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Understanding of dynamic characteristic of existing steel truss bridges for structural health monitoring

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ABSTRACT: Vibration measurement of an existing steel bridge was conducted in order to understand its dynamic characteristics for structural health monitoring. Investigated bridge is a steel Gerber truss bridge. Its total length and the number of spans are 850.8m and 13 respectively. About 70 years have passed after construction. At first, measurements of ambient and traffic-induced vibration were carried out using MEMS-based tri-axial accelerometers. As a result, acceleration responses vibrating only in one direction were observed. Since it was impossible to evaluate the magnitude of acceleration under traffic, re-measurement was conducted using a servo-type accelerometer. Comparison of the maximum vertical accelerations indicates that the response at suspended spans is 2 to 13 times larger than that at anchor spans. Moreover, the response at a vertical member above an expansion joint having big gap reached about 2000gal.

1 INTRODUCTION

Many accidents and damage to existing bridges have occurred due to aging or deterioration. In spite of these situations, visual inspection or hammer tone method have been conducted mainly as conventional maintenance techniques. However, these techniques tend to be subjective or qualitative because they require experiences. Therefore, it is strong necessary to develop quantitative structural health monitoring techniques for bridges (Fujino et al. 2008).

The object of this paper is to understand dynamic characteristics of an existing steel bridge from vibration measurement for the purpose of developing structural health monitoring technique. The type of investigated bridge is a steel Gerber truss bridge located in Nagaoka, Japan. Measurements of ambient and traffic-induced vibration were carried out using newly supplied MEMS-based tri-axial accelerometers and a conventional servo-type accelerometer.

2 WIRELESS LAN ACCELEROMTER

A wireless LAN accelerometer utilized in this study is a commercial product DATAMARK SU100 supplied by Hakusan Corp. as shown in Fig. 1. Specification of the accelerometer is

Figure 1. Wireless LAN accelerometer

Table 1. Specification of accelerometer

Type	Electric capacity
Freqauency	0.1 to 50Hz
Channels	3
Range	±1.5G
Resolution	18bits
Sampling rate	100Hz
Wireless LAN	IEEE 802.11b
Transfer rate	11Mbps
Distance	About 100m (Outside)
	About 60m (Inside)
Battery	6V
Size	147×125×75mm
Weight	About 850g including batteries

shown in Table 1. Although it inevitably lacks measured data due to no-checking of data transmission, it has following merits; wireless measurement at about 100m distance on outside, tri-axial measurement, synchronized measurement between sensors and battery drive (about 10 hours). Wireless measurement can eliminate a lot of works and time such as needed in connecting cables. Also, tri-axial measurement can capture local three-dimensional behavior. Fundamental performance of the wireless LAN accelerometer and its applicability to bridges have been already checked (Miyashita et al. 2008).

3 VIBRATION MEASURMENT USING WIRELESS LAN ACCELEROMETERS

Construction year, the number of span and total length of investigated bridge are 1937, 13 and 850.8m respectively. Fig. 2 shows a picture of the bridge. The number of measured span using wireless LAN accelerometers was 9 as shown in Fig. 3. Fig. 4 shows measurement positions, which are supports, Gerber hinges and center of spans. Fig. 5 shows installing configuration of the accelerometers. 4 accelerometers were attached on stringers using magnets at both up and down stream sides. They formed one unit. Ambient and traffic-induced vibrations were measured. Sampling frequency was 100Hz, and measurement time was set to become 30 to 60 minutes in each span.

