Special edition paper

Research and Development on Nondestructive Inspection Technology for Civil Engineering Structures




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JR East previously developed and introduced two types of civil engineering inspection cars that check defects inside of civil engineering structures using an electromagnetic radar. One is the under-track survey car (UTRAS) and other is the tunnel concrete lining inspection car for Shinkansen (Shinkansen CLIC). In conjunction with upgrading of UTRAS, we undertook technical development to improve inspection efficiency for the next-generation under-track survey car. We achieved our goal in that of keeping inspection performance equal to that of current UTRAS, even at higher inspection speed, by revising antenna placement and developing a new analyzer. At the same time, we developed technology to apply the Shinkansen CLIC to tunnels on conventional lines. In that development, we devised components such as a new radar support arm, allowing us to achieve the goal of keeping inspection performance equivalent to that of current Shinkansen CLIC even at higher inspection speed.

●Keywords: Under-track survey car, Tunnel concrete lining inspection car, Electromagnetic radar, Inspection speed increase

1 Introduction

JR East has traditionally carried out patrolling on foot for visual checks and hammering tests of earthwork structures and civil engineering structures such as tunnels (Fig. 1 and 2). While those tests have an advantage in that inspectors can visually perceive defects of the structure, they also have a disadvantage in that finding invisible defects is difficult and inspection accuracy varies because results are reliant on the inspector's judgment.

Fig. 1 Patrolling Earthwork Structure

Fig. 2 Hammer Test in Tunnel

To overcome that disadvantage, the Technical Center worked on development of an inspection machine that can inspect defects inside of structures using an electromagnetic radar. In fiscal 2000, JR East introduced an under-track survey car (UTRAS) that can inspect voids in the roadbed that could cause roadbed subsidence (Fig. 3). And in fiscal 2004, we deployed for Shinkansen tunnels the tunnel concrete lining inspection car (Shinkansen CLIC) that can inspect defects under the tunnel lining that could result in accidents where concrete falls from the tunnel lining (Fig. 4). In conjunction with upgrading of UTRAS, we carried out development for the next-generation UTRAS and also development to apply Shinkansen CLIC to tunnels on the conventional lines. This article will cover that development.

Fig. 3 UTRAS

Fig. 4 Shinkansen CLIC

2 Development of the Next-generation UTRAS

2.1 Development Background

We are approaching time to upgrade as more than ten years having passed since introduction and poor inspection efficiency is being becoming a problem with UTRAS. To over come that problem, we launched technical development for the next-generation UTRAS in fiscal 2009.

The electromagnetic radar with UTRAS emits electromagnetic waves from its transmitting antenna to the ground to check the roadbed condition (Fig. 5). The waves are reflected from a substance in which the surrounding ground differs from the

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electrical property (such as voids and underground structures) and return to the two receiving antennas. However, UTRAS has a problem in that its inspection efficiency is not good because the inspection speed of UTRAS is just 2.5 km/h and it has to avoid every ground coil as its radar almost touches the ground surface. It thus has been used for localized checks at sites where roadbed cave-in could occur.

2.2 Development Overview

With an aim of inspecting all lines every five years with the next-generation UTRAS, we developed a radar that has inspection performance equivalent to that of the current UTRAS (inspection depth 1.5 m, detection of 50 cm^3 voids) at an inspection speed of more than 10 km/h. With the developed radar, we increased the number of transmitting and receiving antennas to four each (Fig. 6) to pick up the reflected waves even at faster inspection speeds. The radar was set at a maximum of 25 cm above ground, a height at which the radar would not hit wayside equipment such as ground coils.

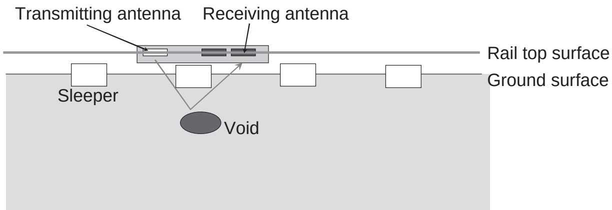

Fig. 5 Radar of UTRAS

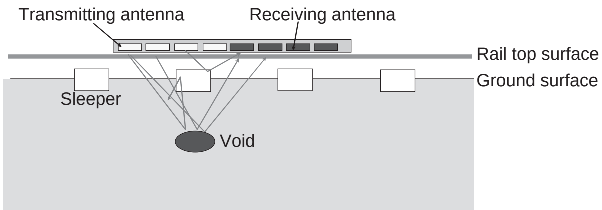

Fig. 6 Radar Developed for Next-generation UTRAS

2.3 Performance Check Test on Commercial Line

To check the performance of the developed radar, we put that radar on a railway cart and carried out tests on a commercial line.

