Field Tests of RC Deck Slabs Deterioration Assessment System by Digital Images

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1. Abstract

Currently, there is a strong call for development of a bridge management and maintenance system that extends the service life of bridges in a rational and effective manner. In this study, we focused on deterioration of concrete slab of steel bridges due to cracking, the damage to which is exacerbated by increases in heavy vehicle traffic and by the application of anti-freezing agent. For this study, we developed the "RC Deck Slab Deterioration Assessment System" (hereinafter *the System*), which fully utilizes digital image processing technology. Our five development objectives were: 1) elimination of scaffolding used for inspection and its associated cost; 2) reduction of time expended for field inspection; 3) quantification of and normalization of deterioration assessment results; 4) improvement of tractability of changes resulting from the passage of time since the completion of the bridge, and 5) use of digital information.

This paper reports on the System’s applicability to bridges in service and its cost effectiveness.

2. Evaluation of applicability

Conventionally, detailed inspection on cracking of concrete slab have been made directly with the naked eye: an inspector positioned on scaffolding performs a close-range visual examination to measure lengths and widths of cracks and to judge degree of deterioration. Diagrams of the crack patterns are then made. With the System, images of the lower surface of deck slab are recorded by digital camera from a distance, a diagram of the cracking is generated from the images, and the level of deterioration of the deck slab is assessed.

In this study we report on surveys conducted with the System on some bridges in service. These surveys were carried out to evaluate the System’s accuracy of assess

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-ment. This study compares examples of the System's deterioration assessments with those of conventional detailed close-range direct visual inspections capable of attaining a high level of accuracy. Direct visual inspection was made using the scaffolding set up to re-paint the bridge. The comparisons were made on following items:

1) Accuracy of assessments of deterioration due to cracking

2) Work efficiency in terms of the total time required for both fieldwork and lab work

The bridges in our survey were chosen from those that tend to have damage to deck slab: urban viaducts exposed to heavy traffic, and mountain bridges subjected to heavy application of anti-freezing chemicals.

3. Outline of subject bridges

Viaduct A lies on a section of National Highway 5, which forms a part of Sapporo Shindo, an arterial of the city of Sapporo (population 1.8 million). Some parts of Viaduct A have been repaired for cracking of the deck slab. Bridge B is built on National Highway 274 in Sapporo. The section of National Highway 274 where Bridge B is located is also a part of Sapporo Shindo. Bridges on Sapporo Shindo near Bridge B have undergone replacement of deck slab concrete. Bridge C is on the scenic National Highway 230 in a mountainous area within the Sapporo city limits. Despite its suburban location, Bridge C has heavy traffic. The peak season for tourism brings heavy congestion.

Table 1 Surveyed Bridges

Name	Bridge type	Year of completion (year)	Age (years)	Length (m)	Span lengths (m)	Traffic volume (vehicles / day)	Interval of main girders (m)	Slab height (m)
Viaduct A	 Continuous steel girder bridge with non-composite slab	1971	32	429	4@32.8 ～9@33.0	43,407	3.4	0.22
Bridge B	 Steel composite girder bridge	1979	24	548	43.059 +43.070,other	59,190	2.8	0.21
Bridge C	 Continuous steel girder bridge with non-composite slab	1969	34	48	2@23.65	23,397	3.4	0.19

4. Deterioration Assessment via the System

4-1 Assessment criteria for deck slab deterioration

As the deterioration assessment criteria for the System, we used "Repair and Rehabilitation of RC Deck Slab of Road Bridges" (Apr. 1976, Monthly Report of Civil Engineering Research Institute, Hokkaido Development Bureau). This is one set of assessment criteria used with detailed close-range direct visual inspections. Deterioration level is classified by quantitatively evaluating crack opening width, crack spacing and crack index. The nine categories of deterioration are: no cracks (level 0); early stages (levels 1 and 2); intermediate stages (levels 3 and 4); terminal stages (levels 5 and 6); and failure (levels 7 and 8). Table 2 outlines each deterioration level.

