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EFFECTS OF THERMAL CHANGE AND TRACK CONDITIONS ON THE DEFLECTION OF RC SLAB GIRDER RAILWAY BRIDGES

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ABSTRACT

This paper mention about the application of deflection monitoring for maintenance method of RC slab girder bridges in the Tokaido Shinkansen.
Firstly, it is described that the background of the importance of continuous monitoring regarding railway bridges. The dynamic responses of RC bridges affect to the running safety and the ride quality. The deflection is widely used as the evaluation index of them. Therefore, it is necessary to check the deflection of the bridges. Additionally, measuring large amount of data is useful to grasp bridge characteristics.
Conventionally, deflection is measured from the part underneath a bridge .However, it is difficult to measure large amount of data because this way is limited to several conditions, such as, under-passing roads and rivers. From this kind of condition, our department developed a deflection monitoring device, which can capture the small signal caused by fluctuation of deflection. By using this device, large amount of data could be obtained. The measurement results by the device are described in the second part of this paper. Continuous monitoring of several bridges were conducted to obtain large amount of data. The maximum period was six months.
The third part describes the effects of thermal effects and track conditions on the fluctuation of the deflection and natural frequency. After the track maintenance, the defection tends to be small. This tend might be caused by the reduction of the rolling stock oscillation due to track maintenance. Furthermore, the deflection tends to be small as the temperature went up. This tend might be caused by following mechanism: 1) Thermal expansion may cause contacting girder ends to parapets of abutments, 2) The contact constrains rotation of girder and change boundary conditions, 3) it results increasing natural frequency and reducing deflection.

Keywords: Continuous monitoring, Deflection, Natural frequency, RC slab girder bridges, High speed rail.

1. INTRODUCTION

In Japan, many of infrastructures were constructed in 1950s, and they will be aged in near future. Therefore, it is important to inspect and retrofit them appropriately. However, there is the problem of the shortage of inspectors and budgets. Thus, efficient maintenance and management are required. Furthermore, technological development of monitoring and inspection utilizing sensors and robots are promoted.

Railway bridges deflect due to train passage. Deflection limits have been given by the span length and train speed because large deflection decrease running safety and ride quality. Table 1 and 2 show the limits for running safety and the ride quality [1]. The maintenance and management of railway bridges are performed quantitatively based on deflection and its limit. Thus, the soundness of railway bridges in the

Tokaido Shinkansen can be evaluated by comparing deflection and its limit. However, large gap exists between actual deflection and limit value [2, 3]. Thus, it is necessary to determine evaluation index for the maintenance of RC slab girder bridges based on current situations.

Current design code requires same deflection limit for same span despite of various structural details (RC, PC, Extradosed, etc.). However, the dynamic characteristics of concrete bridges may be affected by beside span, such as condition of foundation, piers, abutments, skew, location, etc. Therefore, it is necessary to grasp the dynamic characteristics of the actual bridges when the new evaluation index is considered.

Ring-type displacement meters and laser-type displacement meters [4] have being commonly used to measure deflection at the span center of the railway bridges. However these methods may be difficult to measure if an obstacle, such as a river, a road, another railway etc., exists under the bridge. In addition, these methods have to be operated by workers at the site, therefore it was difficult to acquire large amount of data. If large amount data could be acquired and analyzed, it will make possible to grasp the features of the structures and to catch the sign of troubles. Then, the fact lead us to new efficient accurate reliable maintenance system instead of traditional maintenance system relied on inspector’s experience and know-hows.

From these backgrounds, this study is aiming to grasp the factors which may affect the dynamic characteristics of the RC slab girder bridges. In this study, influence by track maintenance and temperature effects on the dynamic characteristics of RC girder bridges were discussed by using long-term measured data obtained by a newly developed “Deflection Monitoring Device”, which enables the acquisition of a large amount of data continuously and unattended, regardless of the under the bridge condition.

