The Variable Guide Frame Vehicle for Tunnel Inspection

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Abstract

Ageing of the bridges and tunnels that were built more than 40 years ago has become an object of public concern. Maintenance engineers must approach as close as possible to the inspection point by mobile elevating work platform and conduct the human-eye based close inspection. Especially an inspection of the road tunnel requires traffic regulation. However, it takes much time on the visual inspection and hammering test for wide inspection area. Furthermore those inspection results have variations by inspectors. We have proposed a "variable guide frame vehicle for inspection of tunnel lining concrete" by new technology for infrastructure maintenance. This paper reports about the element technology of variable guide frame vehicle for inspection and each inspection system development situation.

Keywords –

Tunnel lining concrete; Variable geometry truss; Light-section; Hummering

1 Introduction

Many domestic tunnels and bridges that is built more than 40 years ago (at a period of rapid economic growth in Japan) ,towards deterioration and about 20% of road tunnels that were 100 thousand at the time of March 2013 in Japan have passed over 50 years. It is estimated that it will be about 50% in 2033 [1]. It was enforced new road raws in July 2014 that obliged to do close up visual inspection every 5 years. On the other hand, engineers that manage them and inspection cost are insufficient, and it is desired to develop innovative inspection techniques which resolve these problem.

Therefore, we proposed “the variable guide frame vehicle for inspection” as the new infrastructure maintenance technology and described our research and development about it’s elemental technologies.

2 Current situation of tunnel inspection

We have carried out maintenance of tunnels such as repair / renewal based on forecast by holding on the progress of deterioration by periodic inspection because it is difficult to rebuild tunnels after completion. In general, we regulate traffic when inspect road tunnels and engineers and their assistants inspect as close as possible on aerial work vehicles (Figure 1).

However, this method have a problem that it is forced to work for a long time and requires to regulate traffic for a long time too. Furthermore, there are different with each engineer for the results of inspection about visual inspection and hammering tests. We cannot hold on the progress of deterioration accurately in this method because the results of inspection for visual inspection and hammering tests are not recorded.

Administrators of tunnels are difficult to judge the optimal repair method and it’s timing because professional knowledge is required to evaluate tunnels based on inspection data. Futhermore, it is desired to build maintenance management systems that minimize economic impact considering LCC (Life Cycle Cost) for increasing a great deal of load tunnels which require maintenance and management. Therefore, it is required systems which do not require expert to go to the site and can show the state of deterioration and optimal repair methods based on various data which obtained by inspection.

3 Outline of The Vehicle for Tunnel Inspection

The variable guide frame vehicle for inspection (Figure 2) (hereinafter, this is called the inspection system) is the system which aims to greatly reduce the traffic regulation during inspection and substitute remote control robots for close up visual inspection and hammering tests by engineers. To realize this system, we mainly developed 4 elemental technologies, ①the variable guide frame (hereinafter, this is called VGF) and ②the protective frame vehicle, ③the hammering tester, ④the crack inspector.

We decided specification of this system as shown in Table 1 referring to the third type of load (that is Japasese load type) because targets of this system is local tunnels.

Figure 1 tunnel inspection

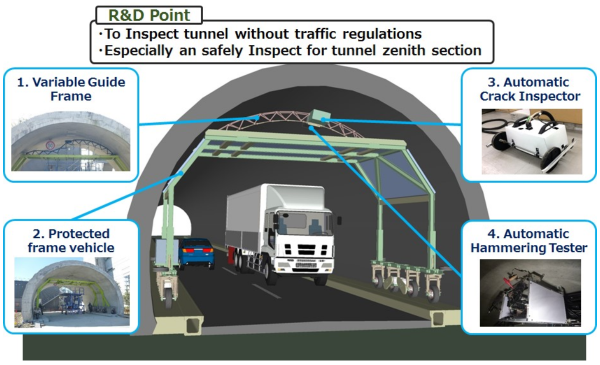

Figure 2 VGF vehicle

The length of this system is 5m and the width is expandable accrording to the width of the road by using expandable frame structure. The weght is 4t according to the load standard specification because this system Travels by tires in the tunnel and weght is 4t and we can control this system along the curve of tunnels of the minimum radius of curvature 50m

The VGF is set with arch shape at a certain distance from tunnel surface. We can obtain images of the concrete surface and hammering sounds by moving devices along the VGF. Our target is 150m2/h at maximum which is the alomost same as the inspection speed by engineers. However, the inspection speed is depends on these device performances. We aim to build systems which can output quantitative inspection data obtained by this system as resulting drawing of tunnel inspection and photographic ledger of tunnels. We let described about each elemental technologies as below.

