ON CHARACTERISTICS OF EARTHQUAKE BEHAVIOR OF CAISSON-PIER

by

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SUMMARY

The authors have continuously conducted an earthquake observation of bridge from the time of the construction of the girder. This paper is intended to clarify the characteristics of earthquake behaviors of caisson-pier, specially putting emphasis on the influence of the addition of the girder. The obtained results suggest the following properties: the predominant period of pier is mainly affected by that of the ground or of the superstructure according to the frequency characteristics of the applied earthquakes. The characteristics of the earthquake behavior of pier are analized by considering the epicentral distance of the earthquake and the time-depending characteristics is also discussed.

1. INTRODUCTION

For the anti-earthquake design of bridge, it is necessary to study the characteristics of earthquake behaviors for both of substructure and superstructure. The authors have conducted an earthquake observation at the Iinogawa Bridge in Miyagi Prefecture (Japan) before the construction of the superstructure. This paper will report some considerations on the obtained results which intend to clarify the change of characteristics of the earthquake behaviors of substructure caused by the addition of the superstructure(1).

2. OUTLINE OF EARTHQUAKE OBSERVATION

Fig. 1 shows the general side view of the Iinogawa Bridge in which the earthquake observations were carried out. This road bridge consists of two series of continuous steel-slab box girder with three spans. The foundation type of the substructure is pneumatic caisson. The soil profiles and N values are shown in Fig. 2.

As shown in Fig. 1, accelerometers are placed at the base of caissons of P_2 and P_5, the top of these piers, middle of the girder between P_4 and P_5, and in the grounds with depth 25m and 59m. The number of components of every accelerometers is three, i.e. longitudinal, transverse and vertical directions of the bridge.

The predominant periods of the ground are 0.3 sec and 0.5 sec from the results of the micro-tremor observation.

The numbers of the obtained earthquake records are six and forty before and after the construction of the superstructure respectively, and the range of J.M.A. intensity is about I to III.

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3. VIBRATION CHARACTERISTICS OF THE CAISSON-PIER

3-1 Predominant periods

The dominant periods calculated by the Fourier spectrum analysis are shown in Table 1, and some examples of spectrum are shown in Fig. 3. From them, it is presumed that the value of 0.2 sec in horizontal direction is a natural period of caisson-pier and that of 0.4-0.5 sec is one of the girder, and the value of 0.4-0.5 sec in vertical direction is one of the ground. From these results it is seen that a predominant period of the caisson-pier after the construction of the superstructure becomes longer than that obtained before the construction and this fact clearly suggests that the influence of the superstructure appears in the predominant period of the caisson-pier.

The fundamental natural period of caisson-pier (P_S) calculated by the model shown in Fig. 4 is 0.19 sec and this value agrees with the observed value sufficiently.

The periods of the maximum accelerations on the earthquake records are plotted against the epicentral distance Δ in Fig. 5. From this figure it is observed that the periods at the top of pier before the construction of the superstructure are almost constanat in the range 0.2 sec and 0.3 sec, on the other hand this period takes different values for $\Delta < 120$ km and $\Delta > 120$ km after the construction of the superstructure, especially in transverse direction. It is seen that the dominant period of the top of pier is presumed to be both of the natural periods of the caisson-pier and the superstructure and the former becomes predominant against the case of the short epicentral distance, the latter against that of the long epicentral distance respectively.

3-2 Frequency transfer characteristics

Some examples of the spectral ratio of the top of pier to the base of caisson are shown in Fig. 6 and the frequencies against the peak value of spectral ratio are plotted against the epicentral distance Δ in Fig. 7. These figures show that the predominant frequency is almost constant value of 5 Hz for the distance Δ before the construction of the superstructure, while it changes from 5 Hz to 2 Hz after the construction. This results also agree with those mentioned in 3-1.

3-3 Damping factor

The damping factors calculated from the Fourier spectral ratios in 3-2 are about 0.061% and 0.067% respectively before and after the addition of the superstructure. This results show that the damping factor of sub-structure does not change remarkably by the addition of the superstructure.