Table 1 Limits for running safety (Shinkansen)

Maximum speed (km/h)	Span (m)	Design deflection ration
260	L/700	1.429
300	L/900	1.111
360	L/1100	0.91

Table 2 Limits for ride quality (Shinkansen)

Maximum speed (km/h)	Span (m)	Design deflection ration
260	L/2000	0.455
300	L/2800	0.357
360	L/3500	0.286

2. CONTINUOUS MEASUREMENT

2.1 Measuring Device

An author’s department developed a new deflection monitoring device [5]. Table 3 and Figure 1 shows the outline of this device. The body of this device is made of polycarbonate resin. In order to avoid power consuming, this device records with intervals and it sleep after recording train passage. Recording is triggered by train’s vibration, and measured acceleration data is stored to SD memory card.

This device includes MEMS acceleration sensor. To convert with high accuracy, it is necessary to have high resolution and low noise. The EPSON M-A351AU10 was selected to use this device by comparing multiple sensors.

Measured acceleration response data is converted to displacement data via velocity by integration twice.

Table 3 Outline of deflection monitoring device

Manufacture's type	DEICY
	BCMX01
Measurement range	±50cm/s²
Resolution	0.6μm/s²
Frequency band	10Hz
Sampling frequency	500Hz
Pre-trigger time	1s
Trigger acceleration	0, 0.2, 0.5, 1.0m/s²
Recording time	maximum 9s
Power source	size C battery × 3
Weight	1.5kg
Size	(H)100mm
	(W)123mm
	(D)123mm

deflection range (see Figure 4).

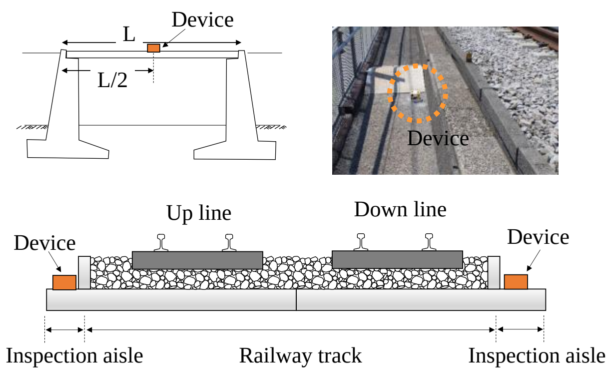


Figure 2 Installation method

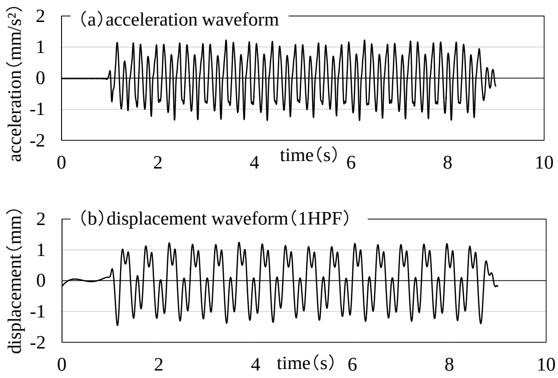


Figure 3 Acceleration waveform and displacement waveform

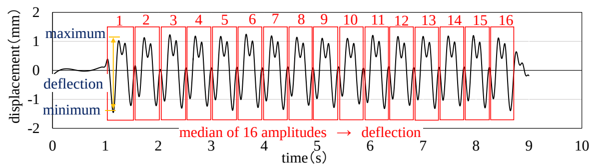


Figure 4 Calculation method of deflection range

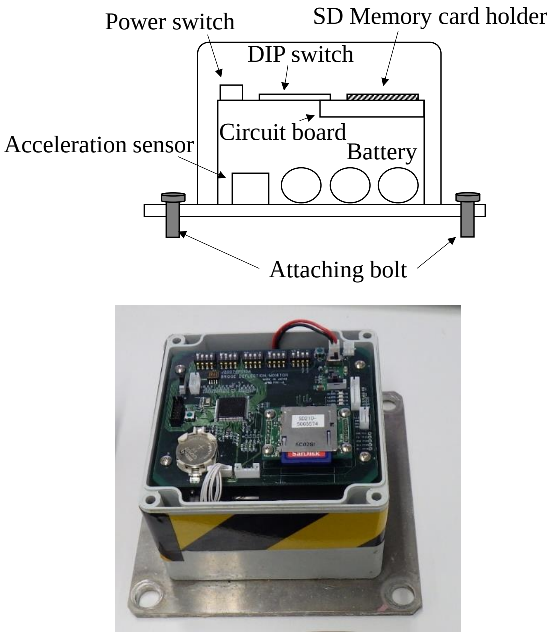


Figure 1 Deflection monitoring device

2.2 Measuring condition

It was carried out by using the device that continuous measurement of deflection of RC girder bridges in the Tokaido Shinkansen.