Level		Condition of cracks			
		Cross cracking	Spacing L(m)	Cracking index p(m/m2)	Notes
	(0)	No	-	-	No cracking
Early Stage	(1)	No	L≧LG	0.5≧p	Scattered parallel cracks.
Early Stage	(2)	No	LG＞L≧0.5	2.0＞p＞0.5	Scattered parallel cracks. Generation of free lime and slurry.
Medium Stage	(3)	Yes	LG＞L≧0.5	3.0＞p≧2.0	Generation of cross cracks in two directions.
Medium Stage	(4)	Yes	0.5＞L≧0.3	5.0＞p≧3.0	Linking of cracks generating an alligator crack.
Terminal Stage	(5)	Yes	RP≧L	5.0≧p	Alligator cracks. Crack spacing becomes small.
Terminal Stage	(6)	Yes	RP≧L	5.0≧p	Alligator cracks. Small scale spalls occur.
Breakdown	(7)	Yes	RP≧L	5.0≧p	Alligator cracks. Spalling occurs. (Delamination about to occur.)
Breakdown	(8)	Yes	RP≧L	5.0≧p	Delamination of concrete.

Crack width: equal to or over 0.1 mm, LG: interval of main girders, RP: reinforcement pitch

Table 2 Criteria for Deterioration Assessment

4-2 Assessment of deterioration

Following are the results of the System's assessment of deck slab deterioration. The panels in our survey were located on and near the intermediate supports, where damage tends to occur.

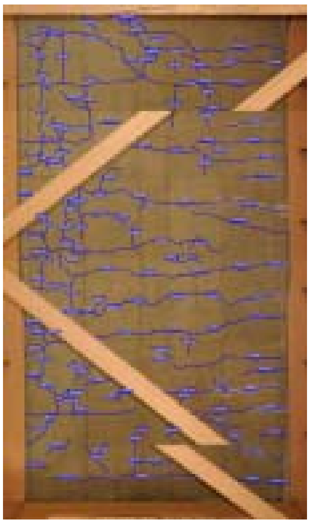
4-2-1 Viaduct A

One of slab panels of Viaduct A was evaluated with the System. First, we traced the cracks from digtal images of the panel. The automatically calculated cumulative length of the cracks was 58.5m. Based on the spacing between cracks and crack index, the panel was evaluated to have a deterioration level of 4.

<Assessment by the System> Deterioration level 4

Following is the System's computer output.

Panel No.	Deterioration level	Crack width (mm)	Crack spacing (m)	Crack index (m/㎡)	Cumulative crack length (m)	Spalling area (㎡)
Panels 19 - 22	4	0.1	0.363773	3.183892	58.456254	0



<Calculated from the System's output>

Interval of main girders: LG = 3.40 m

Interval of diaphragm: B = 5.40 m

Slab area: A = 3.40 × 5.40 = 18.36 m^2

Crack spacing: L = 0.36 m

Cumulative crack length: $\sum$ L = 58.45m

Crack index: p = 58.45 / 18.36 = 3.18 (m/m^2)

<Assessment results>

Following is the deterioration level determined by manually consulting Table 2 with the above values calculated from the System output.

Cross cracks

Crack spacing: 0.3 m ≤ L < 0.5 m

Crack index: 3.0 m/m^2 ≤ p< 5.0 m/m^2

Deterioration level: 4 --- This assessment result conformed to the assessment produced by the System automatically.

4-2-2 Bridge B

Two slab panels of Bridge B were evaluated for their slab deterioration using the System. Example 1 has a cumulative crack length of 9.12 m, which was calculated automatically. Based on the spacing between cracks and the crack index, the panel was judged to have a deterioration level of 2.

Example 1

<Assessment by the System> Deterioration level 2

Following is the System’s computer output.