3-4 Magnification Factor

The maximum accelerations at the top of pier are plotted against those at the base of caisson in Fig. 8. It is seen that the magnification factor of caisson-pier becomes slightly small after the addition of the super-structure. This is also considered the influence of the mass of girder which makes a predominant period of the top of pier longer.

The magnification factors α of caisson-pier are plotted against the epicentral distance Δ in Fig. 9 and are listed in Table 2. From these it is seen that the values of α of P_S in horizontal direction depend on Δ , i.e. for the increase of Δ , α decreases in the longitudinal direction and on the contrary increases in the transverse direction. The difference of the characteristics in two directions is considered to be caused by the support conditions of the girder. Namely for the movable direction the superstructure seems to affect less to the earthquake behavior of the caisson-pier.

The factors α to almost equal epicentral distance are plotted against the magnitude of earthquake M in Fig.10. This figure shows that the factor α increases a little with the magnitude M.

3-5 Vibration mode of caisson-pier

The cross-correlation of the acceleration waves at the base of caisson and the top of pier is 0.2 to 0.6. Therefore it is presumed that the predominant vibration mode of caisson-pier is a rocking type, and the rocking center is located lower than the base of caisson. This result corresponds to the calculated value using the model shown in Fig. 4.

4. ON STATIONARITY OF THE CHARACTERISTICS

To examine the time-depending properties of the characteristics of the earthquake behavior(2), predominant periods calculated by the Fourier spectrum analysis over a constant time interval of 2 sec are plotted against the time in Fig.11. The figure shows that in the longitudinal direction, though the periods of the ground and the girder vary with time, those of the caisson and the pier are almost constant value of 0.22 sec, while in transverse direction, the periods of the ground, the caisson, the pier and the girder vary with time and those of the caisson and the pier correspond to those of the ground and the girder respectively. Examples of Fourier spectrum are shown in Fig.12 and in this figure these correspondences are also seen. These results show that if the support condition of the superstructure is not movable, the time-depending property of the predominant period of caisson and pier is observed.

By the same method, the cross-correlation coefficients of the base of caisson and the top of pier are plotted with the time in Fig.13. This figure shows that in the initial step where the maximum acceleration appears, the coefficient is positive and comparatively large. Therefore it is presumed that in the step which the maximum acceleration appears a rocking vibration of the caisson-pier is predominant.

5. CONCLUSIONS

1) After the addition of the superstructure, the predominant period of the caisson-pier becomes longer and the magnification factor decreases a little. Moreover it is found that the predominant period and the magnification factor depend on the epicentral distance. These properties may come from the vibration characteristics of the superstructure.
2) If the predominant period of the earthquake motion coincides with the natural period of the superstructure, the response at the top of pier may become remarkably large. On the other hand, it coincides with the natural period of the caisson-pier, the natural vibration of the caisson-pier may be excided.

3) After the addition of the superstructure, the time-depending properties in the vibration of pier are observed. It is considered that the effect of the vibration of the superstructure appears sometimes after the beginning of its vibration.
4) The damping factor calculated from the Fourier spectral ratio of the top of pier to the base of caisson does not change remarkably by the addition of the superstructure.

REFERENCES

(1) Satake,M., Tano,H., Asano,T., and Honma,K.,"Comparison of Vibration Characteristics during Earthquakes of Caisson Pier Before and After Girder-Construction," Proceedings of the Fouth Japan Earthquake Engineering Symposium-1975, pp.495-pp.502, 1975
(2) Satake,M. and Asano,T.," ON THE RESPONSE CHARACTERISTICS OF CAISSON-PIERS DURING EARTHQUAKE," Proceedings of Fifth Japan Earthquake Engineering Symposium-1978, pp.385-pp.392, 1978