So far, we have measured on 16 bridges [6]. The measurement period is at least one week and up to six months.

As shown in Figure 2, the devices were installed at span center on the up and down line sidewalks. Data were acquired about 16 data a day, measured from 7 o'clock to 22 o'clock with an hour intervals. Sampling ratio is 500 Hz. Triggering rates, which is made the automatic measurement which begins to measure, was set to 0.2m/s².

Figure 3 shows an example of acceleration waveform and displacement waveform. The acquired acceleration data were processed to calculate a displacement data (deflection). Specifically, for the purpose of baseline correction, the acceleration data was prepared with by 1 Hz high-pass filter before converting into displacement data.

2.3 Deflection Range

In this paper, the displacement range is used to evaluation. It is calculated from the deflection wave with the peak-to-peak amplitude being one displacement range, and the eighth largest value of the deflection range is defined as the deflection range (see Figure 4).

2.4 Target Bridges

From the results of continuous measurement of several bridges, we confirmed these bridges that change in deflection range and natural frequency under the influence of track maintenance and temperature effect.

This paper presents these two measurement results shown in Table 4. Table 4 shows the details of each bridge. The influence of track maintenance was confirmed in "A bridge". The influence of temperature effect was confirmed in "B bridge".

Table 4 Details of each bridge

	A bridge	B bridge
Span	10m	12.5m
Angle	left 65°	nothing
Liner	straight section	relaxation curve
Foundation form	pile foundation	pile foundation
Maximum train speed	285km/h	285km/h
Meteorological observation point	Shizuoka	Ebina
Measurement period	from Sept. 5, 2017 to Feb. 1, 2018	from Sept. 26, 2018 to Oct. 23, 2018
The number of data	3805	1880

3. RESULT OF A BRIDGE

3.1 Measurement result

Figure 5 shows the transition of deflection range. During the measurement period, the deflection range was distributed in the range of 2 to 6 mm, and the average value was 3.79 mm. However, the average value of deflection range for various train speeds does not make much sense because deflection range is affected by trains speed. Therefore it is included only as a reference.

The deflection range peaked at around 235 km/h from the relationship between train speed and deflection range shown in the figure 6. It was confirmed that resonance occurred at the train speed. Such resonance might enlarge the daily variation of deflection range.

The transition of natural frequency during the measurement period is shown in Figure 7. Natural frequency was distributed in the range of 8 to 9 Hz except for the data which deviated greatly. The median value of the natural frequency was 8.30 Hz.

Figure 8 shows the daily transition of deflection range, natural frequency and average temperature near this bridge. The average temperature fluctuated in the range from 0 to 30ºC during the 150-day measurement period.

Furthermore, the correlation coefficient of deflection range and average temperature was −0.20. The correlation coefficient of the natural frequency and the average temperature were −0.51. Thus, correlations were not strong. From this result, it was found that this bridge might not affected by temperature change.

On the other hand, the variation of the deflection range decreased in some period. These periods overlapped with events such as track maintenance. For example, the result of around Oct. 5 was overlapped with track maintenance.

