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ANALYSIS OF STRONG MOTION RECORDS AND BUILDING DAMAGE DURING THE EARTHQUAKE OF JANUARY 9, 1987

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SUMMARY

This paper presents the results of analysis on the observed strong motions by Building Research Institute of Japan, and building damage during the Iwateken-chubu (Middle of Iwate Prefecture) earthquake on January 9 of 1987. Response spectrum analyses of the strong ground motions evaluate responses of the damaged building. Ambient vibration studies of the damaged building after the 1987 earthquake estimate the effect of strengthening after the 1968 Tokachi-oki earthquake on the natural frequencies of the building. These analyses clarify that the strengthening was insufficient from stiffness and ductilities viewpoint.

INTRODUCTION

Effects of asiesmic strengthening of buildings are verified during real earthquakes. During the magnitude 6.6 1987 Iwateken-chubu earthquake, one of buildings at Hachinohe City which had experience of earthquake damage during the 1968 Tokachi-oki earthquake and had been repaired and strengthened after the 1968 earthquake, was slightly damaged again. Building Research Institute had been installed accelerographs in the adjacent building to the damaged building and observed strong motions during the 1987 earthquake.

EARTHQUAKE and DAMAGE OF BUILDING

Earthquake data during the 1987 Iwateken-Chubu earthquake is summarized in Table 1 (Ref.1). Isoseismal map of the 1987 earthquake is shown in figure 1. Observed results by Building Research Institute Strong Motion Networks are summarized in Table 2 (Ref.2). The damage of buildings during the 1987 earthquake was reported from Hachinohe city. More than one hundred of window panes of the main building of Hachinohe city office were damaged (Ref.3). The damage of expansion joints because of the collision between the main and the annex building of Hachinohe city office is shown in photo 1. Slight shear bending damage of columns on the third floor is shown in photo 2. Small shear cracks of walls occurred on the second and the third floors. Positions of the damage of Hachinohe city office building is indicated in figure 2.

OBSERVATION SITES and BUILDINGS

Hachinohe City Office The main and the annex building of Hachinohe city office

are presented in Photos 3 and 4. The main and the annex building was completed in 1960 and 1969, respectively. The main and the annex building are jointed by expansion joints. The main building was damaged during the 1968 Tokachi-oki earthquake. This damage was reported in the reference (Ref.4). Soil profile at the site of Hachinohe city office is shown in figure 3. Building Research Institute installed accelerographs on the first basement and the fifth floor of the annex building in 1979. After 1987 earthquake, ambient vibration studies utilizing microtremer measurements were performed in order to evaluate natural frequencies of the site and the buildings. The plan and the section of Hachinohe city office building, the positions of installed accelerographs and the ambient vibration measurements are shown in figure 2.

Atago Junior High School in Miyako City Atago junior high school in Miyako city was the closest site to the epicenter among the BRI stations. After 1987 earthquake, the ambient vibration studies were performed. The plan and the section of Atago junior high school, positions of the accelerograph and the ambient vibration measurements are shown in figure 4.

ANALYSIS OF STRONG MOTIONS and AMBIENT VIBRATIONS

Strong Motion Analyses of Annex Building Corrected accelerograms on the first basement and the fifth (roof) floor of the annex building are shown in figures 5 and 6. Elastic response spectra of NS and EW component records on the first basement are indicated in figures 7 and 8. The maximum values of corrected accelerograms EW (longitude) components are larger than those of NS (transverse) components. Figure 9 presents calculated displacements from the observed accelerograms on the fifth floor. The maximum response displacement of EW component is evaluated about 3 cm. These results estimate the annex building deformed 1/500 of the height by adopting the assumption of fixed base. However, any structural damage of the annex building is not observed excepting around the expansion joints during the 1987 earthquake.

