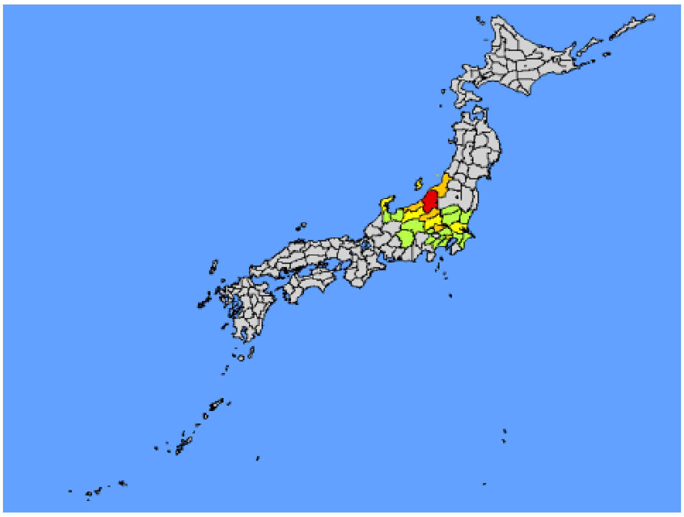
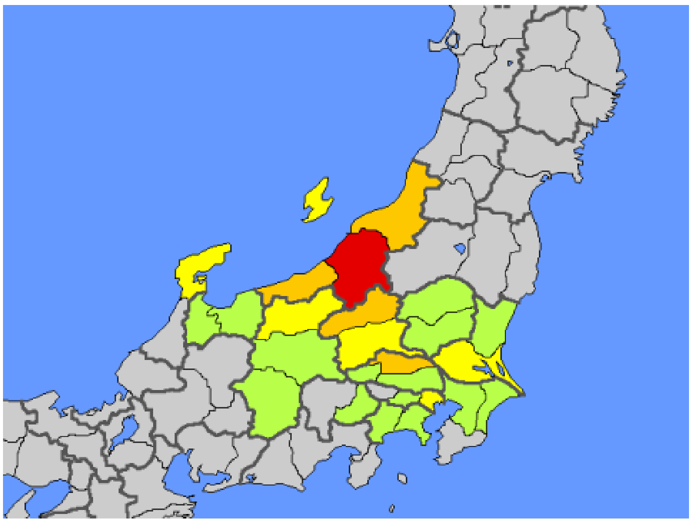
Analysis report with measured ground motions by K-Net during NIIGATAKEN-CYUUETSU Earthquake on Oct. 23, 2004

Senior Researcher of Structural Engineering Department
Building Research Institute of Japan
& Visiting Assistant Project Scientist
at Structural Engineering Department,
University of California, San Diego
Koichi KUSUNOKI





(www.jma.go.jp)

(http://www.mainichi-msn.co.jp/shakai/jiken/niigatajishin/etc/ShingenMap.html)

Measured seismic intensities

1 Ground motions studied in this report.

Ten ground motions during the earthquake at 17:56, 10/23/2004 recorded by K-Net, of which PGA were greater than 250 gal, were studied. In this chapter, the data which were presented by K-Net were used without any modification. However, in other chapters, the average value of the record was subtracted from the original data in order to neglect the base-line shift.

The PGAs, which were presented by K-Net, are listed on Table. 1. The time histories of the records are shown in Fig. 1～Fig. 10. The EW components were greater than the NS components except NOJIYA and KASE sites. It can be remarkable that the PGA of OJIYA and KASE exceed 1,000gal. The NS component of NIG021 can be found the "so-called" spike. It can be the reason why the measured PGA was so big. As for other records, any Spike can be found. Relatively long period component can be found in the NIG019 record from the time history.

Table. 1 Peak Ground Accelerations (PGAs) for each record (cm/sec^2)

		Lat. North	Long. East	EW	NS	UD
NIG021	TOKAMACHI	37.12	138.75	849.554	1715.5	564.395
NIG019	OJIYA	37.30	138.79	1307.91	1147.43	820.172
NIG028	NAGAOKA Branch	37.42	138.89	706.447	871.042	435.509
NIG020	KOIDE	37.23	138.97	407.401	521.431	312.136
NIG017	NAGAOKA	37.44	138.85	369.012	468.393	330.974
NIG023	TSUNAMI	37.01	138.66	274.563	397.039	86.4849
GNM003	NUMATA	36.65	139.08	292.507	359.115	126.051
NIG022	SHIOSAWA	37.03	138.85	341.602	342.113	126.512
GNM002	MIZUKAMI	36.78	138.97	279.321	340.904	194.497
NIG012	KASE	37.68	138.48	291.116	236.716	62.9275