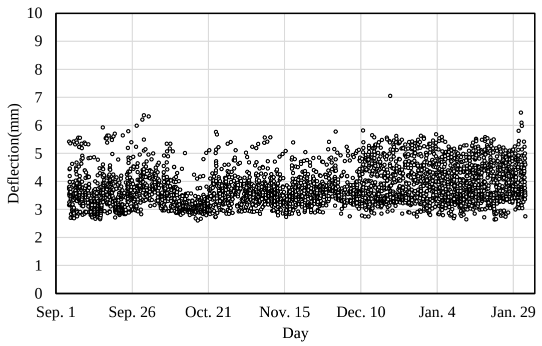


Figure 5 Transition of deflection

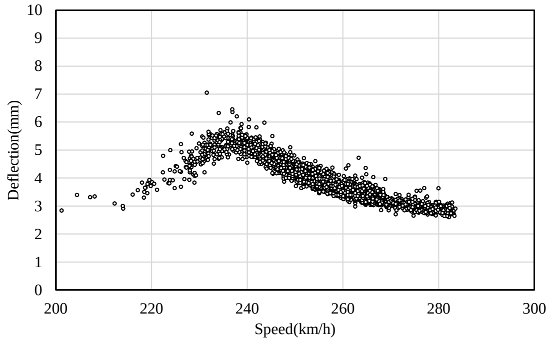


Figure 6 Relationship between deflection range and train speed (A bridge)

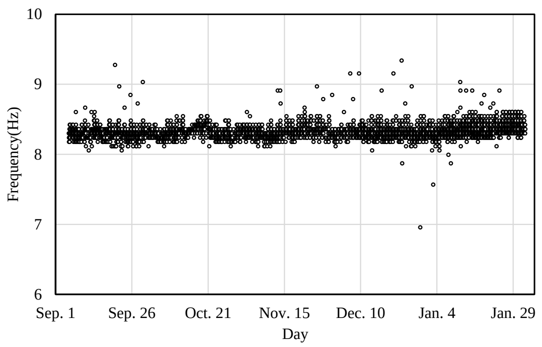


Figure 7 Transition of natural frequency (A bridge)

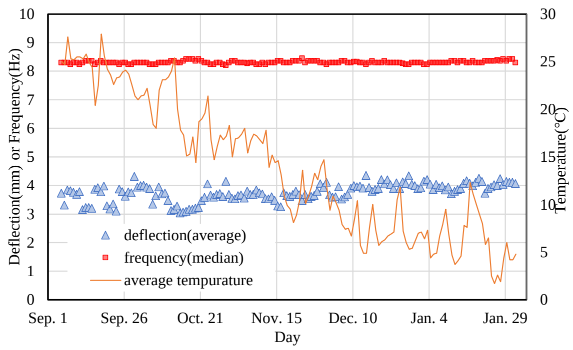


Figure 8 Transition of daily deflection, natural frequency and average temperature in A bridge

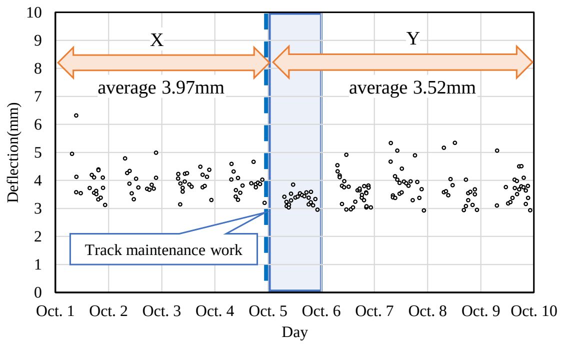


Figure 9 Result of around Oct. 5

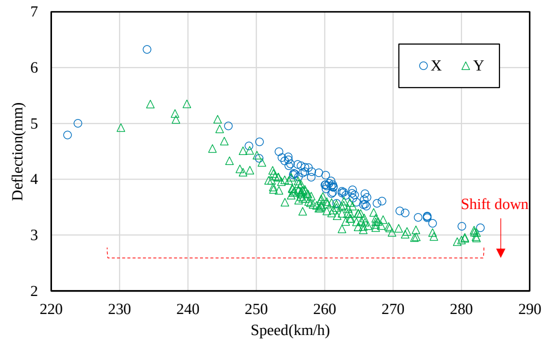


Figure 10 Relationship between train speed and deflection of A bridge

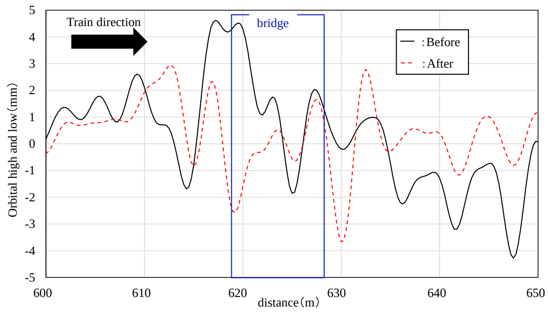


Figure 11 Spatial distribution of level deviation of A bridge (left rail)

