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A STUDY ON EFFECT OF GROUND UPON EARTHQUAKE DAMAGE TO A BRIDGE

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SUMMARY

In order to estimate the mechanism of earthquake damage to a bridge in the axis direction, we have carried out microtremor measurements and seismic response analyses in the Toshibetsugawa bridge that suffered the damage to bearings and so on by the 1993 Off-Kushiro earthquake. The bridge had been constructed on the upside-down type ground in which soft clayey layers existed under the gravelly sandy layer. The damage to bearings on piers-5P and -8P had occurred at sudden changing sites of the soft clayey layer thickness. Fourier spectral ratios been calculated from microtremors measured on tops of the adjacent piers. Also, the simultaneous vertical distribution of horizontal displacements of the bridge and ground has been gained by seismic response analyses. It has been estimated from synthesizing ground condition, damaging states, the result of microtremor measurements and seismic analysis that the damage to bearings will be induced by large lateral differential displacements of the ground.

INTRODUCTION

We have carried out microtremor measurements and seismic response analyses in the Toshibetsugawa bridge that suffered the damage to bearings and so on by the Off-Kushiro earthquake of magnitude 7.8 in January, 1993, and we have investigated the cause of earthquake damage to the bridge.

EARTHQUAKE DAMAGE TO THE TOSHIBETSUGAWA BRIDGE AND ITS GROUND CONDITION

The Toshibetsugawa bridge on the Nemuro main line of the Japan Railways group company is the prestressed concrete girder bridge of the overall length of 415.7m and has reinforced concrete piers and caisson foundations as shown in Figs. 1 and 2. During the Off-Kushiro earthquake of magnitude 7.8 in January, 1993, oblique cracks occurred at fixed end parts of main girders, and damage to rocker bearings did at movable ends of piers-5P, -8P and so on[Nasu,1]. As shown in Fig. 3, especially, movable rocker bearings on the pier-8P tumbled down toward the bridge axis and the girder fell on the top of the pier. As

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shown in Fig.2, a gravelly sandy layer GS is distributed all over the bridge in the surface layer of the ground, and under it the soft clayey layer of clay layer C, gravelly clay layer GC and fine sandy clay layer SfC and so on are deposited. This ground belongs to an upside-down type one. The thickness of the soft clayey layer changes in the pier-5P and -9P neighborhoods that bearings were damaged and it is clear that the bridge is in a heterogeneous bearing ground condition where much earthquake damage is observed. Because the horizontal ground displacements occur larger on the thick side of the soft clayey layer than on the thin side of it during the earthquake, a large extension or contraction of the intervals will occur between the tops of two adjacent piers that are before and behind a changing site of the soft clayey layer thickness. Accordingly, it is estimated that damage to bearings and so on will be induced by the differential displacement of the ground during the earthquake.

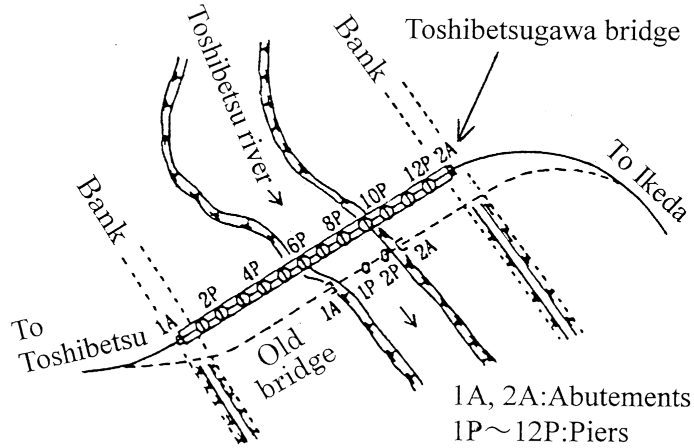


Fig.1 Location map of Toshibetsugawa bridge

MICROTREMOR MEASUREMENTS

Microtremors have been measured at the tops of piers-5P to -9P as shown in Fig.4. Fourier spectral ratios of bridge axis direction components of the microtremors have been calculated[Nasu,2]. The curves of Fourier spectral ratios 5P/6P, 6P/7P, 7P/8P and 8P/9P are shown in Fig.5. In which, for example, the curve 5P/6P shows the ratio of the Fourier spectrum of microtremors that were measured at the top of adjacent piers-5P and -6P.