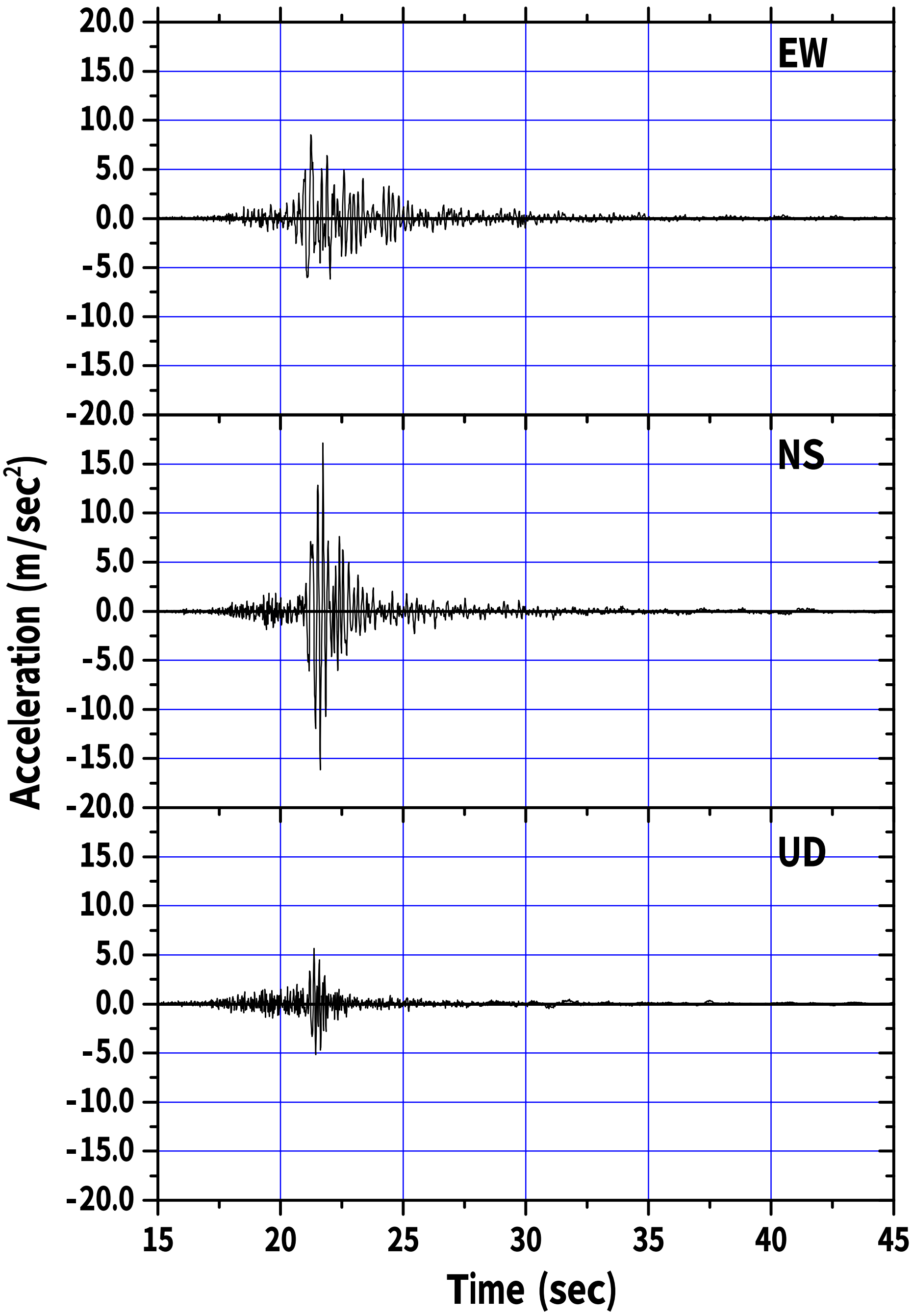


Fig. 1 NIG021 TOKAMACHI

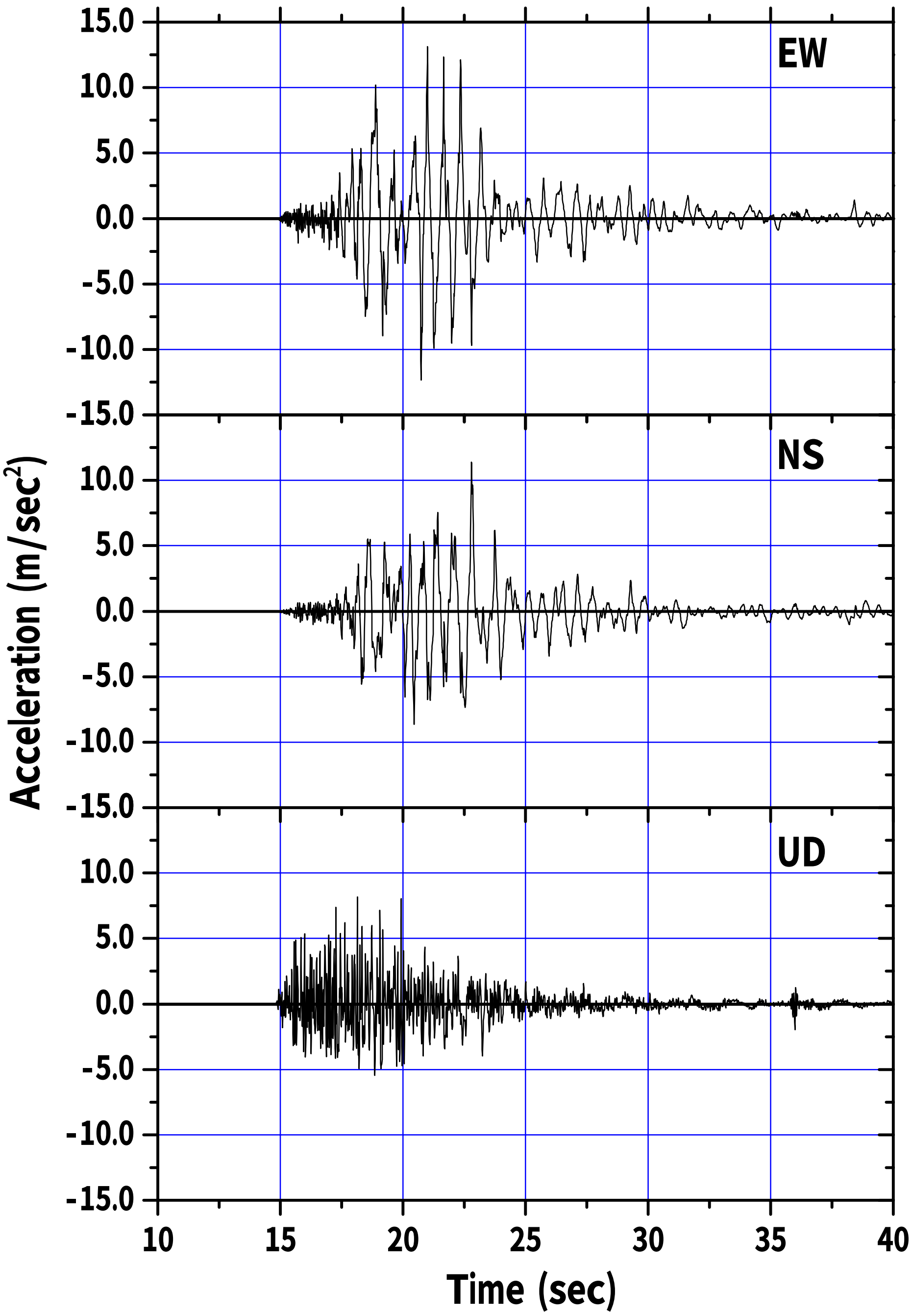


Fig. 2 NIG019 OJIYA

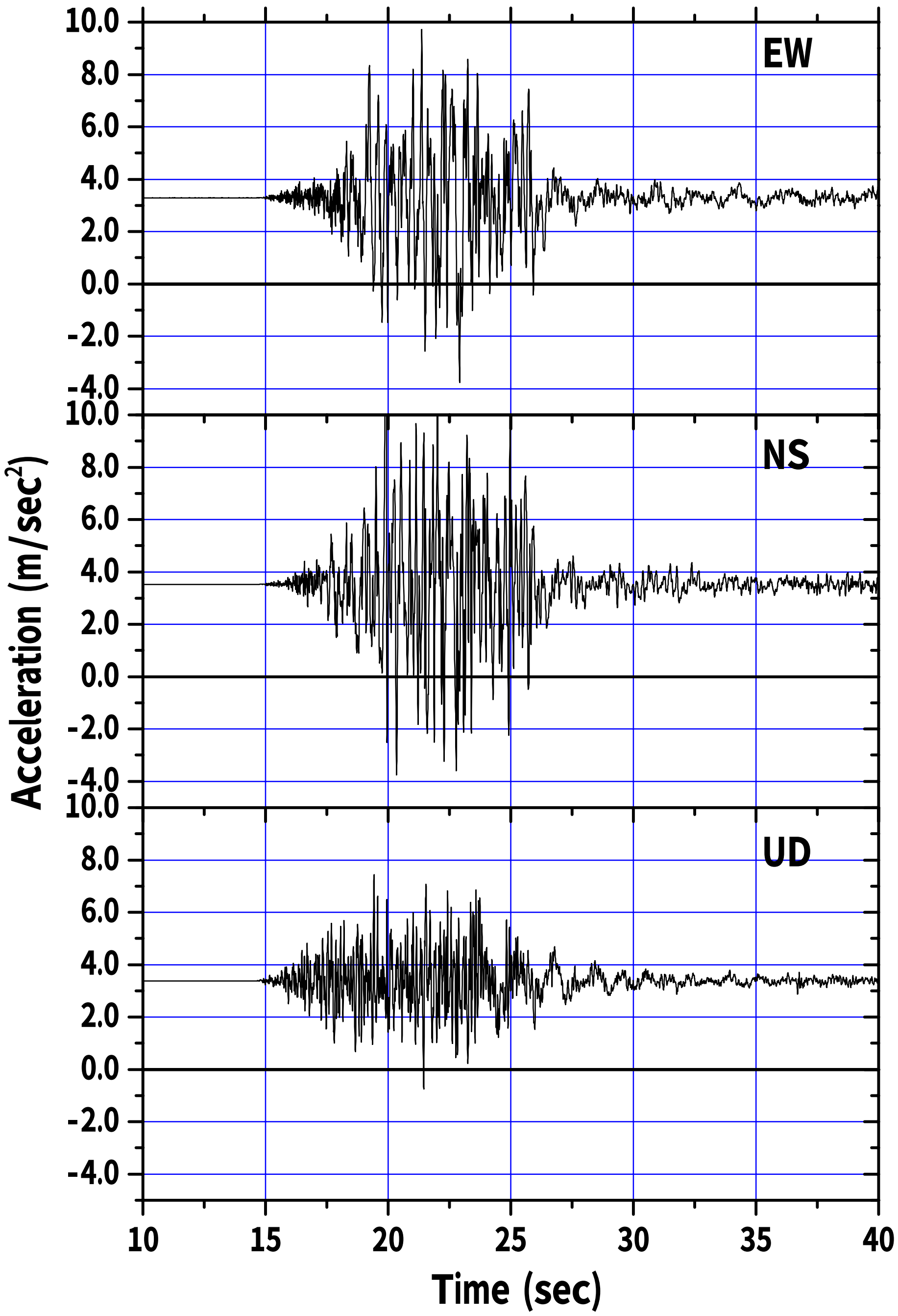


Fig. 3 NIG028 NAGAOKA Branch

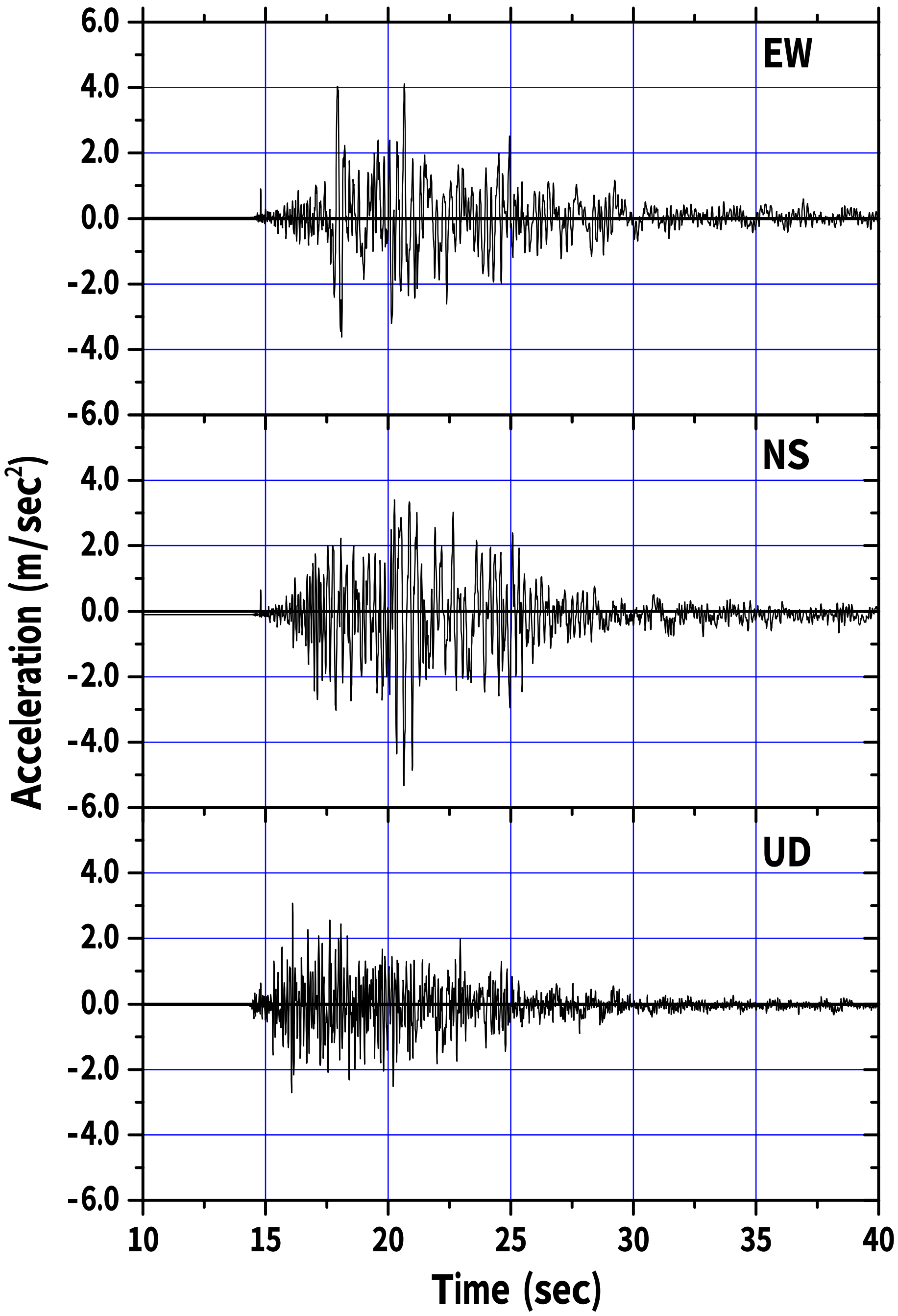


Fig. 4 NIG020 KOIDE

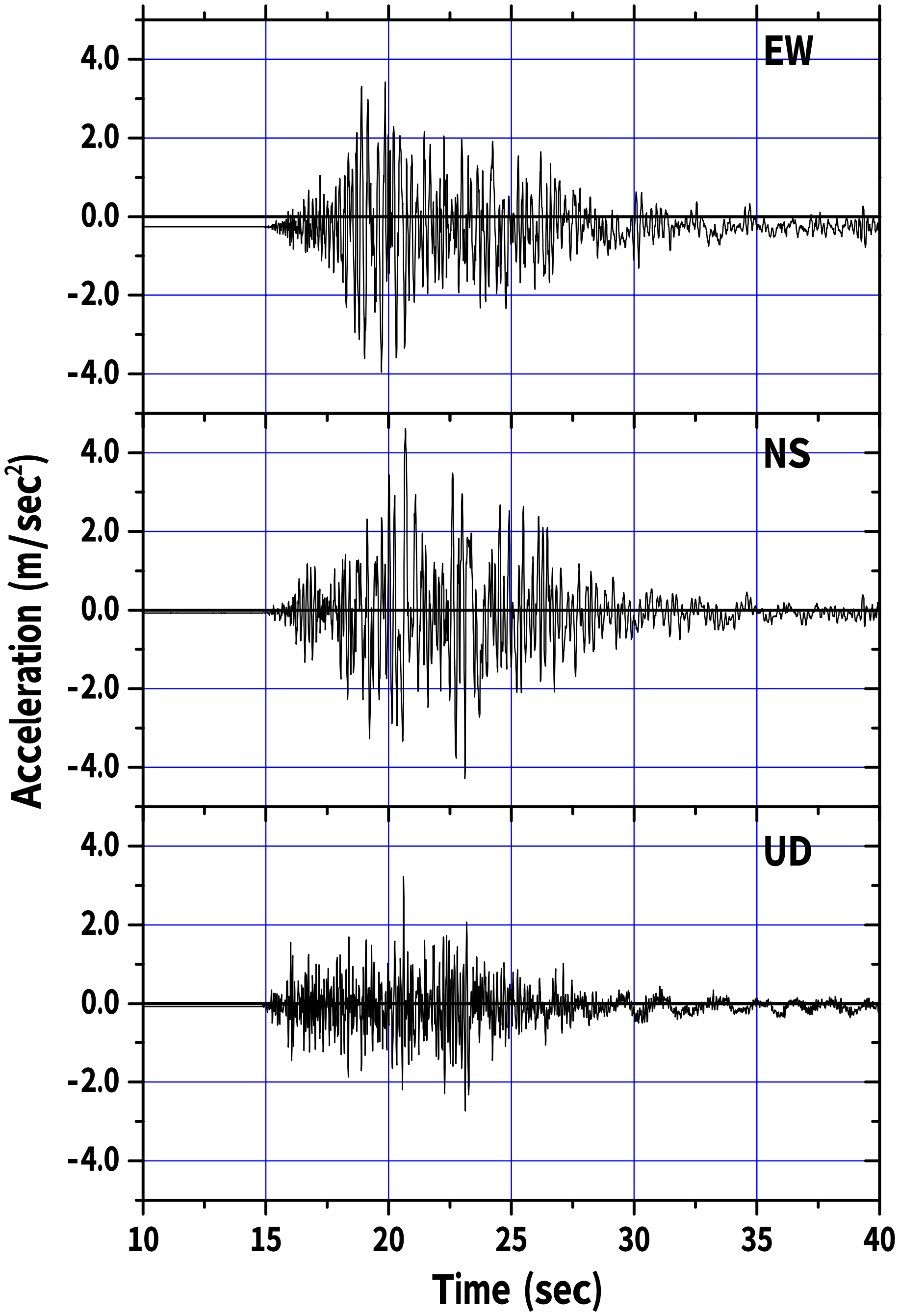


Fig. 5 NIG017 NAGAOKA

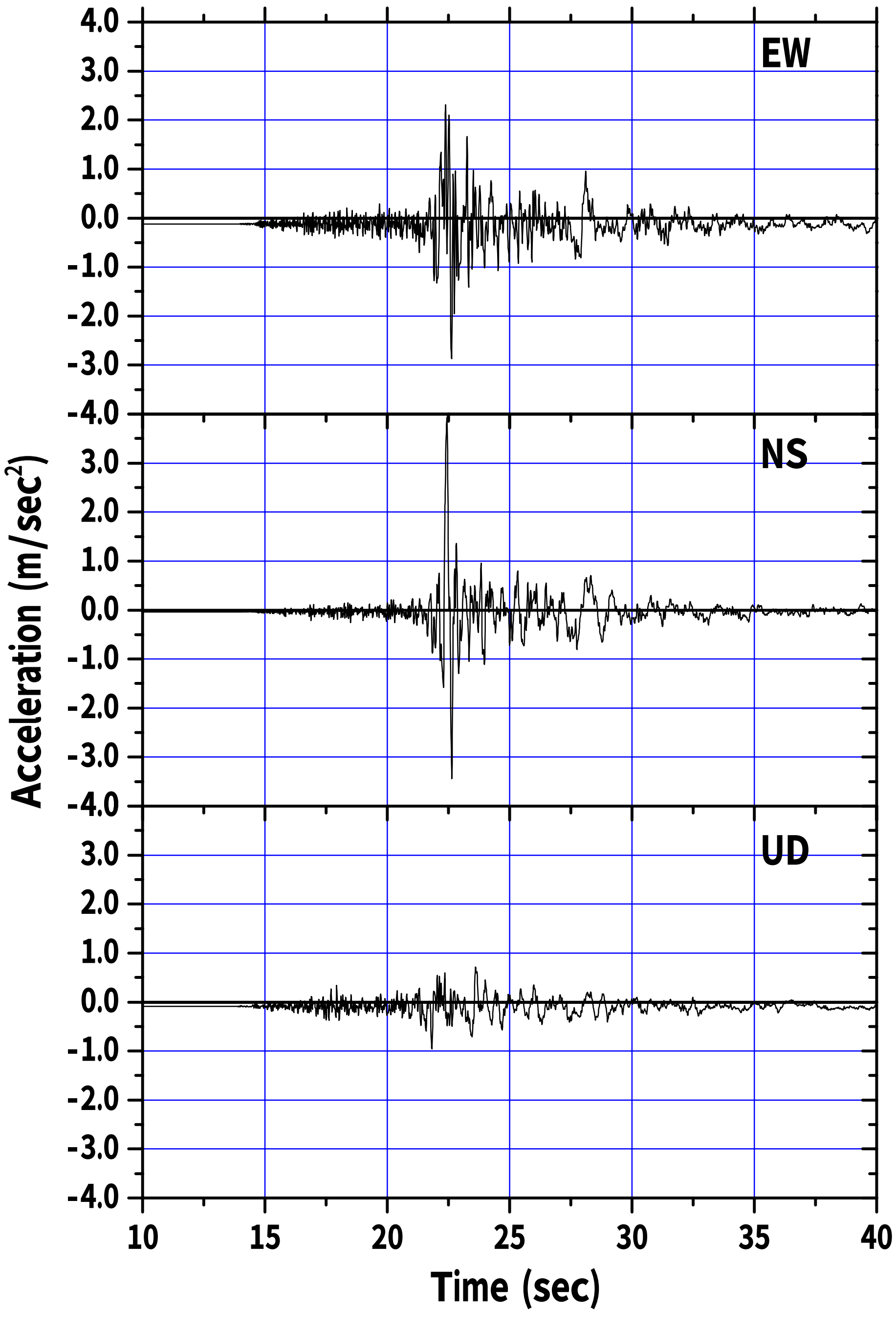


Fig. 6 NIG023 TSUNAMI

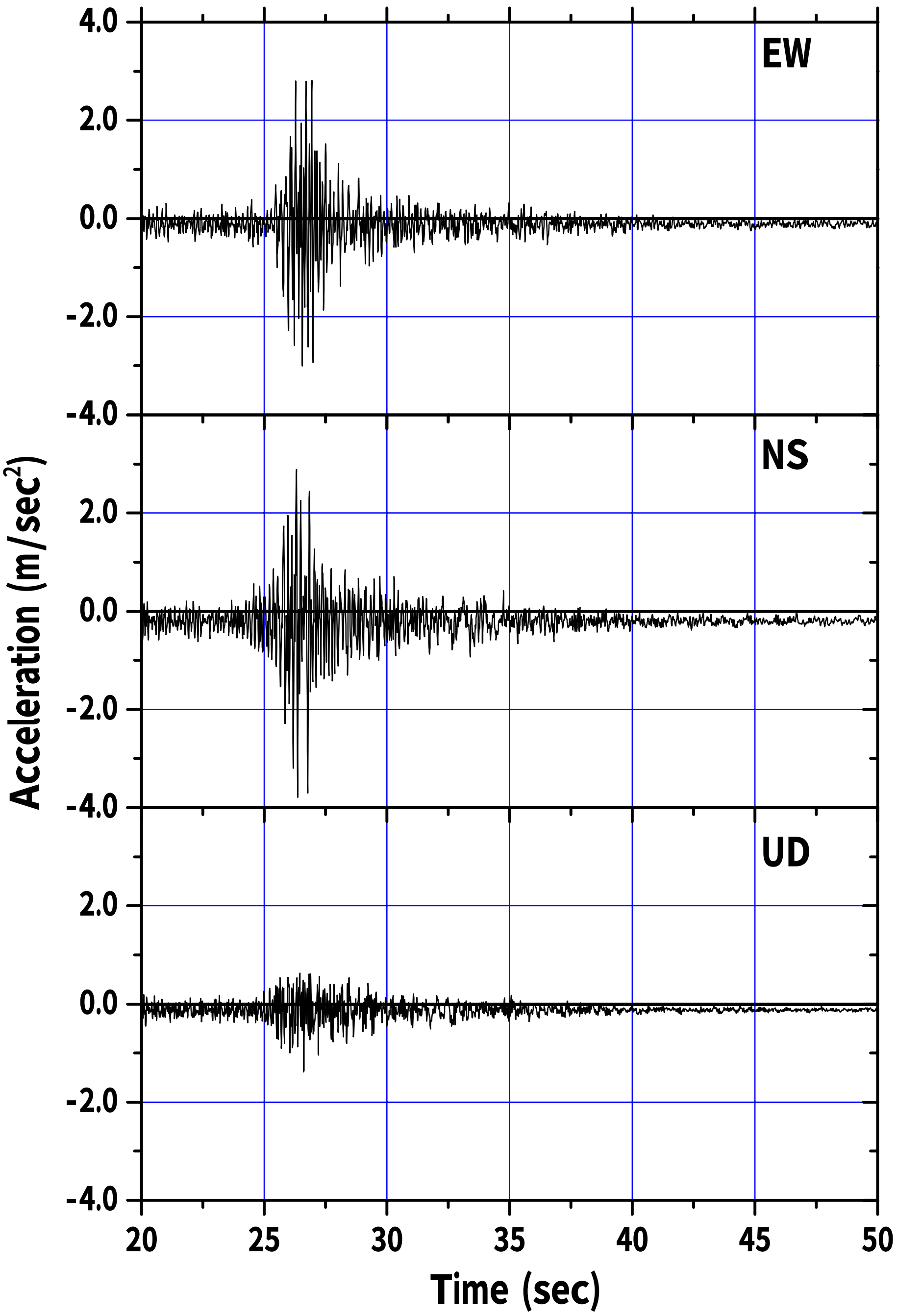


Fig. 7 GNM003 NUMATA

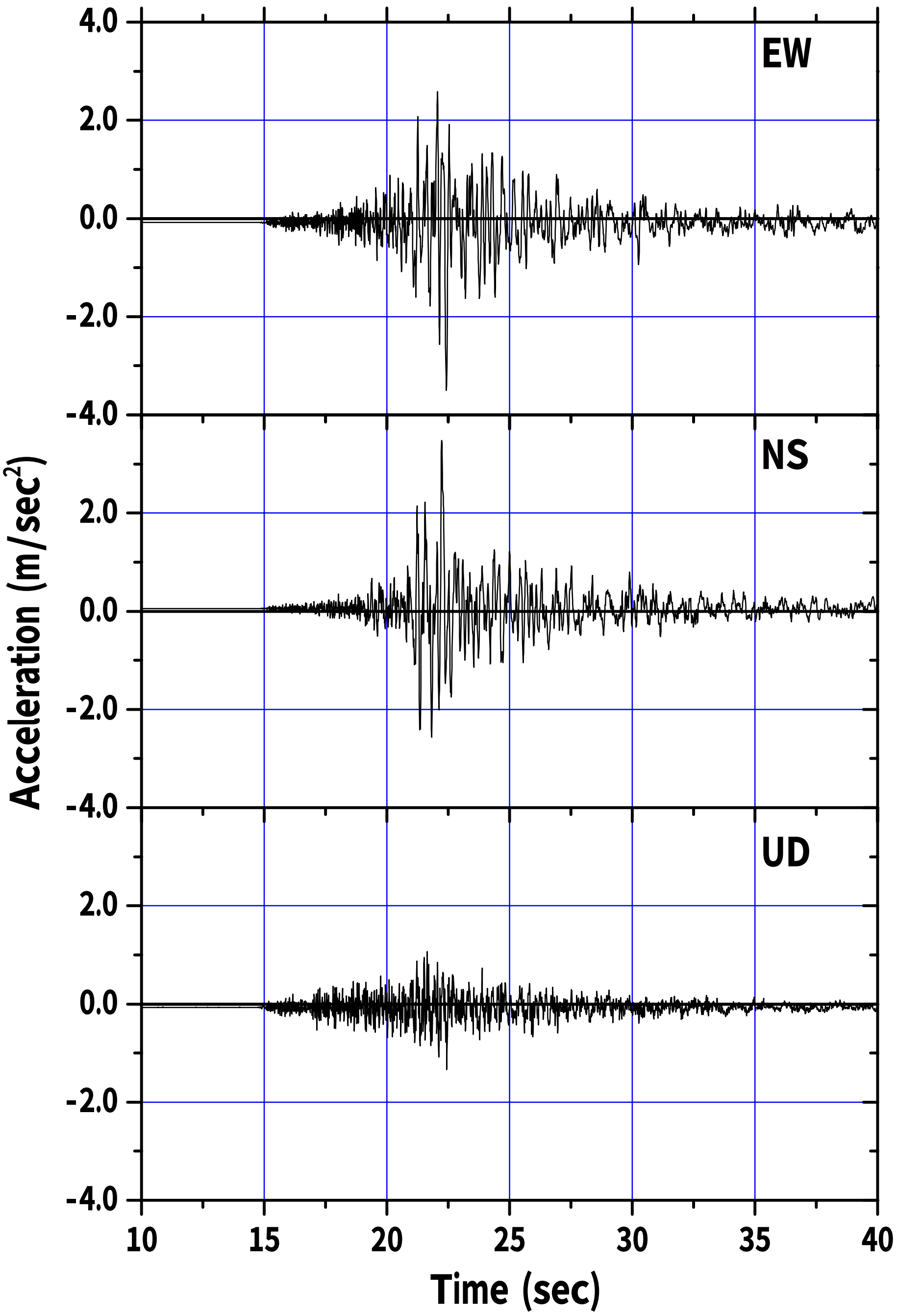


Fig. 8 NIG022 SHIOSAWA

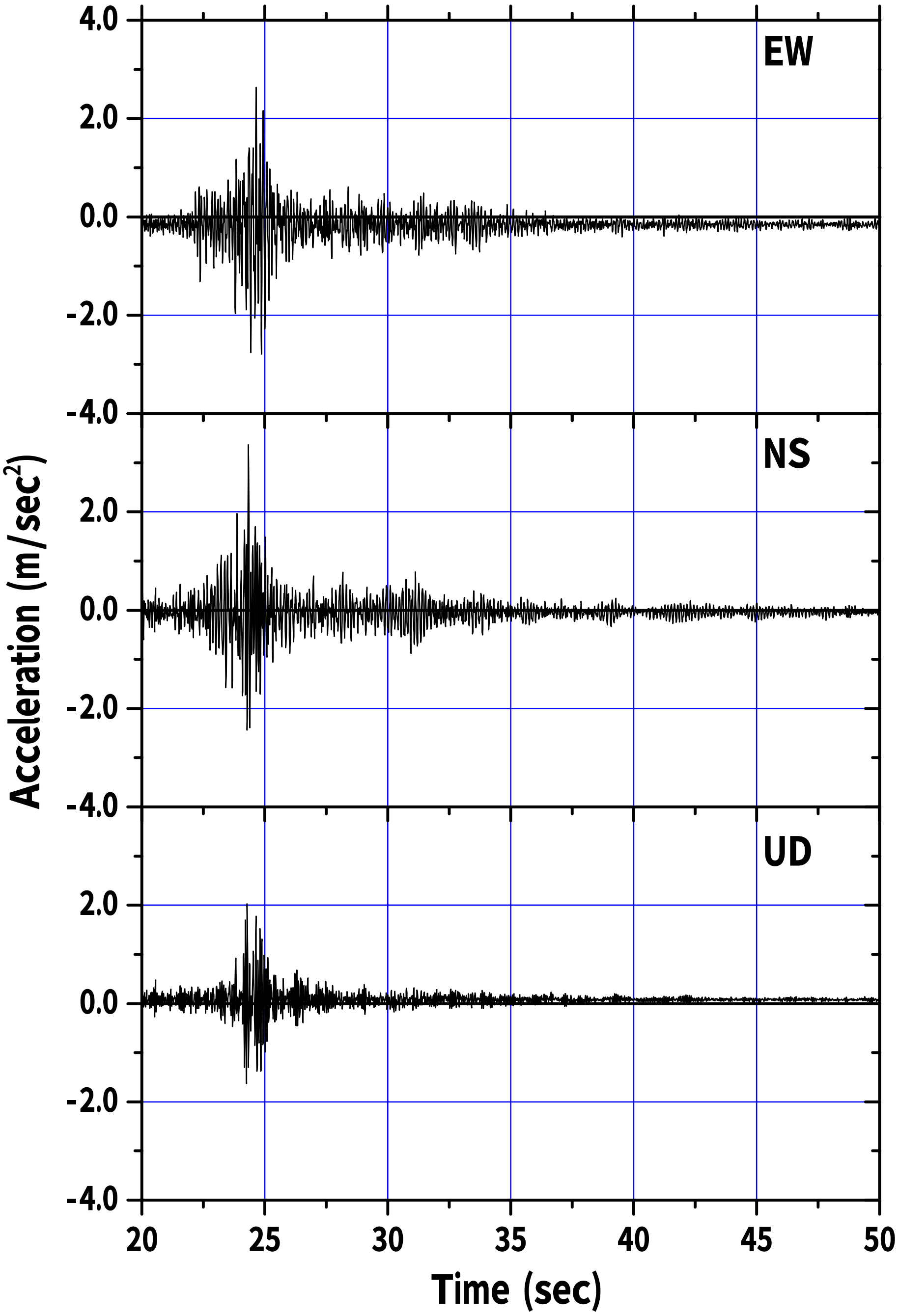


Fig. 9 GNM002 MIZUKAMI