Ambient Vibration Studies of Hachinohe City Office Fourier amplitude spectra of NS and EW components of the ambient vibrations on the first basement and the fourth floor of the main building are shown in figures 10, 11, 12 and 13. Fourier amplitude spectra of the ambient vibrations NS and EW components on the fifth floor of the annex building are shown in figures 14 and 15. Natural frequencies of the ambient vibrations of the main and the annex building are summarized in Table 3. The natural frequencies after 1968 earthquake in table 3 was quotation from the reference (Ref.4). It is considered the collision of expansion joint with the main building was due to the difference among the natural frequencies of the main building and those of the annex buildings. Calculated natural frequency of the main building from $f=1/(h*0.02)$ is 3.9 Hz. This formula is an empirical formula for typical reinforced concrete buildings in Japan, and a symbol of h is a height(m) of buildings. Measured natural frequencies are lower than the calculated natural frequency of the main building. Presuming the natural frequencies did not change during the 1987 earthquake because the damage was slight and the weight of the main building was typical, these lower frequencies suggest the stiffness of the main building is worse than that of typical reinforced concrete buildings in Japan.

Applying the natural frequencies of the main building to the response spectra in figures 7 and 8, the maximum response accelerations and displacements of the main building are evaluated about 600 gals and 2 cm for EW direction, 500 gals and 1.5 cm for NS direction in the assumption the damping ratio of the main building is 5 percent. These evaluations suggest the damaged main building deformed about 1/600 of the height for EW direction and 1/800 for NS direction. Although these deformation of the main building are less than those of the annex building, the main building had damage. These results are summarized as follows. The main building is less ductile than the annex building. The strengthening of the main building after the 1968 earthquake did not improve the lack of ductilities.

Strong Motion Analyses and Ambient Vibration Studies in Miyako Figure 16 shows corrected accelerograms on the first floor of Atago junior high school in Miyako. Figures 17 - 18 show elastic response spectra of the accelerations in Miyako 1F. Figures 19 - 20 show Fourier amplitude spectra of the ambient vibrations on the first floor and the second floor. Figure 18 suggests the ground of Atago junior high school has the short periods. Although the maximum accelerations in the school were large, there was no remarkable damage around the school. The reason is that short periods predominate in the records.

CONCLUSIONS

During the 1987 Iwateken-chubu earthquake, strong motions were observed and a building was damaged again. Response spectrum analyses evaluate the damaged building deformed about 1/600 of the height. The strengthening of the building after the 1968 earthquake was insufficient with respect to stiffness and securing ductilities of the building.

Table 1 Earthquake Data

Date & Time	Jan. 9 , 1987 15 : 14 (JST)
Location	Northern Iwate Prefecture (Middle of Iwate Pref.)
Epicenter	39 50.0' N 141 46.8' E 72 km depth
Magnitude	6.6 (JMA)

Table 2 Observation Results

Observation Sites				Max. Acceleration (gal)		
station	floor	instrument	Epicentral Distance (km)	component NS	EW	UD
MIYAKO Atago junior high school	1F	SMAC-M	27.6	186 (N03W)	389 (S87W)	219 (UP)
HACHINOHE City office (Annex Bldg.)	B1F	"	77.2	148 (S16E)	197 (N74E)	88 (UP)
"	5F	"	"	312 (N16W)	562 (S74W)	218 (UP)
SENDAI Tohoku univ.	1F	"	195.2	31 (N68W)	27 (S22W)	20 (UP)
"	9F	"	"	103 (N68W)	80 (S22W)	35 (UP)

Table 3 Natural Frequency of Ambient Vibrations (Hachinohe City Office)

	Main Bldg.		Annex Bldg.	
Component	NS	EW	NS	EW
After 1968 earthquake	2.13 Hz(E) 2.63 Hz(W)	2.63 Hz		
After strengthen	unknown	unknown		
After 1987 earthquake	2.64 Hz(E)	2.73 Hz	2.82 Hz	2.46 Hz

(E) East block of Main bldg.
(W) West block of Main bldg.

REFERENCES

1).The seismological bulletin of the JMA for January 1987.
2).'Strong motion Earthquake Observation News, Kenchiku Gijutsu No.427
3).The Mainichi News Papers
4).'The Reconnaissance Reports for the disasters of the Tokachi -Oki Earthquake of 1968', AIJ, Dec. 1968

