Field Application of Tunnel Half Section Inspection System

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Abstract –

To inspect Road Tunnels every five-years is obliged in Japan, because for managing base the LCC (Life cycle cost). However, there are serious issues that not enough of engineer and budget to maintenance, so new technology for growing inspect efficiency is desired.

To solve these issues, we developed Tunnel full section inspection system within Crack measurement unit, Hammering unit and Protective frame. Our target tunnel of this system was one-lane on one side road tunnel, so especially protective Frame was designed for this kind of section. On the other hand, it needs to huge modify the frame to apply for another shaped section tunnel for example two-lane on one side road or train tunnel.

Therefore to expand application these inspection system, we developed the tunnel inspection system to apply varied tunnel section with mounted on aerial work vehicle. In this paper, we report the result of field application at two different shaped section tunnel with this system.

Keywords –

Inspection; Tunnel; Field application

1 Introduction

In Japan, many infrastructure face ageing issue. Especially half of road tunnels will over 50 age in 2033. Now in Japan, road tunnel must be inspected every five-years based on the road laws, because for managing base the LCC (Life cycle cost) [1]. However, there are serious issues that there are not enough of engineer and budget to maintenance, so new technology for growing inspect efficiency is desired.

From these background, we developed Tunnel full section inspection system (hereinafter, referred to as Full-Section-System) within Crack measurement unit, Hammering unit and Protective frame as in Figure 1 [2] [3]. Our target tunnel of Full-Section-System, especially the shape and size of Protective frame was designed for one-lane on one side road tunnel, because this size of road tunnels are major type at country areas in Japan.

Full-Section-System has advantages as follows.

- Protective frame secured space through which the vehicle can pass.
- To inspect full section of tunnel at one time.
- To avoid accident with falling concrete piece or another material under inspection by Protective frame.

On the other hand, Full-Section-System was designed for one-lane on one side road tunnel, therefore it needs huge modify to apply another shaped section tunnel for example two-lane on one side road. Add another thing, component parts of Full-Section-System are huge, so high transport cost and long preparing time at inspection site are taken.

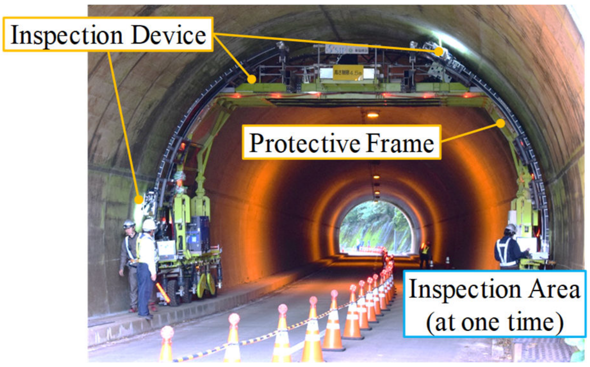

Figure 1. Full-Section-System

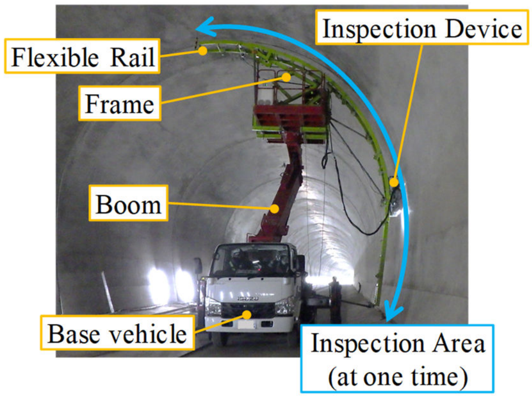

Figure 2. Half-Section-System

We thought these are the weak points of expansion of application. So to apply this system to many shaped section tunnel, we started to develop another type of frame as second generation system. The concept of development for second generation are as follows.

- To design flexible rail that easy to adjust for many section types of tunnel.
- Decrease component parts for easy to transport.
- Reduce preparation time at inspection site.
- To increase mobility, use truck based vehicle, instead of Protective frame.

The Gen2 of tunnel inspection system (hereinafter, referred to as Half-Section-System) as in Figure 2.

2 Outline of System

Functions of Half-Section-System are as follows, specifications of Half-Section-System are as in Table 1.