2.3.1 Test Method

On a commercial line, we tested the radar on a cart pulled by a track motorcycle (Fig. 7). The maximum inspection speed at that test was 30 km/h. Using a pipe culvert (30 cm diameter) crossing under the track to simulate a test void, we checked the inspection images displayed.

2.3.2 Test Results

Fig. 8 shows the inspection images at a depth of 2 m and inspection speeds of 10 km/h, 20 km/h, and 30 km/h. While we could sufficiently confirm the waveform of the pipe culvert at 20 km/h, we were not able to do so at 30 km/h.

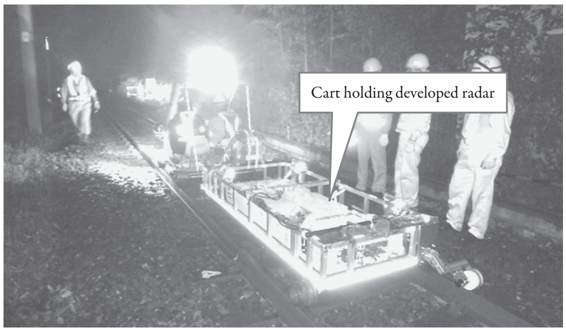

Fig. 7 Performance Check Test on Commercial Line

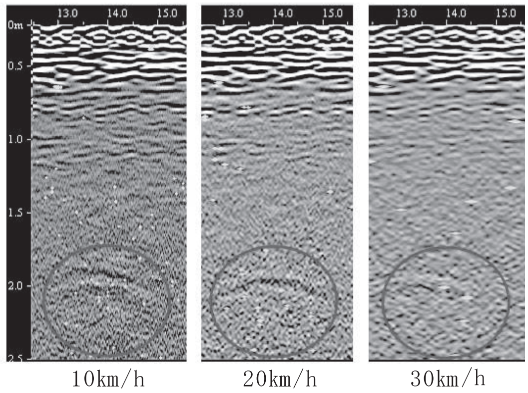

Fig. 8 Inspection Image of Pipe Culvert (30 cm diameter) at 2 m-depth

2.3.3 Improvement of the Marking Function

For easy differentiation of voids and underground pipe culverts, UTRAS has a marking function developed and introduced in the past. With this function, received waves over the preset threshold are marked in yellow or red according to the level of received wave's intensity as a result of comparison with the average intensity at the same depth (Fig. 9).

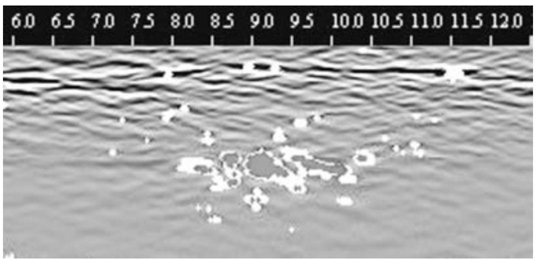

Fig. 9 Example of Inspection Image with Voids Marked

We tried to mark such waves this time too, but the developed radar did not mark the pipe culvert in the inspection images shown in Fig. 8. The reason why the pipe was not marked could be because setting the radar at a higher position allowed external noise, reducing relative reflection intensity rate. In light of that, we applied averaging and a median filter, both multipurpose image processing techniques (Fig. 10). Processing with those techniques can cancel noise and clearly show just the target. In verification with the inspection image at 20 km/h in Fig. 8, the noise around the pipe was cancelled and marks for the pipe tended to increase as shown in Fig. 10. That demonstrated remarkable improvement of the visibility of the pipe culvert.

With these measures, we could achieve the goal of keeping inspection performance at 20 km/h, equivalent to that of the current UTRAS.

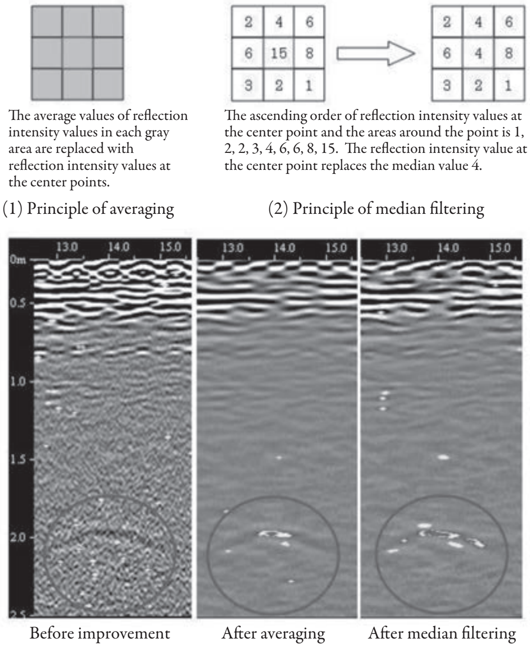

Fig. 10 Marking Function Improvement Results

3 Development of CLIC for Conventional Lines

3.1 Development Background

The Shinkansen CLIC is equipped with a multi-path linear array radar (MPA radar). Being in close contact to tunnel lining, it detects in three dimensions voids and honeycombs under the concrete lining with the radar (Fig. 11). The Shinkansen CLIC cannot be used for tunnels on conventional lines without modification because there are many obstacles (countermeasure constructions) in those tunnels, while tunnels on Shinkansen lines with few obstacles are easy to inspect. We thus started technical development for the CLIC for conventional lines in fiscal 2009.