At first, it was expected that natural frequencies in each span became same because their lengths of span were same. However, 1st natural frequencies in vertical direction at suspended and

anchored spans were identified as 2.5 to 2.6 Hz. and 1.7 to 1.8 Hz respectively as shown in Table 2. In order to clarify this reason, we focused on Shimada's equation (Kato et al. 1981), which is statistical equation predicting 1st natural frequency in vertical direction based on the length of span and bridge type. This equation is expressed as follows.

$$F = 10^{\alpha} L^{-0.828} \tag{1}$$

where F is a 1st natural frequency in vertical direction of a bridge L is the length of a span and α is constant value depending on bridge type. For a steel truss bridge, $\alpha = 1.793 + 0.082$. Since the length of a suspended span is 65.0 m, F becomes 2.37 Hz. This value is close to identified values. For an anchored span, when we adopts its length as not 65.0m but 100.0m, which is the length between Gerber hinges including an anchored span, F becomes 1.67 Hz. Therefore, vibration in anchored span is not vibration between supports but one between Gerber hinges including an anchored span. Although spans having same structural details differ in the condition of local damage such as corrosion or lack of bolt, they show almost same 1st natural frequencies. Therefore local damage of bridge seems not be reflected in global dynamic characteristics.

Examples of time history in vertical direction are shown in Figs. 6. Numbers in figures correspond to the measurement positions in Fig. 5. Usually, damped waveforms are observed in Gerber hinges and the centers of spans. However, at supports, characteristic waveform, which vibrates into only one direction, is observed. The maximum amplitude of damped waveforms is 378.9 gal. On the other hand, the maximum amplitude of characteristic waveform is 1058gal. The maximums of absolute value of acceleration are summarized in Fig. 7. Here, red frames indicate the occurrence of characteristic waveforms. The characteristic waveform is based on the type of MEMS-based accelerometer, which is capacitive-type sensor. Laboratory experiment made clear that it took long time until electric capacity became constant after impact. Although the value of amplitude in characteristic waveform is uncertainty, the occurrence of impact can be recognized. And also, it is confirmed that there is a place such as P6 support where characteristic waveform frequently occurs. Actually, there is a joint with big gap around P6 support as shown in Fig. 8.

Figure 2. Investigated bridge

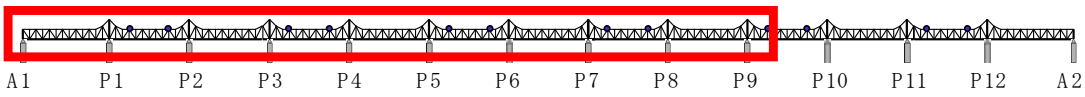


Figure 3. Measured spans (● indicates Gerber hinges)

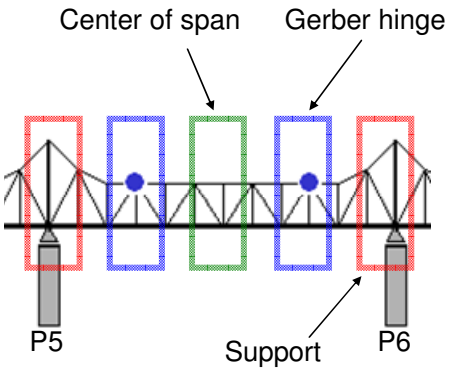


Figure 4. Measurement positions

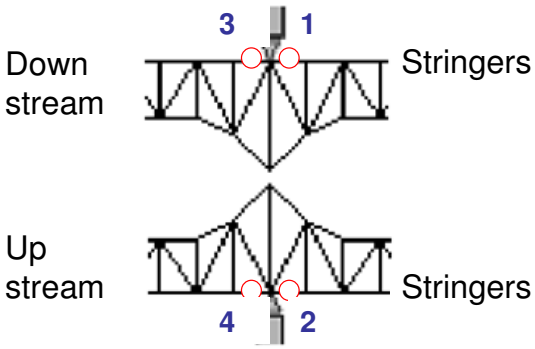
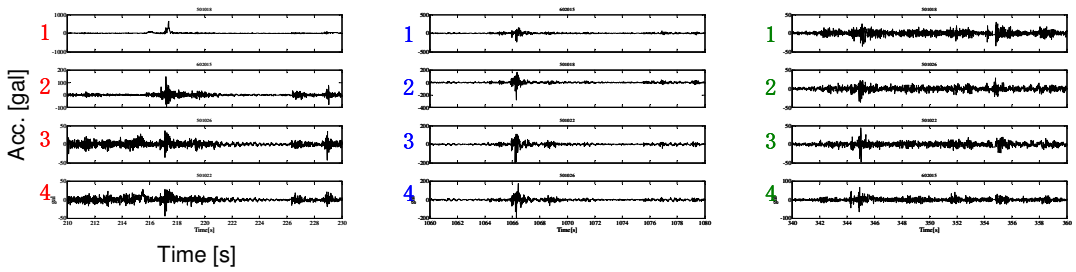


