DAMAGES TO BUILDING STRUCTURAL SYSTEMS DURING THE MIYAGI-KEN-OKI EARTHQUAKE OF JUNE 12, 1978

by

Kiyoshi NAKANO[I], Yuji OHASHI[II]

SUMMARY

The intensity of ground motions due to the Miyagi-Ken-Oki Earthquake was stronger than those of averaged with magnitude 7.4. The peak acceleration was 0.2 $\sim$ 0.3g in Sendai City, approximately 100km from the reported epicenter. And the world largest peak structural response (1,040cm/sec^2) was scored in 9th floor of R.C. University Building.

Though overturning of concrete block or masonry fences and gates deprived lives of 16 people, less than half a percent of total number of houses and buildings in Sendai City have suffered severe damage.

1. EARTHQUAKE GROUND MOTIONS

The source mechanism of the earthquake worked out so far [1] has revealed that it is one of the thrust type earthquake due to the subduction of the Pacific Plate.(see Fig.-1) Unusually small attenuation of seismic wave for this earthquake might be associated with this fact. It is demonstrated in Fig.-2, where peak acceleration values obtained by the strong motion accelerographs are plotted in terms of epicentral distances. In this Fig.-2 averaged attenuation relation obtained from the past 75 earthquake accelerograms is represented by dotted line and solid thick line represents mean relation between peak acceleration values (in horizontal component) and epicentral distances due to this earthquake. Comparison of these two lines reveals that the intensity of ground motions due to this earthquake was extraordinarily stronger than those estimated by past earthquake data, in terms of magnitude and epicentral distance of earthquake. In Fig.-3 and Fig.-4, are shown accelerograms recorded at the ground level and top floor level of 9th floor in Structural Engineering Building, Tohoku University. Among these accelerograms, it should be noted that peak acceleration in structural response of N-S component at the top floor of this building is the largest value - 1,040gals - ever recorded in the world history. According to these accelerograms, peak acceleration values in ground motions are 259gals and 153gals in N-S, E-W and U-D component, respectively. Through integrations of these accelerograms in terms of time, time histories for velocity and displacement can be obtained, peak values of which are tabulated in Tab.-1. In Fig.-5 and Fig.-6 these resulted time histories of N-S component at ground level and top floor are illustrated as examples. Acceleration response spectra of N-S component accelerogram at ground level are shown in Fig.-7. In Fig.-8, tripartite response spectra of the same accelerogram are as well shown. These response spectra suggest that the predominant periods are 0.3 to 0.4 second and 1.0 second. With 5 percent of fraction of critical damping, the largest response value (approx. 1,000gals)

I. Director General, Building Research Institute, Ministry of Construction, Japanese Government.

II. Research Engineer, Structure Division, Structural Engineering Department of the same Institute.

is found at the period of 1.0 second, where response amplification factor becomes 3.86. The fundamental period of the building is about 0.7 second in N-S direction evaluated by ambient vibration. However the predominent period of accelerogram in N-S component is 1.0 second. Therefore during this earthquake, the fundamental period became larger by 1.43 times than that evaluated by ambient vibration. Provided, this building responded linearly or elastically, the peak acceleration in structural response at top floor is calculated as 1,350 gals. The difference between this calculated value of 1,350 gals and 1,040 gals recorded at top floor may be due to the non-linear behavior of this structure which was subjected to slight damage at upper part of stories. It is interesting to note that elastic displacement response value of 29.7cm is very close value to the actual displacement response value of 25.9cm which is evaluated through the double integration of the relevant accelerogram in terms of time.