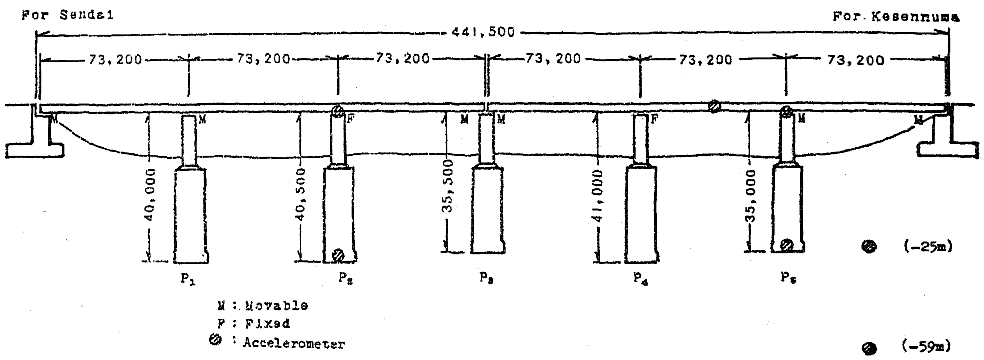


Fig. 1 Side View of Iinogawa Bridge

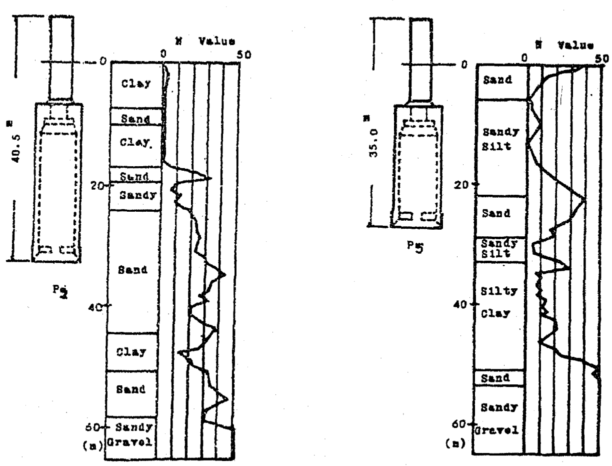


Fig. 2 Caissons(P_2,P_5) and Soil Profiles

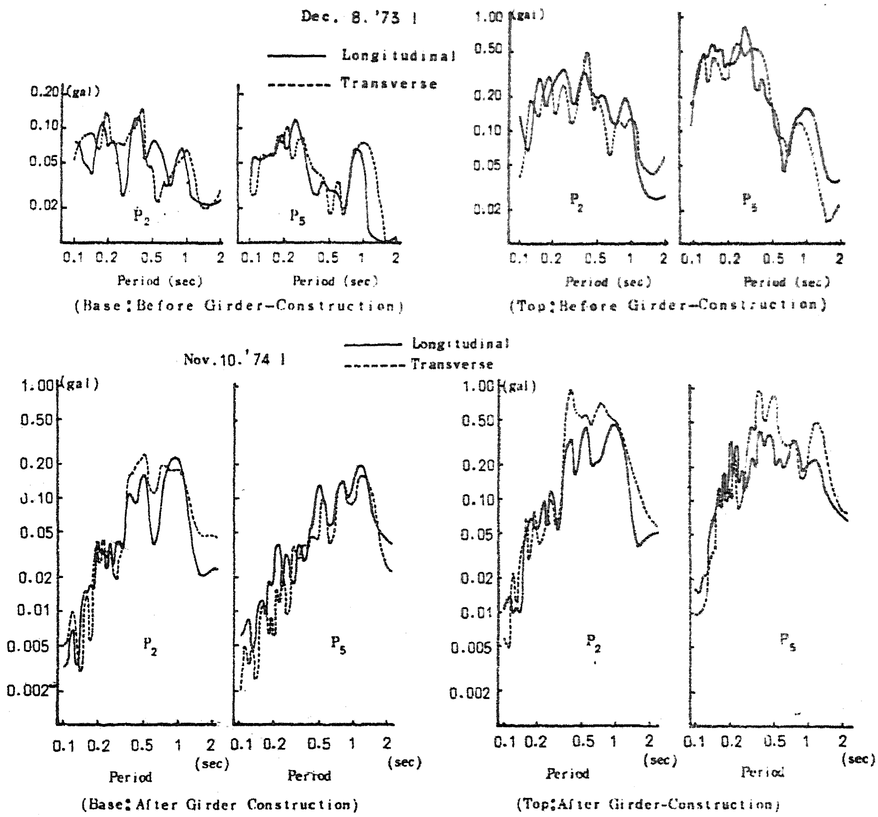


Fig.3 Examples of Fourier Spectrum

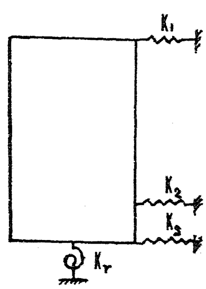


Fig. 4 Model of Caisson(P_5)

