INPUT EARTHQUAKE WAVES AS DEDUCED FROM THE MEASURED RESPONSE OF A BUILDING

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SUMMARY

In our papers already published elsewhere, the authors have proposed the calculation method called "the Inverse-response calculation" by which the Input waves are deducible from the response waves recorded in a building at the time of earthquake.

In this paper, we discuss the characteristics of ground motion, by using the Inverse-response waves deduced from the response waves of buildings at the times of some recent earthquakes. A remark should be made that the main portion of the earthquake appears less clearly, and longer periods predominate in the ground motion as the epicenter lies farther from the observation point.

INTRODUCTION

In order to study the behavior of the building during the earthquake, the observation of earthquake has been made on many buildings in Japan, by means of the SMAC-type seismograph. If the self-vibration of building can be eliminated from the waves observed in the building and the Input waves can be obtained, such Input waves may be very useful in the study of ground motion at the time of earthquake. From this point of view, we have already proposed the method of calculation to obtain the Input waves theoretically from the response waves of a building at the time of earthquake. The Input waves thus obtained are called "the Inverse-response waves" (Ref.1 ~ 3).

In this paper, the following matters are discussed by using the Inverse-response waves which were determined from the response waves recorded in buildings at the times of some earthquakes.

i) The vibrational characteristics of ground motion which were determined at one site in Tokyo, at the times of some recent earthquakes.
ii) The vibrational characteristics of ground motion determined in Sendai and Kanto districts, at the time of Miyagi-ken-oki earthquake, June 12th, 1978.

METHOD OF CALCULATION OF THE INVERSE-RESPONSE WAVES

In this analysis, the building is represented by an equivalent model as shown in Fig.1 in which the swaying of basement is rendered possible so as to meet the condition existing at the basement of actual building. The Inverse-response waves are calculated by transforming the response waves of the building into Fourier series and the coefficient of the series is multiplied by a reciprocal of the magnification factor of multi-storied building which is called "the Inverse-response factor" here. The actual calculation of the Inverse-response waves is made by going through the steps in turn as shown in Fig.2.

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THE VIBRATIONAL CHARACTERISTICS OF GROUND MOTION AT ONE SITE IN TOKYO, AT THE TIMES OF EIGHT DIFFERENT EARTHQUAKES

In this part, a discussion will be made of the vibrational characteristics of ground motion revealed by the Inverse-response waves which were deduced from the response waves recorded on the first floor of the building (Naito Memorial Laboratory of Waseda University,Tokyo) at the times of eight different earthquakes, and also by comparing the above results with the waves actually observed in the underground (G.L-1,-17,-67,-123m) at a point lying in the campus of the Sc. and Eng. Res. Lab. of Waseda Univ.

The building is a three-storied reinforced concrete structure with earthquake resistant walls, and a Strong-motion accelerograph (DC-type) is installed on the first floor. The plan and elevation of this building are shown in Fig.3, together with a brief result of the vibration test (Ref.4). From this result, it will be noticed that the percentages of displacement due to the swaying and rocking against the total displacement are rather large. In Fig.4 are shown the boring logs at the observation site together with the depths of underground seismographs, and the S- and P-wave velocities at various depths.

In Table 1 are shown rough informations about eight different earthquakes selected for our analysis, and in Fig.5 are shown the position of observation site and the epicenters of earthquakes. Earthquake No.1 ~ No.5 occurred in the land area and earthquake No.6 ~ No.8 occurred in the sea.

In Fig.6-a is shown the acceleration patterns of the waves observed in the building, in Fig.6-c the Inverse-response waves deduced from the response waves, and in Fig.6-b.-d,-e and -f the waves observed in the underground (G.L-1,-17, -67,-123m) at the time of Miyagi-ken-oki earthquake (Eqke.7). The response waves observed in the building indicate clearly a fundamental period of vibration of the building (0.28sec), and in comparing the response with the waves observed at a depth of 1.0m, we find that these waves coincide fairly with each other in amplitudes and phases.

On the other hand, the wave-patterns of the Inverse-response waves, in which the self-vibrations of the building are eliminated, are different from those of the waves observed at a depth of 1.0m, but rather similar in tendency, to those of the waves recorded at a depth of 17m. This fact is recognized similarly in the cases of other earthquakes listed in Table 1. From this result, it may be said that the waves observed at a point very near from the building can not be treated as the actual ground motion at free surface.

