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DYNAMIC CHARACTERISTICS OF A BRIDGE USING AMBIENT VIBRATION MEASUREMENTS AND FINITE ELEMENT ANALYSIS

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ABSTRACT

This paper describes dynamics characteristics of a girder steel bridge based on ambient vibration measurements and finite element method of analysis. The bridge, known as Asuka Oohashi was constructed in 1979 and spans 256 m over the river Koyoshi located at Yurihonjo city, Akita Prefecture, Japan. In this research, the target bridge is investigated by means of micro vibration measurements and Fourier analysis to obtain its dynamic characteristics in especial predominant frequencies and their modes of vibration. In addition Finite element model was constructed and analytical results are compared with those result obtained from measurements. Analysis permits to identify modes of vibration of the bridge and also permits to validate measurement results. Combination of in-situ measurements and analysis permits also to construct a reliable analytical model which can be used for dynamic analysis using real earthquake record as input motion

INTRODUCTION

Estimation of dynamic characteristics of bridge structures it is an important task to evaluate their seismic response and to investigate their structural safety. Potential damages can be detected by a periodical of continuing monitoring to prevent the collapse of bridges. In Japan, after The Second World War many bridges were constructed as an important part of the reconstruction tasks. Therefore these bridges present some deterioration due to ageing and due to action of past earthquakes. Moreover, in the decade of 1980 of the last century constructions of large projects of building and bridges were initiated. Then high demand of materials, in special for reinforced concrete structures, induced the used of sea sand which contains salts that in reaction with water and cement originates the corrosion of steel reinforcement.

To implement a monitoring system and to verify its reliability, basic estimation of dynamic characteristics of a target bridge was done in this research. The Asuka Oohashi Bridge which is located at Yurihonjo city in Japan was selected as target structure and ambient vibration measurements were performed by authors to estimate natural frequencies of vibration in the selected structure. The structure is a continuous beam type bridge with steel beams of variable sections and reinforced concrete slabs to support the asphalt carpet. The bridge consists of seven spans with a total length of 256 m. Micro vibration sensor were set up at middle of each span and measurement were performed simultaneously. Since girder sections are not equal for each span and spans at bridge end have different length, predominant frequencies are also different for each span.

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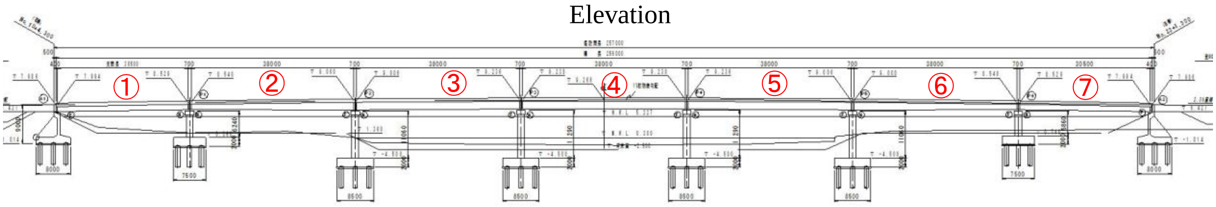
Using finite element method for analysis, modes of vibration were identified and correlated with peaks of Fourier spectrum obtained from in-situ vibration measurements. The main modes of vibrations correspond to vertical vibration of the bridge.

TARGET BRIDGE AND AMBIENT VIBRATION MEASUREMENTS

The investigated bridge was constructed in 1979 and it is part of the Japanese national route number 105. The name of the bridge is Asuka Oohashi (actually, in Japanese Oohashi means large bridge and was designated with this name by comparison with an old bridge near the site which had less length).

The bridge has 256 m of length and connects the south and north-east part of Akita prefecture as a part of the route 105. It must be noted that the routes of Japan are numbered according their year of construction, where lower numbers corresponds to oldest routes. Elevation scheme, plan view and a photograph can be appreciated in Figure 1. The deck is 22.8 m wide and consisted of cast in place reinforced concrete slab supported by longitudinal steel girders. The structure consists of seven spans where spans at both ends have 30.5 m of nominal length and other central spans have 38 m de nominal length. Details of girders an a view of road carpet are show in Figure 2.

