Experimental study on application of damage detection and measurement technology of steel bridge

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Abstract

It is important to accurately and efficiently clarify phenomena that reduce the safety of structures in order to efficiently maintain road bridge stock. It is, therefore, necessary to develop the technologies that clarify damages and structural behaviors causing damage and to improve its detection capability. This report introduces a number of cases of experimental studies of these technologies to investigate their detection capability of damages and change of behavior and applicability to steel highway bridges.

1. Introduction

To contribute to more efficient performance of maintenance tasks such as inspections and surveys of the vast road bridge stock and to the quantification and improvement of objectivity of the evaluation and diagnosis of the state of structures, it is necessary to develop inspection and diagnosis technologies to support these activities and to improve the precision of those technologies that already exist. At the same time, in order to apply these inspection and diagnosis technologies, it is necessary to study and clarify just how they are applied in what types of maintenance activities.

In response to these background circumstances, the authors have performed a variety of tests of technologies that directly detect damage (non-destructive inspection methods:NDI) and of measurement technologies and monitoring technologies used to clarify the change of behavior of bridges when damage may occur. NDI can be

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considered to be technologies that perform detailed diagnosis by examining parts of a structure invisible from its surface, while measurement technologies are those that can obtain information unobtainable by a visual examination to contribute to more efficient inspections. This report introduces examples of research and of measurements performed by this research team ranging from applied to basic research.

2. Case 1 Non-destructive inspection method for cracks in steel deck plates

2.1 Background

Cracks that pass completely through a steel floor slab deck have been reported for several years (see Photo 1). If a crack passes through a floor slab deck, it may cause the road surface to sink, public injury, so these cracks must be discovered as quickly as possible. But the problem is that the damage appears and propagates in the portion where it is difficult to be confirmed by visual inspections. Among ultrasonic testing methods (UT), the applicability of general purpose type UT and methods of its application have been tested.

2.2 Description of the study

The applicability of four probes having general purpose and easy to perform was confirmed. Specifically, they were an angle probe with refracted wave of 70°, an angle probe with refracted wave of 85°, a creeping wave probe, and a surface SH wave probe. Figure 1 summarizes their characteristics. Cracked welded model specimens (Fig. 2) were used for experiments to inspect cracks passing through steel floor slab decks. The specimens had cracks with depth from 0 to 10mm created by cyclic loading.

2.3 Experiment results

Figure 3 shows the experimental results. The figure shows that the detection depth limit is about 6mm using the 70° and the 85° angle probes. It was also confirmed that, using the creeping method, it is possible to detect cracks no matter how shallow they are. But if they are as shallow as 3mm or so, in a large specimen or an actual bridge, it will be impossible to distinguish other echoes from those of the cracks.

As a future direction of technology, we believe that further innovations will be able to improve the crack detecting precision to about 3mm. To improve precision, semi-automatic detection and detection without removing the paint film will be tested.. Although no investigation has been made, the application of infrared thermography for flaw detection may be possible after cracks repair. As one case of its application, the detection of temperature change may be possible caused by water and soil deposition after cracks formation.

3. Case 2 Corrosion of a light pole foundation

3.1 Background

During the 40 years since the light poles were installed, it has been reported that under the old standards, foundations have been corroded (Photo 2) and broken toppling the poles. Although only a few cases have been reported, this may lead to public injury and there needs some measures in inspection. This has occurred because the foundations of light poles are usually underground and even when corroded, this damage is not easy to observe. So technologies ranging from applied to basic technologies are now being studied.

3.2 Description of the study

A method of directly inspecting corroded locations was studied accompanied by a study to find out if corrosion can be detected by clarifying the change of structural properties by corrosion itself. The former was done by a UT experiment, and the latter was studied by focusing on frequency changes.

(1) Ultrasonic testing method using waves with long wave length (electromagnetic ultrasonic testing)

This part of the report focuses on the electromagnetic ultrasonic testing method that is used in Europe for pipeline corrosion inspections. Because ultrasonic waves are input with a magnetic field in this method, it is a non-contact method that can apply waves deeply into the material, even from above a paint film. The equipment used had already been developed. The experiment was done using a specimen with artificial damage made to simulate corrosion (see Photo 3).

This inspection was performed by installing the probes about 800mm from the end of a steel pipe. Figure 4 shows an example of a result of an inspection when 300 kHz ultrasonic waves were used.

