Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.III)

5-4-16

EARTHQUAKE RESPONSE OF PIER WITH CAISSON-TYPE WALL FOUNDATION AND ITS ANALYSIS

Takaya KAINO [1] and Toshio KIKUCHI [2]

[1] Tokyo Construction Division, East Japan Railway Corporation, Tokyo, Japan
[2] Technical Research Institute of OhbayashiCorporation, Tokyo, Japan

SUMMARY

This report describes the results of earthquake observations on an existing pier supported by a caisson-type wall foundation and their FEM simulation analysis. The observation and analytical results are summarized as follows; (1) It was found that the predominant frequency of the foundation and pier assembly including girder is dependent on that of the ground. (2) The deflection mode of this foundation showed a slight flexibility. (3) Waveform and spectrum obtained from the FEM simulation analysis are coincident to these observation results and the validity of the analytical model was proved. (4) It is possible to use the seismic deformation design method in designing the pier with caisson-type wall foundation.

INTRODUCTION

A continuous diaphragm was originally developed as a provisional retaining wall and has come to be utilized as a part of the pile or structure. Recently, in an increasing number of cases the continuous diaphragm has been put into use as a foundation of bridges by firmly connecting unit panels to each other with lap joints having transverse reinforcements, which is called here "caisson-type wall foundation". This foundation has the following advantages in comparison to caisson foundation: (1) the surrounding internal soil remains intact, (2) the skin friction is larger, and (3) the deflection mode of this foundation shows a slight flexibility. However, there have been few seismic observations on the behavior of this type of pier with caisson-type wall foundation. The authors, therefore, have conducted earthquake observation at the site of Sasame River Bridge of the Tohoku Shinkansen Line from Jan. 1985, aiming at studying the dynamic behavior of the ground-foundation-pier interaction system and examination of the analytical model, together with data collection for earthquake resistant design. This paper will give the observation results of the earthquake in the East of Chiba Pref. ($M=6.7$) that occured on Dec. 17, 1987, while referring to the simulation analysis results with FEM.

OUTLINE OF STRUCTURE AND GROUND

The Sasamegawa River Bridge here under study is a three span continuous prestressed concrete girder bridge having caisson-type wall foundation as shown in Fig. 1. The foundation is 10.0×12.0m in sectional area, 1.5m in wall thickness and 35.7m in wall length. It is known from Fig. 2 that the ground is soft, mainly consisting of silty sand with 0 - 5 level of N value up to about 30m in depth.

OBSERVATION SYSTEM

The seismic observation utilized, as shown in Fig. 2, accelerometers, strain meters, a crack meter and a relative displacement meter. The accelerometers were installed at the following places, totaling 18 sets: at the girder (8A-X), on the pier top (7A-X and Y), on the footing (1A-X and Y), inside of the wall foundation (2AW-X, 4AW-X, 6AW-X), inner ground (2AG-X, 4AG-X), neighboring ground (G1-X, Y and Z, G3-X, G4-X, G6-X, Y and Z). Among the above, the observed ground point is at a location 11m in the transverse direction. X,Y and Z directions in the above denote the longitudinal direction, transverse direction and vertical direction, respectively. Records catched up each sensor, subjected to amplification in each amplifier, are simultaneously recorded with the digital data recorder incorporating analog/digital converter, starter circuit and delay device and clock.

OBSERVED RECORDS

Observed Earthquakes Table 1 shows the cases where reading was over class IV on the JMA seismic intensity scale among 40 earthquakes observed untill March 1988 in Tokyo. Fig. 3 shows the epicenter and magnitude of these earthquakes. This paper refers mainly to the observation result of Dec. 17, 1987 (earthquake No. 4).

Waveforms Recorded Fig. 4 shows the longitudinal directional acceleration waveforms and the relative displacement waveform of earthquake No.4. It is learnt from the figure that main shock continues for 10 sec. (time of duration) and forms a waveform which has relatively smaller Magnitude (M=6.7). The maximum accelerations at the same depth are found to be almost same between ground, wall foundation and inner ground observation point, each other. The phases near the main shock are also very much coincident.

Fourier Spectrum Fig. 5 indicates the Fourier spectrum of the acceleration waves measured at observation points. It can be seen from the figure that the waves at GL-40m (G6 and 6AW) and at GL-32m (G4, 4AG and 4AW) comes to the peak at near 0.8 - 0.9Hz, 1.6 - 1.8Hz and 2Hz respectively, whereas the points above GL-12.1m (2AG and 2AW) have a dispersed peak in a range of 0.9 - 1.8Hz. The spectrum of the wall foundation, inner ground and neighboring ground at the same depth looks like almost the same pattern.