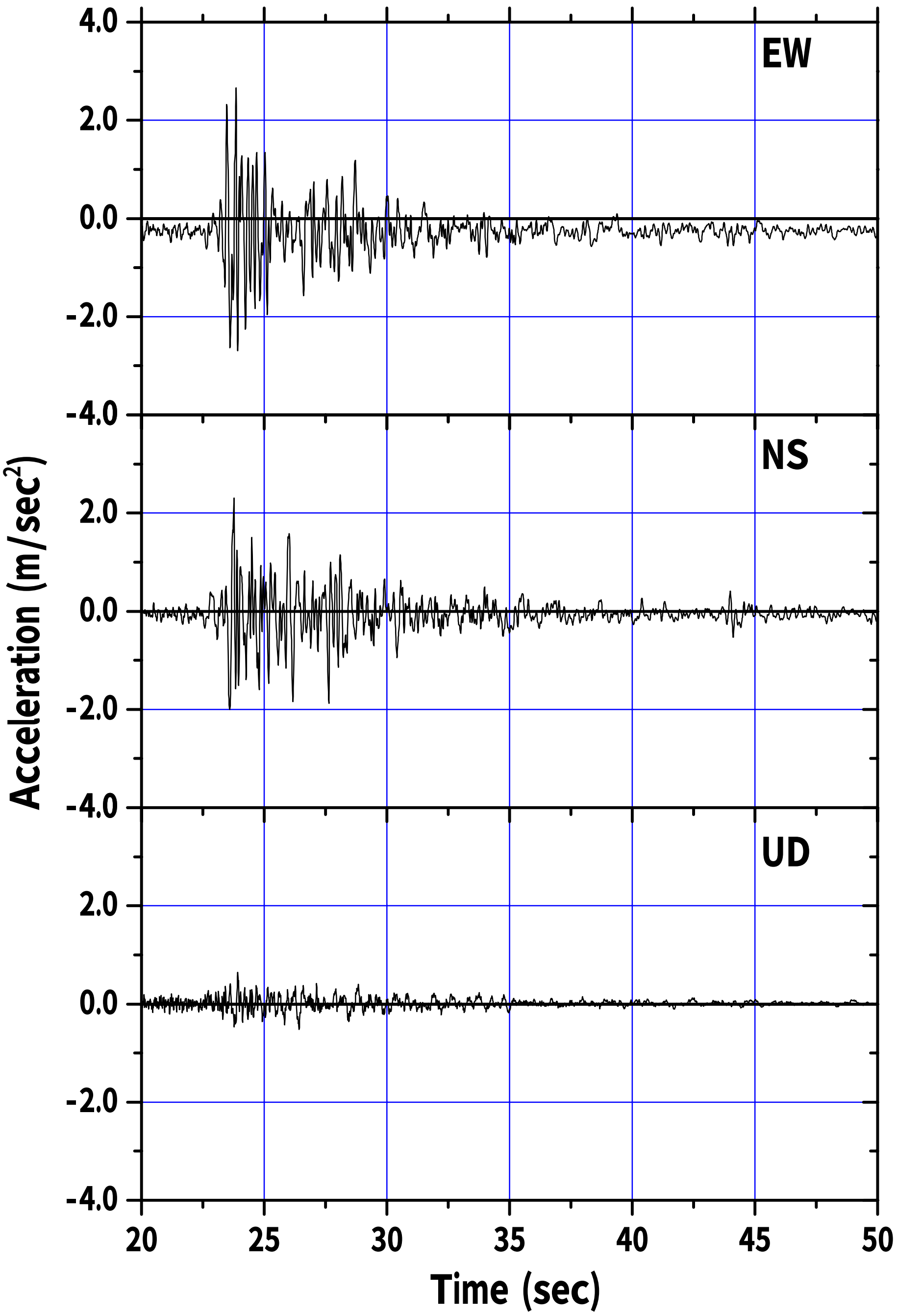


Fig. 10 NIG012 KASE

2 Response Acceleration Spectrum

The calculated response acceleration spectrum of the EW and NS components of 10 records are shown in Fig. 13～Fig. 22. The Rt curve for moderate stiff soil are also superimposed on the figures. The Rt curve show the required elastic response capacity specified in the Japanese Building Code. The value will be reduced with Ds, which is ductility factor. If the structure does not have any eccentricity or vertical irregularity, the Ds can vary from 0.3 to 0.55 according to its ductility.

