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| journal or publication title | Proceedings of the 11th International Conference on Engineering, Science, Construction, and Operations in Challenging Environments 2008 |
| volume | 323 |
| page range | 144 |
| year | 2008-01-01 |
| URL | http://hdl.handle.net/2297/18157 |

doi: 10.1061/40988(323)144

# Ground vibration measures for the rocking vibration of the piers with two-box girders bridge

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**Abstract**

Vibration caused by running vehicles on a highway bridge is spread to the superstructure, substructures and ground. The ground vibrates both in horizontal and vertical direction. When vehicles load at the tip of the cross beam in the T-shaped pier, rocking vibration of the pier occurs. Its ground vibration in transverse direction is the biggest. In the two-box girders bridge, which bearings are installed at the tip of the cross beam of the T-shaped pier, the ground vibration has greatly occurred due to the rocking vibration of the pier. Two measures to mitigate the vibration are proposed in this study. The evaluation the change of the vibration characteristics and effects of the measures to mitigate the vibration are also discussed in the study.

## Introduction

Running vehicles on a bridge causes bridge vibration including the impact vibration generated by running vehicles in the faulting of the expansion joints (Y. Kajikawa, 1997). The vibration transmitted from a superstructure to the circumference ground of the pier with frequency range 1-100Hz. Although the vibration with higher frequency than 10Hz damps as it gets distance from the footing, the vibration with lower frequency than 10 Hz spread far away (K. Usui *et al.*, 2001).
T-shaped piers (Figure 1) are often adopted as the pier of the highway bridge in a city in order to secure the clearance below the bridge. The T-shaped pier vibrates in three-axis-direction caused when vehicles load on the tips of the beams of the piers. In particular, the horizontal vibration is observed rather than the vertical vibration from the measurement on the circumference ground of such piers (K. Usui *et al.*, 2001). Since the superstructure and the substructure behave as a unit, the measurement and analysis were conducted to grasp the vibration characteristics of the superstructure, the substructure and ground.
This paper describes the vibration characteristics of two-box-girder bridge with T-shaped piers under rocking vibration due to eccentric load on the tips of the beams of them. This study proposed countermeasures to reduce the vibration. Moreover the authors estimated the change of the vibration characteristics and the effectiveness of the countermeasures.

## Examination

An object bridge is three spans continuous two-box-girder bridge (four-lane) with T-shaped pier. The outline of the object bridge with the measured points is shown in Figure 1. The bridge comprises 64.0m, 84.0m and 64.0m spans. The pile foundations support the T-shaped piers.

The authors had running tests using test truck with 196kN. The running speed of the truck was 60 km/h. The frequency of the leaf suspension spring vibration and tire spring vibration gained from the results of acceleration data in the test truck were 3.4Hz and 10 Hz respectively.