Panel No.	Deterioration level	Crack width (mm)	Crack spacing (m)	Crack index (m/㎡)	Cumulative crack length (m)	Spalling area (㎡)
Panel 2	2	0.1	1.623063	0.638485	9.117565	0

<Calculated from the System’s output>

Interval of main girders: LG = 2.80 m

Interval of diaphragm: B = 5.10 m

Slab area: A = 2.80 × 5.10 = 14.28 m^2

Crack spacing: L = 1.62 m

Cumulative crack length: $\sum L = 9.12$ m

Crack index: p = 9.12 / 14.28 = 0.64 (m/m^2)

<Assessment results>

Following is the deterioration level determined by manually consulting Table 2 with the above values calculated from the System output.

Parallel cracks

Crack spacing: 0.5 m ≤ L < LG

Crack index: 0.5 m/m^2 ≤ p< 2.0 m/m^2

Deterioration level: 2 --- This assessment result conformed to the assessment produced by the System automatically.

Example 2

<Assessment by the System>　Deterioration level 4

Following is the System’s computer output.

Panel No.	Deterioration level	Crack width (mm)	Crack spacing (m)	Crack index (m/㎡)	Cumulative crack length (m)	Spalling area (㎡)
Panel 4	4	0.1	0.435554	3.478134	49.667758	0

<Calculated from the System’s output>

Interval of main girders: LG = 2.80 m

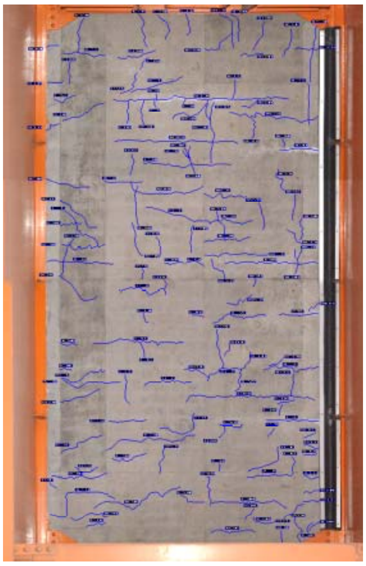
Interval of diaphragm: B = 5.10 m

Slab area: A = 2.80 × 5.10 = 14.28 m^2

Crack spacing: L = 0.44 m

Cumulative crack length: $\sum$ L = 49.67 m

Crack index: p = 49.67 / 14.28 = 3.48 (m/m^2)



<Assessment results>

Following is the deterioration level determined by manually consulting Table 2 with the above values calculated from the System output.

Cross cracks

Crack spacing: 0.3 m ≤ L < 0.5 m

Crack index: 3.0 m/m^2 ≤ p< 5.0 m/m^2

Deterioration level: 4 --- This assessment result conformed to the assessment produced by the System automatically.

4-2-3 Bridge C

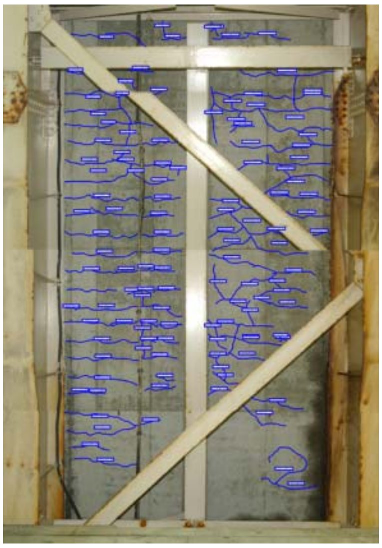
One panel of deck slab of Bridge C was examined with the System for slab deterioration. After the cracks were traced, the cumulative crack length was calculated automatically to be 52.88 m. Based on the spacing between cracks and crack index, the panel was judged to have a deterioration level of 4.

<Assessment by the System>　Deterioration level 4

Following is the System’s computer output.