3.2 Influence of track work

Figure 9 indicates that deflection ranges on Oct. 5 were smaller than deflection ranges on other days. In addition, the overall variation was also smaller. A tamping work with a multiple tie tamper was carried out at night on Oct. 4. We named period from Oct. 1 to Oct. 4 as X, and named period from Oct. 5 to Oct. 10 as Y. X is before the tamping work. Y is after. The average value of deflection range was 3.97 mm in period X and 3.52 mm in period Y. It decreased 0.45 mm by the tamping work.

Figure 10 shows the relationship between train speed and deflections in the period X and the period Y. Deflection range between 220 km/h and 285 km/h decreased.

Figure 11 shows the special distribution of level deviation of left rail. Black line indicates in the period X and red break line indicates in the period Y. This figure showed that fluctuation at the entrance of the bridge have been removed. According to Japanese design code for train structures, the dynamic response acting on the structures can be expressed as following equations [1].

The impact coefficient i is product of coefficients of speed effect i_α and vehicle oscillation effects i_c.

$$i = (1+i_\alpha)(1+i_c)-1 \quad (1)$$

It is thought that the i_c was reduced by eliminating the high and low deviations, and the reduction of the deflection value was affected.

4. RESULT OF B BRIDGE

4.1 Measurement Results

The transition of deflection range is shown in Figure 12. During the measurement period, the deflection range was distributed in 2 to 4 mm. The average deflection range was 2.88 mm.

From the relationship between the train speed and the deflection range is shown in Figure 13. The deflection range increased by train speed. Thus, resonance did not occur in this speed band.

The transition of natural frequency is shown in Figure 14. During the measurement period, the natural frequency was distributed in the range of 8 to 9 Hz except for the data which deviated greatly. Median was 8.30 Hz.

Figure 15 shows the transition of daily deflection range, natural frequency and the average temperature around this bridge. The average temperature fluctuated in the range of 15 to 30ºC. Average temperatures on Oct. 1 and Oct. 7 were over 25ºC. They were warmer than other days. It seems to be that higher air temperature increased natural frequency and decreased deflection range.

Moreover, correlation coefficient of the deflection range and the average temperature was 0.79. It means that they have strong positive correlation. On the other hand, correlation coefficient between the natural frequency and the average temperature was -0.79, strong negative correlation. Thus dynamic behaviour of this bridge might be influenced by the temperature change.

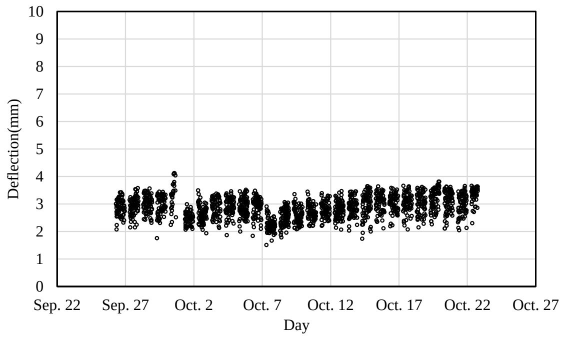


Figure12 Transition of deflection range (B bridge)

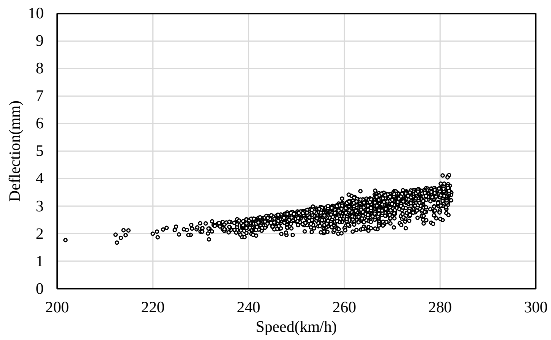


Figure13 Relationship between speed and deflection (B bridge)

