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ON SEISMIC RESPONSE CHARACTERISTICS OF CAISSON-PIER

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This paper is intended to clarify the seismic response characteristics of the caisson-pier during earthquakes by use of observed results. The main obtained results are as following : 1) the (acceleration) response of pier depends on the epicentral distance, and is dominated by the contribution of higher mode when the epicentral distance is short. 2) the frequency characteristics of caisson and pier are almost similar to those of the basement and the superstructure respectively. 3) the time-dependent property of the frequency characteristics in the response of caisson and pier appears when the frequency of acceleration of the basement is time-dependent.

1. INTRODUCTION

The pier constructed on a caisson foundation is a structure placed between the massive caisson and the superstructure, so that its seismic behavior is affected by both of them. Further, as the behavior of the caisson is affected by its surrounding ground, the overall examination on the seismic behavior of ground, caisson, pier and superstructure seems basically important. From this viewpoint, this paper is intended to clarify the seismic response characteristics of the caisson-pier in connection with the behavior of ground and superstructure by use of the seismic records observed from 1973 to 1978 at the Shin-iinogawa Bridge in Miyagi Prefecture.

2. OUTLINE OF THE EARTHQUAKE OBSERVATION AND VIBRATION CHARCTERISTICS OF THE GROUND

The profile of the Shin-iinogawa Bridge is shown in Fig.1, and the positions of the accelerometers with three components, are also indicated in Fig.1. Fig.2 shows the profiles of piers (P_2 and P_5) and the soil profile of surrounding ground. The start of the earthquake observation was before the construction of the superstructure. The numbers of the records are 20 and 62 before and after the construction of the superstructure respectively***. The Maximum intensity of observed earthquakes was J.M.A. intensity 3.

For the vibration characteristics of the ground, the predominant period ranges between 0.3 sec and 0.5 sec, which was obtained from the microtremor observation, and the shear wave velosity in the surface layer

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*** Hereafter, the terms of before and after costruction are used for the meanings of before and after the construction of the superstructure respectively.

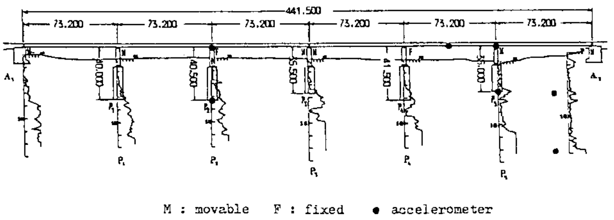

Fig. 1 Profile of Shin-iinogawa Bridge.

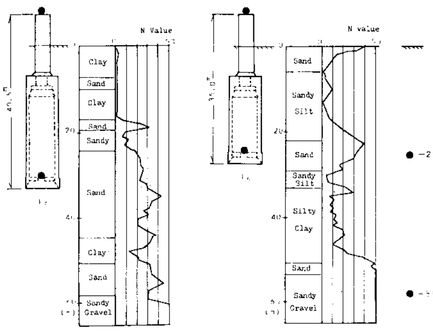

Fig. 2 Caisson-Pier (P_2, P_5) and Soil Profile.

ranges between 120m/s and 190m/s.[1)]

3. OBSERVED RESULTS AND CONSIDERATIONS

(1) Predominant periods

Table 1 gives the predominant periods gained by Fourier spectrum analysis of the accelerograms obtained at the base of caisson and the top of pier (hereafter, briefly called the caisson and the pier respectively) for two ranges of the epicentral distance Δ. As is seen in Table 1, the change of the predominant periods owing to the construction of superstructure is observed evidently at the pier in the transverse direction, for which the restraint of the superstructure is strong, in the case of near earthquakes, and period 0.4 sec is added to period 0.2 sec after construction, where period 0.2 sec corresponds to the seventh mode of P_2 or the eighth mode of P_5[1)], and period 0.4 sec corresponds to the first mode of the whole structure in the longitudinal derection and the third mode of that in the transverse direction[1)]. Periods 0.15-0.30 sec of P_5 may correspond to the first mode of caisson-pier without superstructure (Period 0.18 sec) and that of the surrounding ground (0.3 sec).