Utilizing N-S component accelerogram at ground level at Tohoku University, synthetic accelerograms are generated for three types of subsoil conditions ie. bed rock, medium hard soil and soft soil, latter two of which are representative local soil conditions in Sendai City. For generation of three synthetic accelerograms, the following procedures and assumptions are used;

i) Deconvolution and convolution of accelerogram is based on Haskel's transfer matrix method. [2]

ii) Initial values for shear wave velocity V_s(m/sec.) are estimated by the following equation [3] in terms of N value and depth H(m) of subsoil;

$$V_s(\text{m/sec.}) = 68.79 \cdot N^{0.171} \cdot H^{0.199} \begin{bmatrix} 1.0 \\ \text{(alluvial)} \\ \\ 1.303 \\ \text{(delluvial)} \end{bmatrix} \begin{bmatrix} 1.0 \\ \text{(clay)} \\ 1.086 \\ \text{(fine sand)} \\ 1.135 \\ \text{(coarse sand)} \\ 1.153 \\ \text{(sandy gravel)} \\ 1.448 \\ \text{(gravel)} \end{bmatrix} \quad \text{--- (1)}$$

iii) Damping factor Q is assumed to be independent from frequency and initial value of Q_o is assumed as 25.0.

iv) Shear rigidity G and damping factor Q are dependant on strain level of subsoil, so starting initial values G_o and Q_o, these values are modified in each step of time increment where mean shear strain is assumed to be 0.45 times of the maximum shear strain in each subsoil layer.

The results of these synthetic accelerograms are shown in Fig.-9. In Fig.-10, are shown tripartite response spectra of these three accelerograms in Fig.-9 with 5 percent fraction of critical damping. Housner's Spectral Intensity values for four accelerograms, original one at Tohoku University, one on bed rock, one on soft soil and one on hard soil are 117.0cm, 96.3cm 99.0cm and 136.3cm respectively with 20 percent of critical damping.

Incidentally, directions of "principal axes" [4] of accelerograms at Tohoku University are N5.5°E, E5.5°S and vertical for major, intermediate and minor axes respectively.

2. DAMAGE STATISTICS AND ITS DISTRIBUTION

Damage due to this earthquake was concerntrated to Miyagi-Prefecture, the capital city of which - Sendai City - suffered 500 million dollar damage, about one-third of total loss of 1,800 million dollars in whole Miyagi-Prefecture.

2.1 Damage Statistics Number of death casualties and injured were 28 and 10,247. Among the number of death, 3 lost their lives due to heart attack shocked by ground shaking, 5 inside of houses and 16 due to overturning of concrete block or masonry fences and gates. 46.4 percent of death casualties is inside Sendai City, while 90.8 percent of injured is concentrated inside of Sendai City.

In Sendai City, 42.2 percent of total loss of 500 million dollor is for domestic living houses. Among loss of domestic living houses, 64.4 percent is for loss of houses themselves, 19.5 percent for loss of furniture and 8.7 percent for loss of fences and gates.

2.2 Damage Distribution Damage of houses, buildings and fences was clearly concentrated in the area of soft soil conditions and in hillsides. From this fact and Fig.-9 of accelerograms for local soil conditions, the importance of local soil and geographical features for earthquake engineering will be seen.

3. DAMAGE FEATURES OF BUILDINGS

3.1 Damage of R.C. Buildings Investigations on R.C. buildings have been done by various institutions, school buildings by Tokyo University group, building in Oroshimachi where several suffered severe damage by Tohoku University and over all in Sendai City, all buildings around Oroshimachi, wall R.C. apartment buildings, steel composite tall apartment buildings and precast, prestressed concrete buildings by Building Research Institute.

Damage of R.C. Structures in hard soil area, central part of Sendai City, is not more than slight, while R.C. structures subjected to severe damage almost collapsing are concentrated in soft soil area, eastern or southern part of newly developed area in Sendai City. In school buildings, mean damage ratio (collapse: 100%, half collapse: 50%, non damage: 0%) is 7 percent (after University of Tokyo group). In Oroshimachi area where the highest damage ratio reported mean damage ratio for R.C. structure is 6 percent. Mean damage ratio for walled R.C. apartment building is zero. Precast and prestressed concrete structures were subjected to negligibly little damage. Only in soft soil area of eastern part of the City, tall (9 - 14 stories) steel composite R.C. apartment buildings suffered damage of shear cracks in non-structural walls, but no serious damage was observed in main structural members.