Table 1. Specification of the device

Length（m）	5.00
Width（m）	6.36～9.56（Stretchable）
Weight（kg）	4,000（500 / 1wheel）
Traveling speed（m/min）	1～10（variable）
Inspection items	Flaking，　Peeling，　Crack
Inspection speed（m^2/h）	Max 150

3.1 VGF（Variable Guide Frame）

The inspection efficiency is low because the tunnel have a various shape according to natural ground and usage and dotted with lamp equipments and signs. A variable frame structure is necessary to adapt various tunnel shapes in order to avoid equipment in the tunnel and enhance versatility. Furthermore, it is necessary to have a frame structure which can get a sufficient reaction force even if the equipment is implemented to do inspection by remote control.

In this system, we adopted VGF (Figure 3) which applied variable geometry truss as inspection guide frame. This system has a laser range finder to measure detects shape of tunnels ahead of this system and obstacle of such as a sign position.We can obtain the amount of expansion and contraction of the actuator necessary for deforming the VGF by the results of inverse analysis of this measurement, we can perform deformation operation for VGF (Figure 4). Furthermore, the rails necessary for moving the inspection device are mounted on the VGF,inspect tunnels along the rail.

3.2 Protective Frame Vehicle

The protective frame vehicle (Figure 5) with VGF traveling along the tunnel and can inspect. This system can inspect entire tunnel surface by alternately moving inspection devices along VGF and traveling the protective frame vehicle. We are assumed that this system is used at the local tunnel (the third type of load in Japanese). This system can travel by a electric motor and climb up to 10% in longitudinal gradient. Furthermore, This system can travel along the curve of tunnel by setting the difference speed between the left and right tires using the inverter control at the curve.

Figure 3 VGF

Figure 4 Deform the VGF

Figure 5 Protective Frame Vehicle

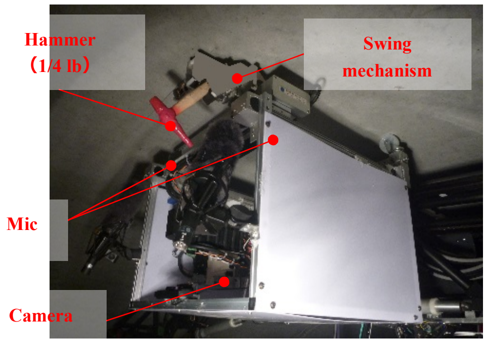

Figure 6 Hammering Tester

It is necessary to secure traffic safety and smoothness by protecting a third party and a car from falling objects such as concrete pieces in order to inspect at the top of the tunnel without traffic regulation. In this system, falling objects are prevented by the steel plate which set at the top of the protective frame vehicle.

3.3 Automatic Hammering Tester

The hammering tester can hammer concrete by the remote control and analyze hammering sound data, and detects the delamination position.

The hammering criterion and the hammering sound analysis method are based on sounds which hammer by engineers using inspection hammer. Considering these criterions and databases, We developed the hammering tester that behave similar to that of a engineers arm and can simulate hammering sounds by engineers (Figure 6). This device is controlled hammering velocity according to hammering directions to make hammering energy constant even if gravity changes when moving along the VGF. This device has two modes. One is the first inspection which hammer at an interval of 20cm while moving to obtain delamination points of the entire tunnel. Another is the second inspection which hammer at an interval of 5cm to obtain delaminations and cracks within a certain range in detail. As a new research, We aim to develop systems for notifying the future damage of the delamination by using the hammering analysis method based on supervised machine learning which estimate depth of crack and cold joint and by using the image processing method which estimate directions of crack and cold joint by fusing camera image of the hammering range and the results of the hammering analysis. Furthermore, we aim to invent a automatic identification technology with robustness to noise considering inspection in the environment where cars runs.

3.4 Automatic Crack Inspector

Many crack inspect devices using images are used on site. Although they do not require traffic regulation, the resolution of the crack width is low, and much effort is required for post-processing work such as noise removal including contamination of concrete.