Panel No.	Deterioration level	Crack width (mm)	Crack spacing (m)	Crack index (m/㎡)	Cumulative crack length (m)	Spalling area (㎡)
12〜15	4	0.1	0.435319	2.800588	52.875098	0

<Calculated from the System's output>
Interval of main girders: LG = 3.20 m
Interval of diaphragm: B = 5.90 m
Slab area: A = 3.20 × 5.90 = 18.88 m^2
Crack spacing: L = 0.44 m
Cumulative crack length: $\sum$ L = 52.88 m
Crack index: p = 52.88 / 18.88 = 2.80 (m/m^2)
<Assessment result>
Following is the deterioration level determined by manually consulting Table 2 with the above values calculated from the System output.



Cross cracks
Crack spacing: 0.3 m ≤ L < 0.5 m → Deterioration level 4
Crack index: 2.0 m/m^2 ≤ p< 3.0 m/m^2 → Deterioration level 3
Selecting lower evaluation level: Deterioration level: 4 --- This assessment result conformed to the assessment produced by the System automatically.

5. Deterioration assessment via close-range direct visual inspection

An inspector performed a detailed, close-range, naked-eye inspection at Viaduct A, where scaffolding installed for re-painting was available.

5-1 Procedure for direct visual inspection

When a detailed direct visual inspection from a short distance is carried out, most of the work time is expended at the bridge site. Figure 2 gives the flow and contents of direct visual inspection.