Fig.5 shows that the ratio curves of 5P/6P and 8P/9P have a peak value of 1.0 more value, and that the ratio curves of 6P/7P and 7P/8P are a flat curve with almost 1.0 value. It is estimated from this figure that the displacement of the pier-6P is larger than one of the pier-5P, one of the pier-8P is larger than one of the pier-9P. and the large extension or contraction of the intervals has occurred between tops of the adjacent

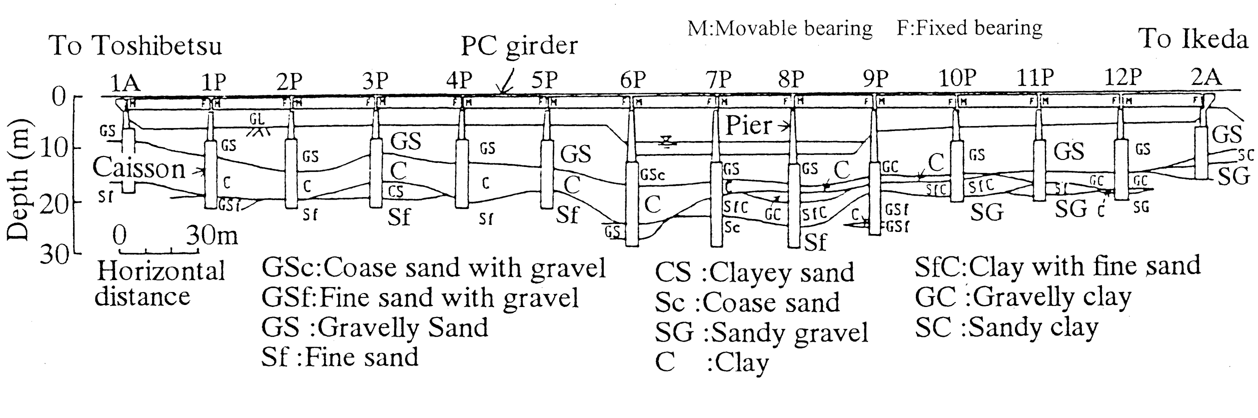


Fig.2 General view of Toshibetsugawa bridge and ground condition

piers-5P and -6P and between the tops of adjacent piers-8P and -9P and during the earthquake. This has occurred at a sudden changing site of the soft clayey layer thickness.

Also, this figure shows that piers-6P, -7P and -8P have done the same movement. This has occurred at sites of the soft clayey layers with same thickness. Consequently, it is estimated from the measured microtremors that the large extension or contraction of the intervals between tops of adjacent piers-5P and -6P and those between tops of adjacent piers-8P and -9P will occur because large lateral differential displacements do in the soft clayey layers C, GC and SfC in the bridge axis direction under the earthquake.