In Fig.7 are shown the wave-patterns of the Inverse-response waves as deduced from the observation of earthquakes in Table 1. In the cases of earthquake No.2 and 5, which occurred in the land area, and with the epicentral distances of 40~50km from the observation site, it will be recognized that at the beginning of principal portion of earthquake motion, the amplitude is distinctively large, but it gradually becomes small with time. On the other hand, in the cases of earthquake No.7 and 8, which occurred in the sea, it will be seen that the waves of comparatively long periods predominate as compared with the waves mentioned above. This fact becomes more remarkable with increasing epicentral distance.

Next, Fig.8 shows the response spectrum curves calculated for the Inverse-response waves determined at the times of earthquakes as shown in Table 1. In this case, the maximum acceleration of the input wave is normalized at 100 gals. In this figure, the type of the ground motion is classified into three groups according to the region in which the earthquake occurred, that is, (1): Central part of Chiba pref. (Eqke.1 and 2), (2): SW part of Ibaraki pref.~Central part of Saitama pref. (Eqke.3,4 and 5) and (3): In the sea distant from the observation point (Eqke.6,7 and 8).

As seen in the velocity response spectrum curves of group 1, it may be said that the amplitude of the response increases up to a point corresponding to a period of 0.4sec in the case of Eqke.1, and the amplitude do so up to a period of about 0.8sec in the case of Eqke.2. The amplitude, however, decreases in the ranges of period longer than those mentioned above. Further, in the earthquakes of group 2, the velocity spectrum curves show a gradual increase in amplitude until a period of 0.5sec, and thenceforth the amplitude seems to tend to a certain constant value. But it may be said roughly that the spectrum curves of group 2 and group 1 are similar to each other in their shapes.

On the other hand, in the case of group 3, it will be noticed that the amplitudes of the spectrum curves increased in the range of period longer than 0.5sec, or more. This differs from the curves of group 1 and 2 mentioned above, that is, the velocity response curves of group 3 differ from those of group 1 and 2 in their shapes.

From the results obtained so far, we found that the shapes of the response spectrum curves are similar to each other in the cases of group 1 and 2 in which the earthquakes occurred comparatively near to the observation point, whereas in the case of earthquake belonging to group 3 which occurred far from the point, the amplitudes of spectrum curves are usually large in the range of longer period when compared with those in groups 1 and 2.

THE VIBRATIONAL CHARACTERISTICS OF GROUND MOTION IN SENDAI AND KANTO DISTRICT, AT THE TIME OF MIYAGI-KEN-OKI EARTHQUAKE OF JUNE 12TH,1978

In this part, a discussion will be made of the vibrational characteristics of the ground motion by using the Inverse-response waves deduced from the response waves recorded in several buildings in Sendai and Kanto district, at the time of Miyagi-ken-oki earthquake of June 12th, 1978, which caused a serious damage in Sendai.

The buildings selected for our analysis are six in total as shown in Table 2, that is, three in Sendai, two in Tokyo, and one in Yokohama. In this analysis are used the ground motions recorded on and under the ground at Ishinomaki, Tsukuba and Iwatsuki for a mutual comparison. There is a distance of about 100km measured from the epicenter to the Sendai city, and that of about 350km when measured to Tokyo, as shown in Fig.9.

Figure 10-b,-d and -e show the Inverse-response waves deduced from the response waves of buildings in Sendai and Kanto districts, and Fig.10-a and -c show the ground motions observed on and under the ground in both districts. In the case of Sendai district (Fig.10-b), it will be seen that an impetuous wave appears with a large amplitude at the beginning of the main part of the earthquake motion, and thenceforth the motion becomes smaller with time. Such a clear onset of the principal part of earthquake motion can be seen also in

Fig.10-a obtained at point S-G1. This type of transition of ground motion is usually seen in the record of near earthquake. A comparison was made between the characteristic periods of the waves observed at a point S-G1 and those of the Inverse-response waves at point S-B2, with a result that the waves at point S-G1 are generally of shorter periods than the waves at point S-B2. This result may be due to some difference in the soft-soil layer lying at these points.

On the other hand, in the waves recorded in the Kanto district (Fig.10-c, -d and -e), it will be seen that the main portion (S phase) appears less clearly and continues for a while without a sudden change in the magnitude of amplitude, and the wave trains recorded in these figures show a similar feature to each other. However, a close examination reveales that the long period waves appear more predominantly as the epicentral distance becomes longer.