Figure 5. Configuration of accelerometer

Table 2. Identified 1st natural frequencies

Span	Natural frequency [Hz]
A1-P1	2.0
P1-P2	2.7
P2-P3	2.0
P3-P4	2.5
P4-P5	1.8
P5-P6	2.5
P6-P7	1.9
P7-P8	2.5



(a) Support (P7) (b) Gerber hinge (P6) (c) Center of span (P6-P7)

Figure 6. Example of acceleration responses in vertical direction

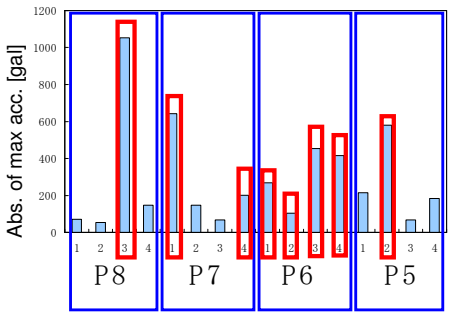


Figure 7. The maximums of absolute acc.

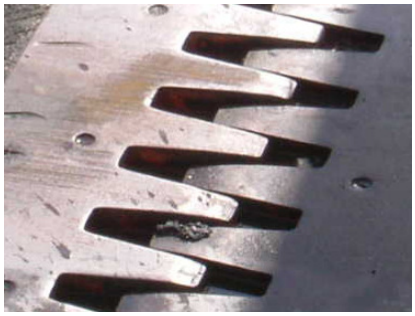


Figure 8. Gap of an expansion joint

4 VIBRATION MEASURMENT USING A SERVO-TYPE ACCELEROMETER

In order to evaluate the magnitude of acceleration in each span, re-measurement was conducted using a conventional servo-type accelerometer (RION, LS-40C). It was attached on accessible vertical member in the middle of all spans. Ambient and traffic-induced vibrations were measured. Sampling frequency was 100Hz, and measurement time was set to become 2 hours in each span.

Fig. 9 shows the maximums of absolute acceleration in each span. Here, blue and red bars correspond to anchored and suspended spans respectively. In comparison with the maximums, P5-P6 span affords the largest value. Fig. 10 shows the cumulative number of acceleration above 40 gal in measurement time. Accelerations at suspended spans are larger than those at anchored spans. In particular, large accelerations frequently occur at P5-P6 span. This is due to impact force given by the gap of the joint near P6 support as above-mentioned.

Then, time histories were classified according to the types of vehicles identified by a video camera. Figs. 11 show distributions of accelerations for suspended and anchored spans respectively. From these figures, the maximum amplitude of acceleration caused by passage of passenger cars is about 30 gal. And also, there are no differences in response at suspended and anchored spans. However, passages of dump trucks or busses generate larger accelerations at suspended spans than those at anchored spans. Especially, at P5-P6 span, accelerations become larger due to the big gap of an expansion joint located near P6 support. This effect results in larger acceleration at P6-P7, which locates in next to P5-P6, than that at other anchored spans.