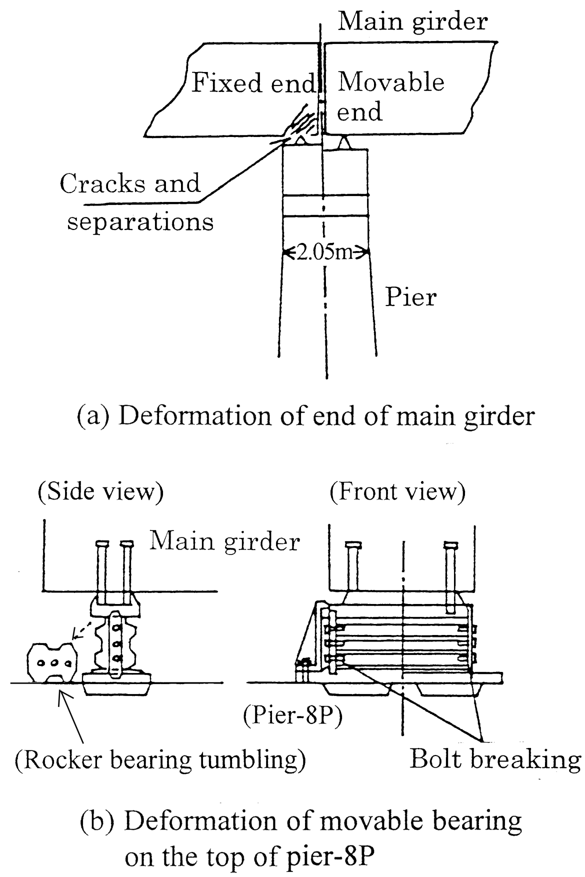


Fig.3 Deformation of Toshibetsugawa bridge due to the 1993 Off-Kushiro earthquake

SEISMIC RESPONSE ANALYSES

A seismic response analyses of the bridge-ground system has been carried out by the M-FLUSH of the finite element method(FEM) computer program. Caissons, piers and girders are modeled by beam elements, and fixed and movable bearings are done by hinge and free elements respectively[Nasu,1,3]. Strain dependent characteristics have been considered to the shear moduli and damping ratios of surface layer soils. An energy transmitting and viscous boundary conditions were set up to the boundary of the side and bottom

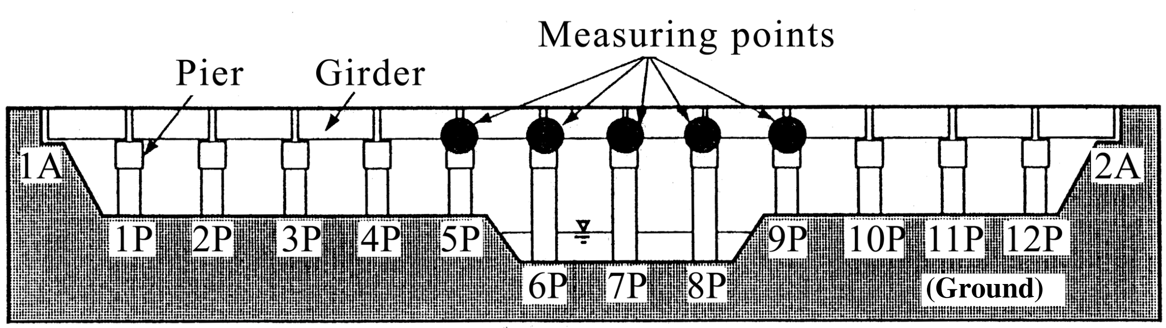


Fig.4 Measuring points of microtremors

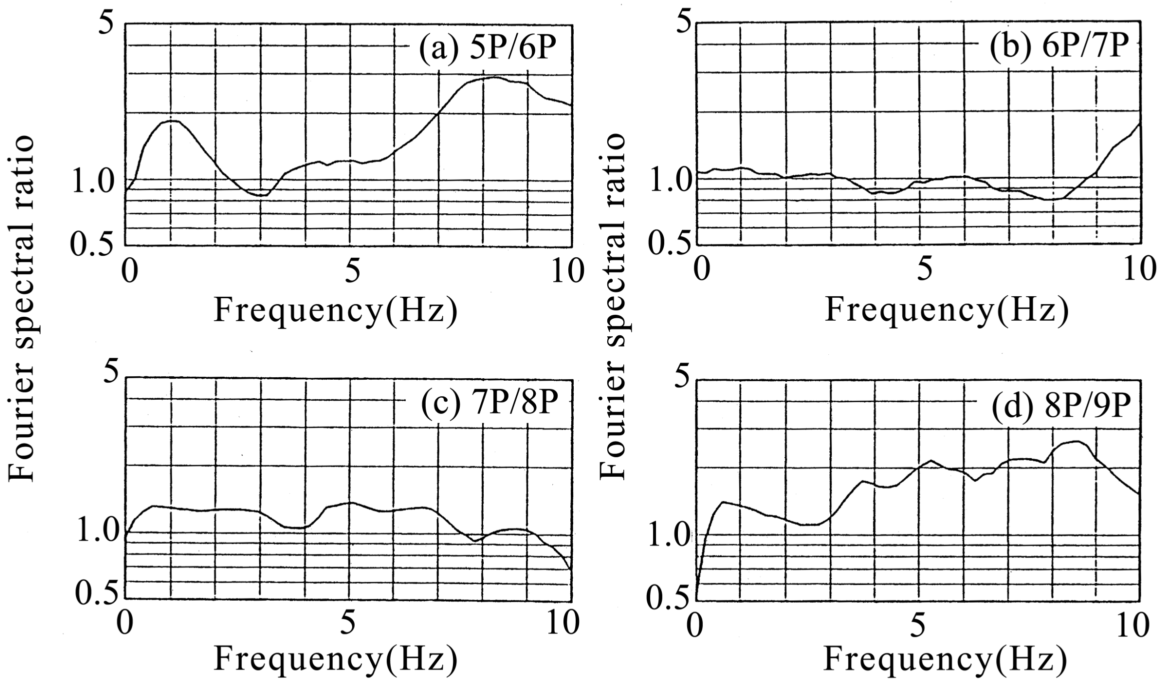
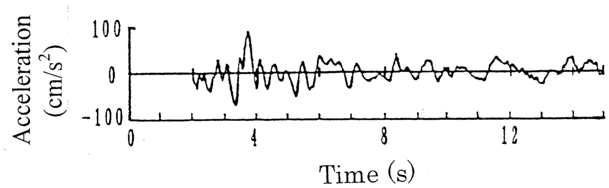


