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Estimation method of bridge vibration using a pseudo-response analysis

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ABSTRACT

Low-frequency noise complaints occur to residences near the highway bridge. In order to control the low-frequency vibration of the bridge, it is necessary to grasp the vibration behavior. "Truck-bridge interaction dynamic analysis" is used as a method for estimating traffic vibrations of bridges. In this method, the bridge surface profile data is set and the dynamic responses when the truck travels on the bridge surface is estimated by dynamic analysis of the truck model and the bridge model. However, this method requires exclusive software, detailed modeling of trucks and road surface profile data. In this research, a relatively simple analysis method called "pseudo-response analysis" is proposed. In this method, the measured truck vibration is set as external force acting on the bridge. So the vibration of the bridge that resonates due to the truck vibration can be approximated. Hence, this analysis method can roughly simulate the effect of the external force in the frequency band that causes complaints. Further, general-purpose software can be used for the analysis program. Modeling case and applicability of the "pseudo-response analysis" method are described in this study.

Keywords: pseudo-response analysis, low-frequency noise, bridge vibration
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1. INTRODUCTION

The complaints against traffic vibrations from elevated roads include noise, vibration and low-frequency noise. These are mainly caused by excitation of bridge vibrations due to vibration of the traveling truck. Among these, it has been confirmed that the low-frequency noise has a strong correlation with the vertical vibration of the upper structures of the bridges[1)]. In addition, in case of the rationalized bridge constructed in recent years in Japan, it has been reported that the bridge vibrations peculiar to the structures with few constituent members considered to be the influence of the out-of-plane vibrations of the decks or girders2). For this reason, it is important to properly estimate the characteristics of the vertical vibration of the upper structures in predicting the occurrence of low-frequency noise and examining the countermeasure structures.

In order to estimate the vibration of the bridges when the truck travels on the bridges, it is necessary to consider the dynamic interaction when the truck travels on the road surface of the bridges[3)] (hereinafter called as, “Dynamic Interaction Analysis”). In this analysis, a dedicated program that can take into account the dynamic interaction between the truck moving on the bridge and the bridge is required. Also, it is necessary to properly set the road surface unevenness of the bridge and the truck model; however it is difficult to reproduce the phenomenon of wheels levitating from the road surface. Therefore, in a high frequency where more detailed modeling is generally required, it is true that the accuracy of analysis has declined. On the other hand, from the viewpoint of utilization in practical design, the application of truck travel analysis is a. Therefore, it is only necessary for the analysis method to be able to reproduce the response of the frequency band as the cause of the complaints, and simplification of the analysis method is desired. Furthermore, traffic vibration countermeasures include momentum exchange type Impact Mass Damper (IMD) countermeasures[4)] with complicated nonlinear behavior and studies using general-purpose programs with abundant material properties are desired.

Therefore, by setting the external force acting on the bridge from the truck using the actual measurement value of the truck vibration, the authors generally reproduced the action of the external force in the frequency band that causes complaints. In this analysis program, a general purpose-program is used and an analytical method (Figure 1) which can be handled relatively easily is proposed and its applicability is examined. In this analysis method, a pseudo-external force acting on the bridges is estimated from the vibration acceleration of the axle when the test truck passes over the bridges and inputs it into the bridge model as a moving load (hereinafter referred to as “Pseudo-Response Analysis”).

For the study of the applicability of pseudo-response analysis, the steel girder bridges, which is generally considered to have many cases of complaints, was targeted, and a 3-dimensional FEM model was used for the analysis model. The applicability of pseudo-response analysis was evaluated by comparing the response acceleration of the decks with the dynamic interaction analysis. In addition, we also compared the measured values when driving the test truck and the response of the pseudo-response analysis. In addition, since the application of numerical analysis using analytical model is an estimation of countermeasure effect, estimated value of countermeasure effect is compared, and consideration on application of pseudo-response analysis to practical design is conducted.

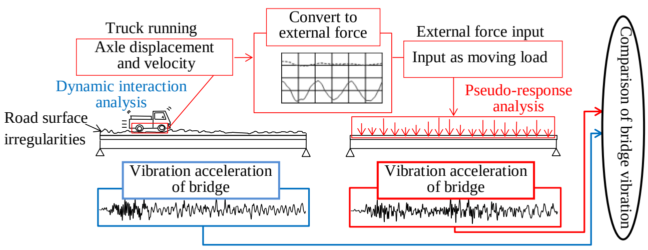


Figure 1 Procedure for analysing the analysis method and its applicability in this study

Table 1 Targeted bridge

Bridge type	Span	Main girder spacing
Steel 10-span continuous plate girder (2 main girders)	34.25m＋35m ×8＋34.25m	6.9m

2. TARGET BRIDGE

As an actual condition survey of low-frequency noises generated from bridges, there are studies that analyzed the data of about 80 road bridges nationwide[5)]. Compared to the concrete bridges, the sound pressure level of the steel bridges is relatively large. Therefore, in this study, steel bridges with a number of steel-plate were considered. Table 1 shows the specifications of the bridge to be analyzed, and Figure 2 shows the general diagram.