(Before Girder-Construction)

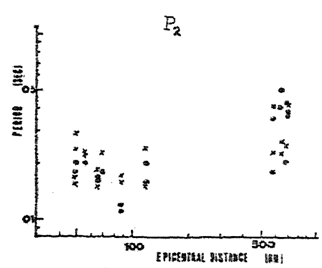
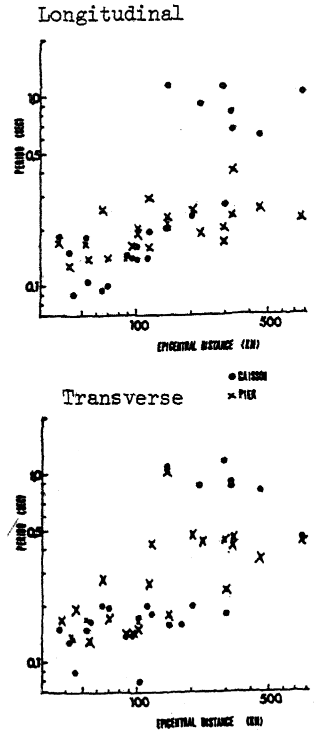
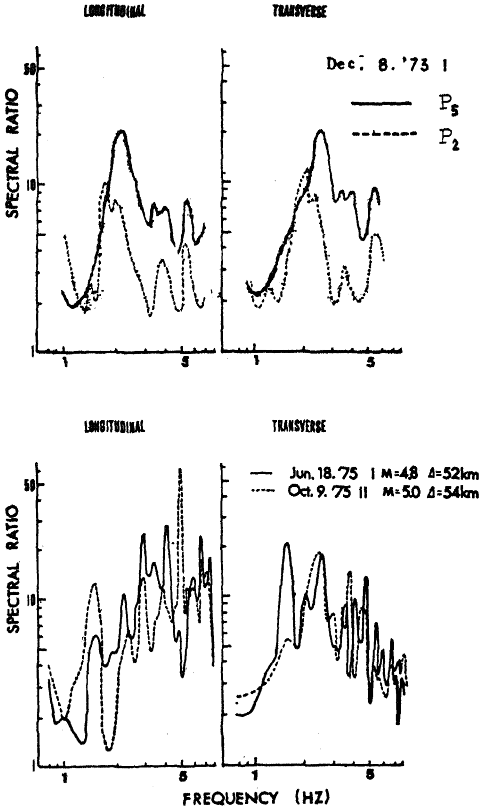


Fig. 5-a Periods of Max. Acc.



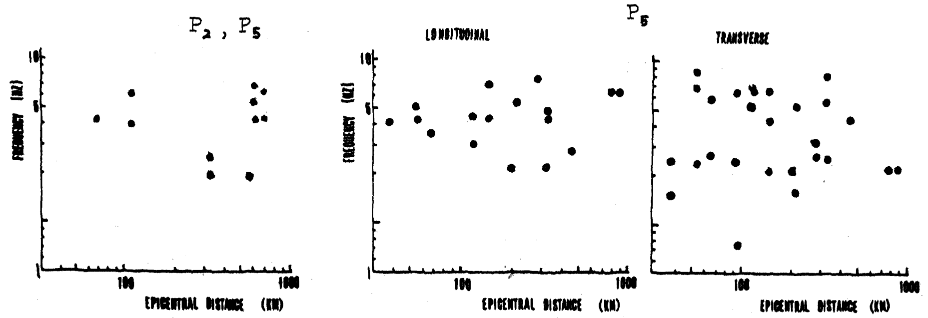
(After Girder-Construction)

Fig. 5-b Periods of Max. Acc.