In Fig.11 the response spectra will be shown which were determined for the waves deduced and observed at nine points listed in Table 2. For convenience, in this determination, the maximum acceleration of the input wave is normalized at 100gals. As will be seen in the velocity response spectrum curves determined for the Sendai registers (Fig.11(a)), the curves seem to have some common peaks in a range of period longer than 0.5~0.7sec, though the value of response at point S-G1 is smaller than those at other points in the range of longer period. On the other hand, the shapes of all spectrum curves drawn for the waves in the Kanto district are very similar to each other quite independently of the epicentral distance.

Lastly, as a comparison of the characteristics of the velocity spectrum curves referring to the Sendai and Kanto districts, it will be recognized that the value of the response at Sendai tends to a constant value in the range of period longer than about 0.7sec, while the response in the Kanto district, increases in amplitude until the period becomes about 1.5sec, and decreases thereafter in the range of period longer than this.

From this result, it may be concluded that the value of the velocity response as refered to Kanto district becomes large in the range of period longer than that determined for the Sendai district, owing to the differnce in the epicentral distance of both districts.

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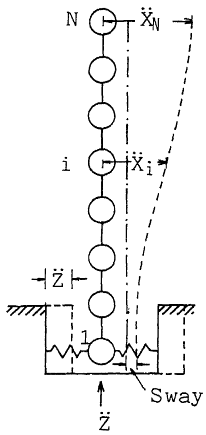

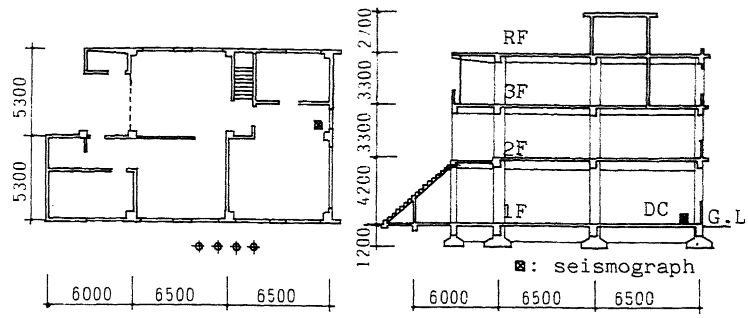

Comp.	Period (sec)	Sway (%)	Rocking (%)
NS	0.253	38	44
EW	0.238	51	24

Fig.1 Equivalent model for theoretical analysis.

Fig.3 Plan and elevation of building (Naito Memo. Lab.) and positions of seismograph.

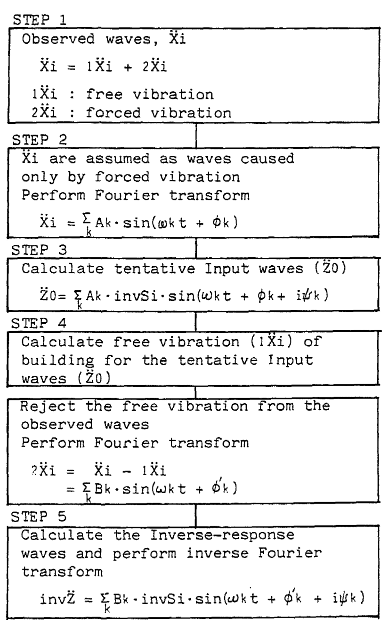

Fig.2 Flow-chart of the Inverse-response wave calculation.

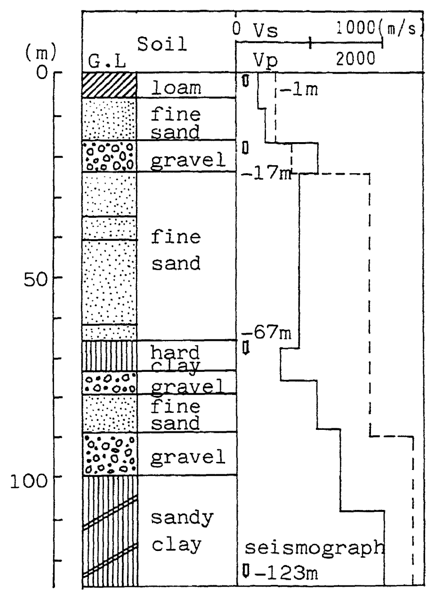

Fig.4 Underground condition at observation site, positions of seismograph and S-and P-wave velocities.