3. PROPOSAL OF EXTERNAL FORCE BY TRUCK AND PSEUDO-RESPONSE ANALYSIS

3.1 Modeling and calculation method of external force by truck

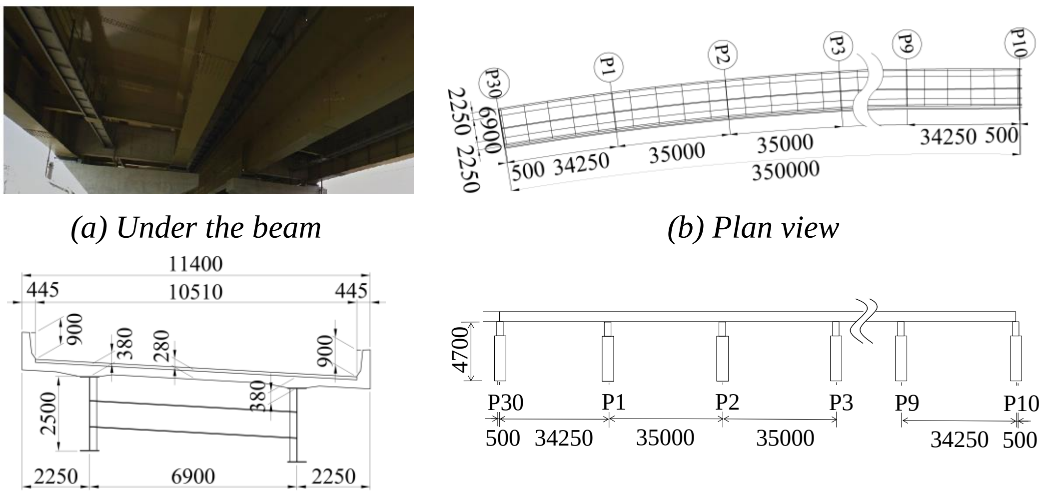
The purpose of use of truck run analysis in practical design is mainly to verify the effectiveness of countermeasures against low-frequency noise and countermeasures against vibration. Thus, regarding to the analysis methods, the authors considered that it is possible to accomplish its objective if the action of external force from the truck in the frequency band that causes the complaints can be easily modeled and reproduce the bridge vibration roughly. Therefore, we proposed a pseudo-response analysis in which a pseudo-external force created from measured values of truck vibration was applied.

Here, a pseudo-external force P' that the traveling truck exerts on the bridge is defined by the following equation.

$$P' = k_T(z_{TR}) + c_T(\dot{z}_{TR}) + (m_S + m_T)g \qquad \text{Equation 1}$$

Here, z_{TR}, $\dot{z}_{TR}$ is the vertical displacement and the vertical velocity respectively which are calculated by integrating the measured value $\ddot{z}_{TR}$ of the vertical acceleration of the tire (axle). The dynamic component is a value obtained by multiplying the spring constant k_T of each tire and the damping coefficient c_T, and a load P' obtained by adding a truck load as a static component to the dynamic component is applied as a pseudo-external force.

Calculation process of pseudo-external force is explained. Originally, the vertical acceleration $\ddot{z}_{TR}$ of the axle given from the measured value of the acceleration sensor attached to the axle is used. However, in this study, in order to clarify that only the influence of external force components is considered in dynamic interaction analysis, the vertical acceleration $(\ddot{z}_T)$ of the axle is calculated by the interaction analysis.



(a) Under the beam *(b) Plan view*

(c) Cross-sectional view *(d) Side view*

Figure 2 Target bridge (rationalized bridge)

By integrating this vertical acceleration once, the vertical velocity $\dot{z}_T$ of the axle is obtained and the vertical displacement z_T is obtained by integrating twice. Further, by multiplying these values by the damping coefficient c_S of the tire and the spring value k_S of the tire, the restoring force of the truck and the spring reaction force are obtained. Therefore, the dynamic component of the external force by the truck is obtained as the sum of both, and the value obtained by adding the static truck load to this is the input load in the pseudo-response analysis. From the above, it can be seen that the external force applied by the truck has a large proportion of the spring reaction force of the truck.

3.2 Outline and scope of pseudo-response analysis

As shown in Figure 1, the pseudo-response analysis is to analyze the response of the bridge by applying the external force by the truck described in the previous section as a moving load on the bridge. Here, when calculating the load acting on the bridge from the truck, the vertical displacement and the vertical velocity are not z_T, $\dot{z}_T$ but the relative value of the axle and the road surface at the axle position (the sum of the vertical profile of road surface unevenness and bridge vibration). The vertical profile r of the road surface roughness is given by actual measurement, but the vertical displacement z_T of the axle and the vertical displacement z_C of the bridge at truck position are obtained as a result of the dynamic interaction analysis. Therefore, the vertical displacement used for calculating external force in dynamic interaction analysis is given by their relative displacement (z_T - r - z_C). On the other hand, the vertical displacement used to calculate the external force in the pseudo-response analysis is the vertical displacement (z_T) of the axle. In addition, the vertical velocity considered in calculation of external force, the dynamic interaction analysis strictly considers the relative velocity of each part where as vertical velocity of the axle is used in pseudo-response analysis. In pseudo-response analysis, vertical displacement (z_{TR}) and vertical velocity ($\dot{z}_{TR}$) which originally obtained by integration of measured values of acceleration from sensor attached to the axle are used. For this reason, it is unnecessary to analyze the response of the truck running on the unevenness of the road surface of the bridge, and the response acceleration of the axle does not include the analysis error.