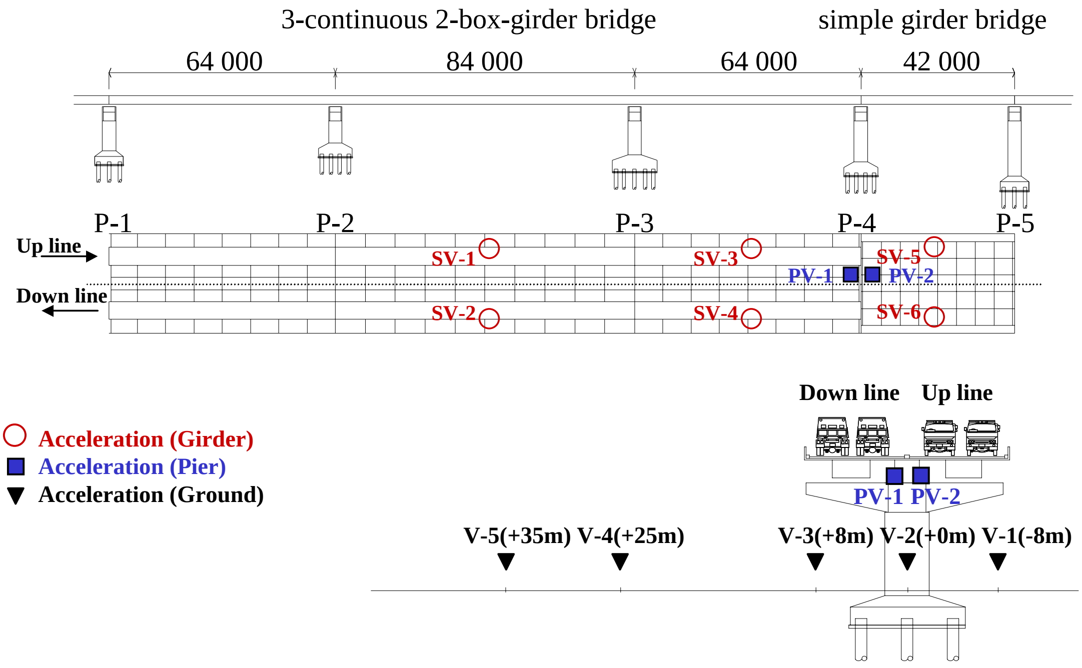


**Figure 1. Object bridge with T-shaped pier**

Maximum and R.M.S. (Root Mean Square) of acceleration amplitudes measured by test truck running at down line were shown in Figure 2. Here, acceleration was measured at each ground point (-8m, 0m, +8m, +25m, +35m) in the three directions (X: longitudinal, Y: transverse, Z: vertical) as shown in Figure 1.

Maximum and R.M.S. (Root Mean Square) of acceleration amplitudes in the Y direction were larger than other directions (X and Z direction) from 0m to 25m points. It is clear that this pier vibrates by the rocking vibration mode in Y direction and also, damping constant of this vibration mode in this ground is very small.

The frequencies of the analysis and examination are shown in Table 1. The bending modes and the torsion modes appear in 1-3Hz. In particular, the frequencies of the torsion 1st mode (P4-P5) and the rocking mode (P4) are close to that of the truck’s suspension spring vibration.

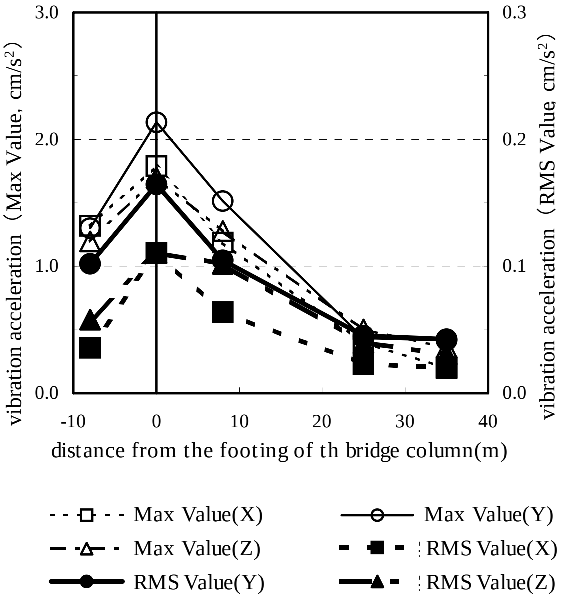


**Figure 2. Comparison of the acceleration amplitude on the ground**

| Vibration mode | Freq. (Hz) | |
|---|---|---|
| | Anal. | Exam. |
| Bending 1st mode (P1-P4) | 1.31 | 1.4 |
| Bending 1st mode (P4-P5) | 2.22 | 2.4 |
| Torsion 1st mode (P1-P4) | 2.55 | 2.8 |
| Torsion 1st mode (P4-P5) | 2.79 | 2.9-3.1 |
| Rocking mode (P4) | 2.79 | 3.1 |

**Table 1. Frequencies of the object bridge and T-shaped pier**

## Countermeasure

As the T-shaped pier supported two-box-girder bridge vibrates in the rocking vibration mode caused by vehicular loads on the tip of the beam, quasi-bearing systems were proposed in this study to load the vehicular loads in the intermediate locations of the beam in order to reduce the rocking vibration as shown in Figure 3.

*Quasi-bearing system*

Quasi-bearing systems were installed to reduce displacement by the live loads at the tip of the beam of the T-shaped piers. The design concept of the quasi-bearing system is that existing bearings support the dead load of superstructure and live loads with quasi-bearings that support a part of live loads. Bearing plate shoes (Reaction force: 600-1000 kN) were employed as quasi-bearing system in this study as shown in Figure 4.