2.1 Flexible Rail

A number of curved rail are connected, top of rail is flexible and rail angle can be adjust by jack mechanism to fit tunnel shape as in Figure 3. Flexible rail and base frame need be compatible to stiffness and lightweight, so there were designed with FEM analysis as Figure 4.

2.2 Transferring Mechanism

Inspection devices are mounted on the tram, and the tram can move up and down by winch as in Figure 5. The caster of tram rolls on inner of lip channel steel, transferring condition is smooth, silent and stable.

2.3 Inspection Device

Crack measurement unit and Hammering unit are mounted on the tram as in Figure 5. We can obtain information of cracks and efflorescence by Crack measurement unit, and we can obtain information of spalling concrete by Hammering unit, these information are detected automatically.

2.4 Base Vehicle

The frame of Half-Section-System mounts on base vehicle with boom and roller type outrigger, it can be easy to set and adjust inspection device to tunnel surface and can drive without storing the outrigger and boom.

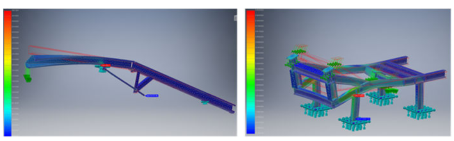

Figure 4. FEM analysis for Rail and Base Frame

Table 1. Specifications of Half-Section-System

Item	Specification
Rail Length	10.2m *1
Applicable Tunnel Inner Radius	R3.5~6.5m *1
Weight	Total 800kg *2 Device 50kg *3
Inspection Speed	9.0m^2/min *4
Inspection Width	600mm/scan
Resolution of Crack Width	0.2mm
Width of Hammering Interval	150mm *5

*1 Rail length and radius are adjustable if needed.
*2 Frame, inspection devices, control board are included, without aerial work vehicle.
*3 Transportable device weight by Tram.
*4 Set up time is excluded.
*5 Hammering interval can be adjustable.

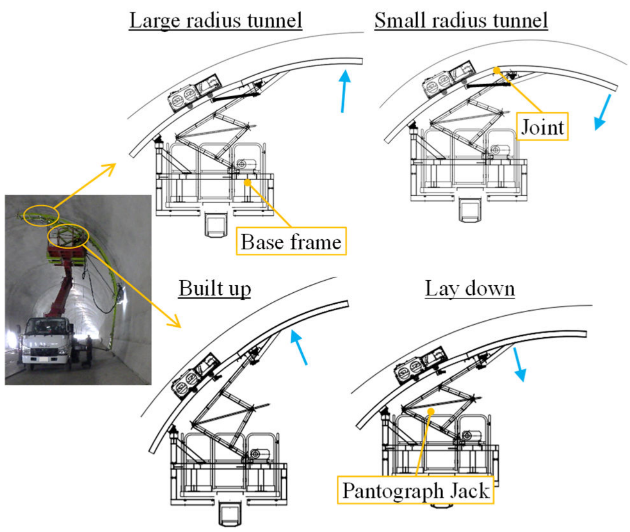

Figure 3. Function of Flexible Rail

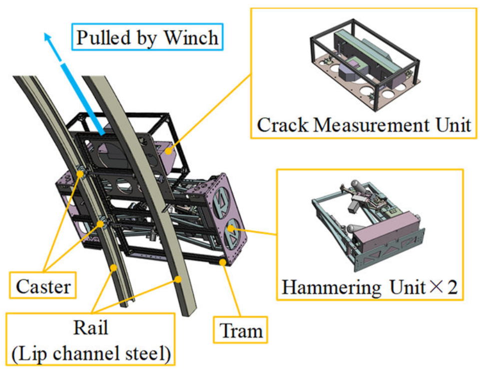

Figure 5. Mechanism of Inspection Device Transfer

3 Outline of Inspection

We applied Half-Section-System to two types of tunnels. Type A is wide section for road tunnel, Type B is tall section for train tunnel. To compare the inspection results, conventional methods inspection by engineer was conducted at same time. Both of them were inspected as completion inspection. These tunnel's specifications are as in Figure 6, 7 and Table 2, 3.