Here, in the pseudo-response analysis, since the calculation is performed only by the vertical vibration of the axle, the interaction is not considered. Regarding to the basis for establishing such an assumption is when the truck (axle) resonates. Alternatively, considering the case where displacement is taken as an example for the case where it does not resonate. It should be noted that, regarding to this content, the same holds true for velocity. Figure 3 shows the difference of the input due to the presence or absence of resonance of the axle. Figure 3 (a) shows the case where the axle (z_T) resonates. In the frequency band that causes complaints, the truck and the bridge resonate, hence both the amplitudes increase and the phases of the axle (z_T) and the road surface (r + z_C) are shifted by 90 °, so the vertical displacement is equivalent to the relative displacement (z_T - r - z_C) between the axle and the road surface.

On the other hand, let’s focus on vibration that the axle does not resonate and does not cause complaints. Figure 3 (b) shows the case where the axle does not resonate and the frequency of the road surface at the axle position is lower than the dominant frequency of the truck. The vertical displacement (z_T) of the axle is almost the same as the vertical displacement (r + z_C) of the road surface at the axle position, and the relative displacement (z_T - r - z_C) between the axle and the axle position is almost zero. Conversely, Figure 3 (c) shows the case where the axle does not resonate and the frequency of the road surface at the axle position is higher than the dominant frequency of the truck. The vertical displacement (z_T) of the axle is opposite in phase to the vertical displacement (r + z_C) of the road surface at the axle position by the same degree or less whereas the relative displacement (z_T - r - z_C) between the axle and the axle position is opposite to the vertical displacement (r + z_C) of the road surface at the axle position by about 2 times or less. From the above, it is necessary to note that the pseudo-external force in the case where the truck does not resonate is different from the originally acting external force that is considered in the dynamic interaction analysis, but in practice, generally, it is thought that it would not be a problem as it becomes a vibrational behavior outside the field of interest. Furthermore, due to low-frequency noise countermeasures against bridges and countermeasures against vibration, if the vibration characteristics of bridges are different, the vibration characteristics of the axle will also be affected but it can be concluded that this effect would not be a problem in the countermeasures that[7] do not significantly change the dominant frequencies of bridges with such as TMD[7] and intermediate struts and cushioning function. For this reason, the range of application of pseudo-response analysis is roughly "3.15 to 5 Hz band" and "10 to 20 Hz band" in which the axle resonates and bridge resonates, and it was thought that it was considered applicable except when large-scale structural alterations such as expansion of intermediate piers and road surface remodeling were carried out.

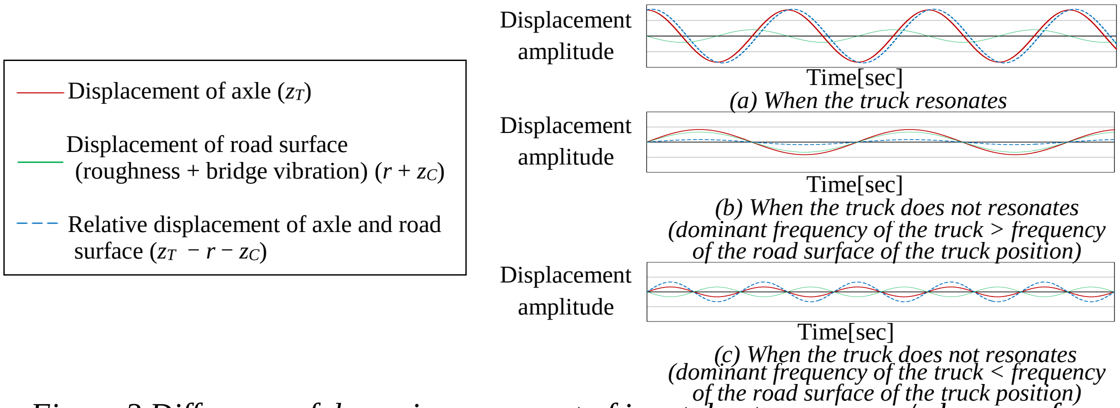


Figure 3 Difference of dynamic component of input due to presence / absence of resonance of truck

4. ESTIMATION OF BRIDGE VIBRATION

4.1 Modeling of bridge

The bridge model is shown in Figure 4. The slab and girder, wheel guard/wall balustrade is modeled as shell element whereas rubber bearing is modeled as spring element. Considering only the mass of the pavement, the lower part of the bridge is judged to have small influence in the reproduction of the vibration characteristic of the upper part of the bridge; hence it was omitted during modeling. As for the division of the model, the length is divided into 8 divisions per span about the bridge axis direction and the full width of the bridge axis in perpendicular direction is divided into 10 divisions. Since the vibration mode which is up to about 20 Hz, upper limit value of the frequency of interest, has about 1.0 wavelength per span with respect to the bridge axis direction and about 0.5 wavelengths in the direction perpendicular to the bridge axis, is sufficiently and compactly divided. Figure 6 shows the dominant period calculated by frequency response analysis. The dominant frequencies of "3.15 to 5 Hz band" and "10 to 20 Hz band" are 3.15 Hz band (2.8 to 3.5 Hz) and 12.5 Hz band (11.2 to 14.1 Hz), respectively which can be seen from the Figure 6 that it is reproduced during frequency response analysis. Figure 7 shows typical vibration mode diagrams of 3.15 Hz band and 12.5 Hz band.