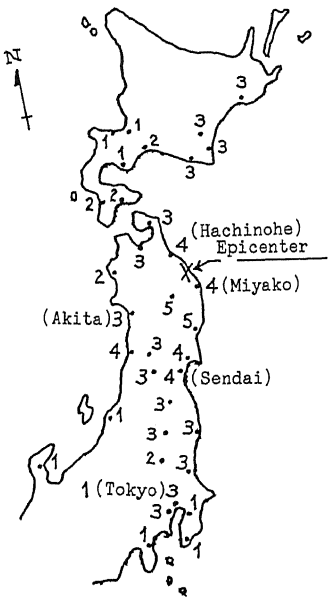

Fig. 1 Isoseismal Intensity Map during the Earthquake of Jan. 9, 1987 (Seismic Intensity on the JMA Scale)

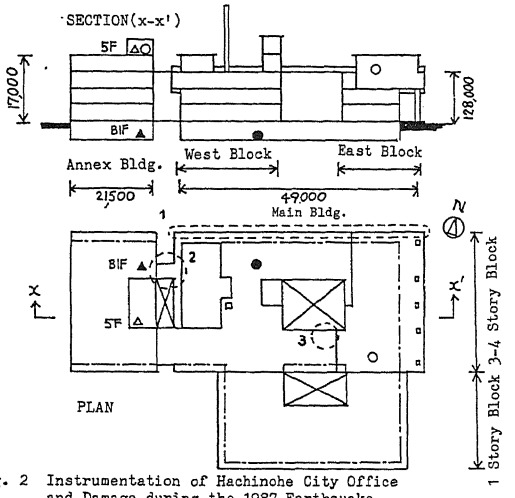

Fig. 2 Instrumentation of Hachinohe City Office and Damage during the 1987 Earthquake
(△ or ▲ Triaxial Accelerometer for Strong-motion Measurements)
(○ or ● Seismometer for Ambient Vibration Measurements)
(1.Breakage of windows, 2.Collision of Expansion, 3.Shear Bending Damage of Columns on 3F)

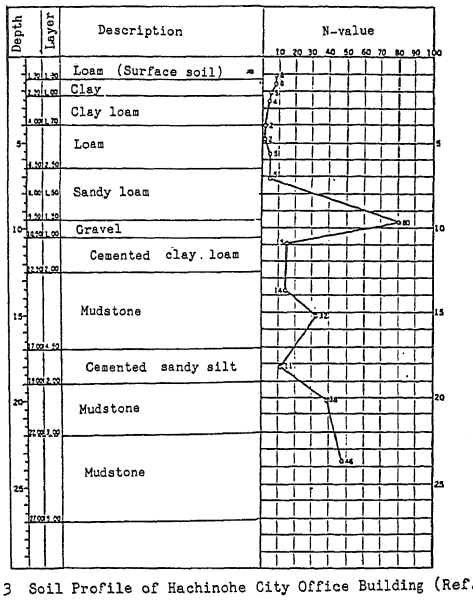

Fig. 3 Soil Profile of Hachinohe City Office Building (Ref.4)

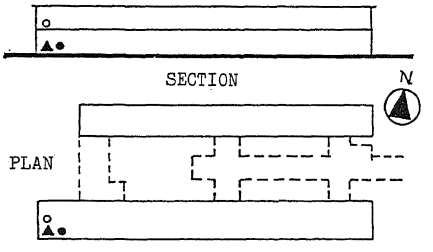

Fig. 4 Instrumentation of Atago Junior High School Building in Miyako
(▲Triaxial Accelerometer for Strong motion Measurements)
(○ or ● Seismometer for Ambient Vibration Measurements)
(2 Story Reinforced Concrete Bearing Wall Building on the Weathered Granite Ground)

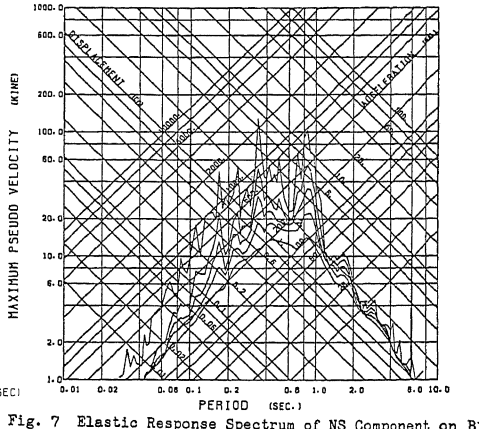

Fig. 7 Elastic Response Spectrum of NS Component on B1F
(Annex Building of Hachinohe City Office)