The results have shown that if appropriate calibration can be performed in advance, it is possible to clarify the location and the degree of damage.

(2) Frequency measurements

Change of vibration frequencies accompanying section damage were studied, but it causes little change considering the level of the impact of external turbulence, and although it cannot be said to be impossible, it is a little difficult.

Figure 5 shows the comparison between the analysis and the measurement of damages tested. The analysis was performed using a 3-dimensional FEM analysis model. As shown by Figure 5, when severe damage has occurred, it can be detected, but slight damage is difficult to detect. There are many issues to be studied i.e., setting the detection target level of damage, or improvement of frequency measurement precision.

4. Case 3 Study of degree of damage using a strain gauge 1)

4.1 Background

The study of monitoring technologies focused on strain that is a physical quantity directly related to the evaluation of safety and fatigue resistance of structures. In order to discover an evaluation method using long term strain measurement data, stain in an actual bridge was measured to perform a basic study.

4.2 Description of the study

The bridge that was measured is a steel simple non-composite I-girder bridge on The bridge that was measured is a steel simple non-composite I-girder bridge on National Highway No. 17 (in the jurisdiction of the Oomiya National Highway Office of the Kanto Regional Development Bureau). Figure 6 is a diagram of the overall bridge. Constructed in 1991 (complying with the guideline of 1990), its daily large vehicle traffic volume is 5,288 vehicles/lane (1999 survey). A visual inspection from underneath the bridge failed to find any particular damage or deformation to the steel members, bearings, or floor slabs. Strain gauges were installed on the bottom flanges at the center of the main girder span and on members that would presumably be impacted by fatigue as a result of the high concentration of localized stress, in order to monitor the behavior of the main girder. The modified Miner's Rule was used to calculate the degree of fatigue damage for use as reference material to clarify the approximate impact of fatigue of each member based on the stress frequency distribution that was obtained.

Figure 7 shows the layout of the measuring instruments.

4.3 Results

. Results of degree of fatigue damage measurements in one hour units and in daily units of main girders confirmed tendencies for fluctuation by time of day and day of the week of the live load stress that is assumed to be a result of the impact of the large vehicle traffic volume (see Fig. 8). Figure 9 has confirmed that there is no specific fluctuation of properties related to stress other than thermal stress under weekly and annual fluctuations, so it appears that abnormal values can be monitored to a certain degree.

5. Case 4 Vibration characteristics of new types of bridges [2)]

5.1 Background

Recent years have seen the growing use of forms of bridges rationalized by reducing the number of main girders by increasing the floor slab support interval through the use of highly durable PC floor slabs and by either simplifying or eliminating horizontal connecting members such as cross beams and lateral bracing (referred to as “steel two-girder bridges”). But in this form of bridge, the simplification or elimination of lateral connecting members reduces torsional stiffness below that of conventional steel bridges with multiple main girders (see Fig. 10), and the use of rubber bearings since the revision to the Highway Bridge Guideline of 1996 has lowered structural damping. It is extremely important to clarify the natural frequency of the bridge, structural damping, and other vibration characteristics to evaluate the wind resistance in particular. Because the precision of modal analysis is not sufficient at present, it needs experimental data to estimate vibration characteristics. Therefore, in order to obtain data with highly reliable precision, it is necessary to perform vibration testing using exciters that cause resonance and produce a certain degree of amplitude, so this test was done.

5.2 Vibration testing

The bridges were two bridges with width of 11m, half wall railings and with rubber bearings. The two bridges had relatively long maximum span lengths (Bridge A: max. span 60m, continuous 4-span 2 main girder bridge, bridge length 225m, width 11m, and Bridge B: max. span 70m, continuous 5-span 2 main girder bridge, bridge length 325m, width 11m). Two exciters (0.1 to 20Hz) owned by the PWRI (Photo 4) were used.

5.3 Results

The vibration characteristics of the structure tested were confirmed. As one result of the test, the vibration frequency and structural damping are found to be amplitude dependent. As an example, the amplitude dependency of structural damping in Bridge B is shown in Figure 11. From these results, it can be said that the degree of amplitude must be checked in evaluating vibration characteristics.

And structural damping was a value that is smaller than that of a box girder bridge with conventional steel bearings. The reason for this is not clear, but an estimation equation was proposed as a criterion because structural damping is necessary to evaluation wind resistance stability (see Fig. 12).