Moreover, the comparison of TOKAMACHI NS, OJIYA EW, NAGAOKA NS, KOIDE NS, of which response acceleration were very large, and JMA KOBE and the record at KPI (Kobe Port Island, artificial land) during KOBE earthquake, is shown in Fig. 11. The Fig. 12 shows the comparison between OJIYA EW and JMA KOBE and KPI. The Rt curves for very stiff, moderate stiff and soft soil conditions were superimposed on the figure.

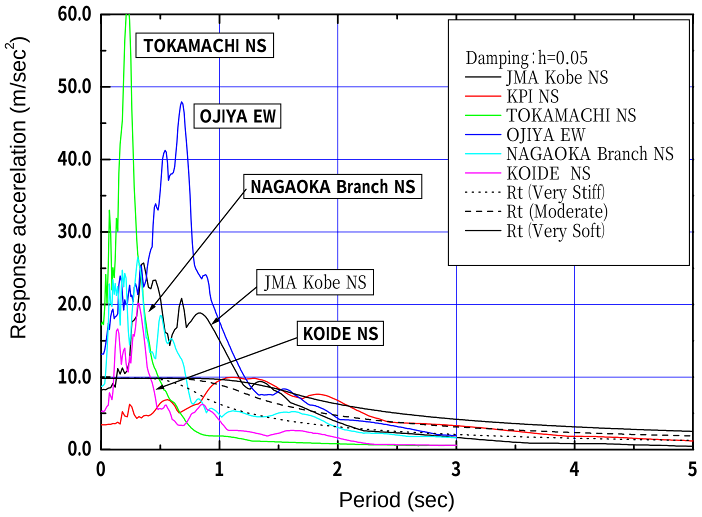


Fig. 11 Comparison of 4 records, JMA KOBE and KPI

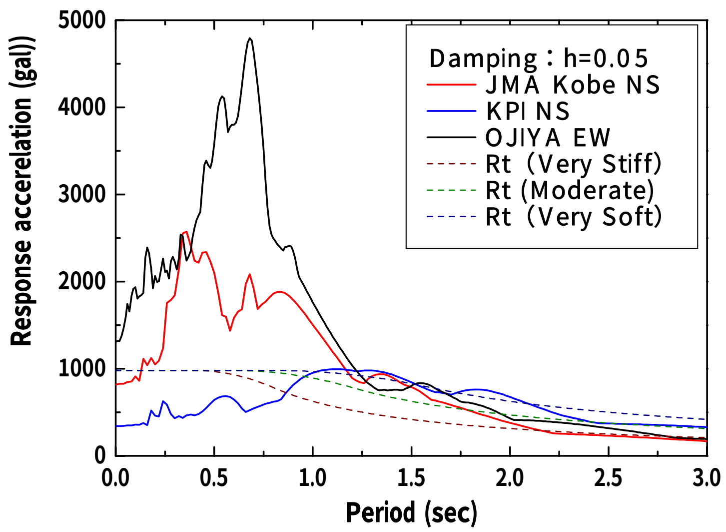


Fig. 12 Comparison of NIG019 OJIYA, JMA KOBE and KPI

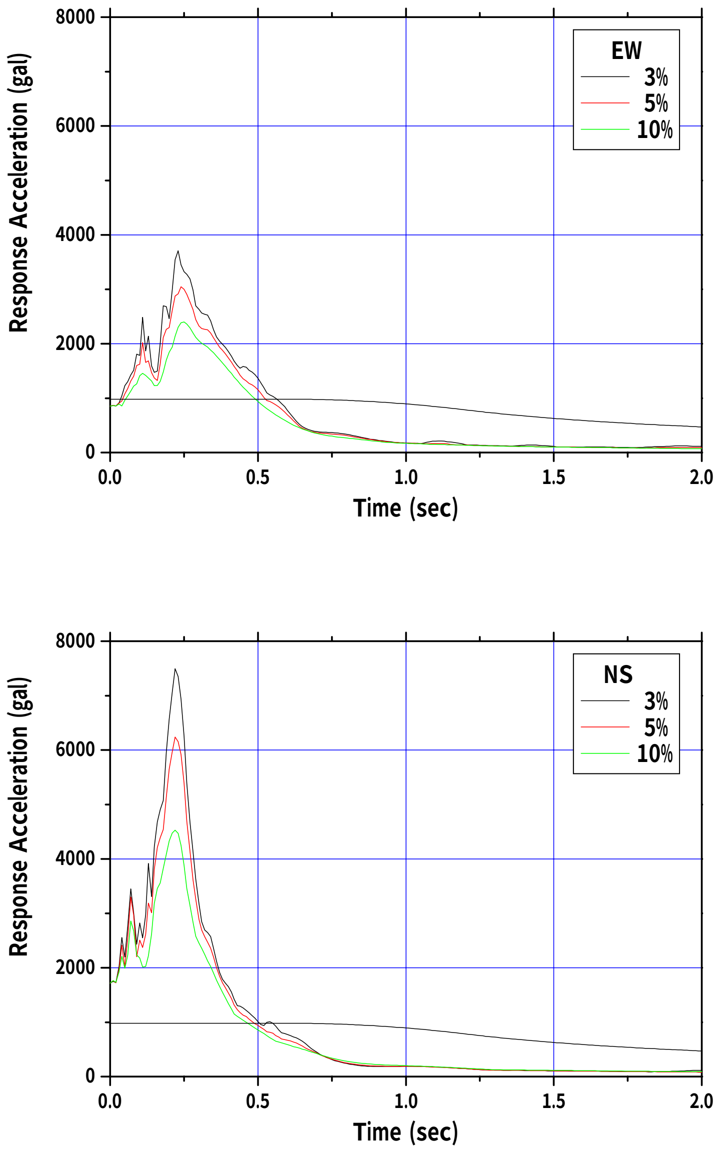


Fig. 13　NIG021 TOKAMACHI

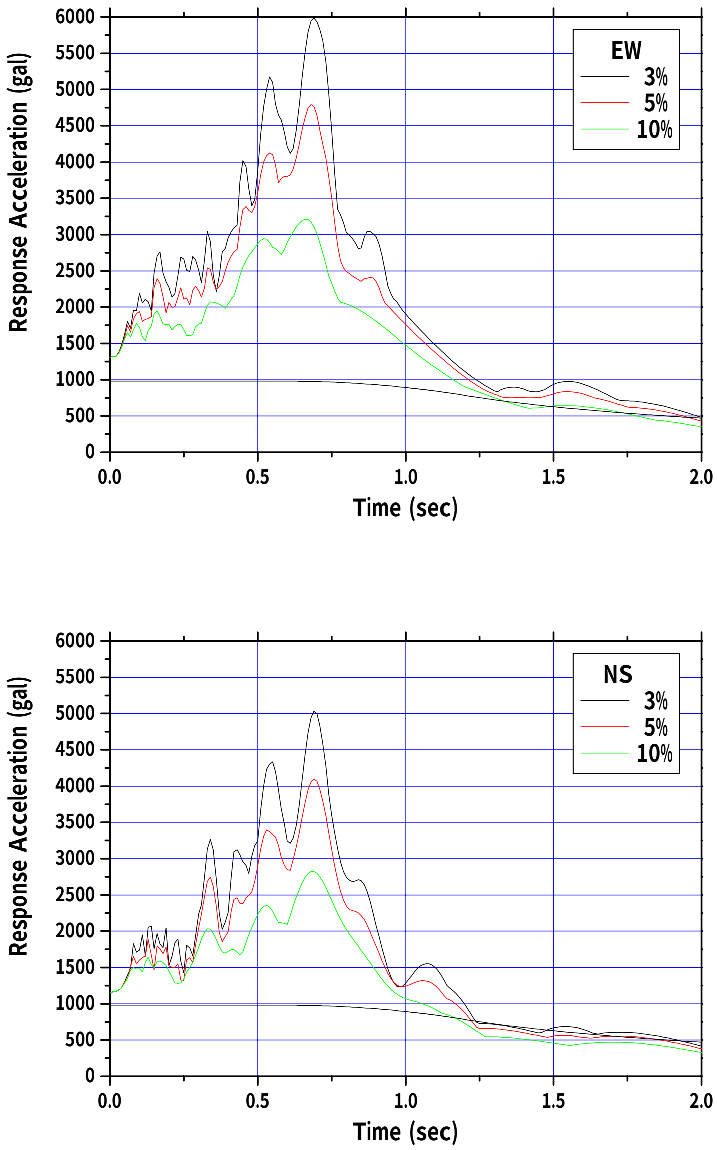
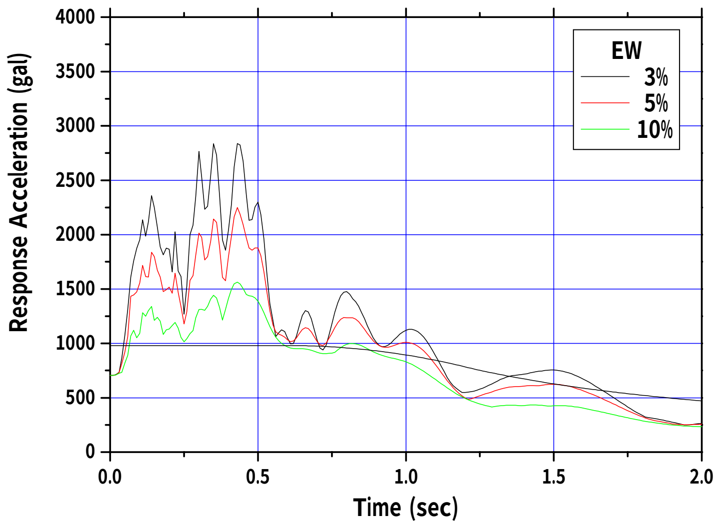