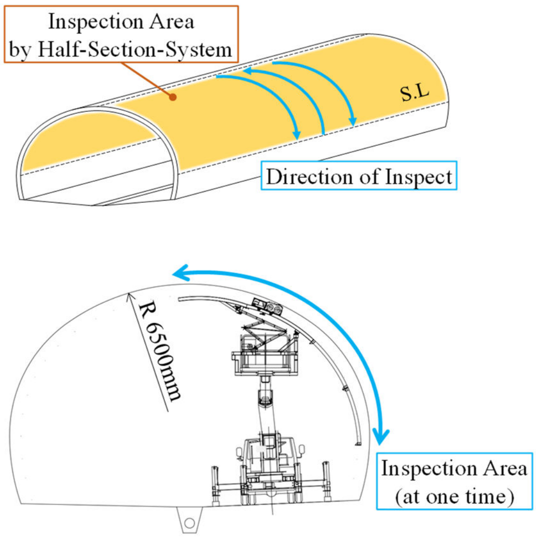

Figure 6. [Type A] Inspect area and Appearance

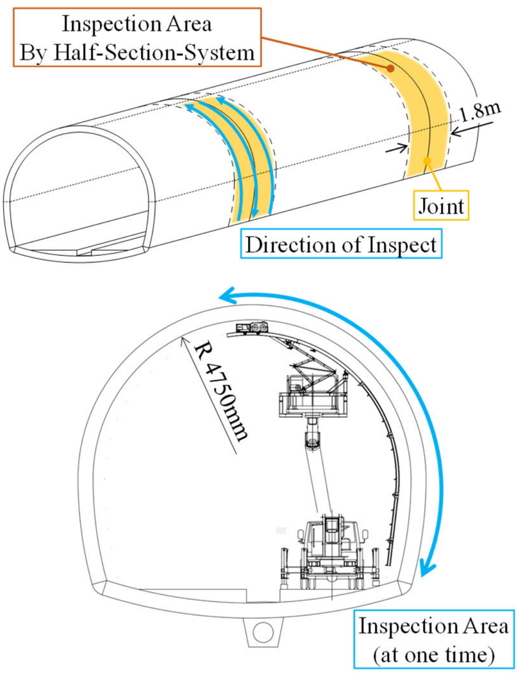

Figure 7. [Type B] Inspect area and Appearance

Table 2. Specifications of Tunnel [Type A]

Item	Specification
Length	397m
Section	H6.9m×W11.0m
Application	Road
Construction Method	NATM
Condition	New construction
Road condition	Non pavement surface
Inspect area by Half-Section-System	All of Surface except under the Spring Line *1

*1 Under the Spring Line area was inspected by another methods.

Table 3. Specifications of Tunnel [Type B]

Item	Specification
Length	1,450m
Section	H8.4m×W9.5m
Application	Train
Construction Method	NATM
Condition	New construction
Road condition	Pavement surface
Inspect area by Half-Section-System	Around the Joint of Lining Concrete *1

*1 the other area was inspected by another methods.

4 Results of Field Application

We inspected two types of Tunnel by Half-Section-System, and we evaluated the results about flexibility, mobility, inspection results comparison between system and engineer and work efficiency (Field work, office work) as follows.

4.1 Flexibility and Mobility

One of concept of Half-Section-System is general versatility, so we designed the frame and flexible rail could be mounted on base vehicle. Then we could inspect two different types of tunnel by one type rail with adjustable mechanism.

Frame, rail and control box of Half-Section-System are compact, so we could transport and assemble by one truck with crane. And another thing, lower section of rails are foldable without crane or another heavy machine. Half-Section-System was able to fold rail and U-turn in the tunnel, so we confirmed that Half-Section-System has high mobility. System transport, assemble and foldable rail are as Figure 8. Results from field applications, we make evaluation that flexibility, stiffness and mobility of Half-Section-System is generally well.