６. Concluding remarks

Several examples of bridge monitoring techniques were briefly introduced. It helps road administrators to evaluate actual bridge condition. With progress of measuring devices, it is expected that more useful and effective monitoring system will be developed in the future.

References

1) Public Works Research Institute: Study of Monitoring Steel Bridges by Long-term Measurement of Member Strength, Technical Note of PWRI 3966, April 2004
2) Public Works Research Institute: Study of Wind Resistance Inspection Methods for Rationalized Steel 2-girder Bridges, Technical Note of PWRI 3982, March 2006

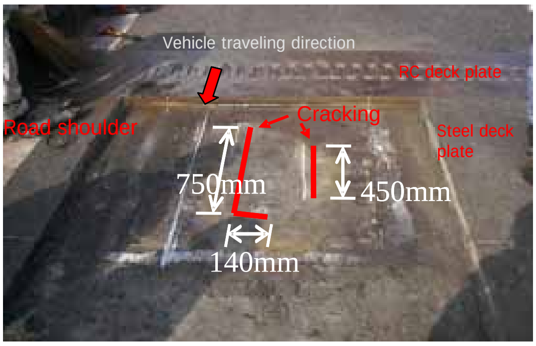
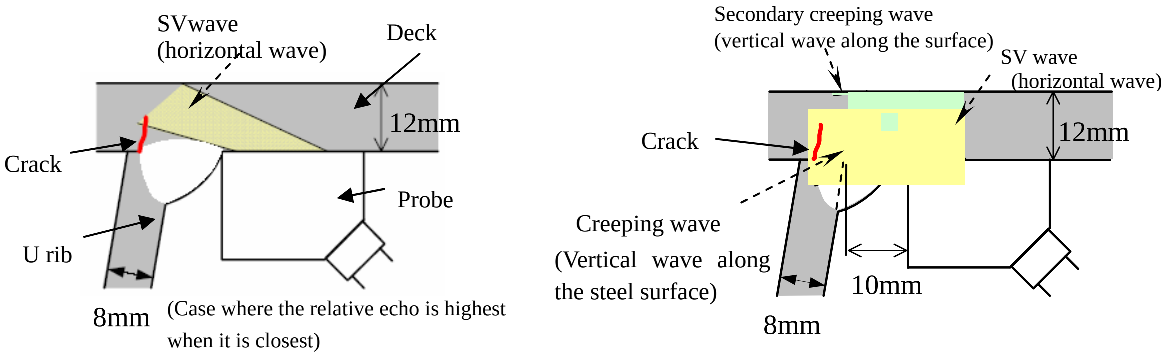


Photo 1 Cracking inside steel floor slab decks



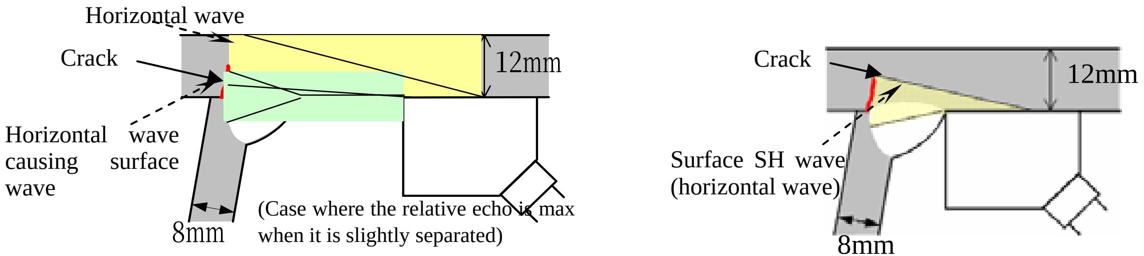
(Case where the relative echo is highest when it is closest)

Normal detection method. When the detection angle is shallow, it cannot detect a shallow crack even when it is closely detected.

Applicable to detection of cracks near the steel surface. There are cases where it is difficult to distinguish other echoes and cracks.

(a) Angle probe with refracted wave of 70°

(b) Creeping wave probe



(Case where the relative echo is max when it is slightly separated)

It is applicable to detection of cracks near the surface. Probe must be precisely manufactured. The probe’s contact surface must be adjusted in advance according to the steel.

Applicable to crack detection (inspection of building steel frames) near steel surface. Depth detection is difficult. There are cases where it is difficult to detect surface welding cracks. Its work properties are poor; it is necessary to use a highly viscous contact medium and push it until the echo is stabilized.