Table 1 List of earthquakes.

No.	Data	Epicenter (Long., Lat.)	Depth (km)	Magni-tude	Intensity in Tokyo (J M A)
1	1968 10.8	SE Coast of Kanto (140°09', 35°31')	70	5.3	3
2	1980 9.25	SE Coast of Kanto (140°13', 35°31')	80	6.1	4
3	1968 7. 1	Central Saitama Pref. (139°35', 35°59')	50	6.1	4
4	1974 8. 4	Southern Kanto (139°55', 36°01')	50	5.8	3
5	1980 9.24	Southern Kanto (139°48', 35°58')	80	5.4	3
6	1972 2.29	Near Hachijo-Jima (141°16', 33°11')	70	7.0	4
7	1978 6.12	Off Miyagi Pref. (142°10', 38°09')	40	7.4	4
8	1980 6.29	Izu Pen. Region (139°14', 34°55')	10	6.7	4

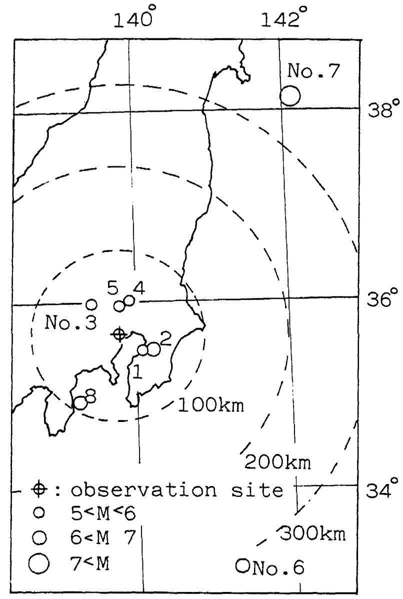

Fig.5 Map showing position of observation site and epicenters of earthquakes.

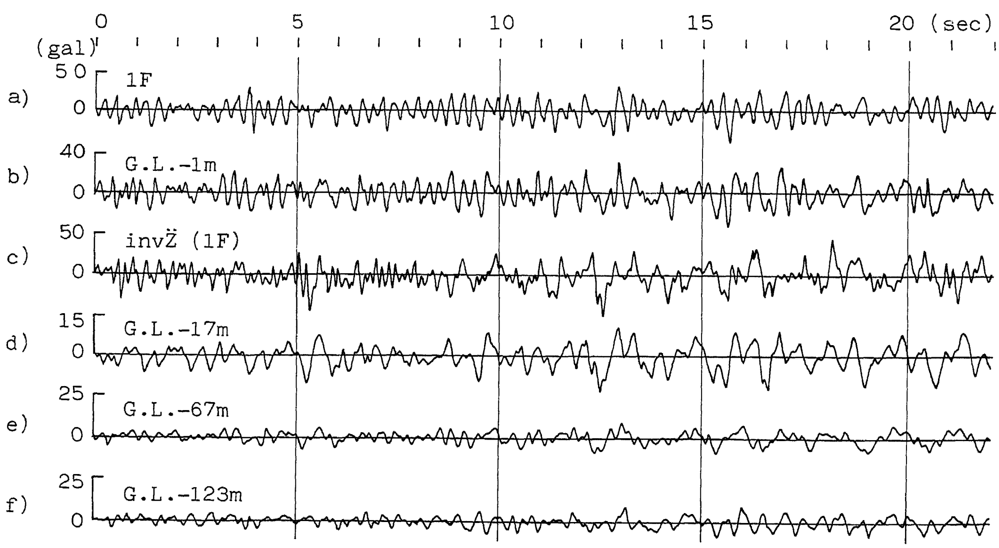

Fig.6 Comparison of the waves observed in the building with Inverse-response waves and the waves observed underground (G.L.-1,-17,-67,-123m).