Elevation



Plan View

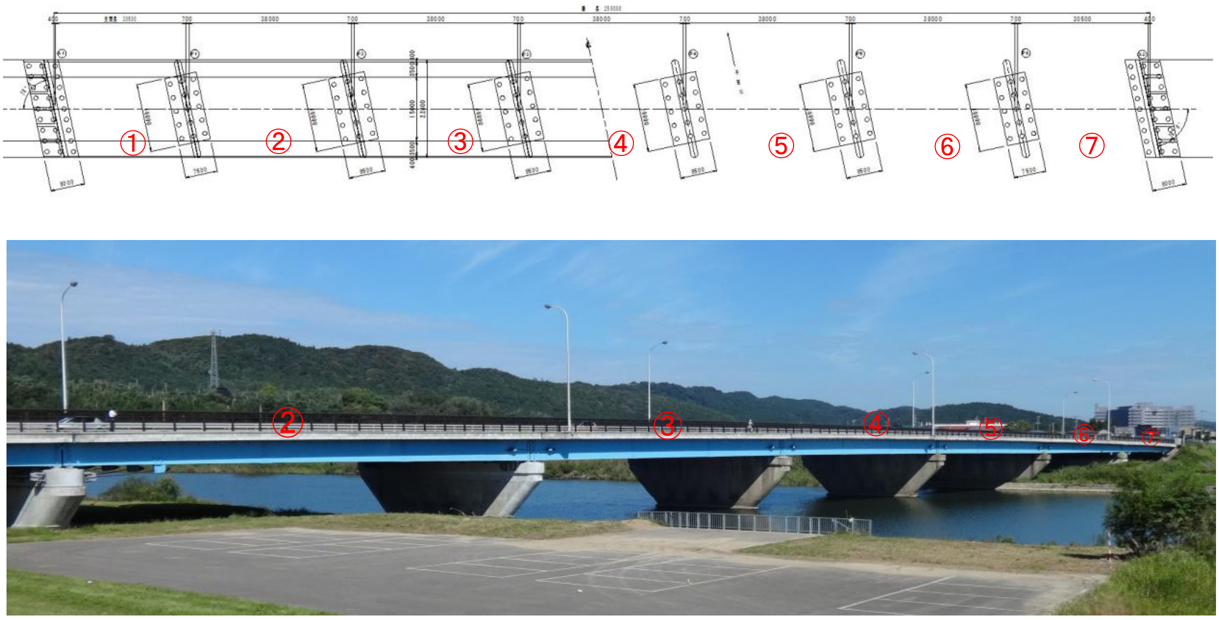


Figure 1. Asuka Oohashi Bridge

Two series of micro vibration measurements were carried out, using 7 simultaneous recording systems with 3 channels per system. That is 21 channels were measured in total. Sensors were located on the pedestrian deck and distributed as is show by encircled numbers in Figure 1. Three components of vibration were measured at each point of observation. All sensors were located on the central portion of each span. 600 seconds were measured using sampling ratio of 100 Hz to provide good wave form definition. Figure 2shows some details of the equipment for micro vibration measurements.

Figure 2. Details of girders and view of bridge deck

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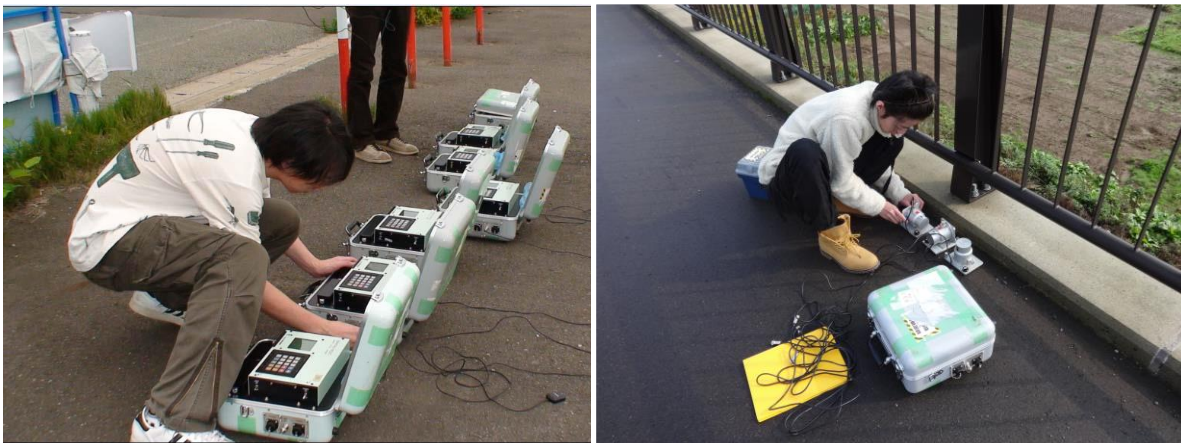