In addition, two or more bearings were installed under the end crossbeam of the box girder bridge as quasi-bearing system. The pre-load correspondent to the reaction at the time of installation was given to the quasi-bearings considering negative reaction by live load.

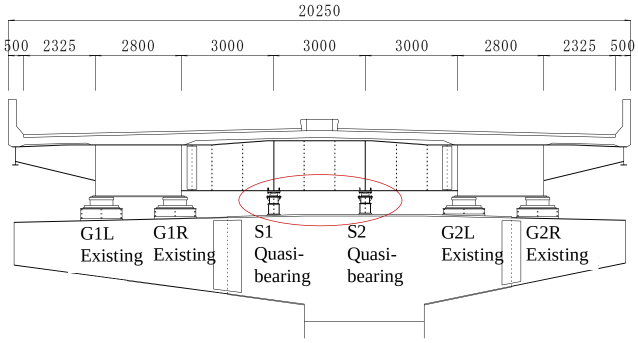


**Figure 3. Position of the Quasi-bearings**

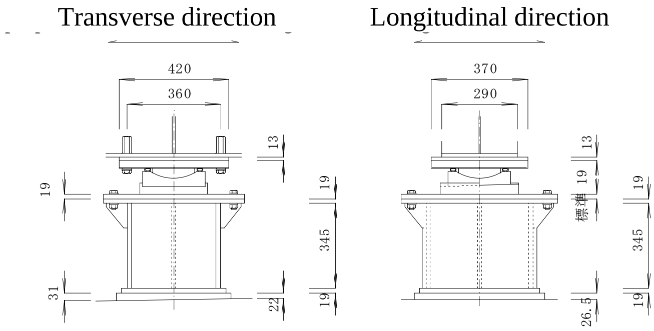


**Figure 4. Outline of quasi-bearing**

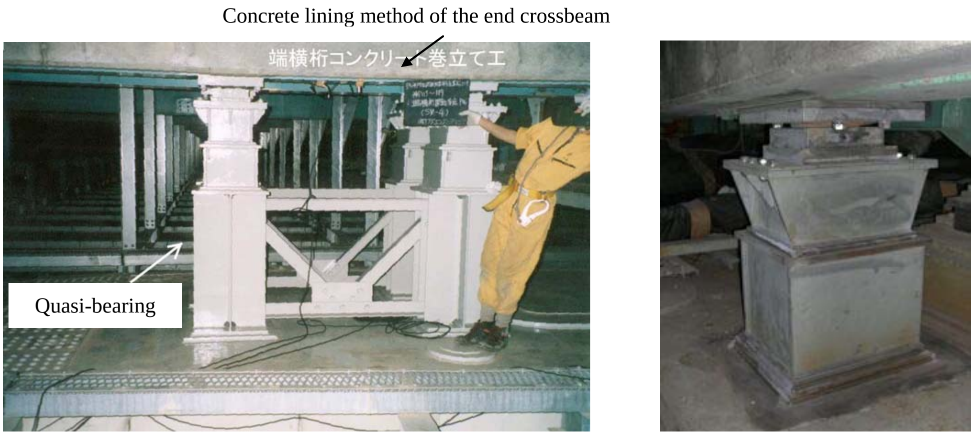


**Figure 5. Quasi-bearings and the concrete lining method of the end crossbeam**

*Concrete lining method of the end crossbeam*

When vehicles pass on an expansion joint, the impact vibration occurs in the end crossbeam of the 2-box-girder bridge. The concrete lining method of the end crossbeam (Figure 5) is adapted not only to reduce the impact vibration generated by running vehicles at the end crossbeam (H. Sato *et al.*, 1995), but also to increase the stiffness of them. In addition, this study expected that this method would reduce the torsion 1st vibration mode of superstructure and rocking vibration mode of the pier.

The thickness of the lining concrete of the end crossbeam was determined as 30cm from the result of the simulation considering the strength of the substructure. Finite element model used in the simulation is shown in Figure 6.