Fig. 14　NIG019 OJIYA



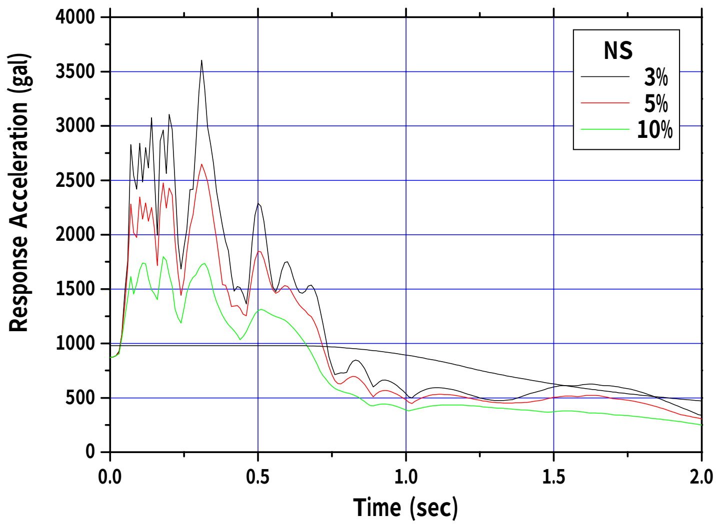


Fig. 15 NIG028 NAGAOKA Branch

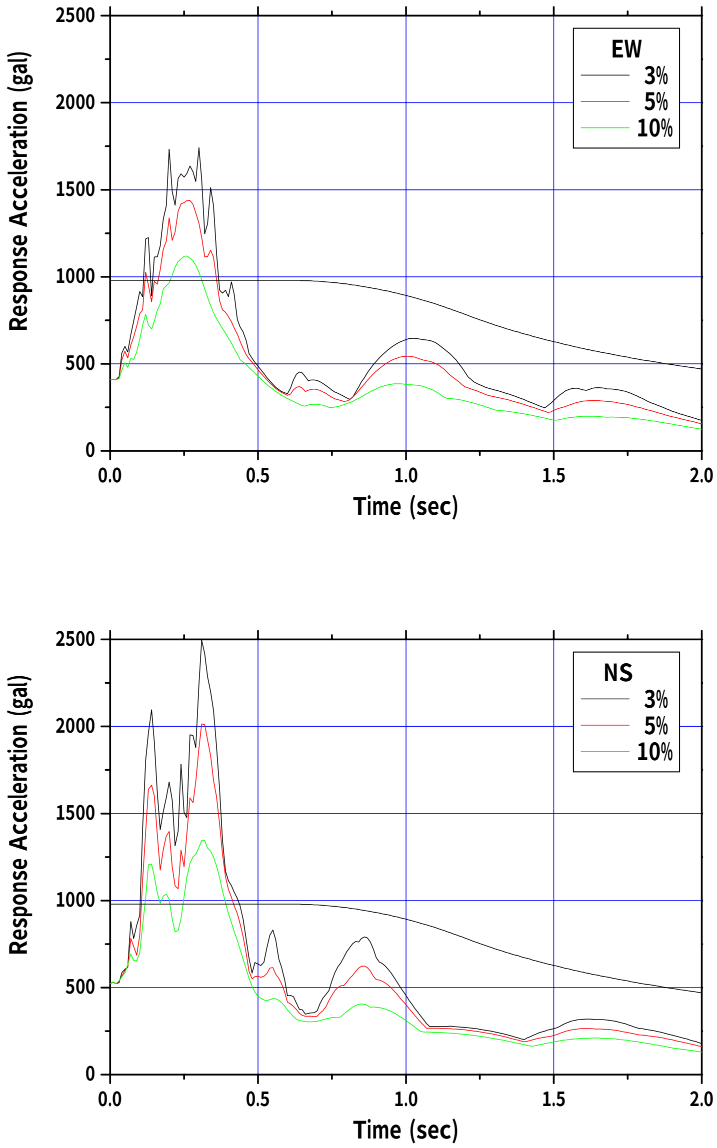


Fig. 16　NIG020 KOIDE

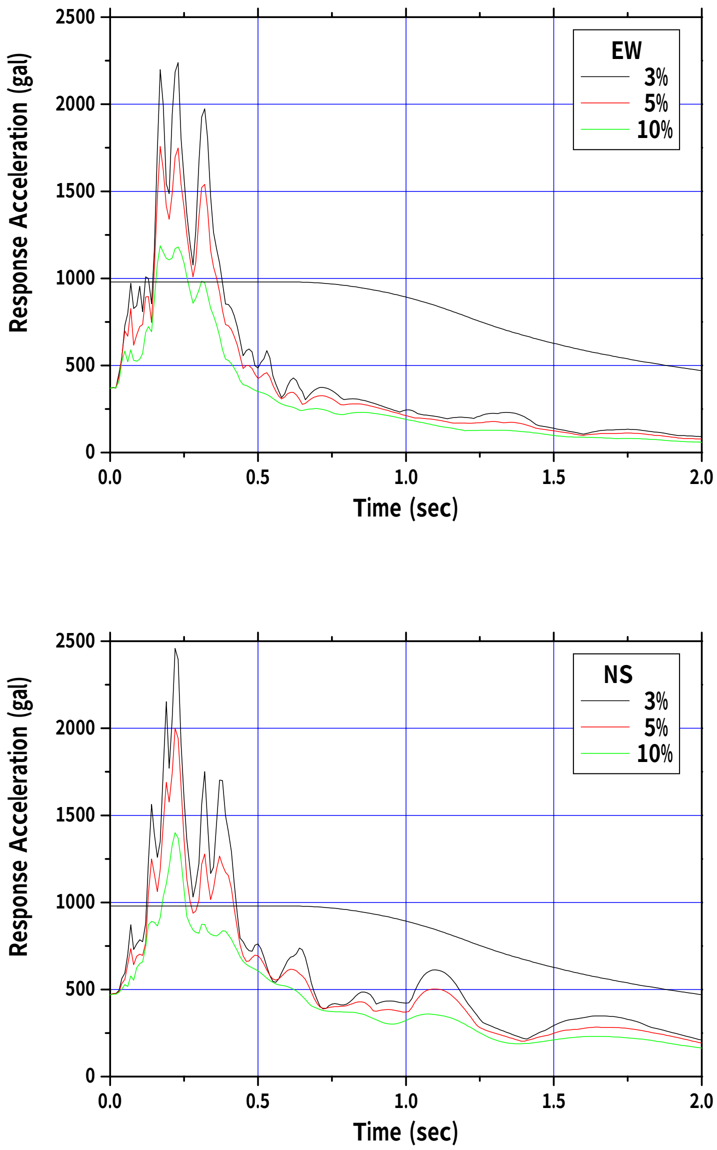


Fig. 17　NIG017 NAGAOKA

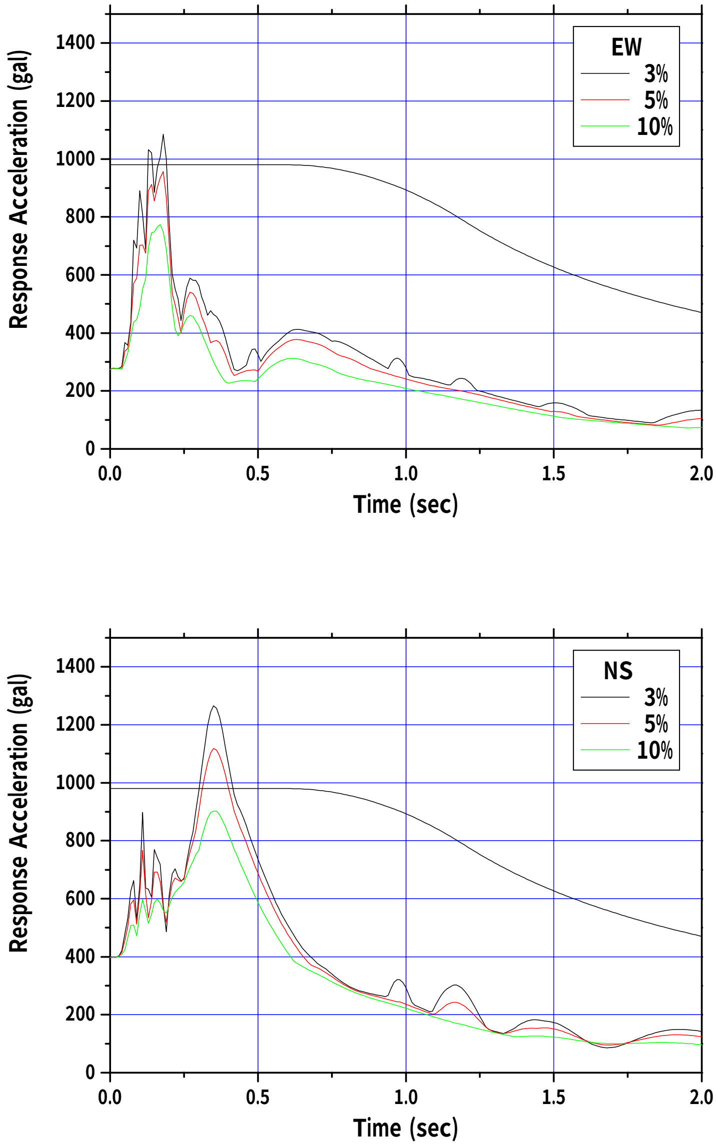


Fig. 18　NIG023 TSUNAMI

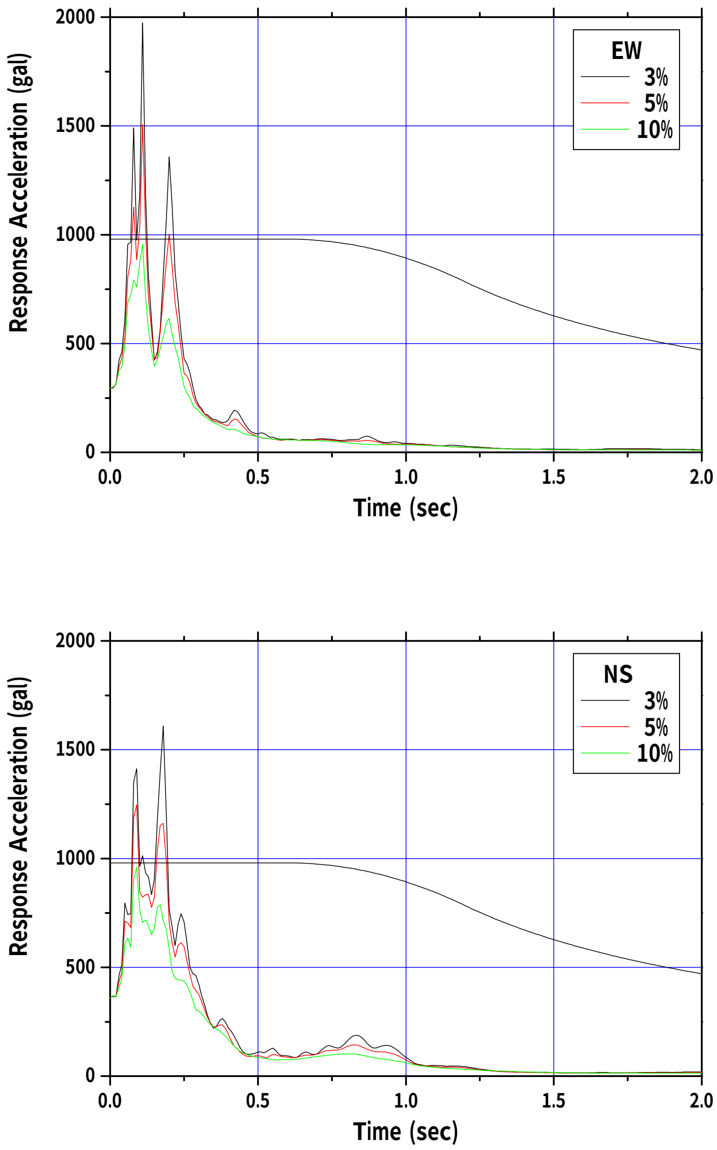


Fig. 19　GNM003 NUMATA

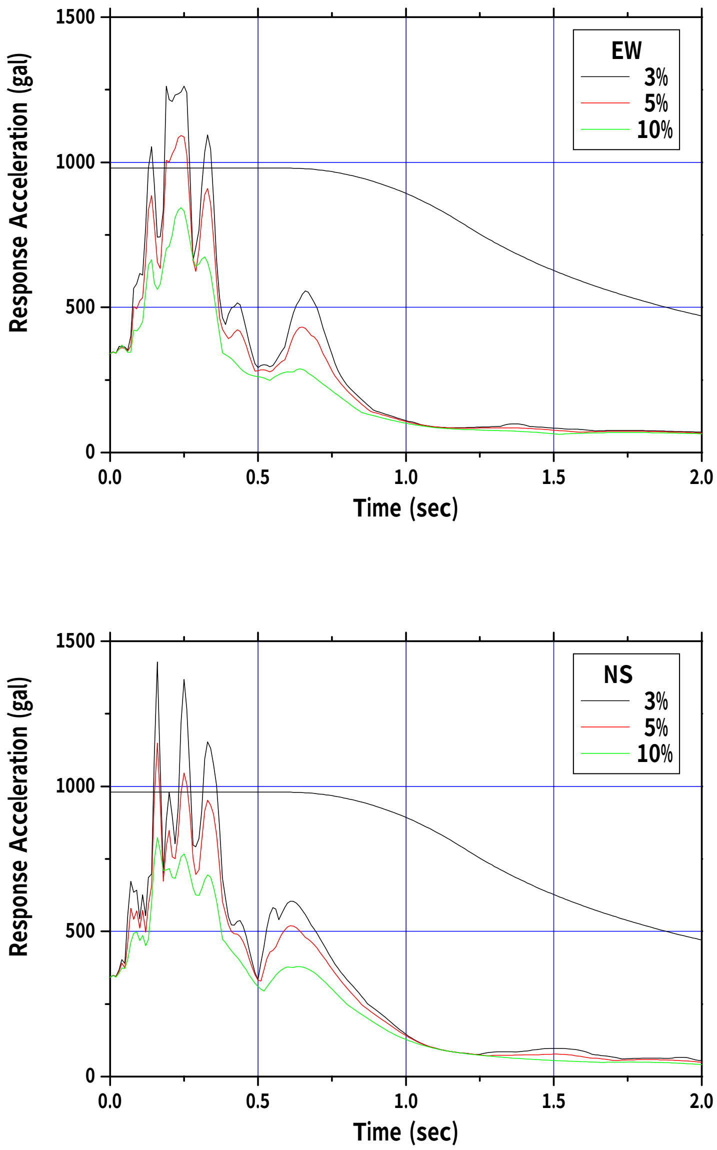
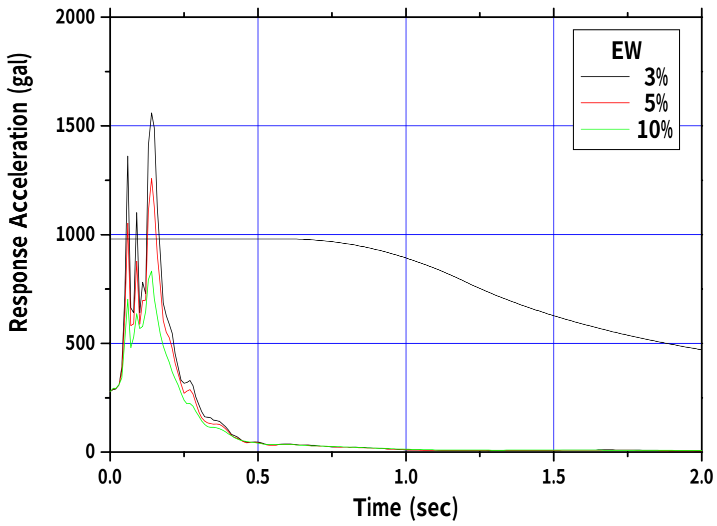


Fig. 20　NIG022 SHIOSAWA



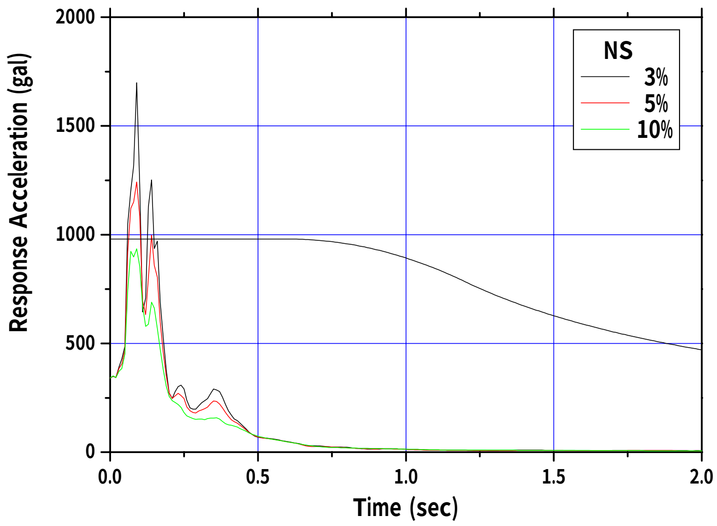
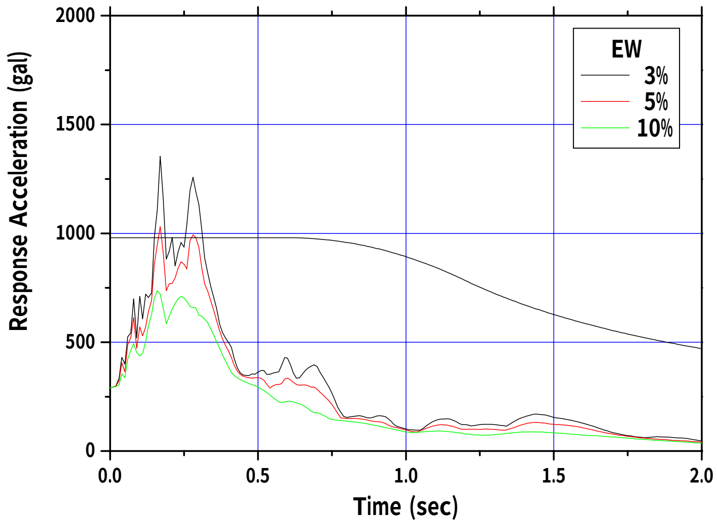