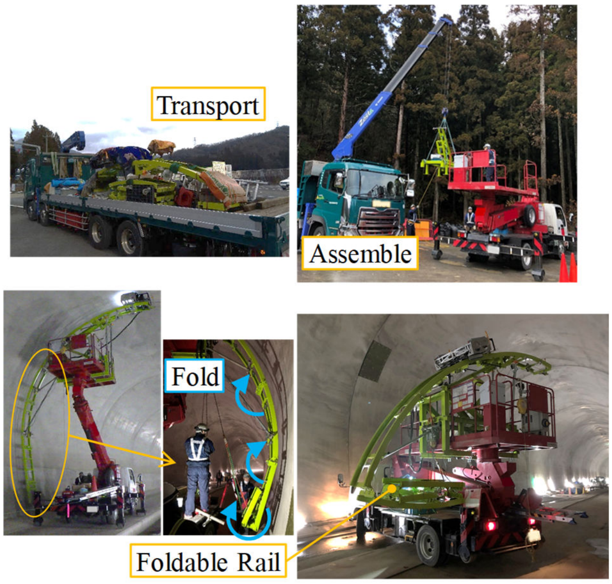

Figure 8. System Transport, Assemble and Foldable Rail of Half-Section-System

4.2 Inspection Results Comparison

We made an inspection results report inspected by Half-Section-System example of tunnel type A as Figure 9. There was no defect, so we reported as no cracks and no defected area.

Tunnel type B, there were few defects, so we compared results by Half-Section-System and by conventional methods (visual inspection and hammering by inspection engineer) as Figure 10.

For comparison, inspection result by Full-Section-System in 2018y is shown as Figure 11. This inspected tunnel is different from type A and type B.

By the comparison, cracks and spalling concrete were detected at same area in both inspection. In report of Half-Section-System, three cracks were detected. It was assumed that crack I and II were connected at out of inspect area and were same as crack A by conventional methods. We assumed that maximum width of crack A was out of inspect area of Half-Section-System, this was the reason that width had difference in between crack I, II and A, we thought.

It was assumed that spalling concrete Ⅳ and spalling concrete B were the same. However the detected length of both were difference (Ⅳ: 0.6m, B: 2.8m). In this case, the detection of spalling concrete was judged by hammering inspect. However, hammering point of Half-Section-System was approx.65mm near the edge of joint. So, if the spalling concrete was located on less 65mm area from edge of joint, it had possibility to be undetected by Half-Section-System. We thought this is the reason detected area of Half-Section-System was shorter than detected by inspector.

We assumed that crack 3 and spalling concrete C were same defect, though both of them were detected another category. In fact, this defect had step and ditch near the joint, so Crack measurement unit could find this spalling concrete as crack. However, Hammering unit could not detect this defect, because spalling concrete was too near to the joint to hammering.

There are some difference in inspected results between system and engineer, however accuracy of inspection results by Half-Section-System are enough to judge the soundness of tunnel.