Table 1 Predominant Period.

epicentral distance			$\Delta \leqq 120$Km		$\Delta \geqq 120$Km	
			Predominant Period(sec)		Predominant Period(sec)	
			Before Construction	After Construction	Before Construction	After Construction
P_2	C	T	(0.2), 0.4	(0.15 ~ 0.2)	0.2, (0.3 ~ 0.45), 0.95 ~ 1.05	0.2, (0.35 ~ 0.5), 0.8 ~ 1.15
		L	(0.2), 0.4	0.15 ~ 0.2	0.2, (0.3 ~ 0.45), 0.95 ~ 1.05	0.2, (0.35 ~ 0.5), 0.8 ~ 1.15
		V		(0.2), 0.35		
	P	T	(0.2), 0.4	(0.15) ~ (0.4) ~ 0.5	0.2, (0.4), 0.7 ~ 1.05	0.15 ~ 0.25, (0.4), 0.85 ~ 1.0
		L	(0.2 ~ 0.25), 0.4	(0.15) ~ (0.4) ~ 0.5	0.2, (0.4), 0.7 ~ 1.05	0.15 ~ 0.25, (0.4), 0.85 ~ 1.0
		V	0.2, 0.4 ~ 0.45	(0.2) ~ 0.5	0.2, (0.4)	0.15 ~ 0.2, (0.4 ~ 0.5)
P_5	C	T	(0.2), 0.9	(0.15 ~ 0.2), 0.9 ~ 1.15		0.15 ~ 0.2 ~ 0.3, (0.4 ~ 0.5), 0.9 ~ (1.15)
		L	(0.2), 1.0	(0.15 ~ 0.2), 0.9 ~ 1.15		0.15 ~ 0.2 ~ 0.3 (0.4 ~ 0.5), 0.9 ~ (1.15)
		V	0.46	(0.15) ~ 0.5		0.2 ~ 0.3, (0.5)
	P	T	0.15, (0.3), 1.0	(0.15 ~ 0.3), 0.4 ~ 0.45, 0.9 ~ 1.15		0.2, (0.35 ~ 0.5), 0.9 ~ 1.15
		L	0.17, (0.3), 1.1	(0.15 ~ 0.3), 0.4 ~ 0.45, 0.9 ~ 1.15		(0.2), (0.4), 0.9 ~ 1.1
		V	0.46	(0.15) ~ (0.4)		0.2 ~ (0.5)
S		T		(0.2), (0.4), 0.9 ~ 1.15		0.2 ~ (0.5), 1.1
		L		(0.2), (0.4), 0.9 ~ 1.15		0.2, (0.4)
		V		0.12, (0.4 ~ 0.45), 0.8		0.2, 0.3, (0.4 ~ 0.45), 0.8 ~ 0.95

T: Transverse L: Longitudinal V: Vertical
S: Superstructure C : Caisson P : Pier
( ): remarkable period

The characteristics of the predominant period of caisson and pier seems to depend, especially in the transverse direction, upon the epicentral distance. For the distant earthquakes, the predominant period of caisson and pier becomes only the longer period of 0.4 sec, which agrees well to that of the superstructure.

In Fig.3, the period corresponding to the maximum horizontal acceleration of the caisson and the pier is plotted with the epicentral distance before and after construction. It is seen from Fig.3 that after construction the period of P_5 in the transverse direction is approximately equal to 0.15 sec, which is same before construction, for the near earthquakes and becomes 0.4 sec, which is the predominant period of the superstructure, for the distant earthquakes.

As described above, the characteristics of the predominant mode of the Shin-iinogawa Bridge depends on the epicentral distance, which seems to be caused by the frequency characteristics of the earthquakes.

(2) Maximum acceleration

In Fig.4 the maximum acceleration of horizontal components of the caisson (P_5) is plotted with that of the ground (−25m). It is seen that the acceleration at the base of the caisson is about 50% smaller than that of the base ground. To describe the change of the maximum acceleration of the ground (y) against the magnitude (M) and epicentral distance (Δ), the following equation is applied ;

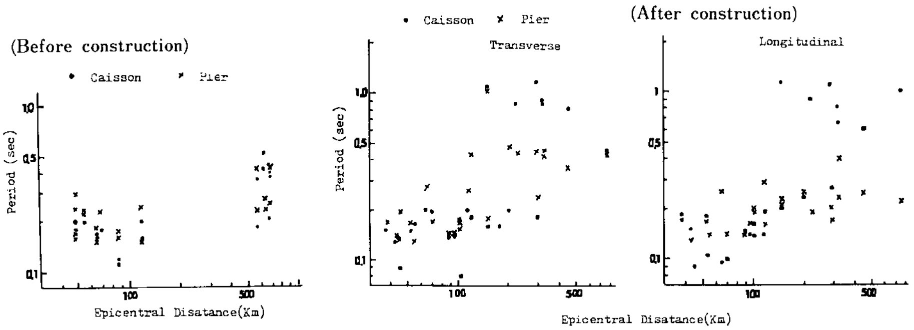

Fig. 3 Period of Maximum Acceleration and Epicentral Distance.

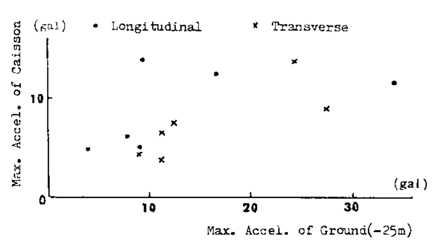

Fig. 4 Maximum Accelerations of Base Ground and Caisson (P_5).