The former is a vertical vibration in which the center of the main girder span is an antinode, and the latter is a vertical vibration in which the center of the deck interspacing is an antinode. For the damping constant of the bridge member used in truck travel analysis, the value of the linear member from the road bridge specification manual is 2% for steel material and the value is 3% for slab concrete and bearing. In addition, regarding to the damping constant of the bridge during running of the truck, analysis of actual measurement data[8] for PC girder bridge has been carried out by Fukada et al. Since the value of about 1.5% which is 1/2 of the linear member of the road bridge specification manual, the value of this study is presumed to be somewhat due to larger setting.

The measured value of road surface roughness and its power spectrum are shown in Figure 8 and Figure 9. Figure 9 also shows the frequency converted into the vibration that acts on the truck when the spatial frequency is assumed to be the traveling velocity of the truck as 80 km per hour. Excellence is seen in the vicinity of 7 Hz to 10 Hz.

The validity of the model is confirmed by comparing the response to the dominant frequency in the comparison between the truck travel analysis and the actual measurement which will be described later.

4.2 Modeling of trucks and calculation of external forces from trucks

The truck model was a biaxial 4 degree of freedom system model shown in Figure 5. Also, the specifications of the model are as shown in Table 2. The vibration mode of the truck is shown in Figure 10. The vicinity of 3 Hz is mainly due to vibration of the truck body and the vicinity of 12 to 12.5 Hz is considered to be mainly due to vibration of the tire. Using the truck model mentioned above, the velocity at passing lane is 80 km per hour and the external forces acting on the bridge were calculated from the truck. The pseudo-external force from the truck calculated from the vibration acceleration of the axle against the external force of the dynamic interaction analysis is shown in Figure 11. The Fourier spectrum of the external force is shown in Figure 12. From Figure 12, the pseudo-external force is equivalent to the dynamic interaction analysis at the dominant frequency of the truck (1.5 Hz, 2.9 Hz, 12.1 to 12.5 Hz), and in other cases, large and small differences are seen. As mentioned above, this is the difference as to whether the relative value of the axle and the road surface (road surface unevenness + bridge vibration) of the axle position is used or the value of the axle is used as the external force to the bridge. As a result, In the pseudo-response analysis, the response is evaluated to a greater extent at frequencies lower than each of the plurality of dominant frequencies present in the truck, Conversely, at high frequencies, the response is evaluated to small degree.

4.3 Vibration analysis result of bridge

Dynamic interaction analysis and pseudo-response analysis were performed on the target bridge and the results of both analyses were compared. The external force of both analyses uses the external force of Figure 11, which is applied as a moving load on the passing lane at the velocity of 80 km per hour as shown in Figure 13. For analysis, SoilPlus (ITOCHU Techno solution Co., Ltd.) was used for both analyses, and it was set as direct integration with an integration interval of 0.005 seconds.

Comparison of the response values of both analyses was done at the point shown in Figure 13. Point “a” is the antinode position of the vibration mode in the 3.15 Hz band which is the vertical first order mode in the bridge axis direction and point “b” is the antinode position of the vibration mode in the 12.5 Hz band which is the vertical first order mode in the direction perpendicular to the bridge axis of the deck slab. The Fourier spectrum of the acceleration waveform is shown in Figure 14.

From this, the pseudo-response analysis method can reproduce the amplitude of 3.15 Hz band at point “a”, and the amplitude at 12.5 Hz band can be reproduced at point “b”. The 1/3 octave band filter waveform of the dominant frequency is shown in Figure 15. It was confirmed from this that approximation of response waveform shape of bridge of dominant frequency band is possible. Here, the high reproducibility of the 3.15 Hz band at point “a” and the 12.5 Hz band at point “b” is considered because the dominant frequency of the truck and the bridge are close, and the accuracy of the truck external force at the frequency at which the bridge resonates is high.