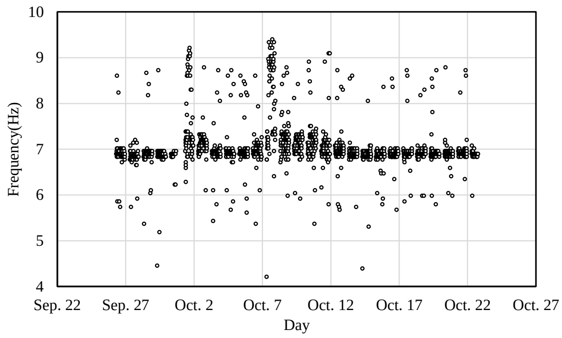


Figure14 transition of natural frequency (B bridge)

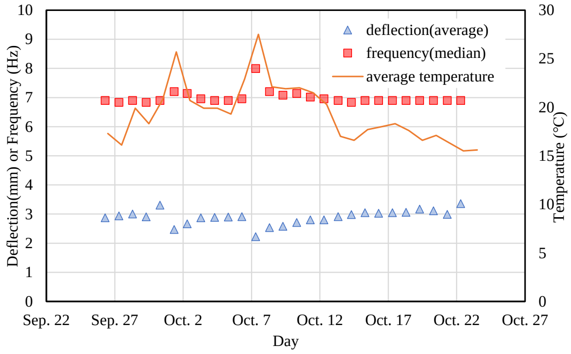


Figure15 Transition of deflection range, natural frequency and average temperature (B bridge)

4.2 Influence of temperature effect

Figure 16 shows the restraint condition of the support of concrete girder. If the outside air temperature is not so high, there is a gap between girder ends and parapets of abutments. This condition may be considered as simple support condition. On the other hand, when the outside air temperature is high, expanded girder causes contacting girder ends to parapets, and fixing rotations at the both ends of girders. It was inferred that the natural frequency increased and the deflection decreased in theory, because boundary condition of the girder is shifted from simple support condition to semi-fixed support condition. It was estimated that the natural frequency was changed by this kind of mechanism which is observed in the up line of the A bridge.

In order to verify this hypothesis, it is desirable to directly confirm the condition of girder ends in the field. However double-reinforcement slab girders cannot be visually inspected in proximity because structural access to girder ends is impossible.

Therefore, the influence of changes in the fixed conditions at both ends on the natural frequency and the deflection was examined by an experiment.

The experiment was carried out by using a 10 m span real scale RC slab girder model. Total length is 10.7 m. Details of the specimen are given in the reference [7]. The girder is simply supported in normal condition as shown in Figure 17. There are gaps between girder ends and parapets. Horizontal movement of the girder is not restricted at movable bearing. In order to simulate the semi-fixed condition (girder ends contact state) of actual structures, girder ends and parapets were integrated by pouring mortar into the gap between them. Horizontal movement of the movable bearing was restrained, too.

Natural frequency was calculated by processing the acceleration data obtained by dropping weight vibration tests. Vertical acceleration at the center of girder bottom was measured about 20 second when a 40 kg weight was dropped from 30 cm above sidewalk. Measurements were performed 10 times for each condition. Fourier spectra were obtained by FFT, and they were averaged. Natural frequency was determined as a frequency at the maximum peak in the range from 1 to 15 Hz of the averaged spectrum, because we focus on the first-order natural frequency.

Figure 18 shows comparison of experimental and measured results. In the case of experiment, natural frequencies were 8.38 Hz for normal condition, and 10.24 Hz for the contact condition. Contacting between girder ends and parapet resulted that the natural frequency increased about 22% by condition change.