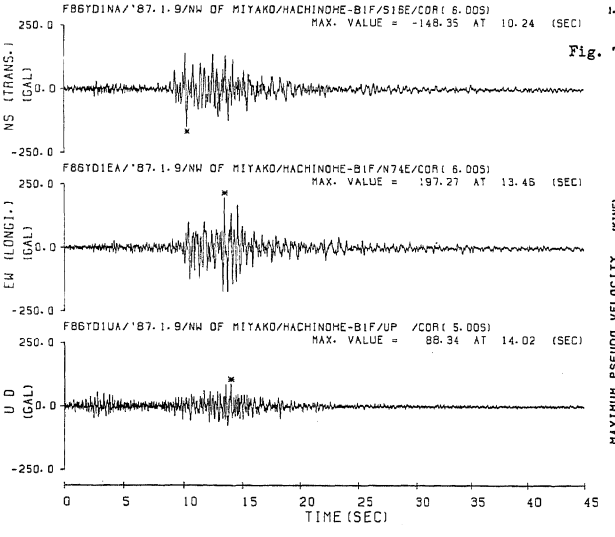

Fig. 5 Corrected Accelerograms on B1F of Annex Building
(Hachinohe City Office)

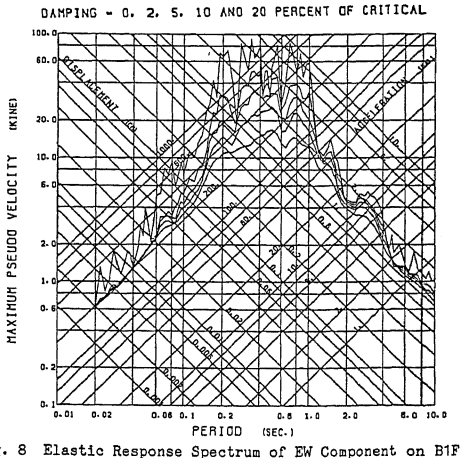

Fig. 8 Elastic Response Spectrum of EW Component on B1F
(Annex Building of Hachinohe City Office)

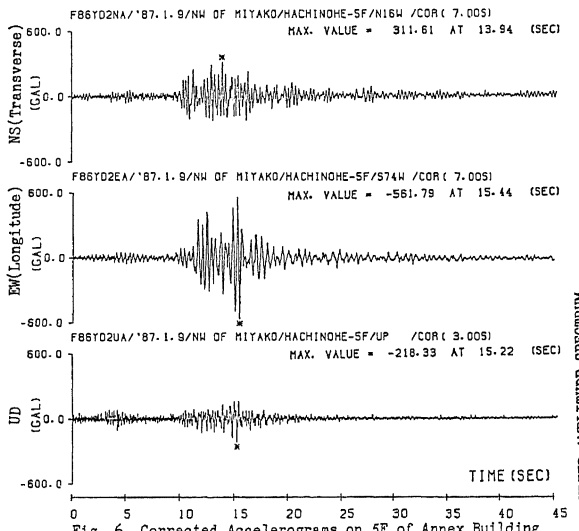

Fig. 6 Corrected Accelerograms on 5F of Annex Building (Hachinohe City Office)

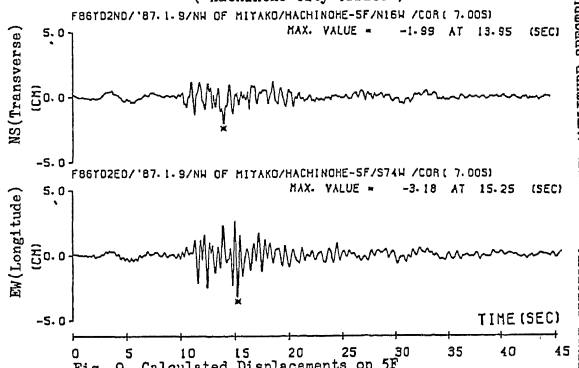

Fig. 9 Calculated Displacements on 5F (Annex Building of Hachinohe City Office)