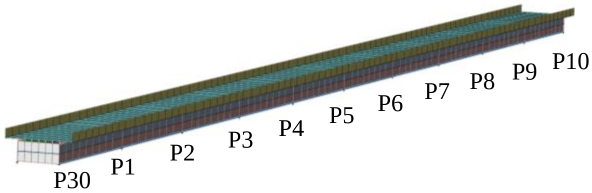


Figure 4 Analytical model of bridge

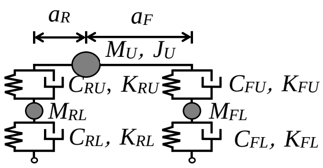
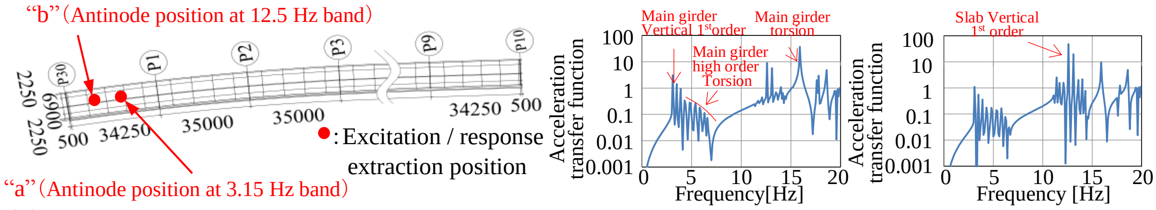
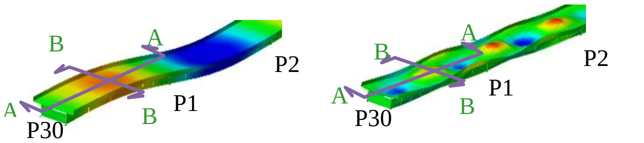


Figure 5 Model diagram of test truck



(a) Excitation/response extraction position of frequency response analysis *(b) Transfer function at ” a”* *(c) Transfer function at ” b”*

Figure 6 Dominant period by frequency response analysis



(a) 3.15Hz band (3.1Hz) *(b) 12.5Hz band (12.6Hz)*

Figure 7 Natural vibration mode of B bridge

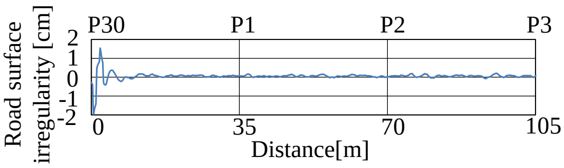


Figure 8 Road surface roughness waveform

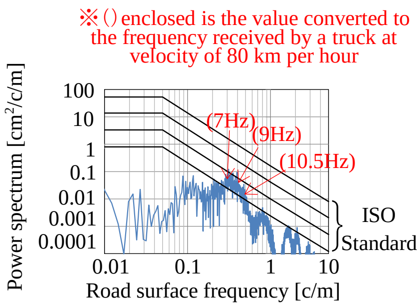


Figure 9 Spatial frequency of road surface roughness

Table 2 Specifications of truck model

Part	Spring constant [kN/m]	Damping constant [kN·Sec/m]	Axle load [kN]	Upper part poad [kN]
Front wheel spring upper part	K_{FU} = 1,470	C_{FU} = 5.88	M_{FL} = 14.3 (a_F = 4.66m)	M_U = 194 (J_U = 4,180 kN·m)
Front wheel spring lower part	K_{FL} = 6,860	C_{FL} = 19.6		
Rear wheel spring upper part	K_{RU} = 9,020	C_{RU} = 31.4	M_{RL} = 37.2 (a_R = 1.72m)	
Rear wheel spring lower part	K_{RL} = 13,700	C_{RL} = 39.2		

Mode Order	1	2	3	4
Frequency [Hz]	1.5	2.9	12.1	12.5
Period [Sec]	0.65	0.35	0.08	0.08
Vertical direction effective mass ratio	0.02	0.89	0.03	0.06

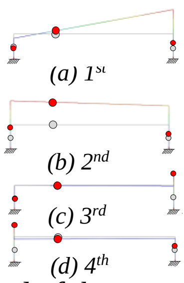
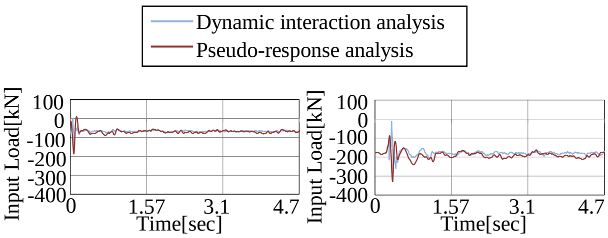
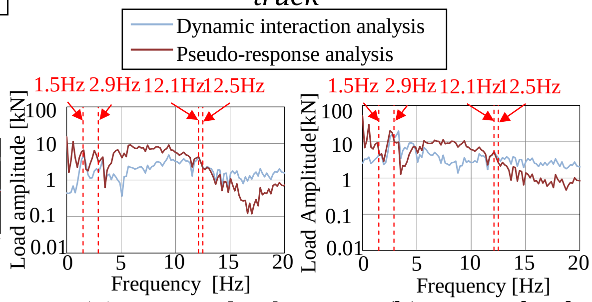