In the case of passages of dump trucks, mean values of acceleration at all suspended and anchored spans are 124.3gal and 49.6gal respectively, and their ratio is 124.3/49.6 = 2.5. When the value at P5-P6 are excluded, mean value of all suspended and all anchored spans are 94.2gal and 49.6gal respectively, and their ratio is 94.2/49.6 = 1.9. The ratio of the maximum value at P5-P6 to mean value of all suspended spans except P5-P6 is 589.5/158.9 = 3.7, and the ratio of the maximum value at P5-P6 to mean value of all anchored spans is 589.5/49.6 = 11.9. As a result, it is found that the maximum value at P5-P6 under the passage of dump trucks is prominent.

In the case of passages of trucks, mean values of acceleration at all suspended and anchored spans are 88.1gal and 34.5gal respectively, and their ratio is 88.1/34.5 = 2.6. The ratio of the maximum value at P7-P8 to mean value of all anchored spans is 154.8/34.5 = 4.5, and the ratio of the maximum value at P7-P8 to mean value of all suspended spans except P7-P8 is 154.8/125.7 = 1.2. As a result, there is no span showing prominent acceleration in all suspended spans under the passages of busses although the maximum value at all suspended is about 2.6 times larger than that at all anchored spans.

In the case of passages of busses, mean values of acceleration at all suspended and anchored spans are 93.0gal and 33.8gal respectively, and their ratio is 93.0/33.8 = 4.6. The ratio of the maximum value at P7-P8 to mean value of all anchored spans is 189.9/33.8 = 5.6, and the ratio of the maximum value at P7-P8 to mean value of all suspended spans except P7-P8 is 189.9/141.3 = 1.3. As a result, there is no span showing prominent acceleration in all suspended spans under the passages of busses although the maximum value at all suspended is about 4.6 times larger than that at all anchored spans.

At P5-P6 span, the maximum accelerations under the passage of dump trucks and passenger cars are 589.5gal and 45.0gal respectively, and their ratio is 589.5/45.0 = 13.1. And also, the weights of a dump truck at full loading and a passenger car are 20tf and 1.5tf respectively. Therefore, it is confirmed that the maximum acceleration becomes about 13 times larger when the weight of a vehicle is about 13 times larger

Fig. 12 shows the maximum acceleration measured at a vertical member above the expansion joint with big gap located near P6 support, which locates just below a Gerber hinge. Here, acceleration above 2000gal was observed. When visual inspection was carried out with scaffold, a crack was found at lower flange of stringer as shown in Fig. 13. Although the cause of crack has not been clearly defined, it seems to be correlation between the big gap of expansion joint and acceleration above 2000gal.