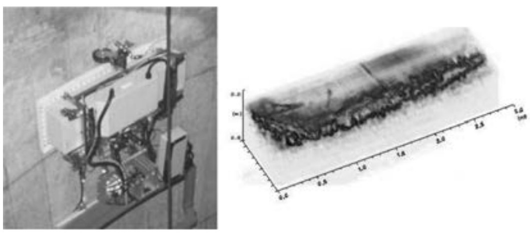

Fig. 11 Inspection with the MPA Radar (Left) and Inspection Image (Right)

3.2 Development Overview

In development of the CLIC for conventional lines, we set the following targets.

(1) Increase inspection speed of Shinkansen CLIC from 3.5 km/h to 7 km/h to allow inspection of all lines every 20 years.

(2) Keep inspection performance of MPA radar equivalent to that of Shinkansen CLIC (ability to detect 10 mm thick void at 40 cm depth).

(3) Give the MPA radar obstacle-climbing performance of more than 5 cm height (Shinkansen CLIC's performance is 3 cm height).

3.3 Fundamental Tests of MPA Radar

In order to check the inspection performance of the MPA radar at higher inspection speed, we carried out performance check tests using a tunnel lining model. To increase the inspection speed to the target 7 km/h, the inspection pitch has to be increased from the 1 cm of the Shinkansen CLIC to 2 cm, so we checked whether the inspection performance could be kept equivalent to that of the MPA radar of Shinkansen CLIC with pitch increased to 2 cm. In the tests, we used a void model buried in the tunnel lining model (Fig. 12). Assuming the basic curvature radius of a single line tunnel on a conventional line, we reproduced the minimum 2.2 m and the maximum 2.8 m curvature radiuses for the surface of the tunnel lining model. Evaluation with the inspection image of a void model at 40 cm depth revealed that it had inspection capacity with which such a void could be detected at 2 cm pitch, equivalent to that at 7 km/h inspection speed. We were also able to confirm that the inspection performance did not vary at different curvature radiuses (Fig. 13).

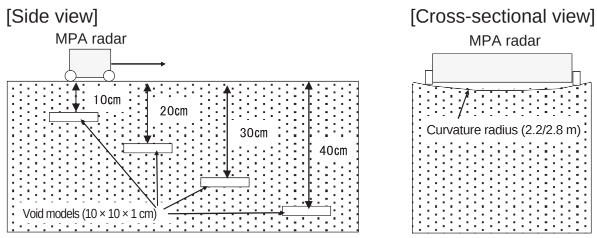

Fig. 12 Tunnel Lining Model

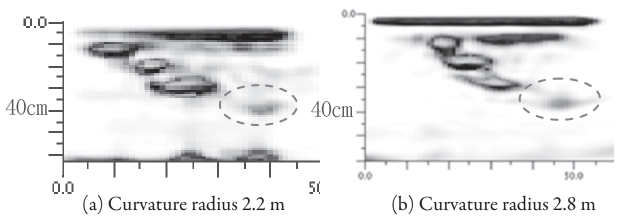

Fig. 13 Cross-sectional Inspection Image at 2 cm Pitch (Equivalent to 7 km/h)

3.4 Development of a Radar Support Arm

The basic test results of the MPA radar offered the prospect that the inspection speed could be increased to 7 km/h. However ability to follow the tunnel lining surface at increased speed is important because the MPA radar makes inspection at close contact to the lining by use of a support arm. Furthermore, it has to have performance to go over obstacles when striking those. We thus undertook the development of a new radar support arm. By changing the parallel link type radar support arm of the Shinkansen CLIC to a linear guide type for the CLIC for conventional lines, we reduced the pressing force on the radar to the tunnel lining surface to allow more flexible movement, improving the ability to follow the surface even at higher speed. We also changed the shape of the sled that directly hits obstacles and increased the height of the inclined part of the sled from 5 cm to 7 cm to enable the radar overcome obstacles higher than 5 cm (Fig. 14). The developed support arm was attached to the tip of the boom of a hi-rail car for actual checks in tunnels.