Figure 10 Dominant period of the test truck



(a) Front wheel *(b) Rear wheel*

Figure 11 External force from the truck



(a) Front wheel *(b) Rear wheel*

Figure 12 Frequency analysis of external force from the truck

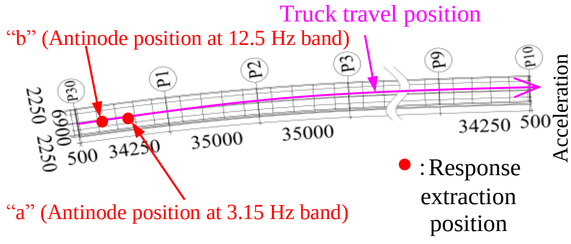
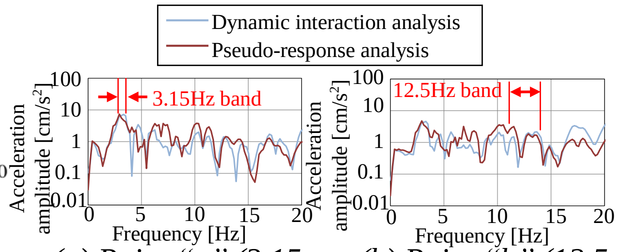


Figure 13 Truck traveling position and comparative position of bridge vibration



(a) Point “a” (3.15 Hz band antinode)

(b) Point “b” (12.5 Hz band antinode)

Figure 14 Comparison of frequency analysis of acceleration waveform

5. ANALYSIS AND EVALUATION OF PSEUDO-RESPONSE ANALYSIS

5.1 Analysis on responses other than the frequency band of interest

In the pseudo-response analysis, the response other than the dominant periodic band has a large difference in magnitude as compared with the dynamic interaction analysis. Therefore, among the external forces acting in both analysis methods, the comparison of the components by which the spring constant was multiplied in the displacement was carried out for the frequencies with different magnitudes of the dominant frequency and the responses before and after the dominant frequency.

As a result, shown in Figure 16, when the truck resonates, the external forces of pseudo-response analysis and dynamic interaction analysis are almost the same. However, when the external force to the truck is lower than the dominant frequency of the truck, the external force of the pseudo-response analysis is larger than the dynamic interaction analysis and hence external force which is obtained by multiplying the displacement of the road surface at the axle position (sum of unevenness of road surface and bridge vibration) by the spring value is applied. Conversely, when the external force to the truck is higher than the dominant frequency of the truck, the external force of the pseudo-response analysis turns to a value of the extent to which the external force with the sum of the road surface unevenness and the bridge vibration as the displacement is inverted, since the reaction force of the dynamic interaction analysis is a relative value between the axle and the road surface, it was confirmed that the pseudo-response analysis was smaller.

5.2 Comparison with measured values of bridges

In the study up to the previous sections, in order to grasp the accuracy of the pseudo-response analysis and the dynamic interaction analysis, pseudo-response analysis was performed using the axle vibration calculated from the dynamic interaction analysis and the results of both analysis were compared. Here, as a usual method of pseudo-response analysis, pseudo-response analysis using the actual value of the axle at the time of running the test truck was compared with the measured value of the bridge at the time of running the test truck. We also compared it with dynamic interaction analysis (Figure 17 (a) - (d)). The comparison point of the response value was taken as the antinode position of the frequency band which caused the complaints or the part where the measured value exists in the vicinity (Figure 13). The comparison items are the Fourier spectrum of the acceleration waveform and the 1/3 octave band filter waveform.

As a result, in the pseudo-response analysis, the dominant frequencies of the 3.15 Hz band and the 12.5 Hz band, which are the frequency bands causing complaints, roughly agreed. In the 3.15 to 5 Hz band, the filter waveform continues to vibrate although the amplitude changes while the truck passes over the bridge and in the 10 to 20 Hz band, when the change of the road surface irregularities of the joint portion is large, immediately after passing through the joint It is possible to reproduce the characteristic[1] of the bridge vibration that vibration excited greatly is applied to the bridge. Here, the response in the 12.5 Hz band is the value of the main girder position with the measured value and the value in the center of the slab base is about 2 times based on the analysis value. Furthermore, it was confirmed that it is not inferior even when compared with dynamic interaction analysis. However, at other frequencies, it was confirmed that there were frequency bands with low Fourier amplitude reproducibility. As a factor of this, modeling of the rigidity of the connection part member in the reproduction of the torsional mode of the bridge model etc. can be considered but since the frequency at which the peak appears can be reproduced roughly. It is considered to be practical for the purposes of estimating the countermeasure effect.

In addition, the dynamic interaction analysis showed a frequency band with low reproducibility. The reason for this is that, in dynamic interaction analysis, it is necessary to match the response of the truck with the actual condition, but it is difficult to reproduce the road surface roughness and the dominant frequency. And it is considered that it is not easy to match the response with the driving situation.