(c) Angle probe with refracted wave of 85°

(d) Surface SH wave probe

Figure 1 Major types and outlines of ultrasonic testing probes

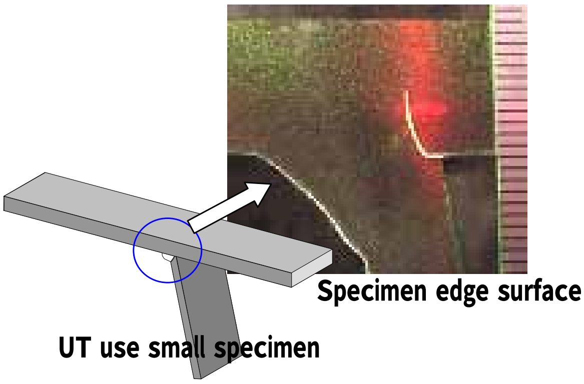
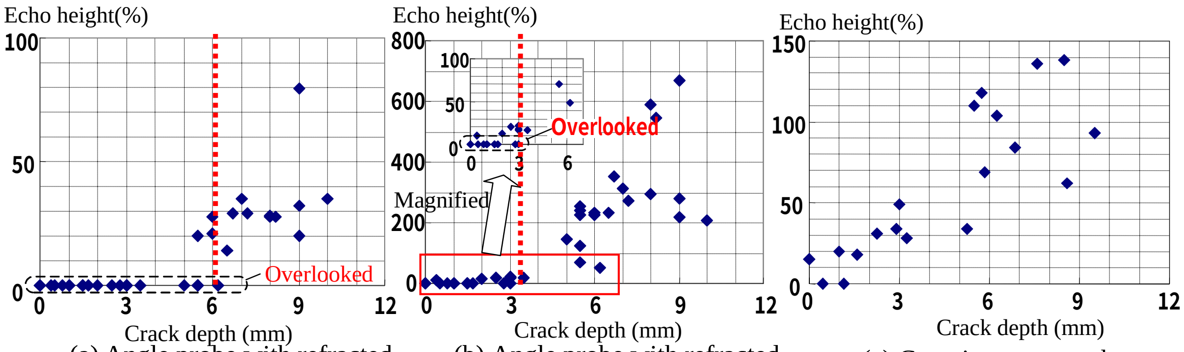


Figure 2 Specimen shape and edge surface condition



(a) Angle probe with refracted wave of 70 °

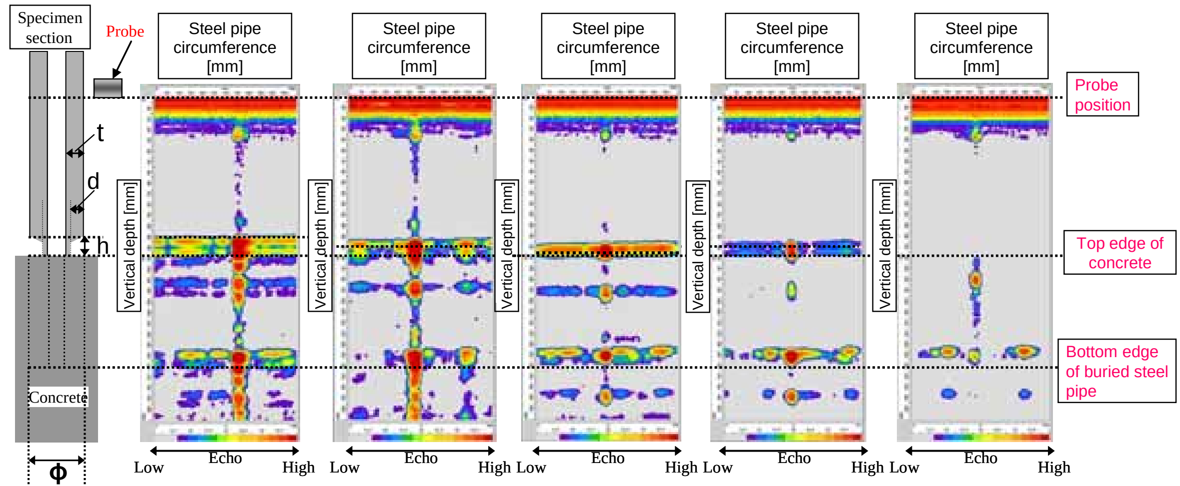
(b) Angle probe with refracted wave of 85 °