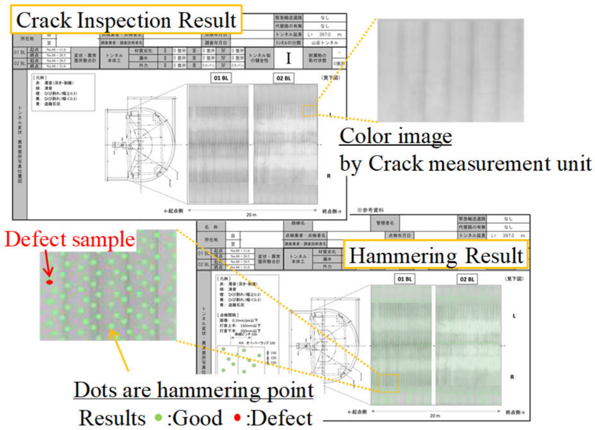

Figure 9. [Type A] Example of Inspection report

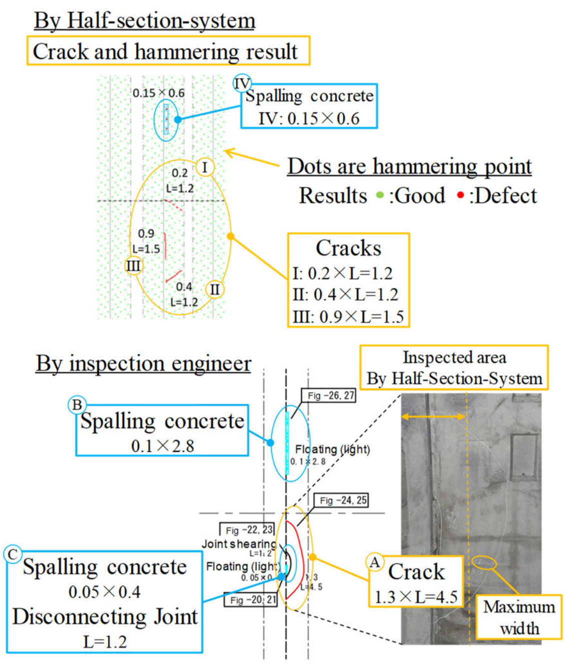

Figure 10. [Type B] Comparison results between by Half-Section-System and by Inspection Engineer

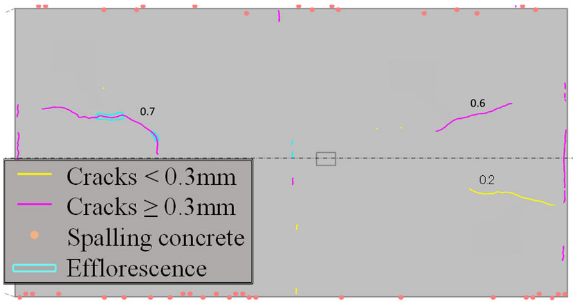

Figure 11. Example results by Full-Section-System in 2018y

From comparison results between Half-Section-System and Full-Section-System, the minimum detected crack width are 0.2mm, so we assume the preciseness of inspection are almost equal between two types of systems.

4.3 Work efficiency (Field work)

We evaluated work efficiency of field work by comparison with estimate and actual work time as Table 4. In table 5, we compared about assemble/disassemble time with Full-section-system and Half-section-system, and compared about inspection time with conventional methods at type B tunnel and Half-section-system.

Especially "Reduce preparation time" was one of the target of Half-Section-System. Working time of assemble and disassemble were shorter than Full-section-system, it means almost satisfied with our target, however actual inspection time were longer than conventional methods.

So we analyzed inspection time of Half-section-system about two types of tunnel as Figure 12. In this chart, "Inspection" means inspection time only. "Drive/Positioning" includes time to drive the vehicle and to position to prepare to inspect next line. "Adjust/Preparing" includes preparation before start working, warming up the system, maintenance the system and daily cleanup. "Fixing" includes repair the system or replace to spare parts if trouble.

"Drive/Positioning" time of Type B is longer than type A, because total drive distance of type B is longer than type A. However, we think "Drive/Positioning" time is too long, Type A is almost 15% of total inspection time and Type B is over 40%, and this process has room for improvement.

" Fixing" time of type B took long, because hammering unit had a breakdown about inner connection trouble of control unit in large part. So it is necessary to improve reliability about these trouble.

Table 4. Detail of work time (Half-section-system)

	Item	Working hours (Hrs.) Estimate	Actual
Type A	Assemble	4.0	5.8
	Inspection (Total)	56.0	99.1
	Inspection	-	48.0
	Drive/Positioning	-	13.8
	Adjust/Preparing	-	31.8
	Fixing	-	5.5
	Disassemble	4.0	3.5
Type B	Assemble	4.0	4.0
	Inspection(Total)	80.0	120.9
	Inspection	-	20.9
	Drive/Positioning	-	51.7
	Adjust/Preparing	-	19.4
	Fixing	-	28.9
	Disassemble	4.0	3.0

Table 5. Working time comparison

For comparison	Working hours (Hrs.)
Assemble	
Full-section-system in 2018y	7.6
Half-section-system [Type B]	4.0 (-47%)
Inspection	
Conventional methods [Type B]	96.0 *1
Half-section-system [Type B]	120.9 (+26%)
Disassemble	
Full-section-system in 2018y	4.8
Half-section-system [type B]	3.0 (-38%)

*1 3teams × 4days (8Hrs/day)