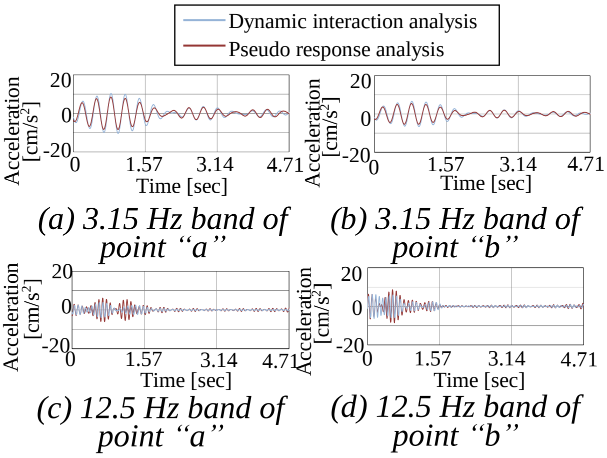


Figure 15 1/3 octave band filter waveform of dominant frequency

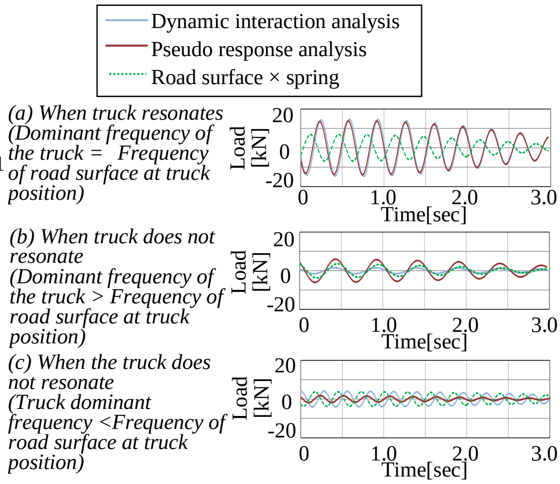


Figure 16 Difference in external force due to presence or absence of resonance of the truck

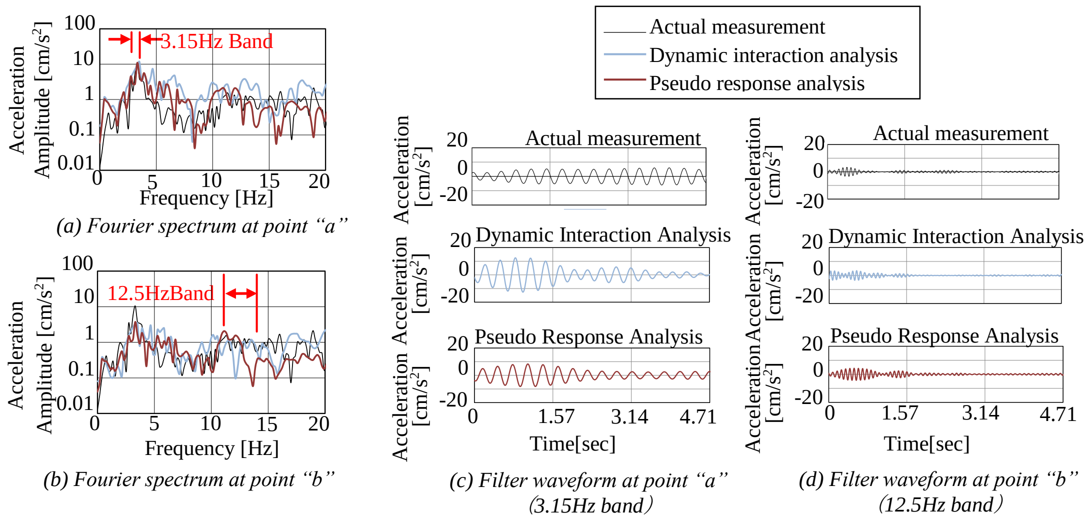


Figure 17 Comparison with measured values

5.3 Accuracy estimation of effectiveness of countermeasures

The main use of truck travel analysis is to estimate the effect of countermeasures such as measures against low-frequency noises. Therefore, in addition to TMD for “2.15 to 5 Hz band” as a countermeasure structure, TMD[6] for 10 to 20 Hz band is used. The effect of countermeasure of pseudo-response analysis when additional longitudinal girder is used for suppressing the deformation of the deck is compared with the countermeasure effect by dynamic interaction analysis. Countermeasures for "3.15 to 5 Hz band" are in the center of the span and countermeasures for the "10 to 20 Hz band" are positions effective for the antinode at the center of the span at the 1/4 point of the span (Figure 18). The specifications of TMD and longitudinal girder are as shown in Table 3, respectively. Here, the external force of the pseudo-response analysis remains the same as before-countermeasure (Figure 11). Also, the analysis program is SoilPlus. On the other hand, in the dynamic interaction analysis, DYNA-VC was used before and after the countermeasure to consider the change of the truck vibration by the countermeasure work, and the truck was made to run on the bridge model on which the uneven road surface was arranged.