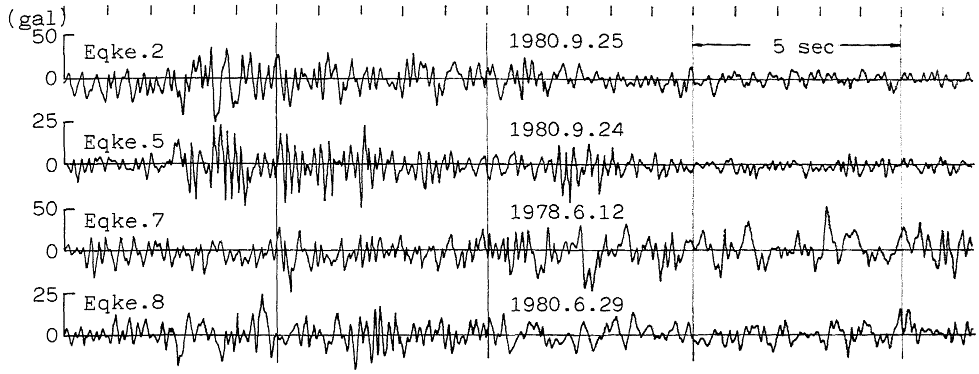

Fig.7 The wave-patterns of Inverse-response waves as deduced from the observation (Naito Memo. Lab.) of earthquake listed in Table 1 (NS comp.).

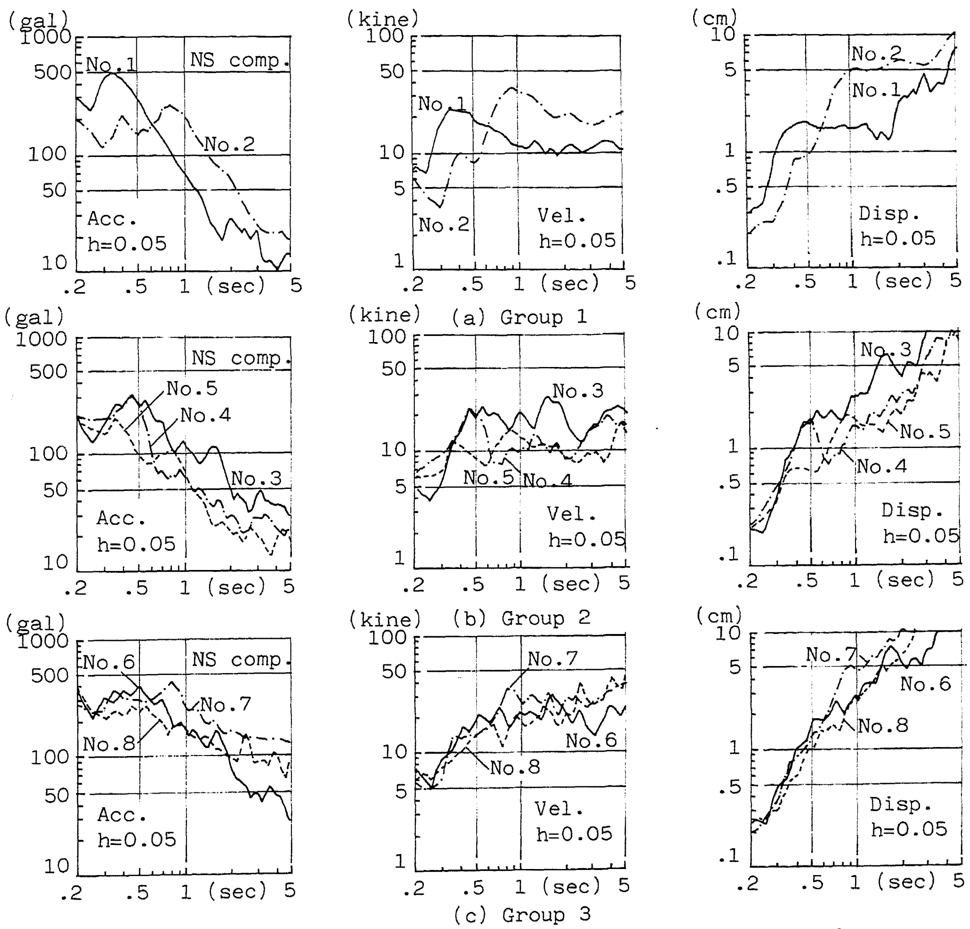

Fig.8 Comparison of response spectrum curves of earthquake classified by regions in which they occurred.

Table 2 Short information about building and its vibration.