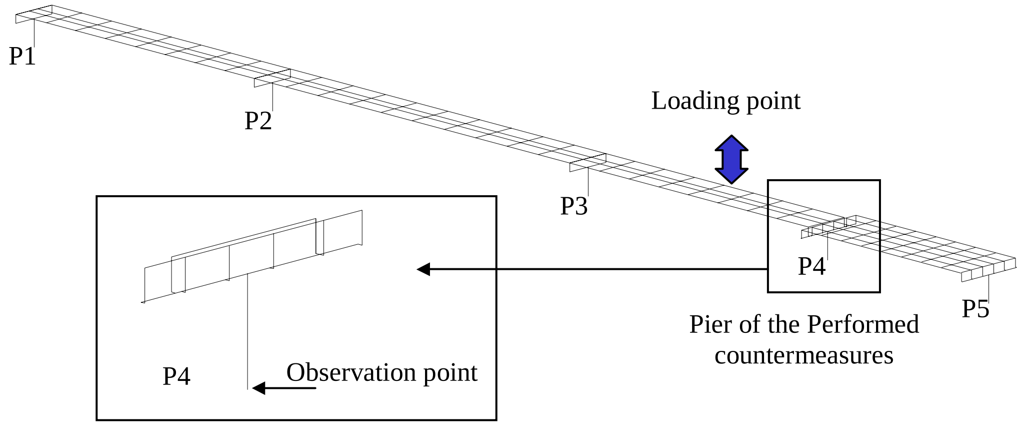


**Figure 6. Analytical model**

## Prediction of effect on the countermeasure

This study estimated prediction of the effectiveness of the countermeasures with the quasi-bearing systems and the concrete lining method of the end crossbeam. The analytical model with beam elements is shown in Figure 6. The estimated items were the accelerations in transverse direction at the observation points located at the bottom tip of the P4 pier, using the frequency response analysis. The cyclic loading force was 10 kN with the frequencies 1-20 Hz in vertical direction as the target on the vibration mode as shown in Table 1.
The results of the vibration reduction effect (average of each vibration mode) in each countermeasure are shown in Table 2 and Table 3.
The reduction effect by the quasi-bearing system was 3 dB; the effect by the concrete lining method of the end crossbeam was 1.5-2.5 dB at the bottom tip of the P4 pier.
The response acceleration level was decreased by 1dB as concrete thickness is increased from 20cm to 30cm. Although it is supposed that the reduction effect became large with increase of the thickness of the lining concrete, the authors determined the maximum thickness as 30cm, considering the strength margin of a substructure. In particular, it is clear that the concrete lining method of the end crossbeam is effective to reduce the rocking vibration mode of P4 Pier.

| Additional weight | | | Reduction effect |
|---|---|---|---|
| Box girder | I girder | Total | |
| 10kN | 25kN | 34kN | -3.0dB |

**Table 2. Reduction effect (quasi-bearing system)**

| Thickness | Additional weight | | | Reduction effect |
|---|---|---|---|---|
| | Box girder | I girder | Total | |
| 20cm | 69kN | 137kN | 206kN | -1.5dB |
| 30cm | 108kN | 206kN | 314kN | -2.5dB |

**Table 3. Reduction effect (Concrete lining method of the end crossbeam)**

## Conclusions

This study proposed countermeasures in order to reduce the vibration of T-shaped piers; they were suffered from the rocking vibration caused by eccentric loads on the tips of the beams of them. Besides, the change of the vibration characteristics and the effectiveness of the countermeasures were also evaluated.
The main conclusions acquired by this study are as follows.

(1) The vibration characteristics of the two-box-girder bridge with the T-shaped piers under rocking vibration caused by eccentric vehicular loads on the tip of the beam were clarified.
(2) As for the vibration characteristics of the ground in circumference of the T-shaped piers caused by the rocking vibration, Maximum and R.M.S. (Root Mean Square) of acceleration amplitudes in transverse direction were larger than those of other directions (longitudinal and vertical direction) at 0m to 25m point.
(3) This study proposed the quasi-bearing systems; they were installed to reduce displacement by live loads at the tips of the beams of the T-shaped piers.
(4) From the results of the analysis, the quasi-bearing systems and the concrete lining method of the end crossbeam were effective to reduce the rocking vibration mode of T-shaped Pier.

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