Equipment calibration and synchronization

Sensors setup

Typical point of measurements

Detail of data logger screen

Figure 3. Details of measurements and equipment

The largest response of the vibration was observed for the vertical component. It was detected that each span has its own predominant frequency. Spans for points ② to ⑥ which were presented in Figure 1, are of the same length however the dimensions of steel beams and support condition are different. Spans for points ① and ⑦ have same length however this length is shorter than length for other spans. Therefore to observe the difference between different types of span, responses at points ①, ②, ③, and ④ were estimated and the correspondent Fourier spectrum are shown in Figure 4.

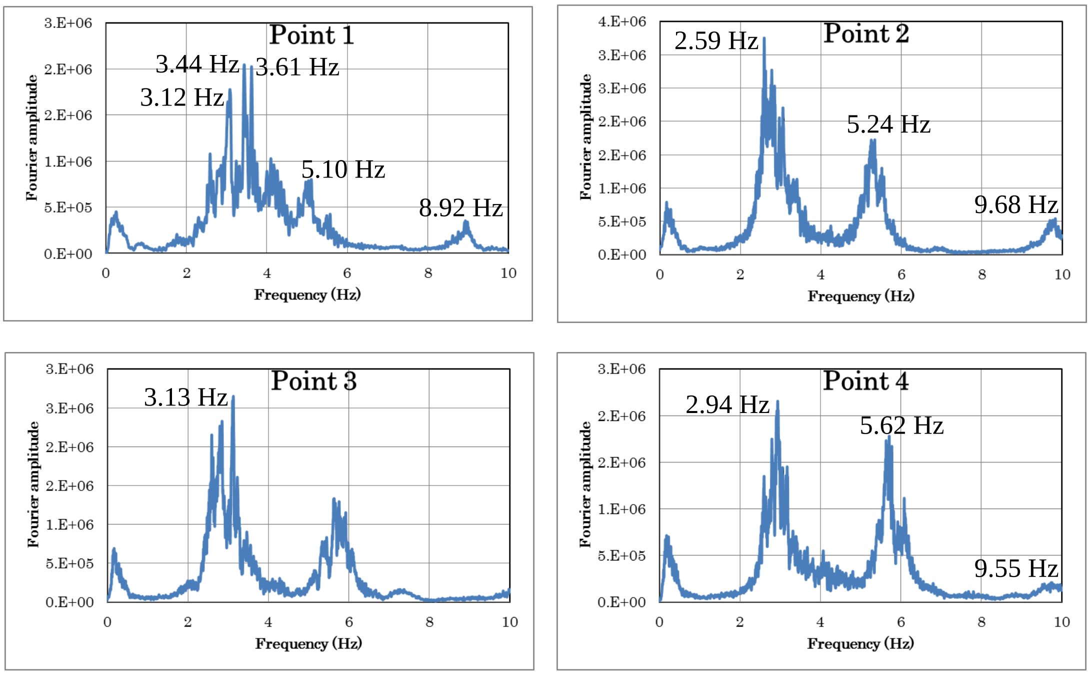


Figure 4. Fourier spectrum responses for different spans of the target bridge

Responses show that natural frequency for span ② presents the lowest value of frequency, since beams have variable depth to connect span ① (smaller depth) and span ③ (larger depth), resulting in lower vertical stiffness and therefore lower frequency. It was expected that Span ③ and ④ could have the same predominant frequency however different frequencies were obtained probably due to different support conditions. Span ① has shorter length and it is reasonable that its predominant frequency is different. However three peaks are observed in this case and therefore more detailed analysis will be required to estimate the predominant frequency.

FINITE ELEMENT MODELLING AND STRUCTURAL IDENTIFICATION

A 3D finite element model of the bridge was created using the commercially available SAP computer program. Since the bridge consists of seven spans, only representative typical spans were modeled since each span is separated by an expansion joint and therefore each span can be analyzed as single supported bridge. Figure 5 shows the general model of the target bridge indicating types of spans in relation with points of ambient vibration measurements. Span C is the shortest span with 30.5 m of length, while spans B and A have 38 m of length. The difference between span A and B is support condition and type of girders. The 3 types of span for the target bridge is shown in Figure 6.

