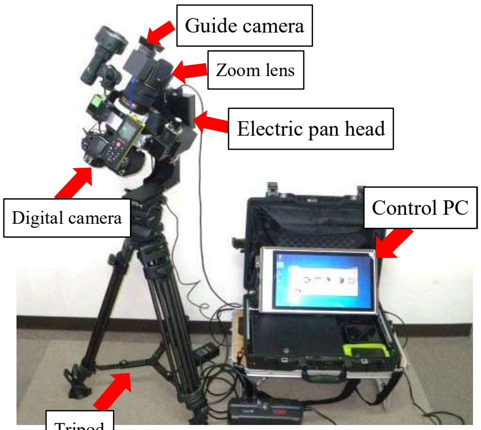

Figure 1. Auto CIMA

Figure 2. Shooting plan

②Image composition

Auto-CIMA can easily check the shooting status of automatically shot images (Fig. 3 (a)). Images that are out of focus due to obstacles such as electric wires during automatic shooting can be re-shot with manual shooting. It is difficult to recognize as a single image due to the color unevenness of the image composition. Therefore, the captured images are stitched together with high precision by image processing. (Fig. 3(b)). Since this high-definition image composition requires processing on a high-performance PC, it is performed indoors rather than immediately after shooting.

a) Simple pasting image b) High-precision stitched image

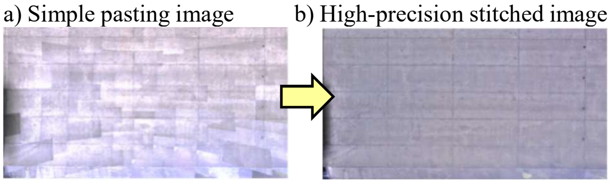

Figure 3. Automatic stitching image

③Automatic crack detection

The automatic crack detection on the concrete surface image uses an algorithm (line matching) to detect cracks as "continuous with lines". Compared with the binarization and contour detection generally used for image processing, dirt on the concrete surface is eliminated as much as possible, and it is specialized for crack detection as shown in Figure 4. Since the accuracy of the captured image is 0.5 mm/pix, the crack detection accuracy can recognize a 0.2 mm wide crack.

3 Application to visual inspection

The application of Auto-CIMA to proximity visual inspection was verified for the following four items.

①Inspection rate

Auto-CIMA is installed under the inspection target to perform the inspection, so there are some parts that cannot be photographed due to obstacles etc. We calculated the inspection rate for each bridge (see below) and verified the inspection range with Auto-CIMA.

Inspection rate (%):
Inspection area by Auto-CIMA (m^2) / Total inspection area (m^2)

②Inspection result

By comparing the visual inspection results with the Auto-CIMA inspection results, we verified whether it could be applied as an alternative method of visual inspection. In addition, Auto-CIMA can inspect only the damage appeared on surface, so the internal damage was inspected by the infrared thermography inspection.

③Cost and capacity

It was feared that Auto-CIMA inspection had lower work capacity than visual inspection. Therefore, in order to confirm the scope of application of Auto-CIMA, we compared and verified the cost and work capacity of visual inspection and inspection by Auto-CIMA.

④Application effect

We compared the work abilities of visual inspection with inspection combining Auto-CIMA and infrared rays (hereinafter, non-destructive inspection) to verify the effect of introducing non-destructive inspection.

3.1 Inspection rate verification

The scope of application was verified for the three bridges shown in Table-2. Table-3 shows the inspection rates for Auto-CIMA inspection for each bridge. The inspection rate of the superstructure was about 50% at the end span and about 100% at other spans due to the influence of obstacles (slopes, trees). The inspection rate for substructures is 0% for abutments and about 80% for piers, as in superstructures. As a result, it was confirmed that the inspection by Auto-CIMA can be applied to about 65% of the entire bridge.

Table 2. Target bridge(Inspection range verification)

Bridge	Type	Span	Shooting distance	Shooting area	Underpass
Bridge A	PC Box-girder	5span	30m	12,705㎡	River and road
Bridge B	PC Box-girder	5span	10～30m	12,296㎡	River and road
Bridge C	PC Box-girder	4span	10～30m	6,137㎡	Train

Table 3. Inspection rate (Inspection by Auto-CIMA)

	Inspection rate					
	Bridge A		Bridge B		Bridge C	
substructure	A1	0.0%	A1	0.0%	A1	0.0%
	P1	54.6%	P1	72.7%	P1	80.2%
	P2	96.3%	P2	62.7%	P2	74.1%
	P3	94.2%	P3	56.1%	P3	69.3%
	P4	62.7%	P4	69.1%	A2	0.0%
	A2	0.0%	A2	0.0%		
superstructure	A1-P1	45.4%	A1-P1	64.1%	A1-P1	81.9%
	P1-P2	100.0%	P1-P2	95.2%	P1-P2	100.0%
	P2-P3	100.0%	P2-P3	100.0%	P2-P3	100.0%
	P3-P4	100.0%	P3-P4	86.9%	P3-A2	95.7%
	P4-A2	47.7%	P4-A2	64.9%		
			average		65.5%	

3.2 Inspection results verification

From the bridges that were visually inspected, we selected RC hollow floor slab bridges and PC box girder bridges where blind spots are less likely to occur during shooting, and verified the inspection results for 12 bridges with 62 spans. The deformation detected by each inspection method was classified into the following patterns, and it was verified whether the nondestructive inspection could be applied as an alternative method with the same accuracy as the precision visual inspection. Table 4 shows the verification results.