(After Girder-Construction)

Fig. 6 Examples of Spectral Ratio



(Before Gider-Construction) (After Girder-Construction)

Fig. 7 Predominant Frequencies of Spectral Ratio

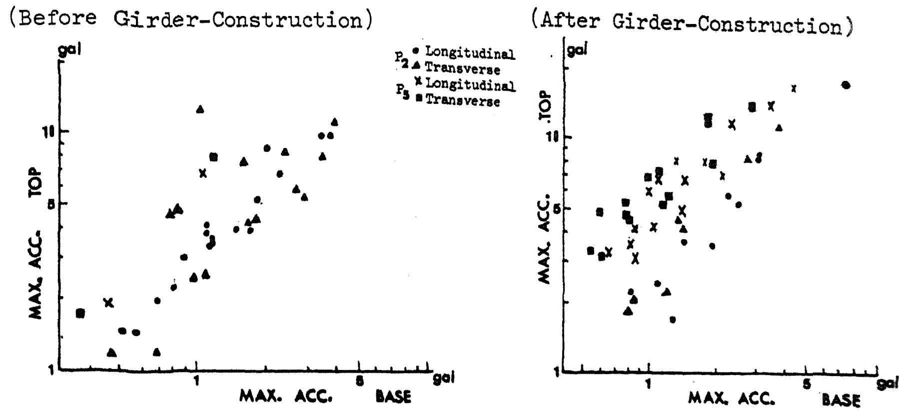


Fig. 8 Max. Acceleration of P_2,P_5

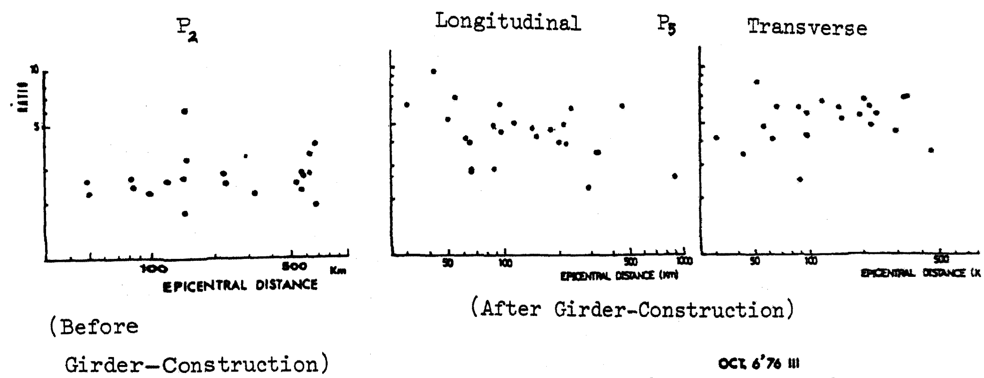


Fig. 9 Magnification Factor and Epicentral Distance

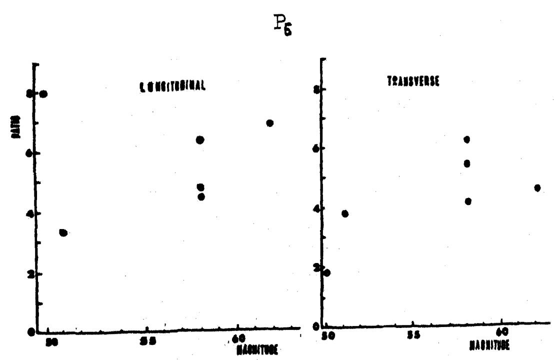


Fig.10 Magnification Factor and Magnitude of Earthquake

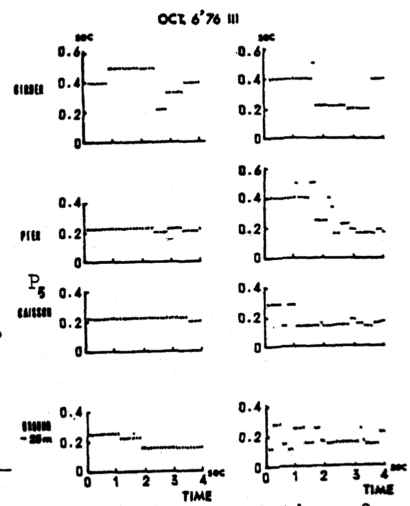
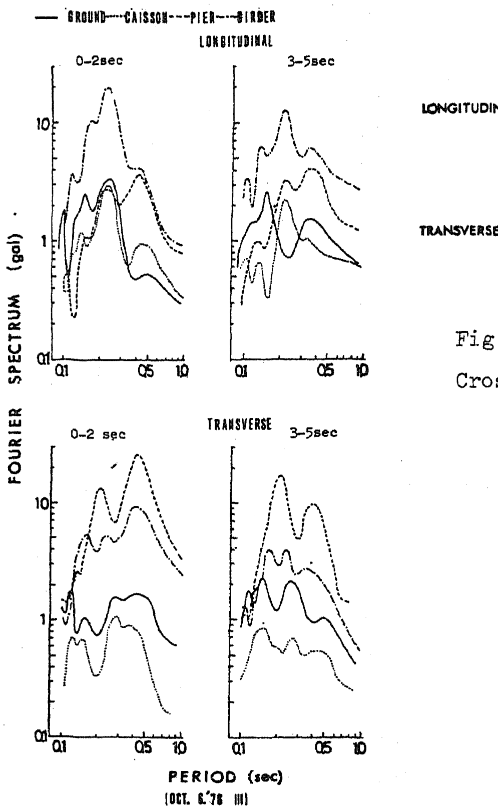


Fig.11 Time Variation of Predominant Period



.2 Time Variation of Fourier Spectra

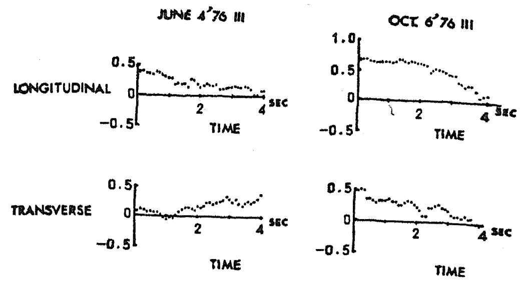


Fig.13 Time Variation of Cross-correlation Coefficients

Table 2 Magnification Factor

E. D.		Δ<120 km		Δ>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
G	T	10	7.05	12	11.93
	L	10	2.81	11	5.33
	V	10	6.62	12	13.90