Maximum Acceleration Amplification Ratio Fig. 6 shows the max. amplification at each observation point concerning 5 earthquake waves. The amplitude at each measuring point becomes larger on the girder and the pier top than underground on average, although No. 5 earthquake shows amplitude as small as 2.5 times of reading even on the girder. This is attributed to the fact that the epicenter distance is shorter than that of other earthquakes and also component in frequency domain is smaller at near 1 - 2Hz.

Transfer Function Fig. 7 shows the transfer function of girder, pier top, footing and G1 points to the GL-40m point. It is made clear from the figure that: 1) the peak around 1.1 - 1.3Hz appears common to the pier top and ground, 2) the transfer function was found greater on the pier top and girder than on the footing.

Mode Shape Fig. 8 depicts the mode shape at around the 1.3 Hz component. This mode shape was obtained from the amplification ratio of the transfer function and phase spectrum. From the figure, the following points can be made: each measuring point is in phase, the deflection mode of the foundation shows a slight flexibility, the magnification ratios increases proportional to the height of level such as on the pier top and next on the girder and the inner ground has the same behavior as the surrounding wall foundation.

From the above, this mode can be regarded as the primary mode of the ground-foundation-pier coupled system including the girder.

SIMULATION ANALYSIS

An analysis was performed using approximate 3-dimensional FEM program (advanced FLUSH). The model is provided with the energy-transmitting boundary on the longitudinal direction side of ground and with the viscous boundary at the bottom and the tranverse direction side (See. Fig. 9). The analysis was done in the longitudinal direction of the bridge.

Analytical Model Fig. 9 shows analytical model. The pier part and wall foundation were replaced with solid element and beam element in order to simulate flexural rigidity as close as possible to the real one. The footing was assumed to be rigid, while shoe reaction force was supposed to be effective up to 10% of the girder load. Nonlinearity of shear moduli and damping factor of soil were determined from experimental results (Ref. 1). The damping factor of structure was set to 2%.

Analytical Results Fig. 10 describes the comparison between the analytical waves and observed one. The figure shows that the analytical waveform becomes smaller by 20% on the pier top compared with the observed one, and becomes almost equal on the footing, and the phase pattern around the main shock is very much coincident (Ref.12). Fig. 11 gives comparison of the Fourier spectrum, in which the analytical spectrum is almost coincident with the observed one.

CONCLUSION

It can be concluded from the observation and analytical results that:
(1) The predominant frequency of the deep foundation and pier assembly including the girder is dependent on that of the ground. (2) The inner ground has no independent behavior. (3) The deflection mode of this foundation shows a slight flexibility. (4) Waveforms and spectrum obtained from the FEM simulation analysis are coincident with those of observation results and the validity of the analytical model was proved. (5) As the foundation body is very much subject to influence by the deformation of the surrounding ground, it is possible to use the seismic deformation design method in designing the pier with caisson-type wall foundation.

REFERENCES

1. Kaino, T. and Kikuchi, T., Dynamic Behavior of Pier with Caisson-Type Wall Foundation, Proc. of the 7th Japan Earthquake Engineering Symposium, December 1986, pp.919-924 (in Japanese)
2. Kaino, T. and Kikuchi, T., Simulation Analysis of Pier with Caisson-Type Wall Foundation, 19th Earthquake Engineering Research Symposium, (Jishin Kogaku Kenkyu Happyokai), July 1987, pp.485-488 (in Japanese)