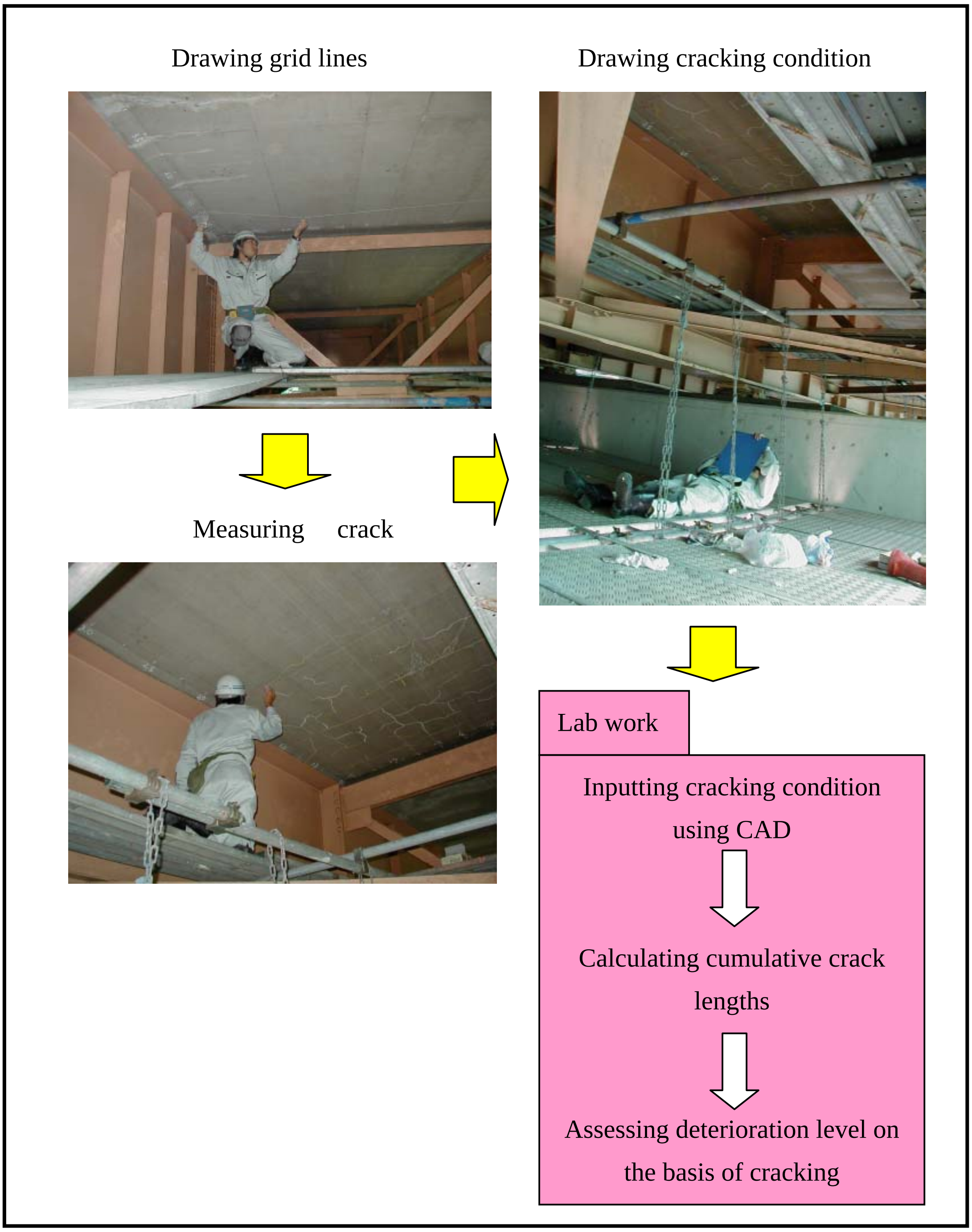


Figure 1 Work Flowchart of Close-range Direct Visual Inspection

5-2　Results of deterioration level assessment

By measuring the crack lengths on the diagram made by the inspector, cracks of widths exceeding 0.1 mm had a cumulative length of 75.04 m.　Based on crack spacing and crack index, the panel was judged to have a deterioration level of 4.　The assessment results and a photograph of the observed deck follow (Figure 2).

<Assessment results>

Following is the deterioration level determined by manually consulting Table 2 with the above values calculated from the System output.

Interval of main girders: LG = 3.40 m

Interval of diaphragm: B = 5.40 m

Slab area: A = 3.40 × 5.40 = 18.36 m^2

Cracks in two directions

Crack spacing: L = 0.3 m:　0.3 m ≤ L < 0.5 m

Cumulative crack length: $\sum$ L = 75.04 m

Crack index: p = 75.04 / 18.36 = 4.09 (m/m^2): 3.0 m/m^2 ≤ p< 5.0 m/m^2

→ Deterioration level: 4

Figure 2　Photograph of the deck panel

6. Verification by Comparison

6-1 Accuracy of deterioration level assessments of cracking

Figure 3 shows the crack diagrams produced from close-range direct visual inspection and those produced by the System. As indicated in Section 5, the cumulative crack length determined by direct visual inspection was 75.0 m, while that measured by the System was 58.5 m, where the short side of the rectangle of the angular fields is set at 2.0 m. The System had a recognition accuracy equal to 78% of that of direct visual inspection. The recognition accuracy of the System was low for cracks 0.1 mm in width. The reason is that the electronic flash made cracks on the deck slab less recognizable because the strong light eliminates shadows of cracks. Lateral bracing may have hidden some cracks during photographing. However, both results had a deterioration level of 4.