E.D. : Epicentral Distance
T:Transverse L:Longitudinal
V:Vertical

N: Numbers of Earthquakes

Table 1 Predominant Periods

		Direction	Base	Top
P_2	Before Girder-Construction	Longitudinal	0.18~0.20, 0.40~0.50	0.18~0.20, 0.40~0.50
		Transverse	0.18~0.20, 0.40~0.50	0.16~0.20, 0.40~0.50
		Vertical	0.46	0.46
	After Girder-Construction	Longitudinal	0.18~0.20, 0.4 0.95~1.0	0.18~0.20, 0.40~0.46 0.95~1.0
		Transverse	0.16~0.20, 0.40~0.45	0.15~0.20, 0.40~0.45
		Vertical	0.20. 0.45	0.16~0.20, 0.40~0.45
P_5	Before Girder-Construction	Longitudinal	0.20, 1.0	0.15. 0.3, 1.0
		Transverse	0.20, 0.90	0.17, 0.3, 1.1
		Vertical	0.46	0.46
	After Girder-Construction	Longitudinal	0.17~0.20, 0.40~0.46 0.95~1.0	0.16~0.20, 0.40~0.46 0.95~1.0
		Transverse	0.16~0.20, 1.0	0.16~0.20, 0.35~0.42 1.0
		Vertical	0.20, 0.50	0.20, 0.45~0.50

Underlines indicate remakable periods. (Unit : sec)