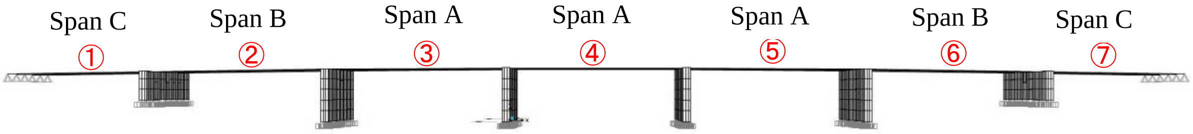
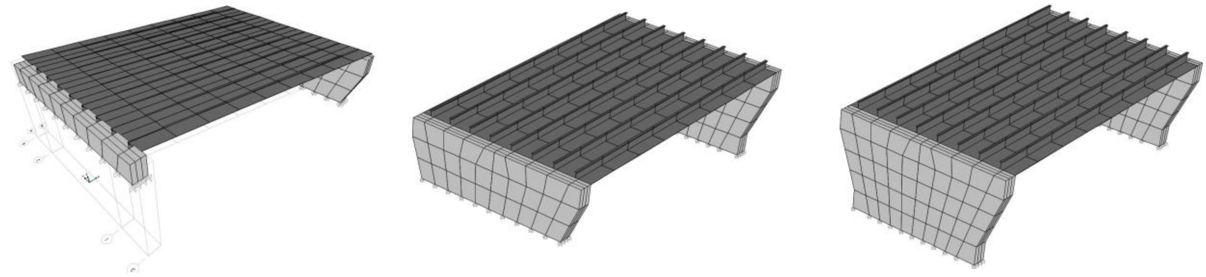


Figure 5. Types of span and vibration measurement point

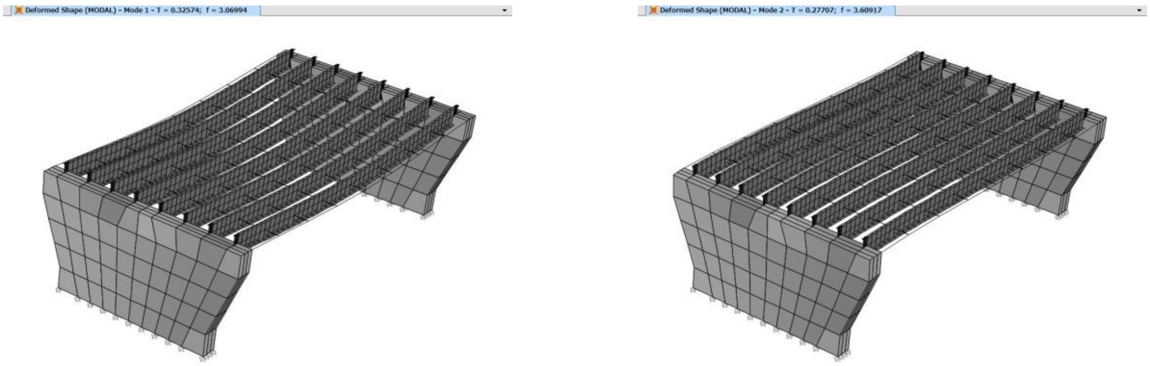


Span C (30.5 m) Span B (38 m) Span A (38 m)

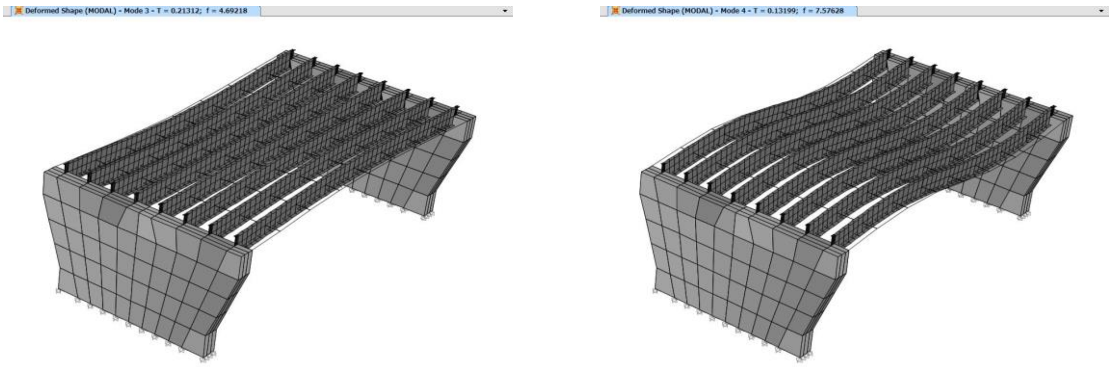
Figure 6. Modelling of typical spans for the target bridge

For each span supports were modelled using solid elements and girders of variable cross section were considered according to bridge design draws. Concrete slab that includes the asphalt carpet were considered for the deck and basically contributes to the mass of structure. Stiffness for vertical vibration was considered basically from girders with a small contribution of the concrete slab.