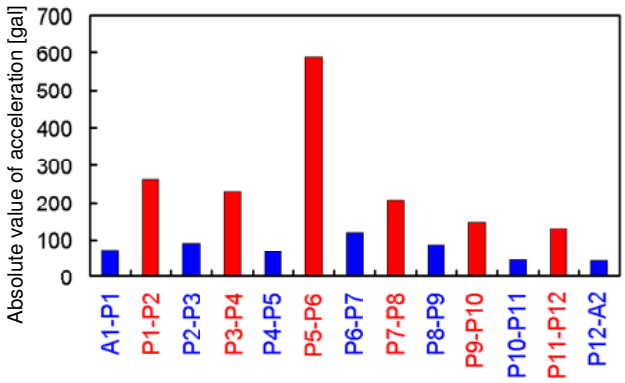


Figure 9. The maximums of absolute acceleration using a servo-type accelerometer

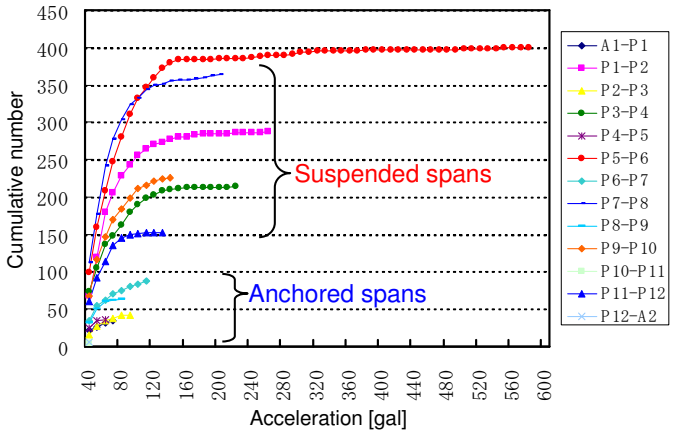
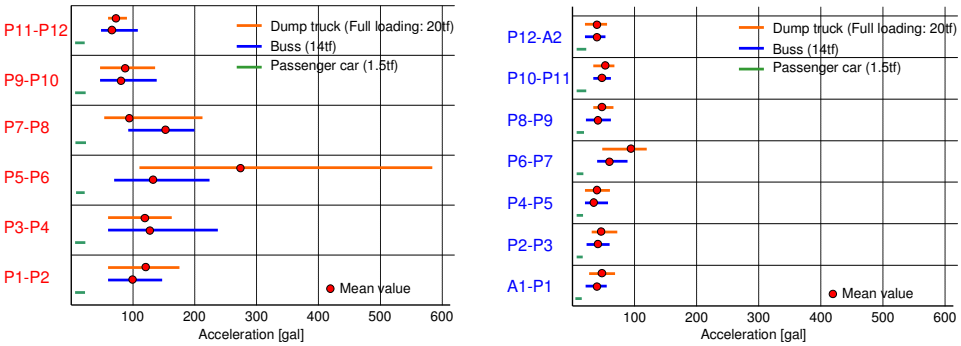


Figure 10. The cumulative number of acceleration above 40 gal



(a) Suspended spans (b) Anchored spans

Figure 11. Distributions of accelerations

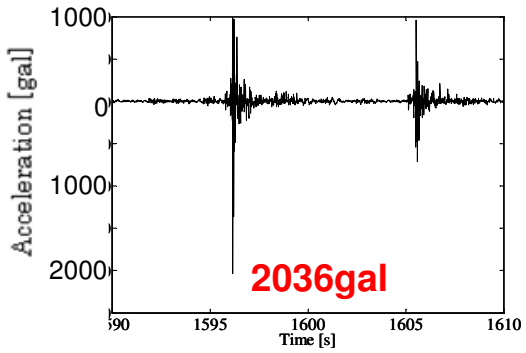


Figure 12. The maximum acceleration

Figure 13. Crack at lower flange of stringer

5 CONCLUSIONS

Vibration measurement of an existing steel bridge was conducted in order to understand its dynamic characteristics for structural health monitoring. Investigated bridge is a steel Gerber truss bridge. Conclusions of this study can be summarized as follows.

1) Newly supplied wireless LAN accelerometer greatly reduces measurement works. When impact force is given to the sensor, characteristic response vibrating only in one direction is induced. Although this response indicates the occurrence of impact force, it is impossible to evaluate the magnitude of acceleration.

2) 1st natural frequencies in vertical direction at suspended and anchored spans were identified as 2.5 to 2.6 Hz. and 1.7 to 1.8 Hz respectively. Shimada's equation made clear that vibration in anchored span was not vibration between supports but one between Gerber hinges including an anchored span.

3) When dump trucks pass through investigated bridge, mean values of acceleration at all suspended and anchored spans 124.3gal and 49.6gal respectively, and their ratio is 124.3/49.6 = 2.5. The ratio of the maximum value at P5-P6 to mean value of all suspended spans except P5-P6 is 589.5/158.9 = 3.7, and the ratio of the maximum value at P5-P6 to mean value of all anchored spans is 589.5/49.6 = 11.9. As a result, it is found that the maximum value at P5-P6 under the passage of dump trucks is prominent.

4) Acceleration above 2000gal was observed at vertical member above the expansion joint with big gap located near P6 support, which locates just below a Gerber hinge. When visual inspection was carried out using scaffold, a crack was found at lower flange of stringer.

REFERENCES

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