Fig. 21　GNM002 MIZUKAMI



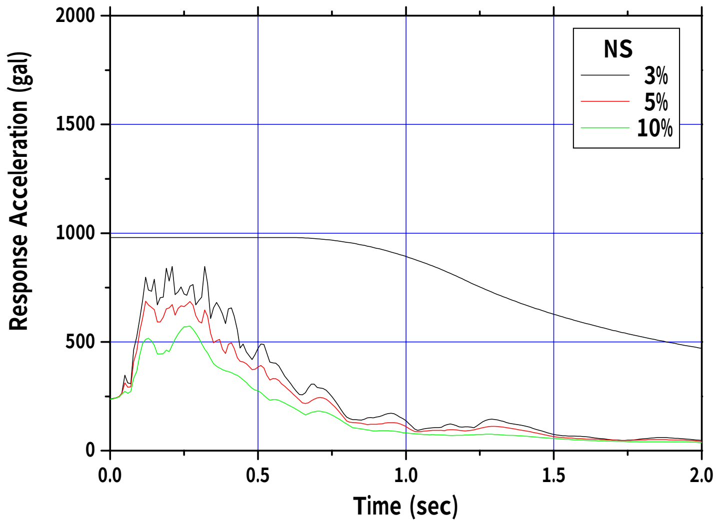


Fig. 22 NIG012 KASE

3 Demand Spectrum

In this chapter, the damage characteristics were studied with demand spectrum, which is defined in the Japan Building Code revised in 2000. The vertical axis and horizontal axis for the demand curve is response acceleration and displacement spectrum, respectively. The slope of the figure is related to the period of the structure. The demand spectrum with 5% and 10% damping are shown in Fig. 25 to Fig. 34. The demand spectrum defined in the Japan Building Code for moderate soil condition was also superimposed on the figures. The upper horizontal axis shows the deflection angle of the structure, of which story height and equivalent height were assumed as 3m and half of the total height, respectively. The actual deflection angle can be calculated as the value of the upper horizontal axis divided by 100N (N: Number of stories).

The Fig. 23 and Fig. 24 show the demand spectrum of TOKAMACHI NS, OJIYA EW NAGAOKA Branch EW and KOIDE NS with 5% and 10% damping. The skeleton curve of the structure, which has elastic period of 0.3 sec and designed with Ds of 0.5 was superimposed on the figures. Moreover, in order to take the effect of small cracks into account, the skeleton curve when the stiffness degrading factor of 0.5 is considered, was also superimposed.

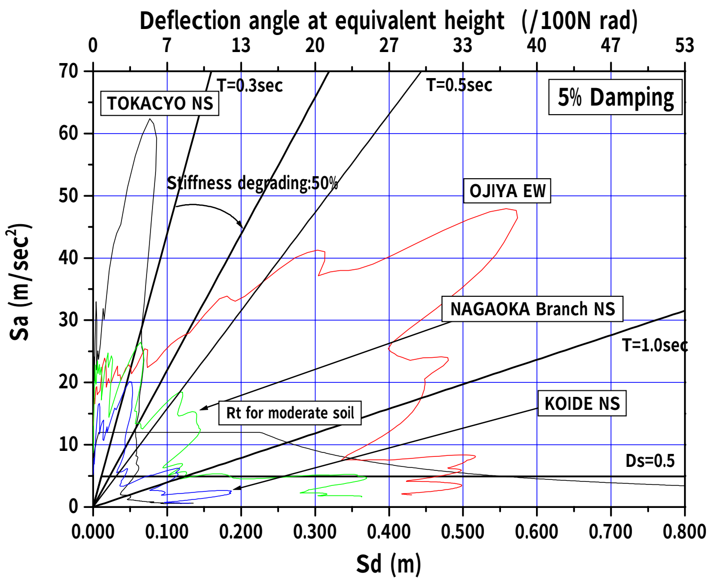


Fig. 23 Comparison at 5% damping

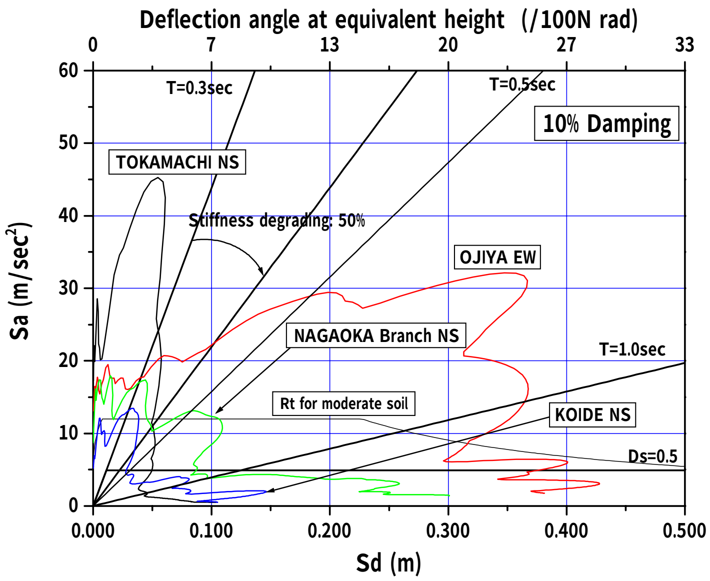
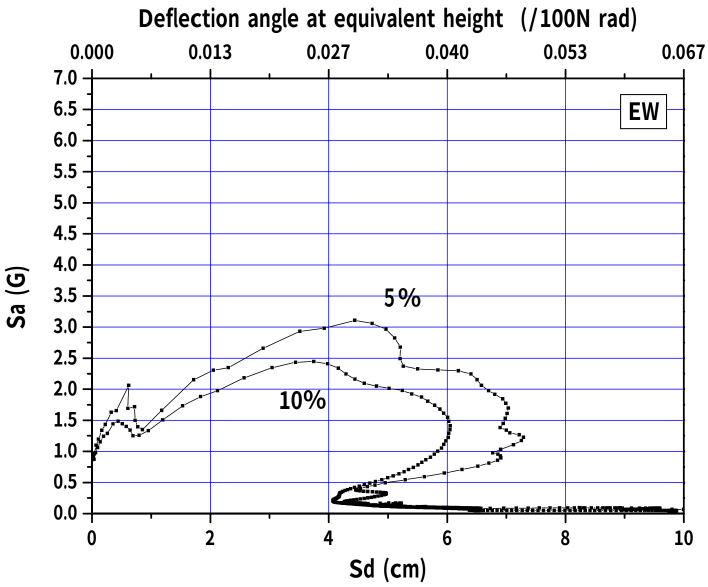


Fig. 24 Comparison at 10% Damping



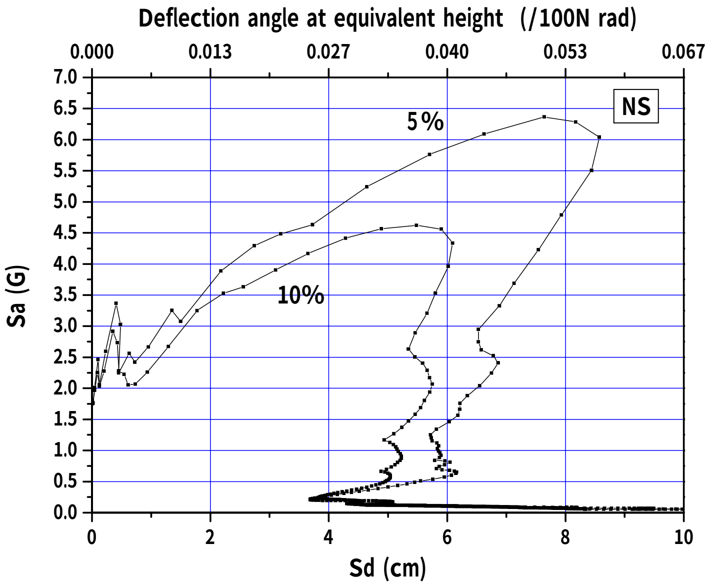
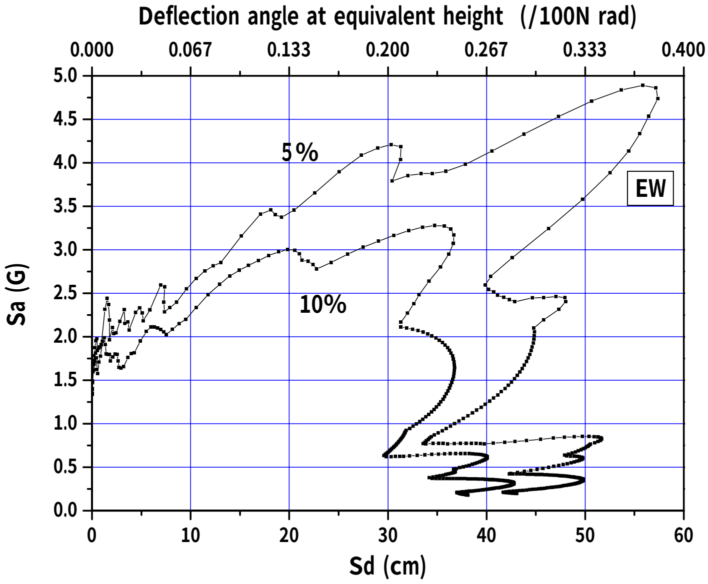


Fig. 25 NIG021 TOKAMACHI



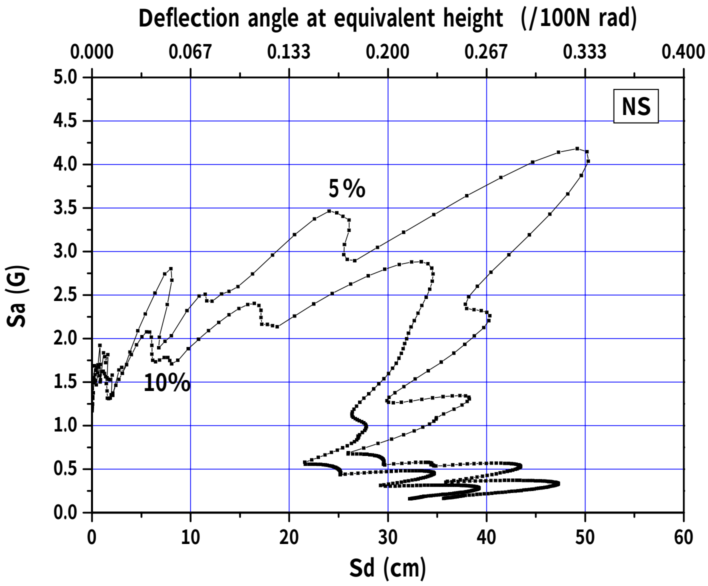
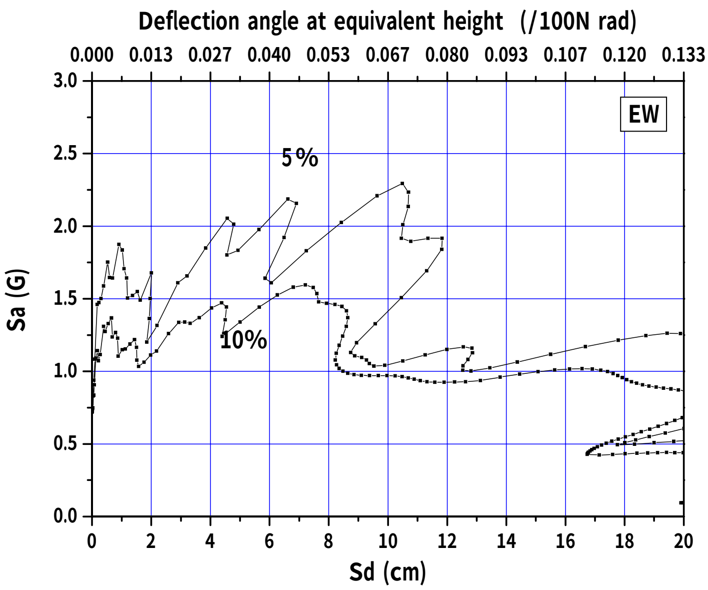


Fig. 26 NIG019 OJIYA



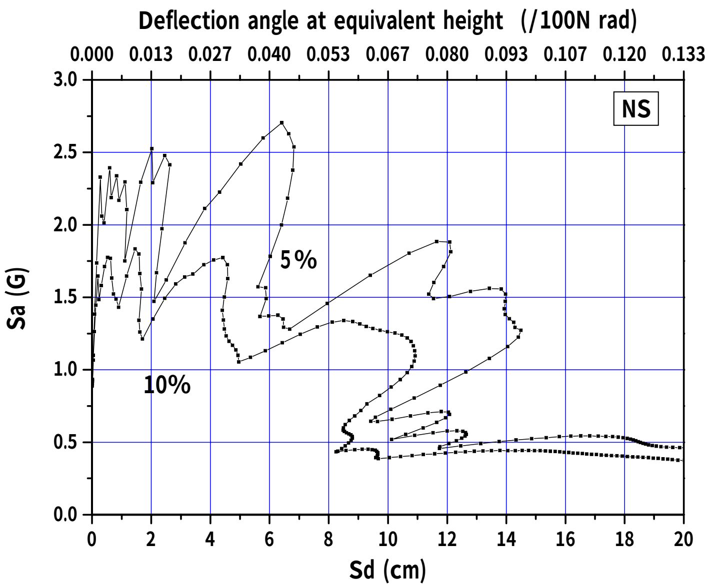
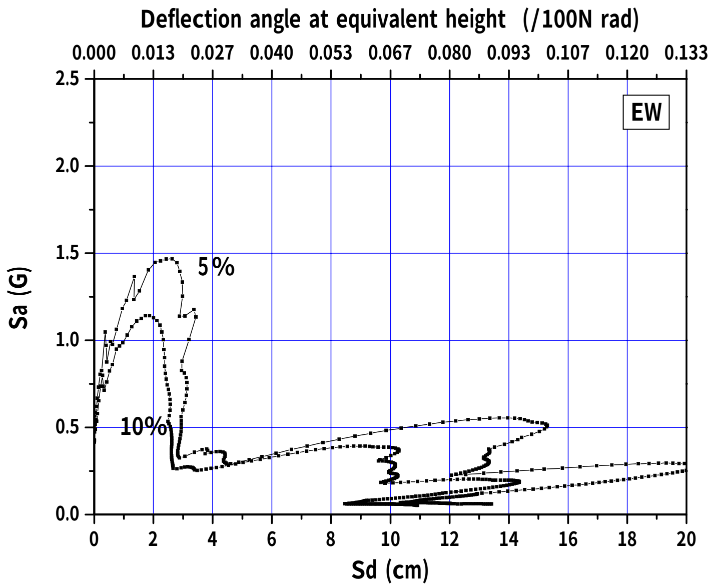