In the case of actual measured result, natural frequencies of the B bridge became higher when high temperature days: Oct. 1 (max. 32.2ºC) and Oct. 7 (max. 33.4ºC). Natural frequency on Oct. 1 was about 4% higher than other days, and it on Oct. 7 was about 16% higher than others. In addition, increase rate of the natural frequency was larger than one on Oct. 7 where the average temperature was approximately 1ºC higher than one of Oct. 1. Comparing with the Oct. 7 result indicates that the measured value showed a smaller increase rate, but the natural frequency increased about 4 to 16% by temperature.

We can say from above findings that the natural frequency was effected by the change of constraint condition at the girder ends due to temperature change.

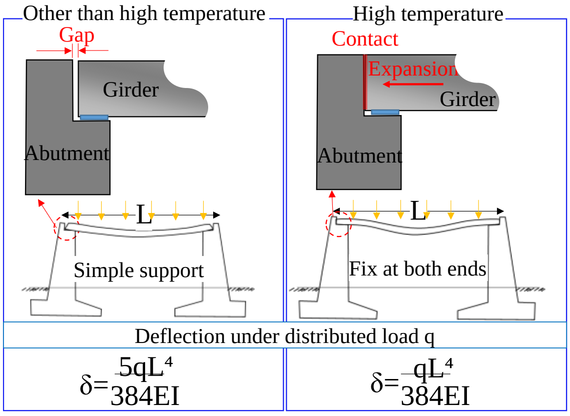
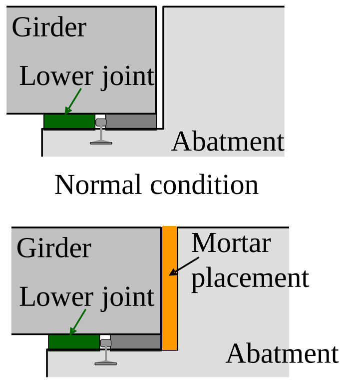


Figure 16 Constraint condition at supports



Reproduce girder end concrete

Figure 17 Girder end condition

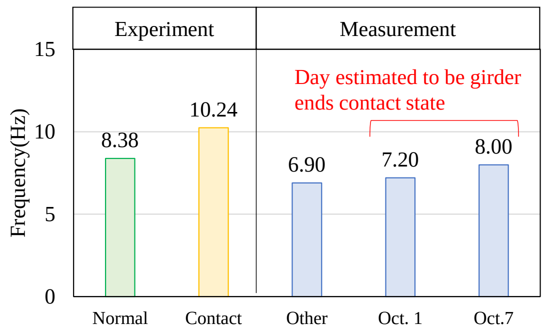


Figure 18 Comparison of experiment and measurement

5. CONCLUSIONS

In this study, effects of track maintenance and temperature on the dynamic characteristics of RC slab girder bridges were evaluated by using continuous measurement data obtained by the newly developed deflection monitoring devices. The following findings were obtained from this study.

1) The development of the deflection monitoring device has enabled continuous measurement.
2) By continuous monitoring, it was confirmed that the tendency of deflection value changes due to the influence of train speed and the influence of track maintenance, during snow damage operation regulation.
3) The analysis of the level deviation waveforms before and after the track consolidation operation showed that the elimination of the level deviations affected the reduction of the deflection value.
4) In a bridge affected by temperature effects, the deflection value tends to decrease as the natural frequency increases, and there is a positive correlation between temperature and natural frequency, and a negative correlation between temperature and deflection value.
5) The expansion of the girder due to temperature effects is considered to be the cause of the change of the natural frequency due to the change of the constraint condition of the supporting point.
6) As a result of carrying out an experiment simulating the condition where girder ends and parapets of abutments were in contact, the natural frequency was 8.38Hz at normal and 10.24Hz at the time of girder end contact.
7) As a result of contact between girder ends and parapets of abutments, the natural frequency is increased by about 22% compared to normal. In the experiment also, the natural frequency changes because the constraint condition of the girder ends changes.
8) In the measurement, the natural frequency increases by about 4 to 16% when the constraint condition of the girder end changes.

Continuous measurement will be continued, and investigations will be conducted on factors that affect girder deflection.

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