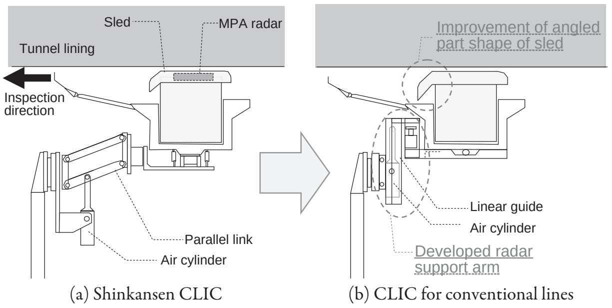

Fig. 14 Developed Radar Support Arm

3.5 Running Tests in Decommissioned Line Tunnel

We placed an actual hi-rail car on the test rails in a tunnel on a decommissioned line and tested ability of the MPA radar to follow the tunnel lining surface and the drive performance of the sled to overcome obstacles at 7 km/h (Fig. 15 and 16). To see the ability of the radar to follow the lining surface, we checked the change of response according to the speed change by measuring the movement of the linear guide using a laser ranging sensor. To see the ability to overcome obstacles, we set a temporary obstacle model on the tunnel lining surface and checked whether the MPA radar could go over that.

Fig. 15 Testing

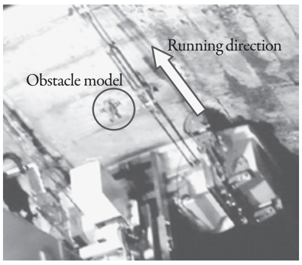

Fig. 16 Test of Overcoming Obstacles

Fig. 17 shows the results of ability of the MPA radar to follow the tunnel lining surface measured with the laser ranging sensor while moving the radar at different speeds. The standard deviation of the change of the distance between the MPA radar and the tunnel lining surface at speeds of 3 to 7 km/h showed that the distance at 3 km/h was 8.2 mm while that at 7 km/h was 8.7 mm. The results proved that speed increase caused little reduction in ability to follow. The radar was also able to overcome a 6 cm high obstacle model at 7 km/h.

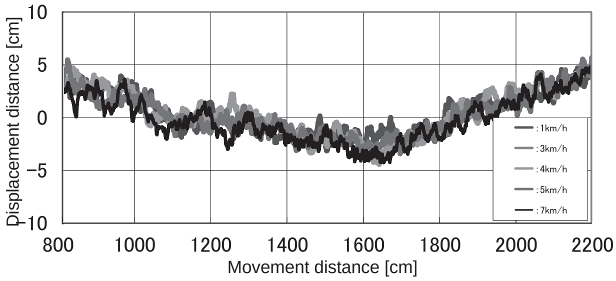

Fig. 17 Ability of MPA Radar to Follow Tunnel Lining Surface

3.6 Running Tests in Conventional Line Tunnel

We carried out running tests in a tunnel of a conventional line to check the inspection performance of the MPA radar at increase of speed to 7 km/h. Fig. 18 shows inspection images of a section at the Shinkansen CLIC inspection speed of 3 km/h (1 cm pitch) and of the same section at the target inspection speed of 7 km/h (2 cm pitch). Comparing those, we were able to confirm that the detection performance for presence and location of defects at 7 km/h was equivalent to that at 3 km/h, while image resolution was lower at 7 km/h. In the development, we thus achieved the target of keeping performance at the inspection speed of 7 km/h equivalent to the performance of Shinkansen CLIC.

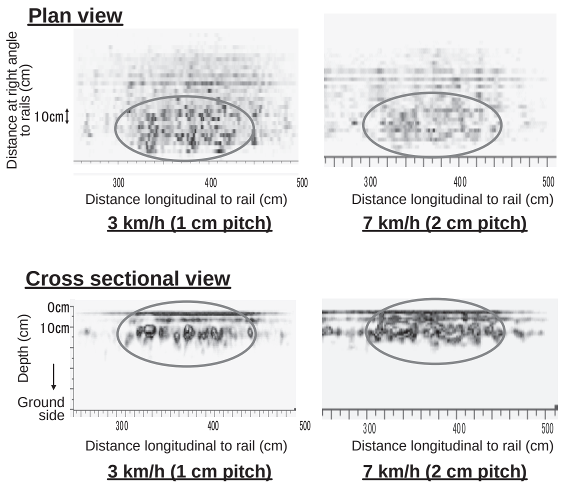

Fig. 18 Inspection Image per Inspection Speed (Possibility of Presence of Honeycomb)

4 Conclusion

As explained above, we confirmed that the next generation UTRAS and the CLIC for conventional lines could keep inspection performance equivalent to that of the current machines at inspection speeds of 20 km/h and 7 km/h respectively. We will study a vehicle for actual use with an aim of introducing those in fiscal 2013.

Reference:

1) Hiroyuki Osawa, Tsukasa Akai, "Tunnel Fukko Kenswasha no Donyu [in Japanese]," *Journal of the Japan Railway Civil Engineering Association*, Vol. 42 (December 2004)