Fig. 27 NIG028 NAGAOKA Branch



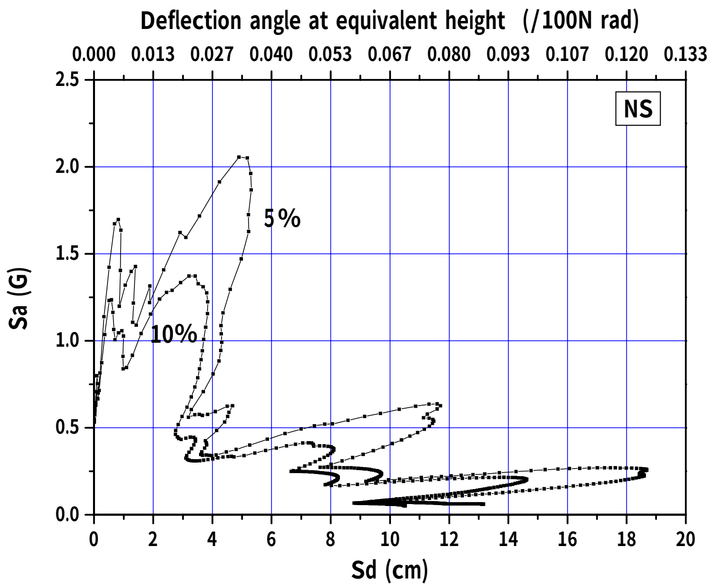
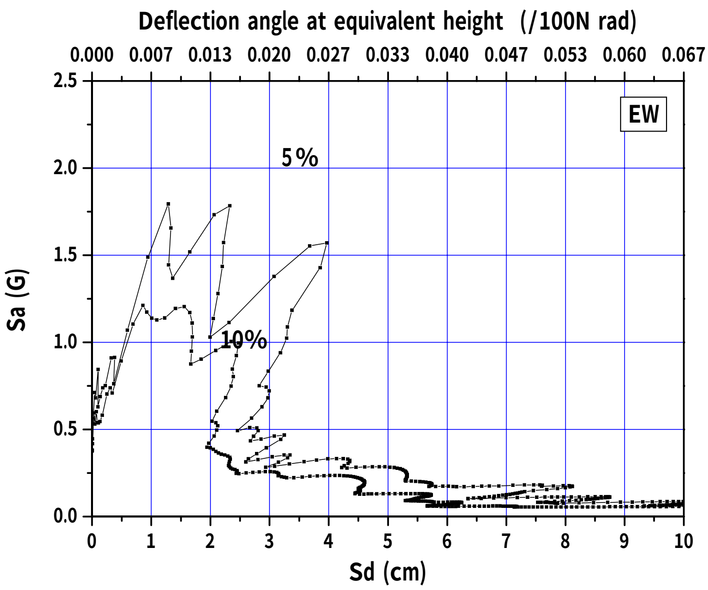


Fig. 28 NIG020 KOIDE



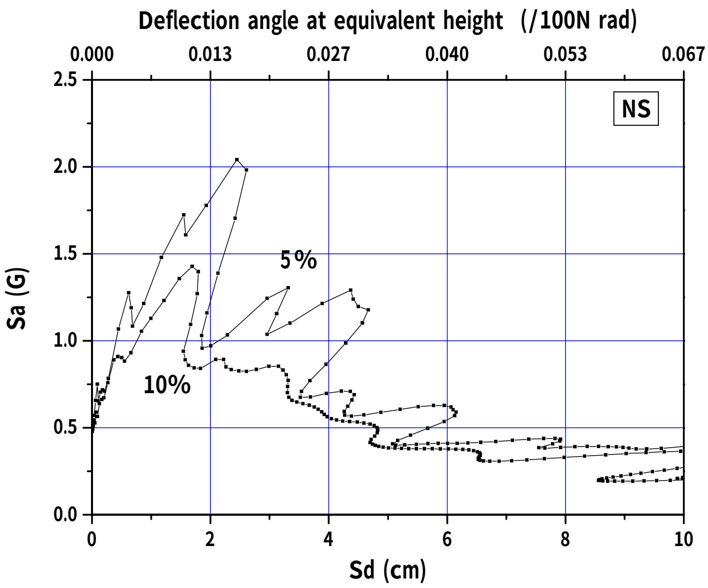
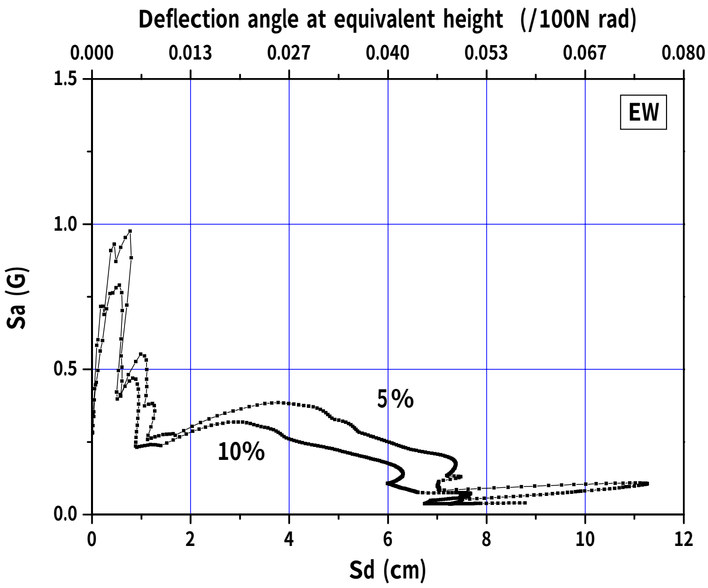


Fig. 29 NIG017 NAGAOKA



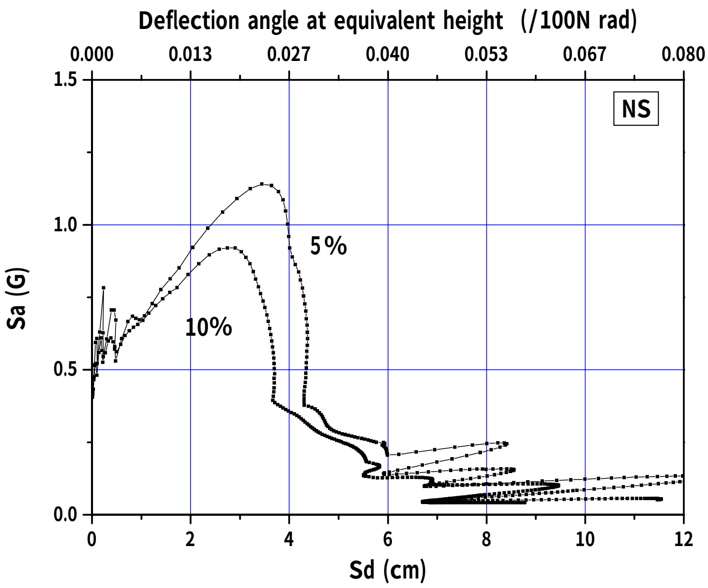
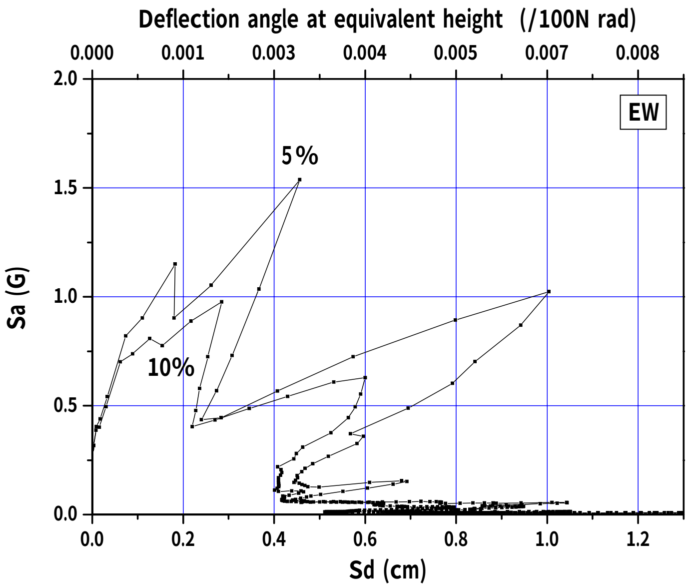


Fig. 30 NIG023 TSUNAMI



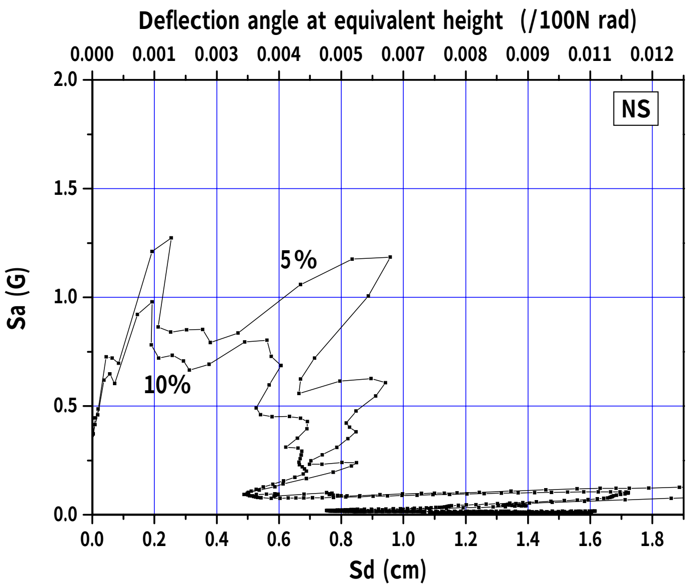
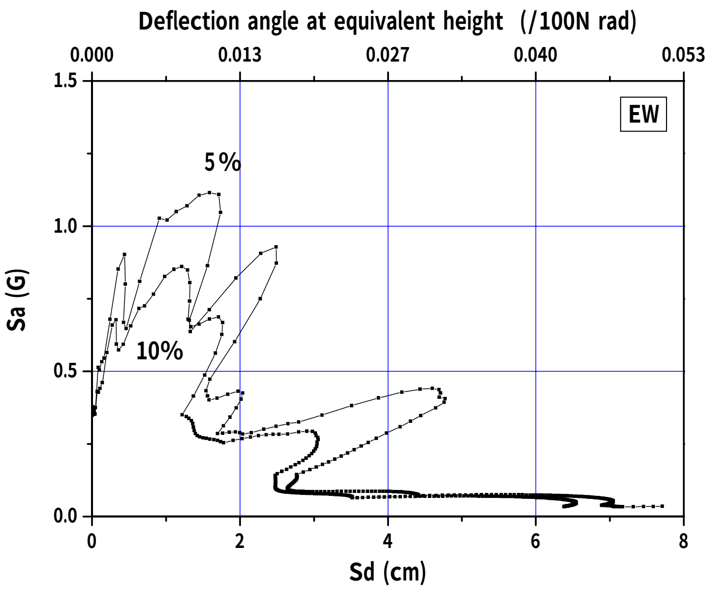


Fig. 31 GNM003 NUMATA



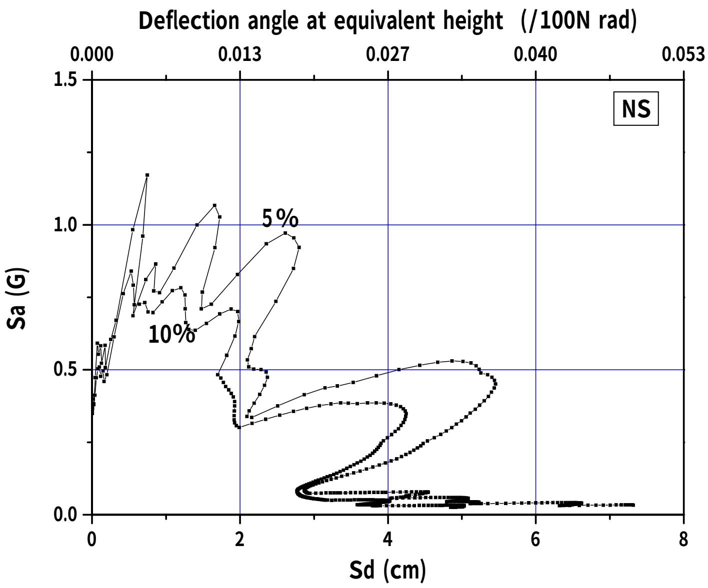
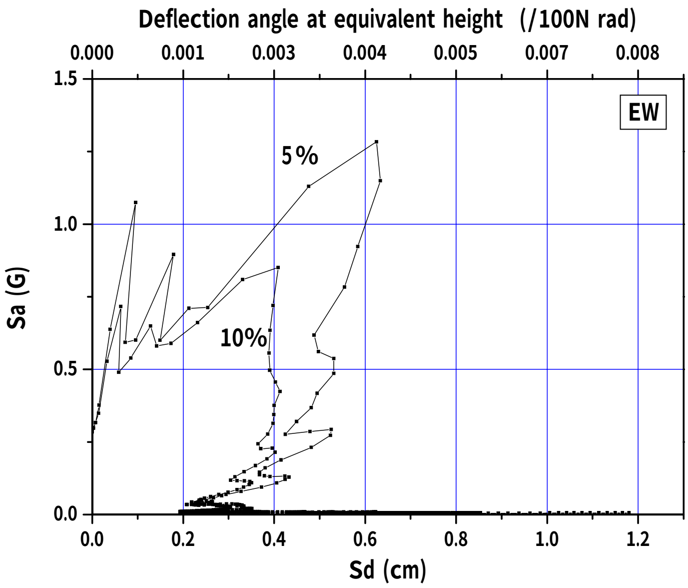