Table 2 Magnification Factor and Epicentral Distande.

Epicentral Distance		$\Delta<120$Km		$\Delta\geqq 120$Km	
		N	α	N	α
P_2	T	3	2.80	4	2.99
	L	3	2.01	4	2.48
	V	2	0.97	2	1.40
P_5	T	19	4.02	24	5.12
	L	16	5.55	22	4.49
	V	21	1.46	20	1.41
S	T	10	7.05	12	11.93
	L	10	2.81	11	5.33
	V	10	6.62	12	13.90

N: Numbers of Earthquakes

$$\log y = aM + b\log\Delta + c \quad (1)$$

where a,b and c are constants. For the acceleration of the base of the caisson (P_2) after construction, the regression equation is obtained as

$$\log y = 0.9006\,M - 2.2402\log\Delta - 0.5507 \quad (2)$$

where the coefficient of correlation is 0.78.

Fig.5 shows the relation between the maximum acceleration of caisson and that of pier. Using Fig.5 and assuming a linear relation, we obtain

$$\log A_p = 0.665 + 1.041\log A_c \quad (3)$$

$$\log A_p = 0.695 + 0.837\log A_c \quad (4)$$

for the longitudinal and the transverse directions respectively. The values of b agree relatively well to that obtained for the Kaihoku Bridge (where the acceleration at the surface ground is used in place of that at the base ground[3]). The equations (3) and (4) show that the magnification factor $\alpha(|A_p/A_c|)$ is almost constant in the longitudinal direction and becomes small in the transverse direction if the acceleration A_c becomes large. As the magnification factor seems to depend upon the frequency characteristics of the eathquakes, the values of the factor are given for two ranges of the epicentral distance in Table 2. Table 2 shows that the factor for the distant earthquakes is larger or smaller than that for the near earthquakes in the transverse or the longitudinal direction respectively. As the higher mode is sometimes predominant in the transverse direction for the near earthquakes, the higher mode is considered to contribute partially to the magnification factor in the transverse direction.

(3) Time dependent characteristics of the seismic response

The time dependent characteristics of the seismic response of ground (—25m), caisson (P_5), pier (P_5) and superstructure are analysed by use of the running spectrum. As an example, the Fourier spectra in the different time durations of the main motion are shown in Fig.6. It is seen from Fig.6 that in the transverse

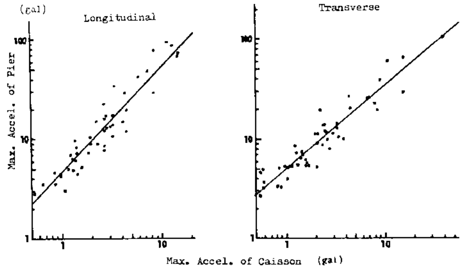

Fig. 5 Maximum Acceleration of Caisson and Pier (P_5 : After the construction).

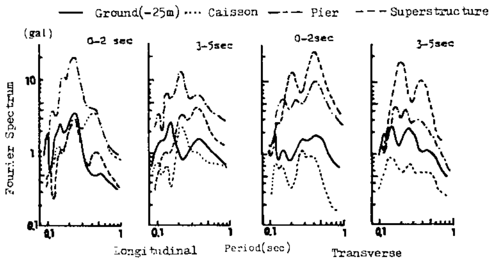

Fig 6 Time Variation of Fourier Spectrum.

direction the predominant periods of the caisson and the pier (P_5), which have a good correspondance to those of the ground and the superstructure respectively, change from 0.4 to 0.15-0.20 sec with time. On the other hand, in the longitudinal direction the predominant period 0.2 sec of the caisson and the pier is kept constant, while that of the ground changes from 0.20 to 0.15 sec. For the reason, it is supposed that in the longitudinal direction, the support condition of P_5 is movable and consequently the natural vibration of the caisson-pier occurs and continues even if the predominant period of the ground changes with time.

4. CONCLUSION

The obtained results are as follows.

(1) For the near earthquakes the higher mode tends to be predominant in the transverse direction.

(2) The acceleration at the base of caisson is smaller than that of the base ground in general.

(3) Equations (3) and (4) express the relations between the maximum acceleration of the caisson and that of the pier. In the transverse direction, the magnification factor Ap/Ac depends upon the acceleration of the caisson and the epicentral distance.

(4) The predominant period of the caisson and the pier in the transverse direction tends to change if that of the ground changes with time.

The change of the seismic characteristics of the caisson-pier in the Shin-iinogawa Bridge owing to the construction of the superstructure is reported in detail in 4). The similar observation at the Hirosegawa Aqueduct Bridge was also carried out.

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