Representative location and pattern of fracture can be observed in columns or walls in ground level floor with shear failure and directions of destructive shear forces are exclusively north-south direction.

Damaged R.C. buildings had one or more items of feature followingly here introduced;

a) Open frame structural system in north-south direction.
b) Longer span length or wider floor area per a column.
c) Extreme eccentricity such as one-side exterior walls.
d) Discontinuity of stiffness weight ratio such as soft first story structural system.
e) Insufficient spacings of column hoops which were constructed before the revision of reinforcing details of column hoops, in 1971, reflected by the damage feature subjected due to Tokachi-Oki Earthquake in 1968.
f) Low strength and rigidity of concrete materials.

3.2 Damage of Steel Buildings Amount of damage in steel buildings due to this earthquake has been the greatest in numbers and in degrees of damage which steel buildings had ever been subjected in Japanese history. Damage features of steel buildings will be summarized followingly;
a) Very severe damage (collapse or too large deformation to repair).
b) Effect of unexperienced or poor construction, especially unskilled welding.
c) Effects of poor structural design.
d) High percentage of damage due to fracture of diagonal bracing systems.
e) Serious damage of claddings.

As for item a), one steel structure was collapsed due to very poor quality of construction by IZU-OSHIMA EARTHQUAKE Jan. 1978. However poor quality of structural design led to collapse in this earthquake. As for problems of item b) and c), these concerns finally came into the real result. Fractures of diagonal bracings have been typically observed in various past earthquakes. The problem of item e) has become serious one by this earthquake. Several claddings not only steel sheet mortar finish but also ALC (Autoclaved Lightweight Concrete) or PC (Precast Concrete) panel walls have fallen down. One thing here should be noted is that a steel building for bowling stadium with long span of 34 meters was collapsed due to vertical ground motions.

3.3 Damage of Wooden Houses and Other Damage Most of Wooden houses which were subjected to severe damage were due to some kind of land sliding. Some of other wooden houses were suffered damage due to eccentricity or discontinuity of stiffness weight ratio. It should be noted however that wooden houses with sufficient amount of walls required by Building Standard in Japan have survived even due to this earthquake.

Overturned concrete block fences which had deprived human lives without exception do not satisfy the reinforcing details which Building Standard requires.

4. CONCLUDING REMARKS

Though various aspects of earthquake damage have been observed due to this earthquake, less than half a percent of total number of houses and buildings in Sendai City have suffered severe damage. In view of the fact as well that peak structural response in acceleration recorded more than 1g value at the top floor of a building with slight damage, standard level of earthquake resistant capacities of building structures in Japan revealed to be satisfactory. However, by this earthquake, importance of overall earthquake resistant considerations as the total systems has been focused here. On the other hand, importance of construction qualities is also emphasized, therefore some systems to avoid poor quality of constructions should be established. These two will be the major tasks for future earthquake engineering in Japan.

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REFERENCES

[1] SENO,T., SHIMAZAKI,K., SOMERVILLE,P., SUDO,K., EGUCHI,T., " REPTURE PROCESS OF MIYAGIKEN OKI EARTHQUAKE OF JUNE 12, 1978," Physics of the Earth and Planetary Interiors (in press).

[2] OHSAKI,Y., 1975, "DYNAMIC CHARACTERISTICS AND ONE-DIMENSIONAL AMPLIFICATION THEORY OF SOIL DEPOSITS," Research Report 75-01, Univ. of Tokyo, Aug.

[3] OHTA,T., GOTO,N., 1978, "EMPIRICAL SHEAR WAVE VELOCITY EQUATIONS IN TERMS OF CHARACTERISTIC SOIL INDEXES," International Journal of Earthquake Engineering, Vol.6, pp.167-187.

[4] WATABE,M., PENZIEN,J., 1975, "SIMULATION 3 DIMENSIONAL EARTHQUAKE GROUND MOTIONS," International Journal of Earthquake Engineering, Vol.3, pp.365-373.