Modes of vibration for span A are shown in Figure 8. The first mode of vibration corresponds to the simplest vertical vibration with a predominant frequency of 3.07 Hz. The second mode corresponds to lateral vibration of supports in this case in the longitudinal direction of the bridge, with 3.61 Hz of predominant frequency. The third mode is transversal vertical vibration with 5.39 Hz as predominant frequency. The fourth mode corresponds to the second longitudinal mode of vibration with 7.58 Hz as predominant frequency. From measurements at point ④, vertical modes (first, third and fourth modes of analysis) were detected as peaks at 2.94 Hz, 5.62 Hz and 9.55 Hz respectively. For span B similar modes were obtained with frequencies of 2.89 Hz, 3.57 Hz, 4.59 Hz and 6.86 Hz respectively.



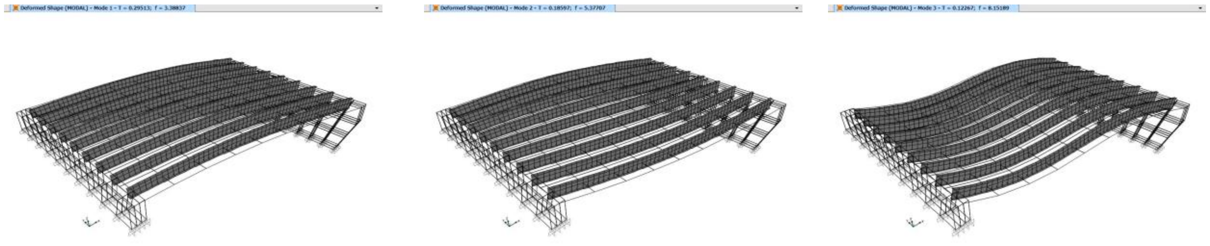
First Mode Second mode



Third mode Fourth mode

Figure 7. Modes of vibration for span A

Modes of vibration for the shortest span C are shown in Figure 8. The first mode of vibration corresponds to the simplest vertical vibration with a predominant frequency of 3.39 Hz. The second mode is transversal vertical vibration with 5.39 Hz as predominant frequency. The third mode corresponds to the second longitudinal mode of vibration with 8.15 Hz of predominant frequency. These modes of vibration were also detected during measurements at point ① as peak at 3.44 Hz, 5.10 Hz and 8.92 Hz respectively.



First mode Second mode Third mode

Figure 8. Modes of vibration for span C

Measurements and analysis results are summarized in Table 1. In general good agreement is observed and from analytical results it was possible to identify the modes of vibration that appears as predominant peaks in the Fourier spectrum curves obtained from measurements. For span A and B the second mode corresponds to lateral vibration of supports and therefore it is not include in the Table 1 since this table only take into account vertical modes of vibration.

Table 1. Comparison of predominant frequencies from analysis and measurements

Span	Mode	Analysis	Measurement
Span A	1st	3.07 Hz	2.94 Hz
	3rd	4.69 Hz	5.62 Hz
	4th	7.58 Hz	9.55 Hz
Span B	1st	2.89 Hz	2.59 Hz
	3rd	4.59 Hz	5.24 Hz
	4th	6.86 Hz	9.68 Hz
Span C	1st	3.39 Hz	3.44 Hz
	2nd	5.38 Hz	5.10 Hz
	3rd	8.15 Hz	8.92 Hz

CONCLUSIONS

A rational methodology for estimation of dynamic characteristics of bridge Asuka Oohashi has been presented and applied in this paper. The approach is based on ambient vibration measurements and finite element modeling that permits to identify modal characteristics of target structure. In this paper the identification of first three modes related to the vertical vibration of the bridge and their predominant frequencies of vibration was possible by comparison of ambient vibration measurements results with analytical results. Measured modes of vibration agree well with those obtained analytically.

This investigation will serve as a basis for future structural health monitoring of the bridge, in especial monitoring with a new system develop by authors which consists in the use of piezoelectric bolt sensors.

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