(c) Creeping wave probe

Figure 3 Results of Ultrasonic Testing by Specimen
(Relationship of crack depth with reflected echo)

Photo 2 Light pole corrosion

Photo 3 Specimen



Major spec. of steel pipe
ϕ=190.7mm
t =4.5mm

Flaw depth d (mm)	3.0
Flaw height h (mm)	54.0

Flaw depth d (mm)	3.8
Flaw height h (mm)	35.0

Flaw depth d (mm)	3.2
Flaw height h (mm)	14.1

Flaw depth d (mm)	1.3
Flaw height h (mm)	32.8

Flaw depth d (mm)	0
Flaw height h (mm)	0

Figure 4 Defects and Results of Electromagnetic Ultrasonic Testing Method

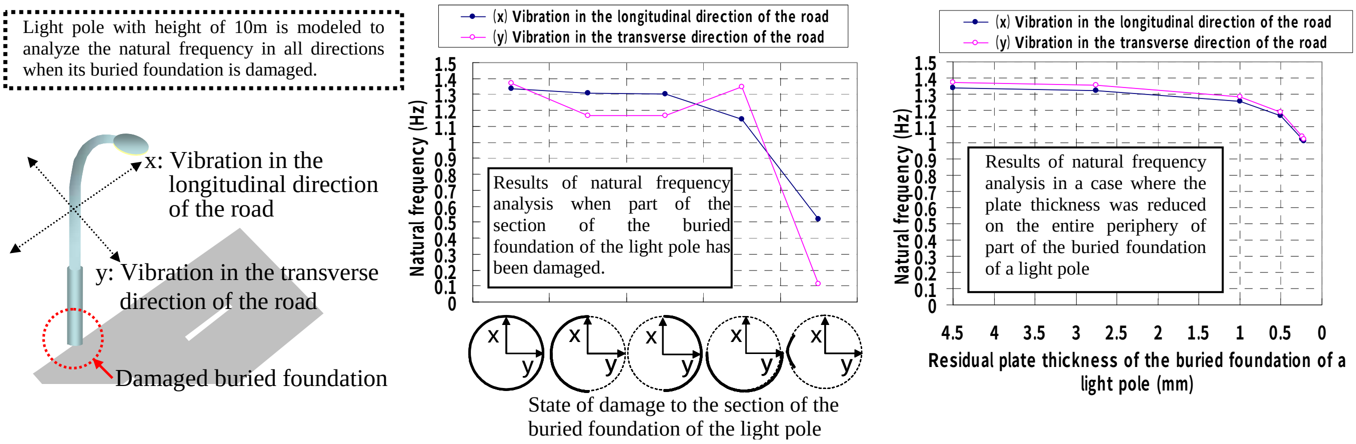
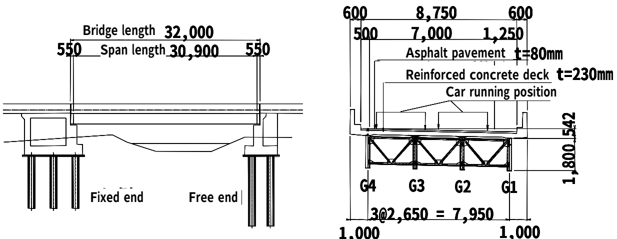
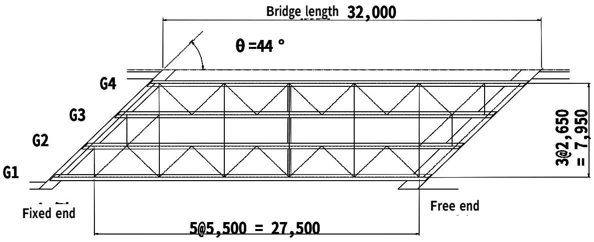