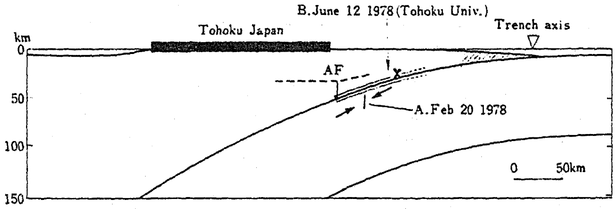


Fig.-1 Source Mechanism of This Earthquake Hypocenter is located on the boundary of subducting plate

Tab.-1 Maximum Values of Vibrations At TOHOKU UNIV.

		acceleration		velocity		displ.	
		max.(cm/sec^2)	time	max.(cm/sec)	time	max.(cm)	time
G.L.	NS	259.23	7.56	36.17	10.8	-14.53	10.56
	EW	202.57	3.10	27.57	2.96	9.11	3.82
	UD	153.04	4.18	11.92	10.44	3.18	10.02
9FL	NS	1,039.98	15.20	150.41	14.96	-25.87	15.20
	EW	-523.92	14.08	-72.76	14.34	16.61	3.40
	UD	-355.56	7.32	22.92	15.48	7.09	8.18

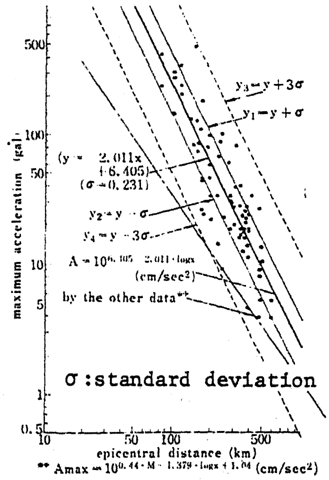
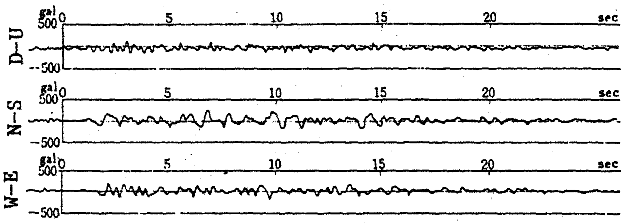
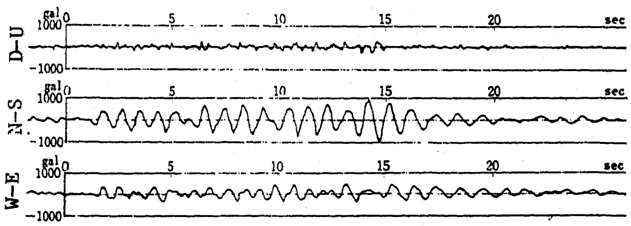


Fig.-2 Relation Between Max. Accel. and Epicen Distance



Max.259gals (N-S Component)

Fig.-3 Accelerograms at Ground Level Installed at Tohoku University



Max. 1040 gals world largest record

Fig.-4 Accelerograms at 9th floor Installed at Tohoku University

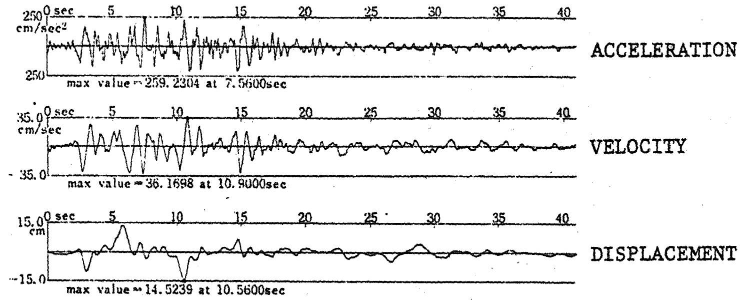


Fig.-5 Time Histories of Vibrations at Ground Level(N-S Component)