Fig.5 Measured results of microtremors on pier tops (Fourier spectral ratio between axis directional velocities of adjacent pier tops)

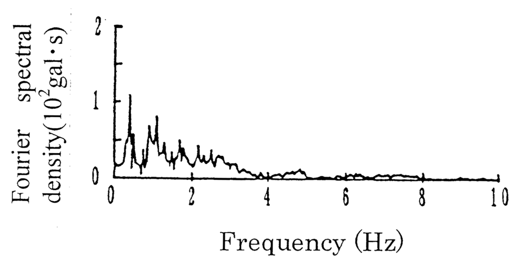
of the ground respectively. A horizontal seismic motion given the name of the Hachinohe wave of Fig.6 has been inputted from the analyzing model bottom. Maximum value of the input motion is 100 cm/s^2.

In Fig.7, broken lines show a simultaneous vertical distribution of the horizontal displacement of the bridge and ground in the left and right directions. This figure shows that the large extension or contraction of the intervals has occurred between the tops of adjacent piers-8P and -9P and between tops of the adjacent piers-5P and -6P during the earthquake, and that it has occurred at a sudden changing site of the soft clayey layer thickness.

Also, this figure shows that the girder end on the top of the pier-8P had fallen at the site in which the largest differential displacement has occurred



(a) Time history



(b) Fourier spectral density

Fig.6 Input earthquake motion of the Hachinohe wave

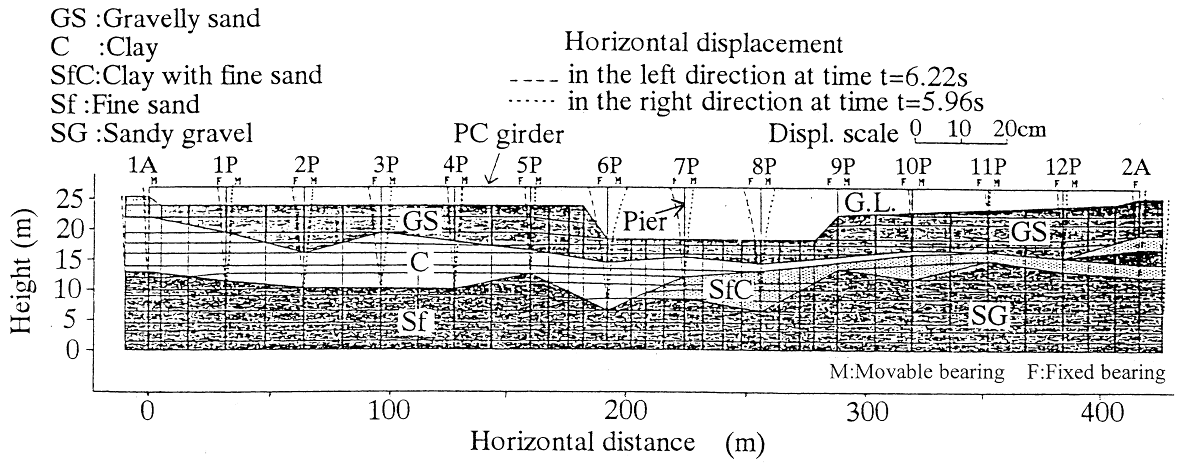


Fig.7 Simultaneous vertical distribution of horizontal displacements of bridge-ground system in seismic response analysis

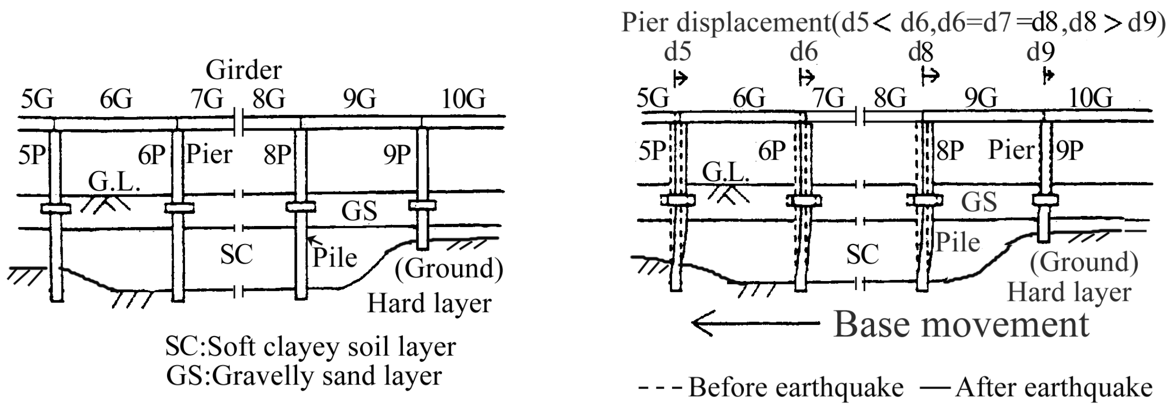


Fig.8 Estimation of mechanism of earthquake damage to bridge

between tops of adjacent piers, and its displacements has done in the soft clayey layers C, GC and SfC in the bridge axis direction under the earthquake.

ESTIMATION OF MECHANICS OF EARTHQUAKE DAMAGE TO BRIDGE