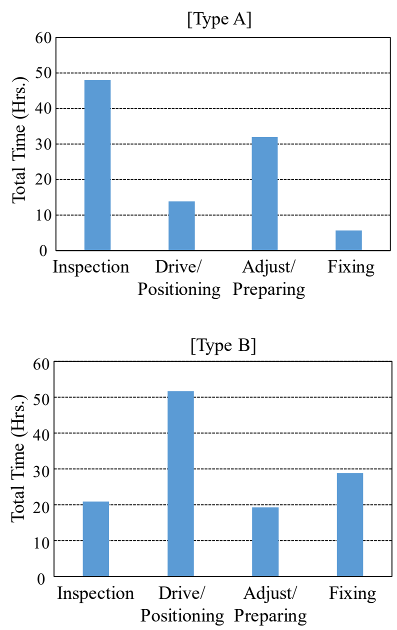

Figure 12. Breakdown of Inspection Time

There are some points need to improve to reduce "Drive/Positioning" time, especially positioning process, as follows and Figure 13.

- Add the target by laser marker line, to help positioning at tunnel lining wall.
- Add angle-meter to notice tilt of rail to operator in control monitor by value.
- Add distance value to inspected data measured by road measure, to help to prepare inspection report by automatically.

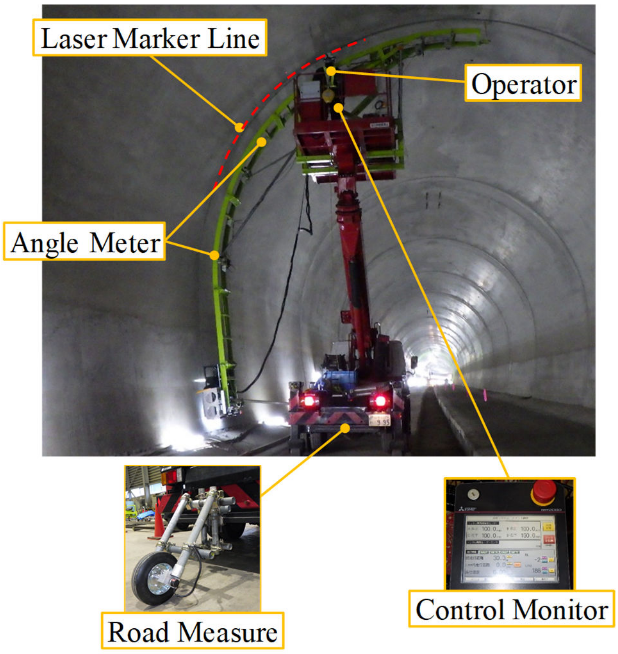

Figure 13. Improvement Plan for Reducing Work Time

4.4 Work efficiency (Office work)

We obtained defect information, cracks by Crack inspection device and peel at surface layer by Hammering inspection device, by Half-Section-System automatically. However the office work for preparing inspection report is almost manually, so there is few merit for office work at this time.

We think that automation of inspection report creation is essential for social implementation. So we will plan to prepare inspection report automatically.

5 Conclusion

In this paper, we evaluated Half-Section-System at two types of tunnel and concluded as follows.

- Working time of assemble/disassemble at field was approx. 40% shorter than Full-section-system of it.
- Confirmed general versatility, flexibility and mobility of Half-Section-System.
- Obtained inspection results enough to judge the soundness of tunnel, and preciseness of inspection is almost equal as Full-Section-System.
- Working time of inspection was approx. 26% longer than conventional methods (inspect by engineer). So especially positioning process needs to improve to reduce work time at field.
- Automation of inspection report creation is essential for social implementation.

In the future, we will develop work efficiency at field and at office.

On field work, our plan is to add sensor and target to frame, our target time of positioning process is half than current process. By this improvement, the working time of Half-section-system will be shorter than conventional methods.

On office work, our plan is to make software, our target is automatic process of making inspection report. That means, first input to software the data inspected by device, then picture and defect data are arranged automatically by software, finally inspector analyses and determines the soundness of tunnel by arranged data.

Our goal from these improvement is, total inspection cost of Half-section-system will be competitive than standard cost of conventional methods, so Half-section-system will solve the tunnel inspection issues that not enough of engineer and budget of inspection.

This result is part of accomplishment supported by Council for Science, Technology and innovation, "Cross-ministerial Strategic Innovation Promotion program (SIP), Infrastructure maintenance Renovation, and Management" in 2014-2018. (Funding agency: NEDO)

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