	0.1mm	0.2mm	0.3mm以上	Total		Length in bridge axis	Length in perpendicular to bridge axis	Area of panel	
Subtotal	48.01	22.78	4.25	75.044	m	5.4	3.4	18.36	m^2
	2.21	0.66	0.633						
	0.348	1.13	0.575			Cumulative crack leng/ Area of deck slab		4.09	m/m^2
	0.225	1.306	0.401						
	0.121	1.18	0.301			Crack spacing		Reinforcement pitch	
	0.119	0.313	0.681						
	1.923	0.536	0.282			Assessment		Deterioration level 4	
	0.597	0.694	0.53						
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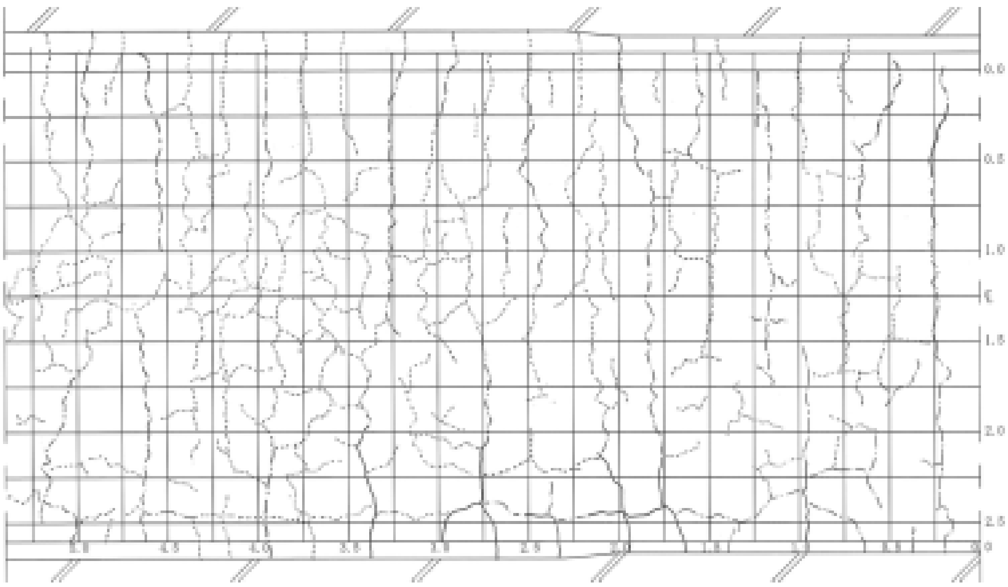

Figure 3 Crack Diagram Produced by Close-Range Direct Visual Inspection

Panel No.	Deterioration level	Crack width (mm)	Crack spacing (m)	Crack index (m/㎡)	Cumulative crack length (m)	Spalling area (㎡)
Panels 19 - 22	4	0.1	0.363773	3.183892	58.456254	0

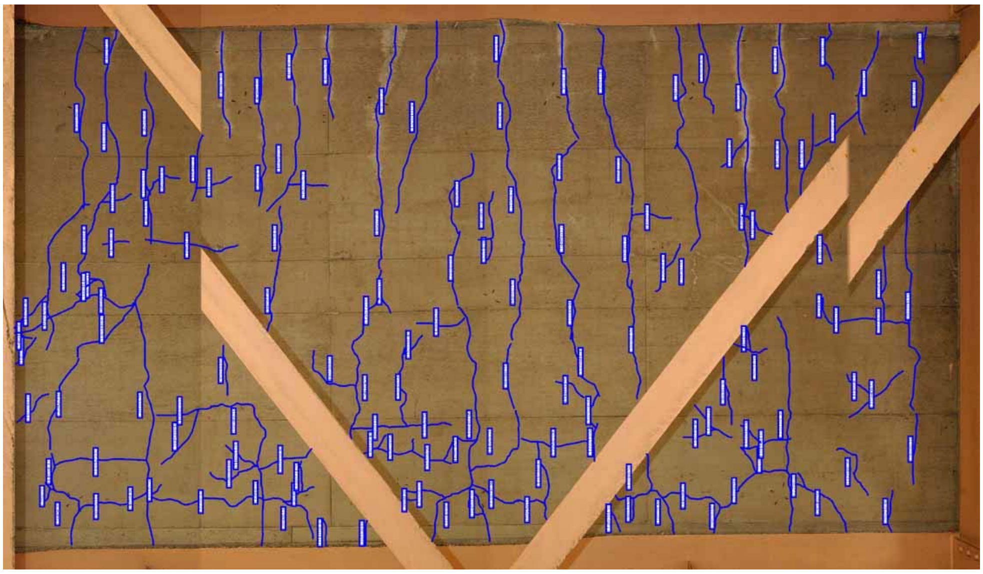

Figure 4　Crack Diagram Produced by the System

6-2　Work efficiency in terms of time

The following procedure is used for the System To assess deterioration level of deck slab.　The example of time taken is assuming a deck slab of deterioration level 4.