Fig. 32 NIG022 SHIOSAWA



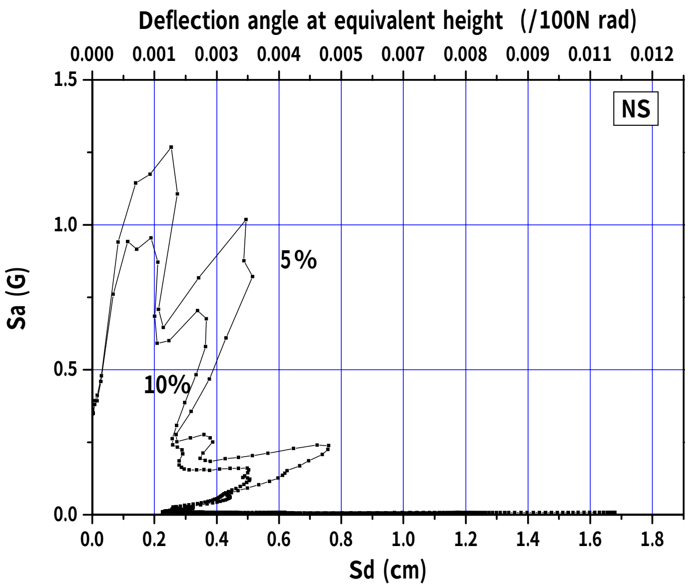
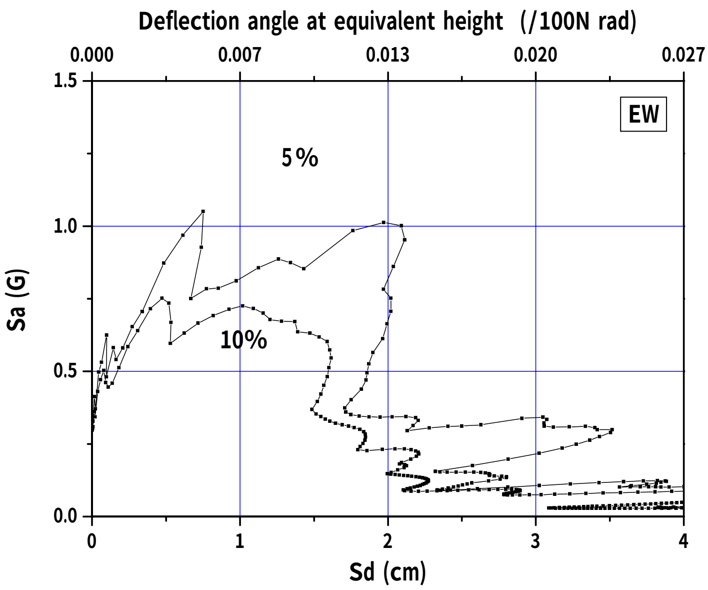


Fig. 33 GNM002 MIZUKAMI



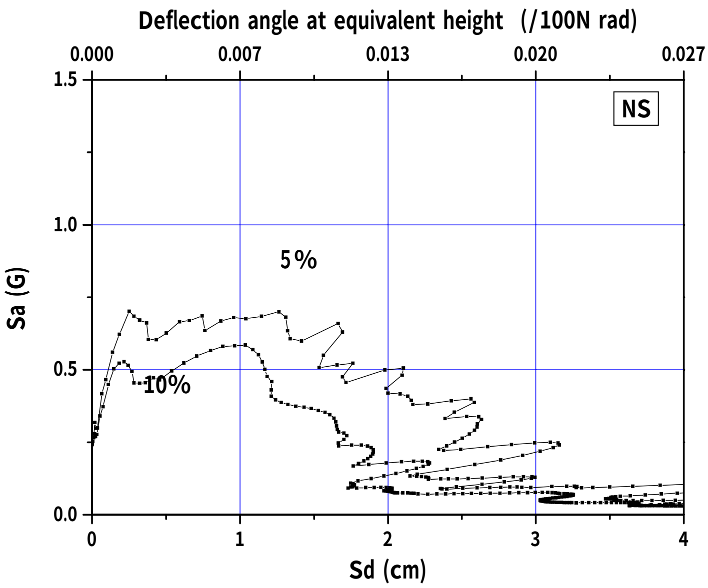


Fig. 34 NIG012 KASE

4 Energy spectrum

Fig. 35 shows the input energy velocity corresponding value ($V_E = \int \ddot{x}_0 \cdot \dot{x} dt$) for TOKAMACHI NS, OJIYA EW, NAGAOKA Branch NS, and KOIDE NS. The duration time of 100sec was applied.

The amount of energy dissipation due to elastic response can be calculated as follows.

$$\frac{1}{2}(M \cdot C_B \cdot G) \cdot \delta_y = \frac{1}{2}(M \cdot C_B \cdot G) \cdot \frac{(M \cdot C_B \cdot G)}{K} = \frac{1}{2} M \cdot \frac{M}{K} \cdot (C_B \cdot G)^2$$

Where, M : Mass, C_B : Base Shear coefficient, G : Gravity acceleration, δ_y : Yield displacement, K : Stiffness of the structure.

Since

$$\frac{1}{2} M \cdot V^2 = \frac{1}{2} M \cdot \frac{M}{K} \cdot (C_B \cdot G)^2$$

The velocity corresponding value of the input energy can be calculated as follows.

$$V = C_B \cdot G \cdot \sqrt{\frac{M}{K}} = \frac{C_B \cdot G}{2\pi} \cdot T$$

Where, T : predominant period of the structure.

The amount of dissipated energy due to elastic response with C_B of 1.0, 0.5, and 0.3 were superimposed on the figure. If the V_E is greater than the each line, the difference of the energy should be dissipated by hysteretic energy (non-linear response). On the contrary, if the V_E is less than the line, the structure remains elastic.

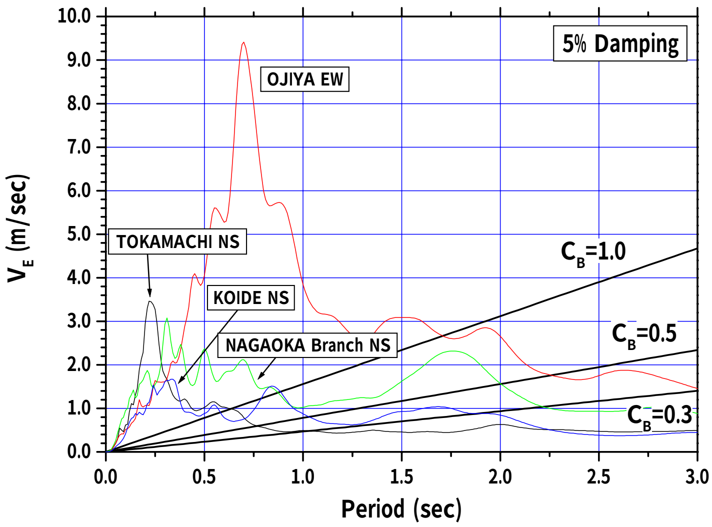


Fig. 35 input energy velocity corresponding values

5 Response velocity spectrum

The response velocity spectrum of the component of which PGA was greater than the other, is shown in Fig. 36.

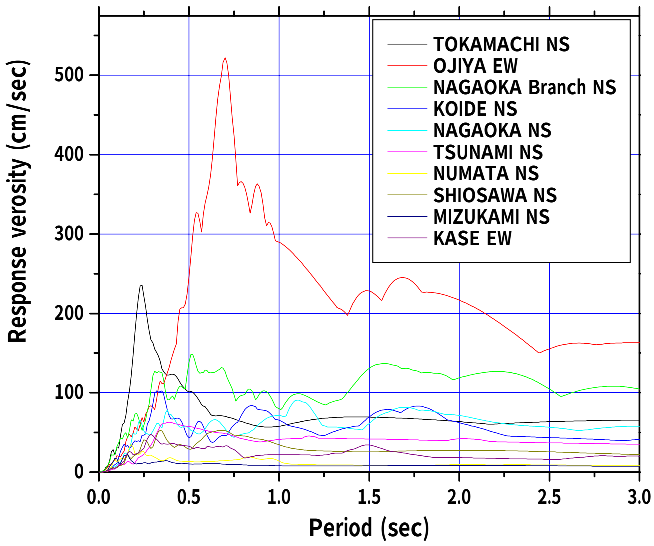


Fig. 36 Response velocity spectrum

6 Nonlinear dynamic response analysis

Nonlinear dynamic analysis were conducted with the structures of which C_B was 1.0, 0.5, and 0.3, and input motion of NIG019 OJIYA EW. The following assumptions were applied for the analysis.

- Takeda Model was applied for the nonlinear model
- Crack strength (Fc) was 1/3 of yield strength (Fy)
- Stiffness degrading factor at yielding was 0.5
- Stiffness after yielding was 1/1000 of the initial stiffness
- Damping model proportional to the instant stiffness was applied. Damping factor was 5%
- Structure weight was 980tonf.

The parameters for the elastic period of 0.3sec are listed on Table. 6-1. The restoring force – response displacement relationship is shown in Fig. 6-1. The maximum yield factor was 3.49 for C_B of 1.0, 9.66 for C_B of 0.5, and 17.45 for C_B of 0.3.

The same analysis were also conducted with the elastic period of 0.5sec. The parameters for the elastic period of 0.3sec are listed on Table. 6-2. The restoring force – response displacement relationship is shown in Fig. 6-2. The maximum yield factor was 2.05 for C_B of 1.0, 5.19 for C_B of 0.5, and 8.04 for C_B of 0.3. The maximum yield factors for the period of 0.5 sec were less than those of 0.3 sec.

It can be said from the results that if the Ds was less than 0.5, and the elastic period of the structure was 0.3 or 0.5 (low-rise timber houses or R/C structure), they can suffer the damage of which yielding factor is greater than 4.0.

Table. 6-1 Parameters（T=0.3）

		Analysis cases		
		Case 1 (C_B=1.0)	Case 2 (C_B=0.5)	Case 3 (C_B=0.3)
Strength (kN)	Fc	3201.33	1600.67	960.40
	Fy	9604.00	4802.00	2881.20
Displacement (mm)	Dc	7.45	3.72	2.23
	Dy	44.68	22.34	13.40

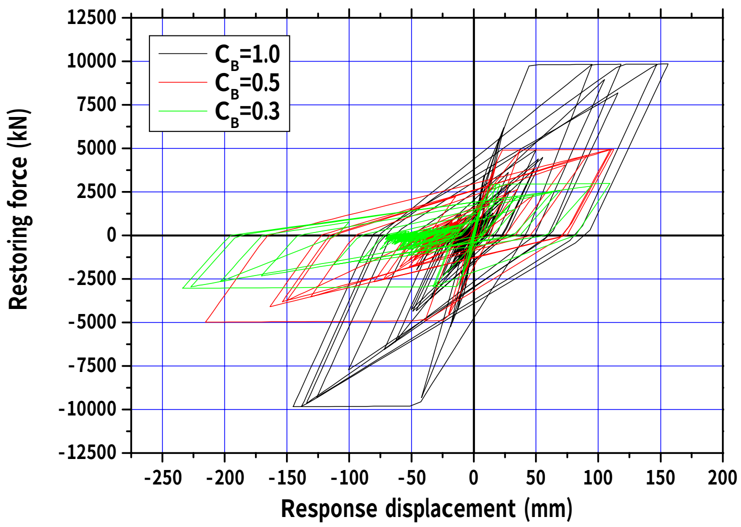


Fig. 6-1 Restoring force – response displacement relationship（T=0.3）

Table.　6-2 Parameters（T=0.5）

		Analysis cases		
		Case 1 (C_B=1.0)	Case 2 (C_B=0.5)	Case 3 (C_B=0.3)
Strength (kN)	Fc	3201.33	1600.67	960.40
	Fy	9604.00	4802.00	2881.20
Displacement (mm)	Dc	20.69	10.34	6.21
	Dy	124.12	62.06	37.24

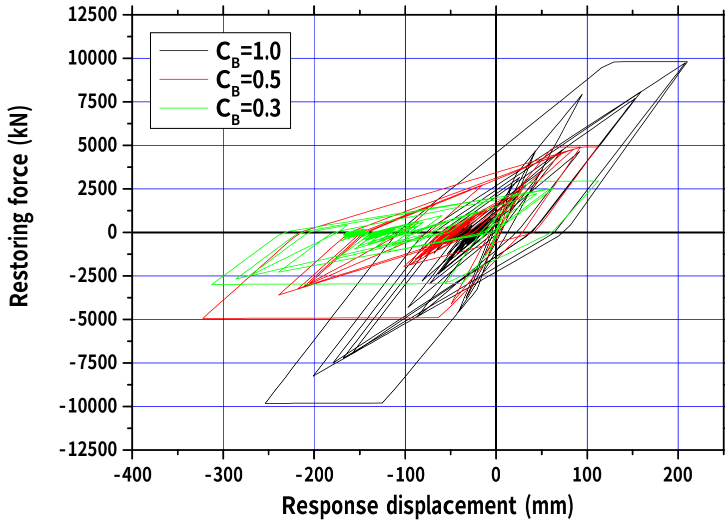


Fig. 6-2 Restoring force – response displacement relationship（T=0.5）

7 Conclusions

Since I am now in USA, the information which I can get is very limited, and many professors, researchers and my colleagues are conducting the investigations in the affected area right now, I would like to wait the detailed information from Japan before describe any conclusions here.

Finally, I would like to express my sincere condolence to the families who have lost their family, their home, and their places where they have many good memories.

The Japanese version of the report can be found at the AIJ (Architectural Institute of Japan) Homepage.
http://kouzou.cc.kogakuin.ac.jp/Saigai/niigata/index.html