Figure 5 Light Pole Foundation Damage and Frequency Changes Based on Analysis



(a) Side view (b) Section



(c) Top view

Figure 6 Bridge Diagram

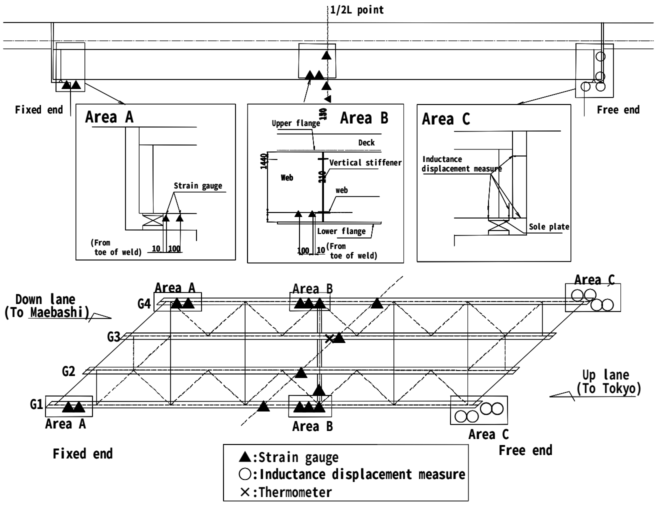


Figure 7 Measurement Instrument Layout

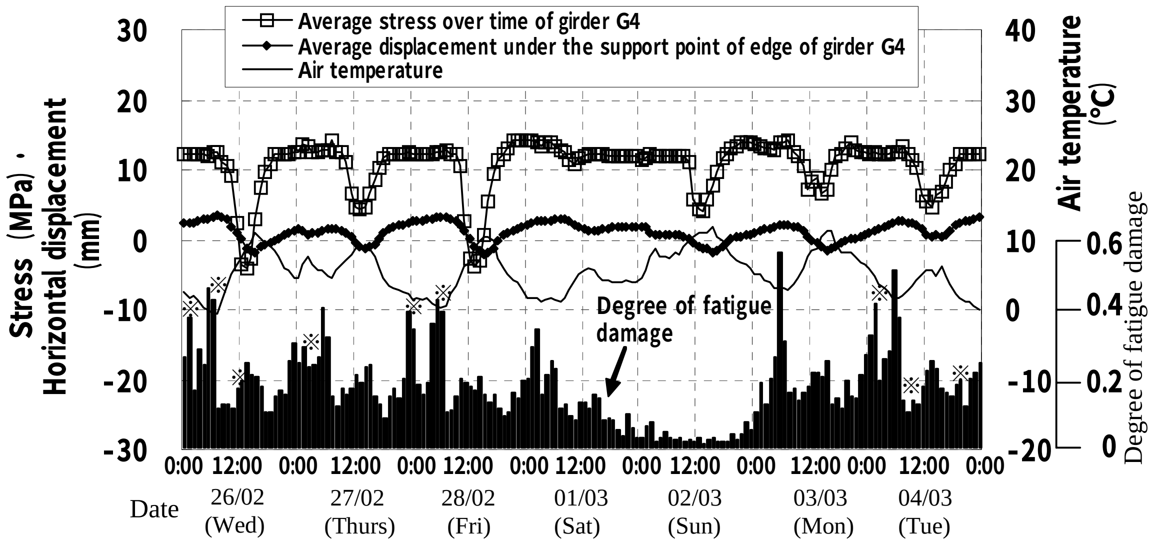


Figure 8 Weekly Fluctuation

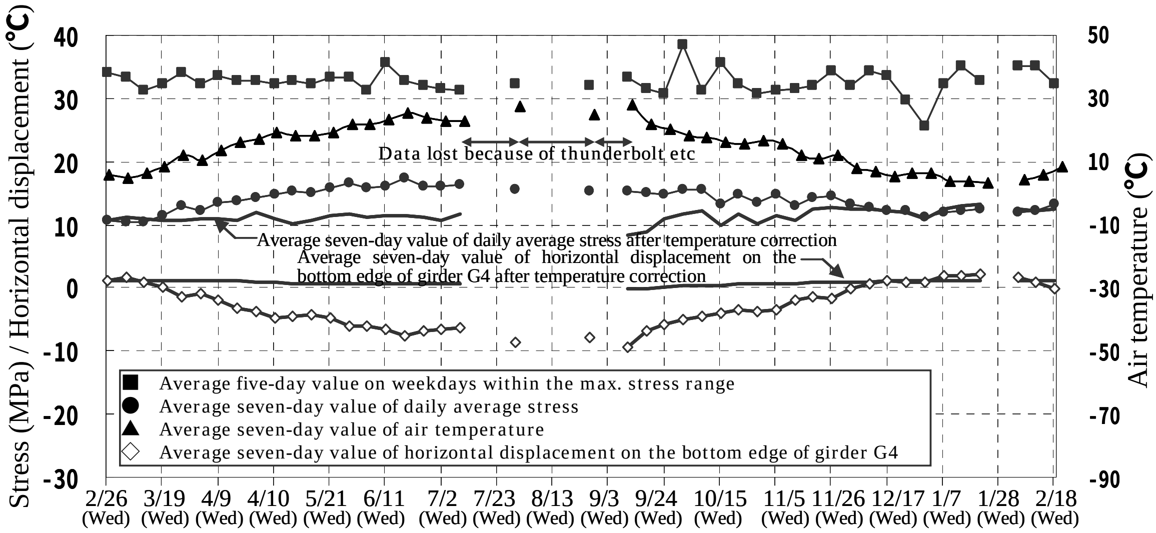


Figure 9 Seven-day Average Value of Stress of Bottom Flange in the Center of Girder G4 Span