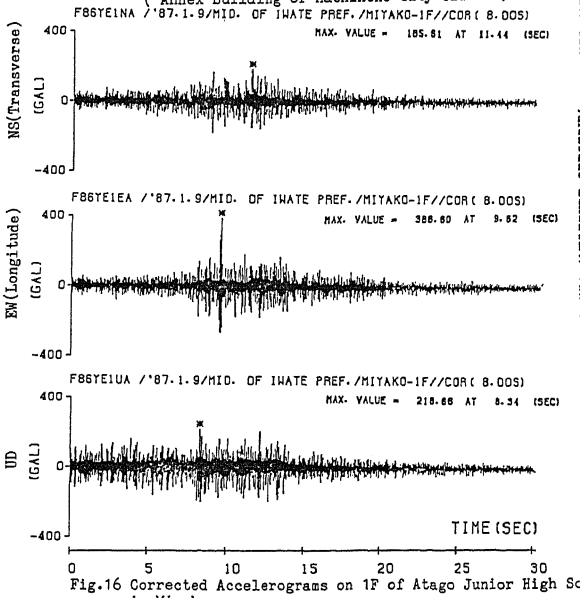

Fig.16 Corrected Accelerograms on 1F of Atago Junior High School in Miyako

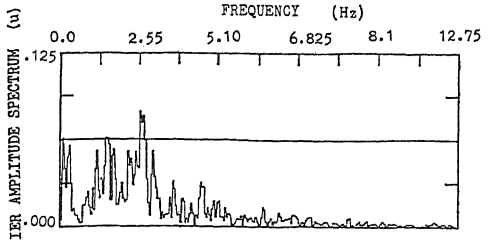

Fig.10 Fourier Amplitude Spectrum of Ambient Vibration (NS Component on B1F of Main Bldg. of Hachinohe City Office)

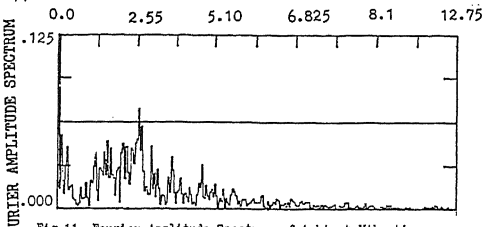

Fig.11 Fourier Amplitude Spectrum of Ambient Vibration (EW Component on B1F of Main Bldg. of Hachinohe City Office)

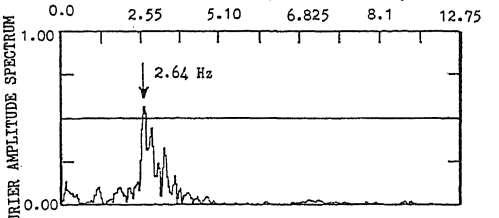

Fig.12 Fourier Amplitude Spectrum of Ambient Vibration (NS Component on 4F of Main Bldg. of Hachinohe City Office)

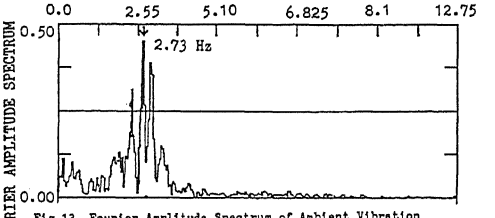

Fig.13 Fourier Amplitude Spectrum of Ambient Vibration (EW Component on 4F of Main Bldg. of Hachinohe City Office)

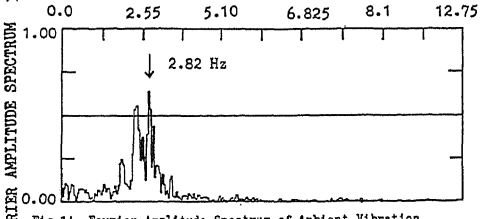

Fig.14 Fourier Amplitude Spectrum of Ambient Vibration (NS Component on 5F of Annex Bldg. of Hachinohe City Office)

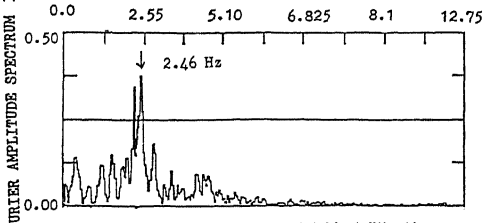

Fig.15 Fourier Amplitude Spectrum of Ambient Vibration (EW Component on 5F of Annex Bldg. of Hachinohe City Office)