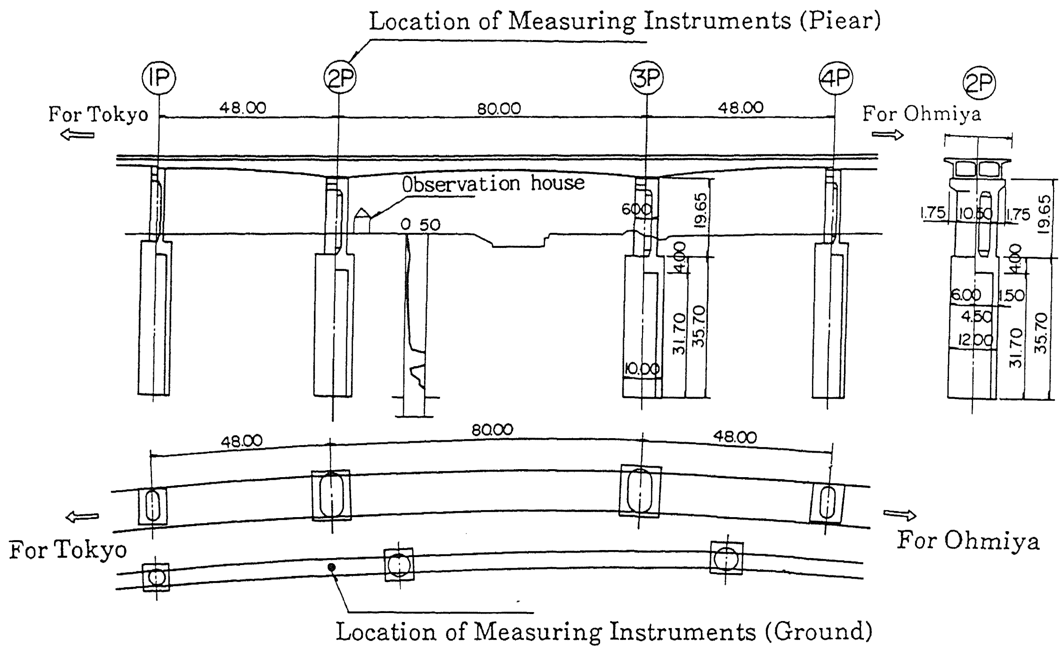
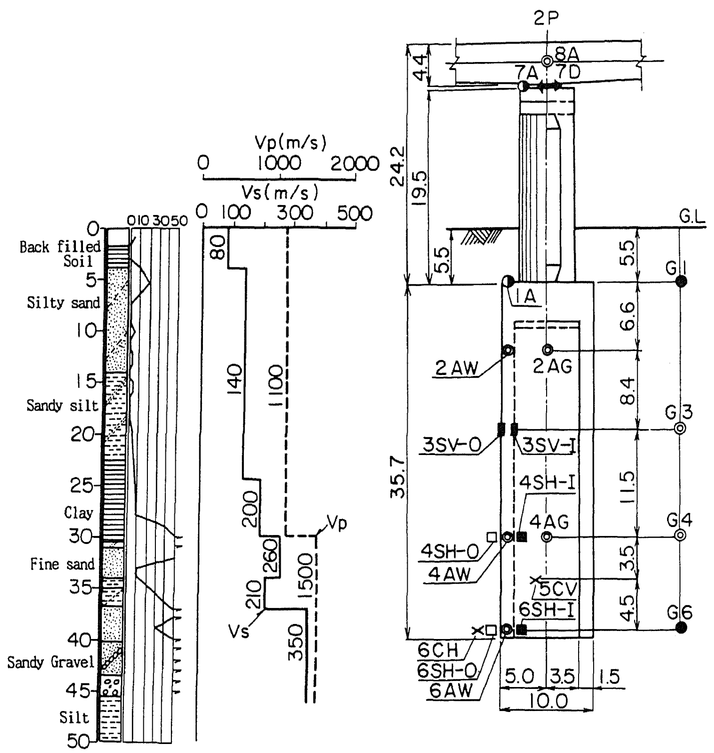


Fig.1 Profile of Sasame Bridge



Sign	Sensor	Number
● A	Acc. (X,Y,Z)	2
◑ A	Acc. (X,Y)	2
◎ A	Acc. (X)	8
↔ D	Relative dis	1
▮ SV	Strain meter (Z)	2
■□ SH	Strain meter (X)	4
X=CV	Crack meter (Z)	1
X=CH	Crack meter (X)	1

Fig.2 Soil Profile and Observation Point

Table.1 List of Observed Earthquake

NO.	Date	M	D (km)	Δ (km)	S.I.	8A-X (gal)	7A-X (gal)	1A-X (gal)	6AW-X (gal)
1	Oct. 4, '85	6.2	78	45	V	106.9	85.8	26.8	20.2
2	Jun. 24, '86	6.5	73	146	IV	43.3	42.2	12.1	8.7
3	Apr. 4, '87	6.6	37	257	IV	20.5	17.6	5.5	3.6
4	Dec. 17, '87	6.7	58	91.1	IV	93.9	93.2	31.8	25.5
5	Mar. 18, '88	6.0	99	17.6	III	52.3	46.8	33.7	20.6