No.	Bldg. or Site	Story	Position of seismograph	T1(sec)	Sway (%)
S-G1	Kaihoku Bridge		G.L -0m	-	-
S-B1	J.N.R	6(B1)	B1F	0.49	15
S-B2	Sumitomo Bldg.	18(B2)	18,9,B2F	1.33	2
S-B3	Tohoku Univ.	9	9F	0.96	10
T-G1	Tsukuba	-	G.L -40m	-	-
T-G2	Iwatsuki	-	G.L - 1m	-	-
T-B1	Naito Memo.Lab.	3	1F	0.28	38
T-B2	Waseda No.51	18(B2)	18,B2F	1.33	2
T-B3	Hotel Empire	22(B2)	22F	1.45	2

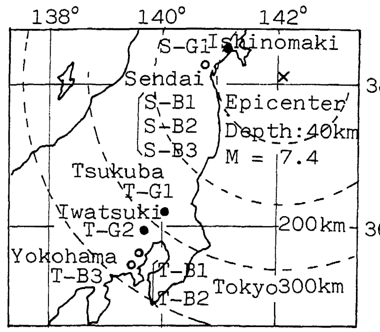

Fig.9 Epicenter and points of observation, Miyagi-ken-oki Eqke.

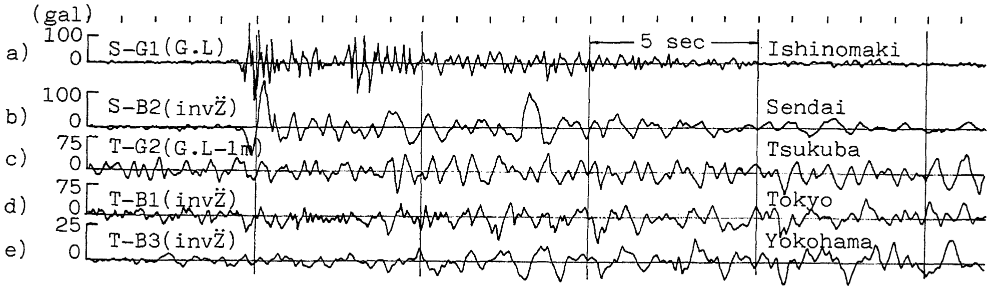

Fig.10 Comparison of wave-patterns of Inverse-response waves.

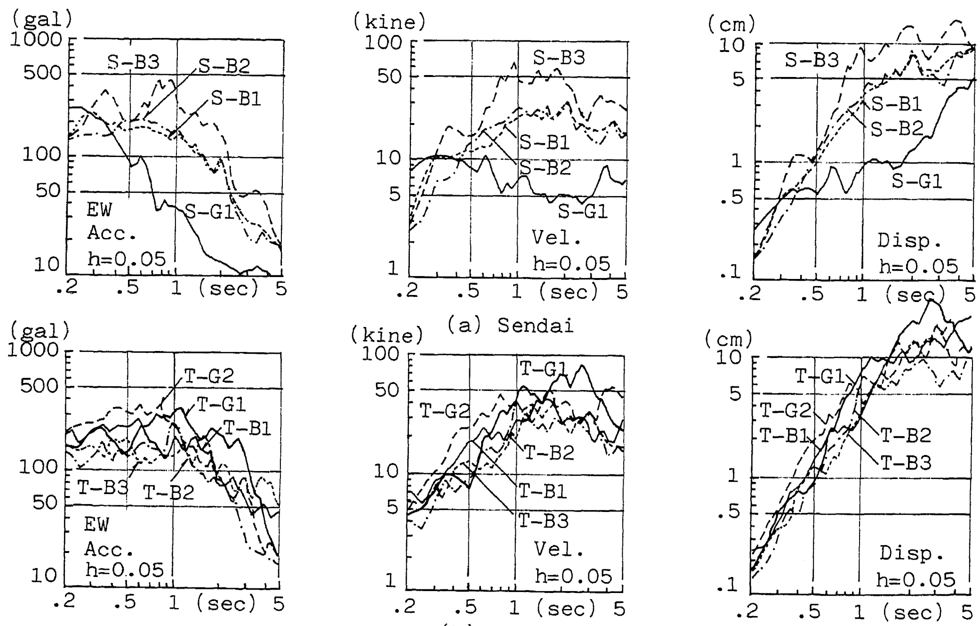

Fig.11 Comparison of response spectrum curves of Inverse-response waves determined in Sendai and Kanto districts for Miyagi-ken-oki earthquake.