We developed systems which output inspection data as resulting drawing of tunnel inspection rapidly by automatically identifying cracks and dirt using the three-dimentional shape measurement based on light-section method to correspond high accuracy and labor saving at crack inspection. We can obtain color images and depth images high accuracy and continuously by moving the crack inspecter (Figure 7) with a light section camera along the tunnel surface. We aim to develop inspection technology which can obtain detailed inspection data such as the step and the water leak by combining the results of hammering tests and three-dimentional shape measurements.

4 Work flow of The Vehicle for Tunnel Inspection

The inspection system is operated in the procedure of 6 steps, ①assemble such as a protective frame vehicle, and ②set it in the tunnel, ③do the firtst inspection, ④do the second inspection, ⑤judge the results of the inspection, ⑥unassemble it. It is shown the inspection step which are asummed in Figure 8.

We assemble this system at out of the tunnel and move it into the tunnel. After that, this system measure the cross-sectional shape of the tunnel ahead of it and expand the frame according to it's results

In the first inspection, the hammering tester specify delaminations of the concrete, and the crack inspector do crack inspection in real time and obtain images using as the resulting drawing of tunnel inspection.

In the second inspection, while returning to the inspection start position, abnormal parts which identified when the first inspection is inspected in detail by hammering tester. Furthermore, this system estimates

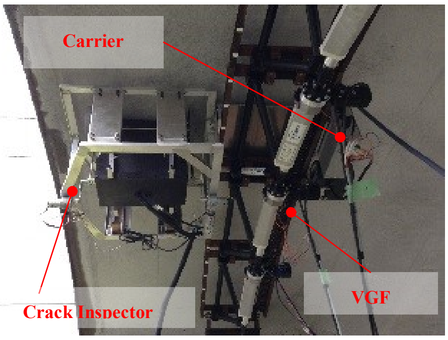

Figure 7 Crack Inspector

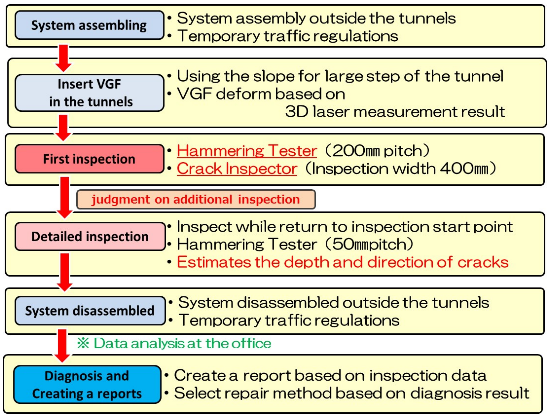

Figure 8 VGF Work flow

the crack depth and the crack direction about these parts in this inspection (Figure 9). When it is judged that repair is necessary, measure concrete physical property. Especially, for parts with high urgency, we drop as a first aid. After returning to the inspection start position, we unassemble this system at the same place where assembled.

We specify abnormal parts from images obtained by the crack inspector and data obtained by the hammering tester, and draw up the resulting drawing of tunnel inspection and the photographic ledger of the tunnel. Furthermore, we select repair methods based oninspection data and calculate LCC for maintenance.

Figure 9 VGF vehicle inspection

5 Practical application

As technologies to accelerate practical application, we also have developed elemental technologies necessary for repairing and so on utilizing the data which obtained from the inspection system as well as hammering tests and visual inspections as above. We described these technologies follows.

5.1 Automated Estimation of Concrete Strength

If it is judged that repair is necessary from the results of the first inspection or the second inspection, it is required to obtain the concrete physical property information for considering the repair method. This system also can implement a drill device which can operate remote control and drill concrete to estimate the concrete compressive strength and neutralization depth on site.

5.2 Tunnel management support system

It can propose optimal repair method and timing based on database of repair methods and materials and so on by input obtained inspection data and basic data of tunnel such as the environment condition and the construction condition, elapsed years. This system can be operated without exparts going to the site.

6 Conclusions

We proposed “the variable guide frame vehicle for inspection” for the tunnel inspection that are expected to increase further in the future. For future work, we will do research and development aimed to develop a versatile inspection system which can inspect enire tunnel surface without traffic regulation.

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