Key: M=Magnitude, D=Depth, Δ=Distance, S.I. = JMA Seismic Intersity

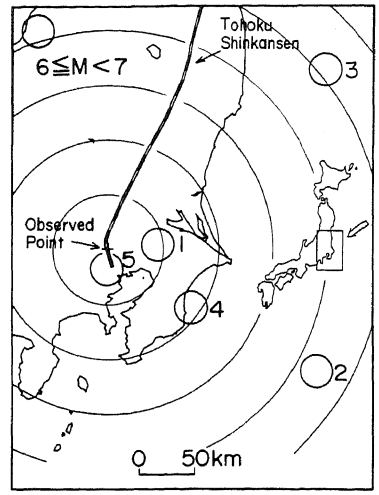


Fig.3 Location of Epicenters

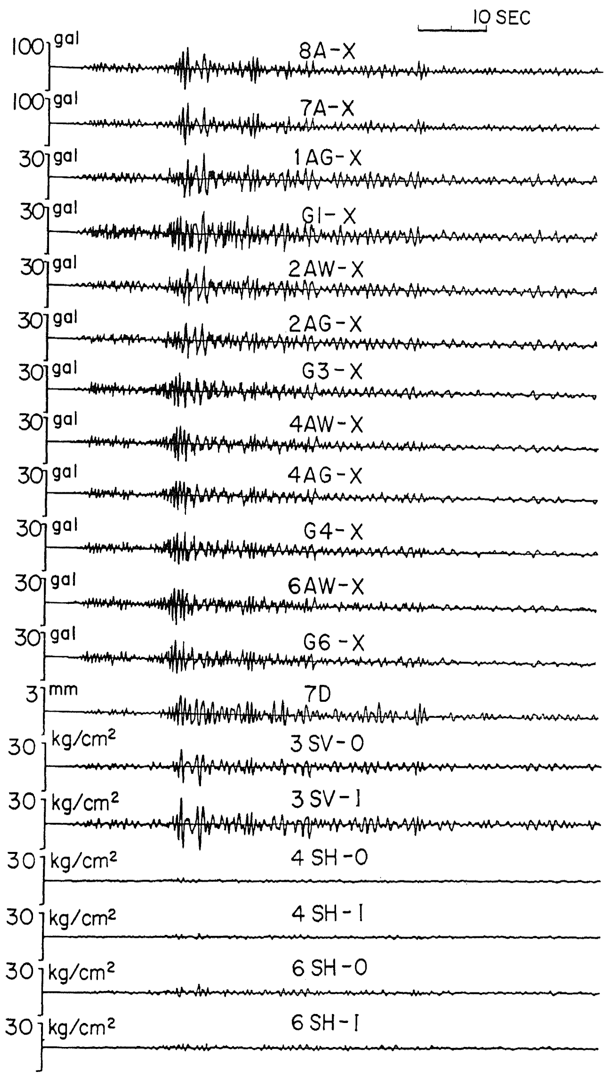


Fig.4 Observed Waves of Earthquake No.4

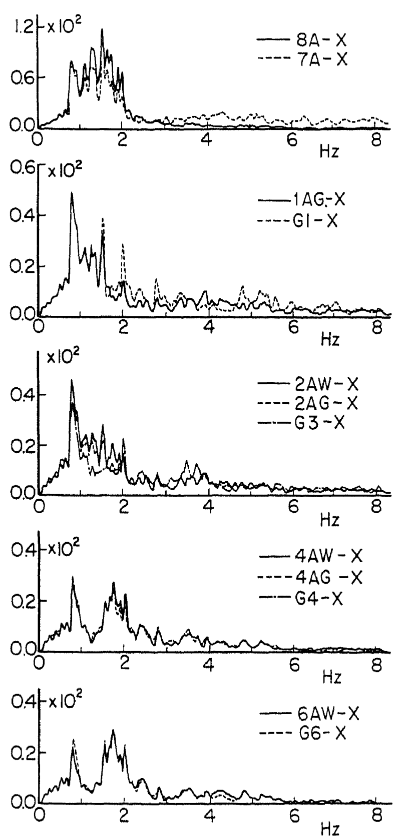


Fig.5 Fourier Spectrum of Earthquake No.4

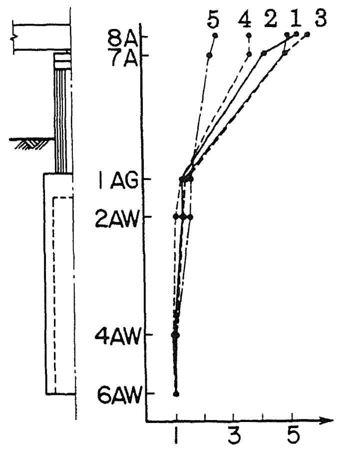


Fig.6 Max. Acc. Amp. Ratio