Pattern A:

Damage found at the same position and in the same area as the visual inspection

Pattern B:

Damage that was confirmed by visual inspection but not by non-destructive equipment inspection

Pattern C:

Damage not confirmed by visual inspection but newly confirmed by non-destructive inspection

Table 4. Verification result of inspection result

Found damages		quantity	Match rate	Remark
Proximity inspection		229	–	
Non-destructive inspection	PatternA	224	97.8%	
	PatternB	5	2.2%	all delamination
	PatternC	353	–	

As a result of the verification, out of 229 deformations visually confirmed, 5 cases (Pattern B) were not confirmed by non-destructive inspection (concordance rate 97.8%). The damage that could not be confirmed by non-destructive inspection was delamination (no change in appearance) as shown in Fig. 4, and no damage could be confirmed by inspection by infrared thermography. We could not confirm it because it was lurking deeper than the range that could be confirmed by infrared thermography.

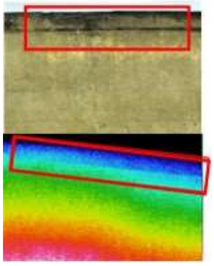

Figure 4. Image of delamination

In addition, nondestructive inspection (Pattern C) confirmed 353 new damages. Of these, 239 were confirmed by Auto-CIMA and 116 by infrared thermography. The new damage identified by Auto-CIMA was a crack. Since the inspection is performed with a high-definition visible image, it can be confirmed more accurately than the visual inspection, and it is considered that the inspection accuracy has improved. Especially, it seems to be very useful for the inspection of PC structures, etc. where cracks have a great influence on the soundness.

On the other hand, the damage newly confirmed by infrared thermography is characterized in that the damaged part can be seen due to the temperature difference. Therefore, a temperature difference occurs depending on the surface condition and the surrounding environment, and a sound part was erroneously detected as a damaged part. When it is judged that the sound part is damaged, it is judged to be worse than the original soundness in judging the soundness of the bridge, and it is judged that repair is necessary even if the bridge is not necessary to be repair. .. However, in most case spalling needs to be repaired, appears with surface damage such as cracks and rust. Since cracks and rust have been confirmed by Auto CIMA, there is no major change in soundness judgment.

Based on the above, as a result of non-destructive inspection, 97.8% of visual inspection damage was detected, and all damage that could not be confirmed was delamination, which was considered to be outside the detection range of infrared thermography. With non-destructive inspection, almost all visual inspection damage was detected, and soundness quality was obtained by using visible and infrared images together.

3.3 Cost and capacity verification

Cost and capacity verifications were performed on the bridges shown in Table 4 which were selected from RC hollow floor slabs and PC box girder bridges that are less prone to blind spots. In the verification, the inspection cost required for visual inspection and non-destructive inspection was compared with the number of inspected persons, and the applicable range of the inspection method was examined. The inspection cost was calculated by comparing the personnel cost with the cost required for the inspection (traffic regulation cost, machine cost, driver cost, security personnel cost, etc.). The number of inspectors was calculated by comparing the total number of inspectors engaged in on-site work and office work. In non-destructive inspection, as shown in Fig. 5, there are areas that cannot be inspected due to blind spots. Therefore, we decided to cover the range that cannot be confirmed by non-destructive inspection with visual inspection and add inspection cost. The verification results are shown below.

Table 4. Target bridge (Cost and capacity verification)

Bridge	Bridge Type	Span	Inspection size	Bridge	Bridge Type	Span	Inspection size
Bridge A	PC	2	108m	Bridge G	RC	7	108m
Bridge B		1	24m	Bridge H		9	24m
Bridge C		1	90m	Bridge I		2	90m
Bridge D		9	348m	Bridge J		6	348m
Bridge E		5	202m	Bridge K		5	202m
Bridge F		3	115m	Bridge L		3	115m

Figure 5. Blind spot range

① Comparison of inspection cost and number of inspectors

Table 6 shows the comparison result of the inspection cost and the number of inspectors between visual inspection and non-destructive inspection, and the consideration from the comparison of the inspection cost and the number of inspectors. The comparison results were calculated by arranging the percentage of nondestructive inspection when the visual inspection was taken as 100%. It also summarizes the under-girder height of each bridge and the characteristics at the time of inspection (necessity of traffic regulation, etc.).