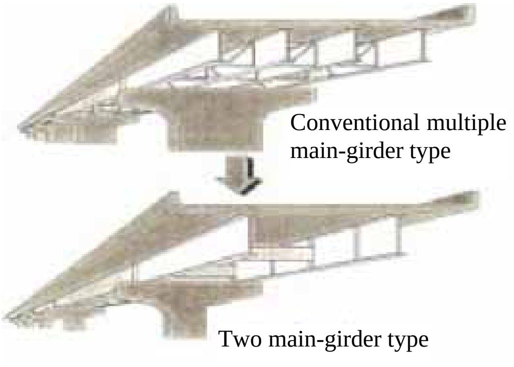
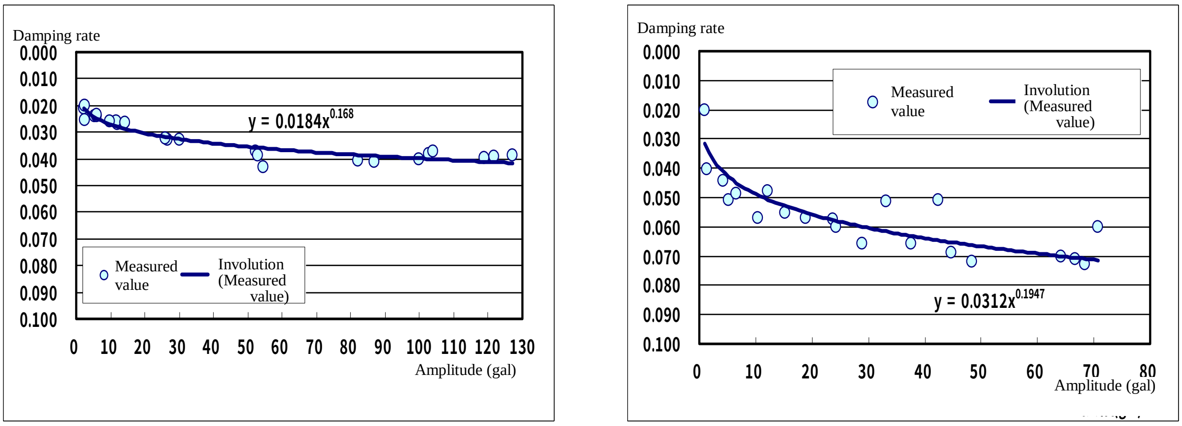


Figure 10 Image of a Steel Two Main-girder Bridge

Photo 4 Installation of Exciters



(a) Vertical deflection primary mode

(b) Oscillation primary mode

Figure 11 Amplitude and Structural Damping

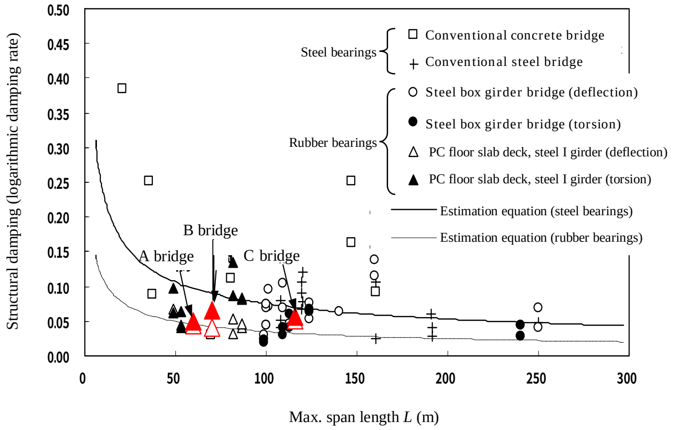


Figure 12 Structural Damping of Girder Bridges (Logarithmic Damping Rate)