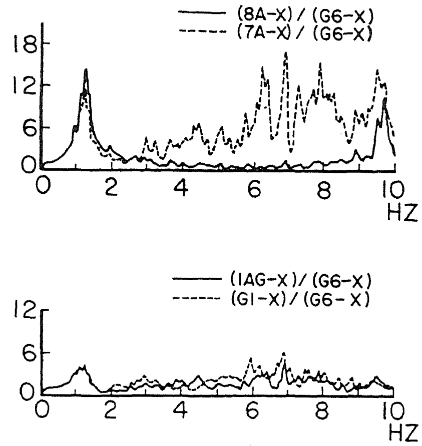


Fig.7 Fourier Spectrum Ratio

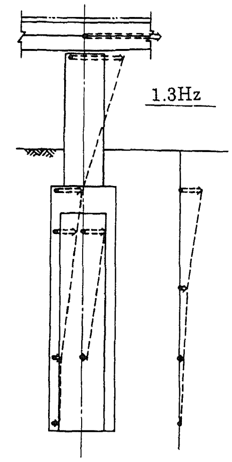
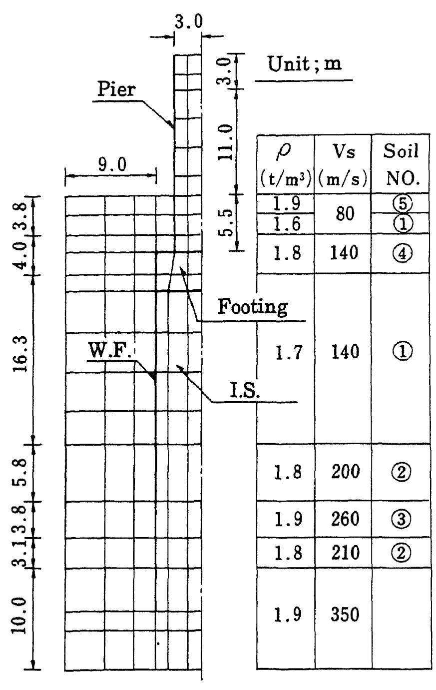


Fig.8 Mode Shape at 1.3Hz



W.F. ; Wall Foundation
I.S. ; Inner Soil

Fig.9 Analytical Model

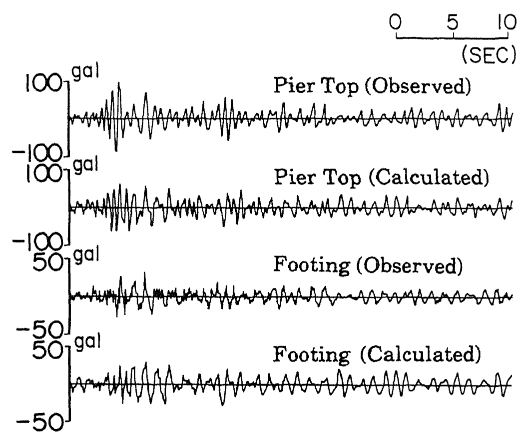


Fig.10 Comparison of Response Waves

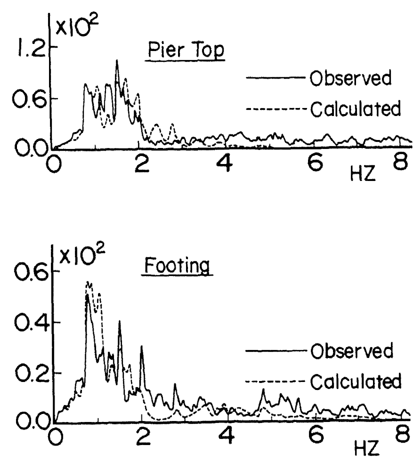


Fig.11 Comparison of Fourier Spectrum