Figure 4.　Photographing the

1) The deck slab is photographed at the bridge site with digital camera, a process which takes less than 5 minutes per panel.

2) In the lab, the digital image is processed, taking about 45 minutes per panel.　Cracks in the panel are traced, taking about 10 minutes per panel.

3) The deterioration level of the panel is assessed from the traced cracks, requiring only a few seconds per panel.

The total time to assess one panel is about one hour.

As shown in Table 3, direct visual inspection requires about 5 hours to assess the deterioration level of one panel.　To do the same work, the System takes only one hour, one-fifth (1/5) of that of the conventional method.

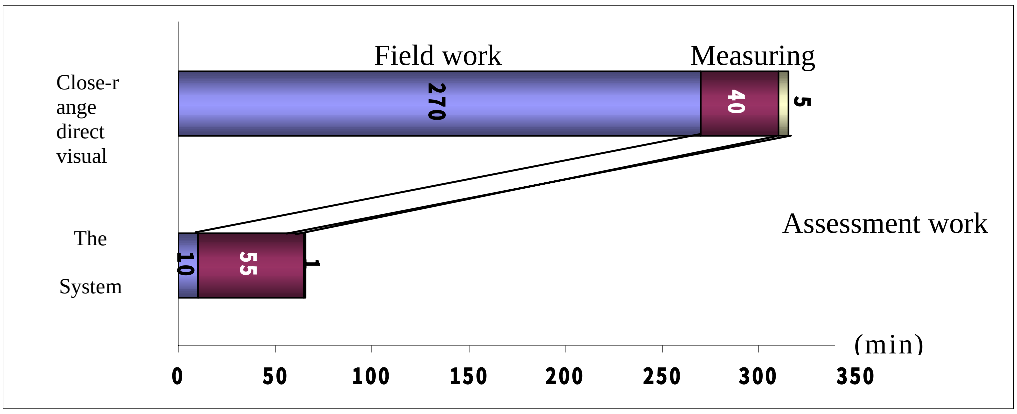

Figure 5. Comparison of Total Time

Table 3 Details of Work Hours

Close-range direct visual inspection	Field work (min.)		Measuring (person)		Assessment work (min)
Fieldwork	90	×	3	=	270.00
Measuring cracks	40	×	1	=	40.00
Assessment	5	×	1	=	5.00
					315.00

The System	Time (min.)		No. of operator (person)		Total time (min.)
Fieldwork	5	×	2	=	10.00
Measuring cracks	55	×	1	=	55.00
Assessment	1	×	1	=	1.00
					66.00

7. Conclusion

We used the System to make surveys to assess the deterioration level of bridges in service. The assessment results of the System and conventional close-range direct visual inspection agreed closely, a fact which verifies the applicability of the System. The effectiveness of the System was confirmed for the use of deterioration level assessment of deck slab cracking.

Also, the comparison of the close-range direct visual inspection and the System revealed following:

(1) Deterioration assessment of cracking

- Recognition ratio of the System was 78 % of that of the conventional inspection method. However, the location information of cracks is much more accurate than manually produced drawings because the cracks are traced from digital image.
- Recognition ratio of cracks can be improved through some additional effort during photography.
- Assessment of deterioration levels by both the conventional inspection method and the System agreed closely.

(2) Work efficiency in terms of time

- The System requires much less time for fieldwork at the bridge site. Total time is reduced to one-fifth of that of conventional visual inspection. This improvement translates into a great reduction in survey cost.
- The System does not require scaffolding to be set up. This also contributes to cost reduction.

From the survey of bridges in service, we confirmed the cost effectiveness and economic advantages of "RC Deck Slab Deterioration Assessment System" over the conventional method. We are planning to develop a manual on photographing deck slab so that the System will be extensively used, and we are aiming to further refine the System.

References

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(3) Y. Sasaki et al., “Development of deck slab deterioration judging system by the digital image,” presented at the 55th Conference of Japan Society of Civil Engineers.

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