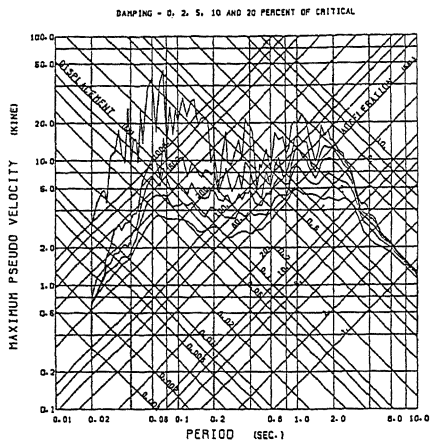

Fig.17 Elastic Response Spectrum of NS Component on 1F
(Atago Junior High School in Miyako)

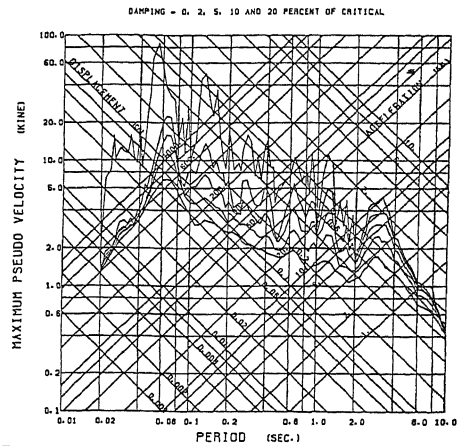

Fig.18 Elastic Response Spectrum of EW Component on 1F
(Atago Junior High School in Miyako)

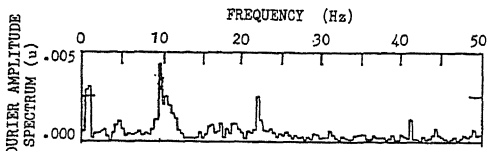

Fig.19 Fourier Amplitude Spectrum of Ambient Vibration
(NS Component on 1F of Atago Junior High School in Miyako)

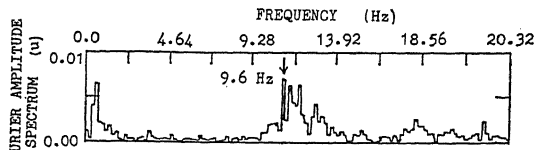

Fig.20 Fourier Amplitude Spectrum of Ambient Vibration
(EW Component on 1F of Atago Junior High School in Miyako)

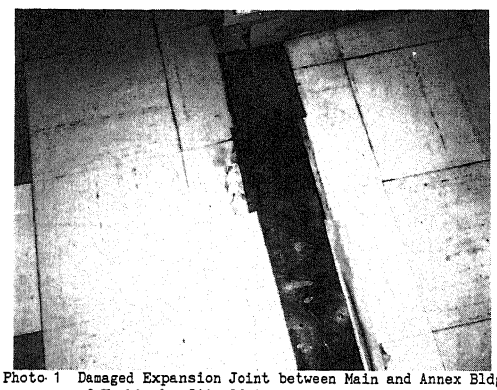

Photo 1 Damaged Expansion Joint between Main and Annex Bldg. of Hachinohe City Office

Photo 2 Shear Bending Crack of column on 3F of Main Bldg. of HACHINOHE City Office

Photo 3 Southeast View of Main Bldg. of Hachinohe City Office
(3 or 4 Story Reinforced Concrete Frame Building with 1 Story Basement Supported by Piles 5 or 9 m lengths)

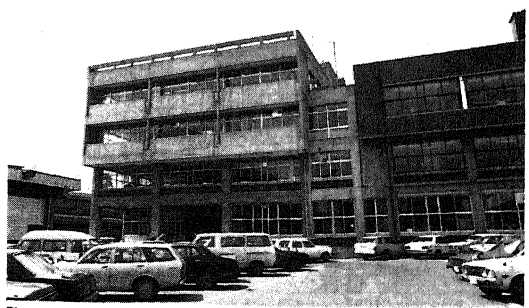

Photo 4 South Side View of Annex Building of Hachinohe City
(4 Story Reinforced Concrete Frame Building with 1 Story Basement)