Fig.8(a) shows the state of a bridge and ground before an earthquake, and Fig.8(b) does the estimated state of a bridge and ground after an earthquake. The thickness of soft clayey layers SC changes suddenly both between piers-P5 and -P6 and between piers-P8 and -P9. During an earthquake, a ground displacement will occur larger in the thick side than in the thin side of the soft clayey layer. Then, piers will be forced to deform by the ground displacement.

Consequently, as shown in Fig.8(b), a large displacement will occur both between piers-5P and -6P and between piers -8P and -9P. It is also estimated that bearings and so on will be damaged by the differential displacement of ground and that movable rocker bearings will tumble down and girder end parts will fall on the pier-8P around which the largest differential displacement occurs.

CONCLUSIONS

It has been made clear from aforementioned damaging states, ground condition, microtremor measurements and seismic response analyses that the earthquake damage to the Toshibetsugawa bridge had occurred at an upside-down type ground, and will be induced by large differential displacement of ground which occurred at sudden changing points of soft clayey layer thickness during the earthquake.

In this way, the effect of ground upon the earthquake damage to the Toshibetsugawa bridge has been clarified by their Fourier spectral ratios of microtremors, seismic analysis result and so on. Namely, it has been firstly estimated from a relation between the deforming states of bridge and the ground condition that damage to bridge will be induced by a large extension or contraction between adjacent piers and that they will be accompanied by large differential ground displacements. Next, the effect of ground upon the extension or contraction between adjacent piers has been confirmed by measuring of microtremors and seismic response analyses.

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