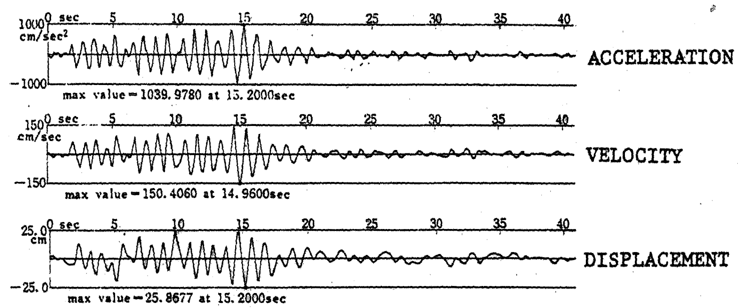


Fig.-6 Time Histories of Vibrations at 9th Floor(N-S Component)

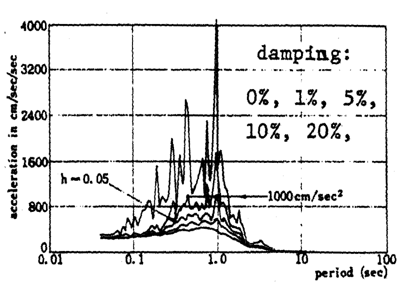


Fig.-7 Response Spectra of Accelerogram N-S Component at Ground Level Univ. Tohoku

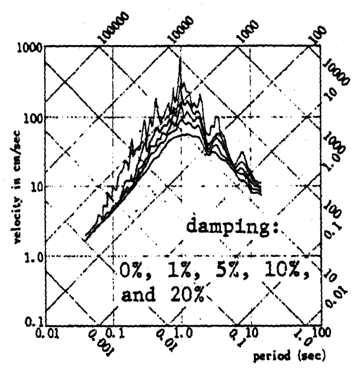


Fig.-8 Tripartite Response Spectra for Fig.-7

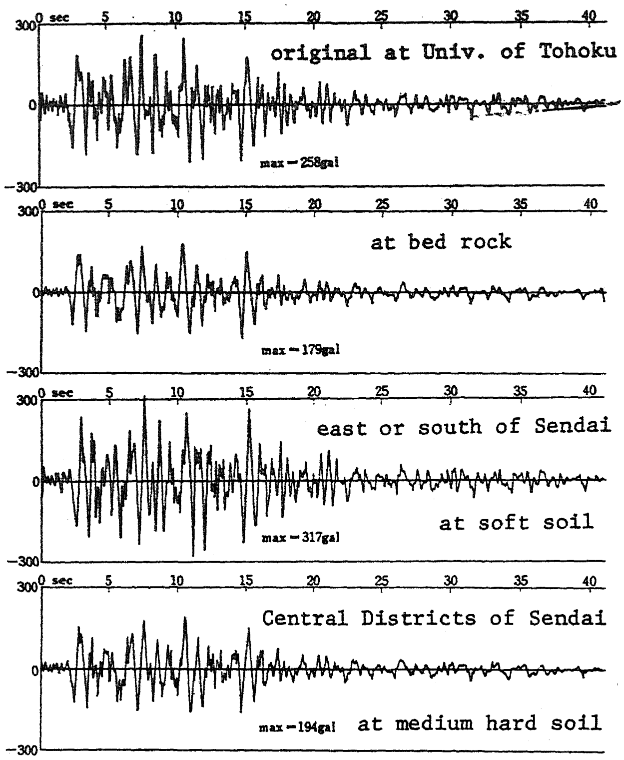


Fig.-9 Synthetic Accelerograms for Different Local Soil Conditions (N-S Component)

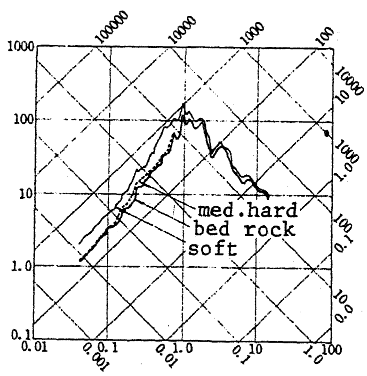


Fig.-10 Response Spectra for Fig.-9 in Tripartite. 5% damping