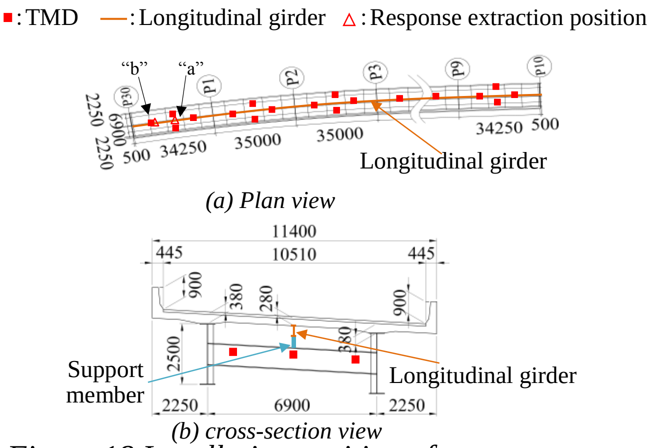
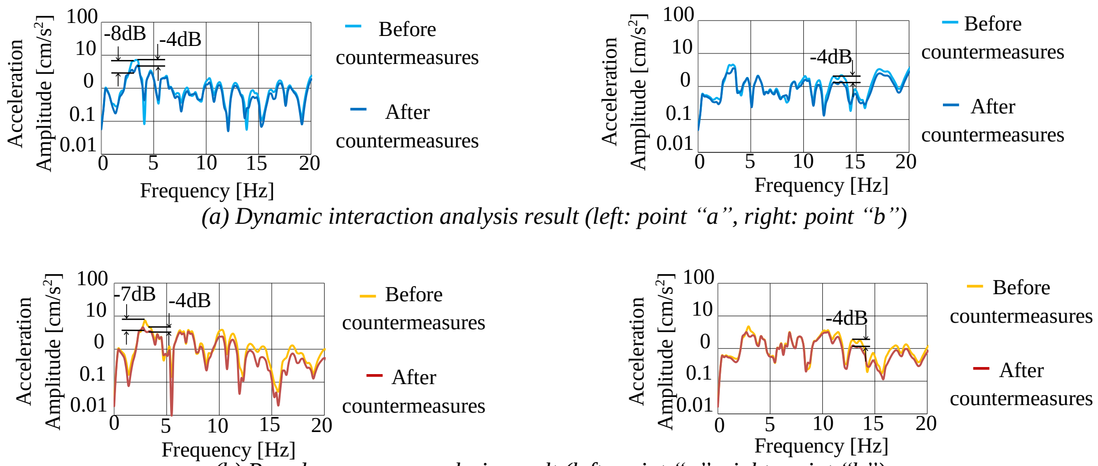


Figure 18 Installation position of countermeasures

Table 3 Specifications of countermeasures

Counter-measures	Specifications of countermeasures
TMD for 3.15Hz band	・Number of TMD : 2 [Numbers/span] ・Weight of TMD : 103 [kN/unit] ・Spring stiffness : 3,460[kN/m]
TMD for 12.5Hz band	・Number of TMD : 2 [Numbers/span] ・Weight of TMD : 103 [kN/unit] ・Spring stiffness : 53,910[kN/m]
Longitudinal girder	・Material: SM 490 ・Longitudinal girder section: H600×300×14×28 ・Support member section: H 200×200×8×12



(a) Dynamic interaction analysis result (left: point “a”, right: point “b”)

(b) Pseudo-response analysis result (left: point “a”, right: point “b”)

Figure 19 Estimation of precision of countermeasure effect

As a comparison of countermeasures effect, the effect of reducing the bridge vibration at the countermeasure installation location is shown in Figure 19. Here, TMD shows the value with respect to the dominant frequency before the countermeasure targeted, but since the peak remained aside at the 3.15 Hz band, the value for this is also shown. From this, it was confirmed that the countermeasure effect estimated in both analysis methods is equivalent.

6. CONCLUSION

Instead of the analysis which is considered the detailed dynamic interactions in truck travel analysis used for the estimation of effects such as countermeasures against low-frequency noise of bridges, a pseud-response analysis method has been proposed in where we input a pseudo-external force that is created from the vibration acceleration of the axle of the test truck. Applying both analytical methods to the plate girder bridge of the conventional structure and the rationalized structure then using the "3.15 to 5 Hz band" as the dominant frequency of 20 Hz band or less which is often the cause of physical complaints among low-frequency noise complaints. Also the vibration of "10 to 20 Hz band" and its applicability was examined by comparing the vibration acceleration of the bridge. As a result, the following was clarified.

1) Since the pseudo response analysis can calculate the acceleration response having the same spectral shape and waveform shape as the dynamic interaction analysis in the dominant frequency band of "3.15 to 5 Hz band" and "10 to 20 Hz band" where the truck and the bridge resonate, therefore same result as the dynamic interaction analysis can be obtained in estimating the effect of countermeasures against low-frequency noise.
2) In pseudo-response analysis, although the response from dynamic interaction analysis is different in magnitude at frequencies other than mentioned above, frequencies at which peaks appear are generally same.
3) In the pseudo-response analysis, it was confirmed that the amplitude and waveform shape of the measured value can be reproduced roughly in the dominant frequency band of "3.15 to 5 Hz band" and "10 to 20 Hz band". It is considered that by using measured values for external force from the truck have led to an improvement in analysis accuracy as it became unnecessary to analyze the response of the truck which is prone to error.
4) In simulated response analysis, it was confirmed that estimation equivalent to dynamic interaction analysis can be obtained in estimating countermeasure effect.

From the above, the proposed pseudo-response analysis is possible to obtain the same effect as the dynamic interaction analysis in the examination of complaints countermeasure which unless the structural system of the bridge is greatly changed or the road surface repair effect is estimated, proposed pseudo-response analysis is considered to be practical in estimating the countermeasure effect.

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