【Consideration】

①Comparison of inspection costs

- For bridges with small spans and visual inspection in one day, nondestructive inspection always requires one more day to cover areas that cannot be inspected due to blind spots. Therefore, visual inspection is inexpensive. (Bridge A, Bridge B, Bridge C)
- For bridges with low under-girder height and no traffic restrictions, visual inspection costs are low. (Bridge D)
- For bridges that require traffic regulation, the cost of non-destructive inspection will be lower than visual inspection due to the impact of regulatory costs. (Bridge F, Bridge G, Bridge H, Bridge I)
- If the height under the girder is high, the inspection cost will be lower than the non-destructive inspection even if traffic regulation is not required for visual inspection. (Bridge J)
- The cost of non-destructive inspection of bridges at rampway is kept low because of complicated traffic regulations and time-consuming inspection. (Bridge K, Bridge L)

Table 6. Comparison result (Cost and capacity verification)

Bridge	Cost ratio (Non-destructive/visual)	personnel ratio (Non-destructive/visual)	Height under girder	Characteristic
Bridge A	178%	281%	16m	Visual inspection only for 1 day
Bridge B	122%	140%	10m	Visual inspection only for 1 day
Bridge C	126%	175%	15m	Visual inspection only for 1 day
Bridge D	108%	130%	6m since	The height under the girder was low and the visual inspection did not require traffic regulation.
Bridge E	93%	252%	Aithough 10m	The height under the girder was low and visual inspection required traffic regulation.
Bridge F	91%	158%	20m	Traffic regulation and bridge inspection vehicle required for visual inspection.
Bridge G	79%	148%	20m	Traffic regulation and bridge inspection vehicle required for visual inspection.
Bridge H	71%	525%	24m	Traffic regulation and bridge inspection vehicle required for visual inspection.
Bridge I	71%	92%	17m	Traffic regulation and bridge inspection vehicle required for visual inspection.
Bridge J	74%	138%	20m	The height under the girder was high and no traffic regulation was required for visual inspection.
Bridge K	37%	77%	25m	Visual inspection needs a lot of manpower due to a rampway bridge where the crossing condition is complicated.
Bridge L	21%	43%	26m	Visual inspection needs a lot of manpower due to a rampway bridge where the crossing condition is complicated.

②Comparison of number of inspectors

- At almost all bridges except rampway bridge visual inspection require less number of inspectors. (Bridge A-H, Bridge J)
- Due to the complexity of crossing condition roads, the number of non-destructive inspectors on rampway bridges is low. (Bridge K, Bridge L)
- Higher heights under the girder increase the efficiency of non-destructive inspection and may reduce the number of non-destructive inspectors due to traffic regulations. (Bridge I)

②Scope of non-destructive inspection

Table 7 shows the inspection methods that should be applied, which were confirmed by the verification conducted so far. The inspection method to be applied was decided by giving priority to the inspection cost. Furthermore, the under-girder height less than 10m was defined as “low”, more than 10m as “high”.

The bridges that were confirmed to be suitable for visual inspection were "bridges with short visual inspection days" and "bridges with low under-girder height that do not require visual traffic regulation". Non-destructive inspection is desirable for “rampway", "bridges that require traffic regulation under the bridges" and "high under-girder height bridges under the bridges".

Table 7. Applicable inspection

Inspection conditions			Comparison item		Applicable inspection
			personnel	cost	
Short visual inspection date			×	×	Visual inspection
Rampway bridge			○	○	Non-destructive
Height under-girder	low (Less than 10m)	No traffic regulation	×	×	Non-destructive
		Traffic regulation	×	○	Non-destructive
	high (10m or more)	No traffic regulation	×	○	Non-destructive
		Traffic regulation	×	○	Non-destructive

3.4 Application effect verification

The effect of introducing nondestructive inspection was verified by comparing that for visual inspection alone with the number of inspection days for introducing nondestructive inspection. The number of days of comparative inspection was confirmed by the number of days of bridge inspection within the jurisdiction of the Kansai branch of NEXCO West Japan. A non-destructive inspection was conducted on bridges that meet the conditions of Auto-CIMA shown in Table 1.

The verification results are shown in Table-8.

Table 8. Inspection days

Inspection method	Inspection days	Reduction rate
Visual inspection	12,463 days	–
Non-destructive inspection	10,136 days	18.7%

As a result of verification, if non-destructive inspection is introduced, numbers of days necessary for inspection will be shortened from 12,463days to 10136days, that is the efficiency will be improved by 20%.

4 Conclusion

As a result of the verification, the non-destructive inspection using Auto-CIMA confirmed the same inspection result as the visual inspection, and was confirmed to be applicable as an alternative method of visual inspection. In addition, we were able to confirm cracks in more detail than humans and improve inspection results.

Regarding the efficiency of the inspection, there were some areas where the inspection could not be performed due to blind spots, but with the introduction, the efficiency is expected to be improved by about 20%. However, depending on the conditions, the efficiency of the inspection may decrease, and it is necessary to be careful such as limiting the inspection target.

In the future, we will consider the development of guidelines and the use of automatic CIMA in the field to realize efficient and advanced bridge maintenance management.