ESTIMATION OF BUILDING RESPONCE DUE TO LARGE-SCALE EARTHQUAKE FROM OBSERVED RESPONSE RECORDS TO SMALL EARTHQUAKES

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SUMMARY

Authors try to estimate the response of a structure to a large earthquake by summing up the records on a structure to small earthquakes, based upon the scaling law of the fault which is the cause of an earthquake. This method is quite different from the conventional ones. And authors reproduce the record which exceeded 1000 gals on the highest floor of a 9 story building in the Miyagiken-Oki Earthquake of 1978 (Japanese Meteorological Agency magnitude Mj=7.4). The synthesized responses are considarably good coincidence with the observed records.

INTRODUCTION

Since 1940s, the methods of estimating the response of a structure against input earthquake ground motions have been adopting for dynamic analysis. However, no definite criterion has not yet been established in selecting input earthquake ground motions. On the other hand, seismology has advanced rapidly since 1960s, and it is now believed that an earthquake is caused by a fault. Besides the reproducing long-period ground motions has been accomplished fairly well. But many obstacles stand to estimating short-period ground motions owing to various complexities. In 1978, Hartzell (Ref.1) used an immediate aftershock and the next year Kanamori (Ref.2) also used the records of the earthquake with a similar source mechanism as a Green function respectively, and they succeeded in reproducing long-period displacement records. Next, authors (Ref.3) intended obtaining adequate input earthquake ground motions by applying the method to the short-period acceleration. In Japan, some scholars (Ref.4 ; Ref.5) started this kind of research at the same time as authors. Afterword it is getting popular gradually. In this paper, authors try to predict the response of a structure on the basis of extending such methods and introducing a new idea which doesn't use the concept of input earthquake motions (Ref.6). The contents are to sum up in the time domain the records on a structure to small earthquakes which occured in the same region as a large earthquake.

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CHARACTER OF THIS METHOD

The aim of this study is to estimate the response of structures to a large earthquake, keeping in balance with amplitude, duration, wave form and period. Let the conception of the conventional response analysis be the exprssion in (1) and the conception of the new method can be represented by the expression in (2).

$$\begin{aligned} \text{response} &= \text{source} \times \text{path} \times \text{surface layer} \times \text{structure} \\ &= \text{input earthquake ground motions} \times \text{structure} \quad \cdots\cdot(1) \\ &= \Sigma(\text{ small source} \times \text{path} \times \text{surface layer} \times \text{structure }) \\ &= \Sigma(\text{ small response }) \quad \cdots\cdot(2) \end{aligned}$$

And the advantages of this method are as follows :

1. The dislocation of a fault is substituted for the actual dislocation in a region close to the source.
2. The effect of topography or surface layers is automatically conside-rd in the procedure.
3. The detailed modeling of structures or the estimation of the damping which accompanies with it are not required, so these errors can be excluded.
4. The smaller the size of an earthquake is, the higher the frequency of the occurrence is, so the records can be obtained easily.

Moreover, the physical meanings are very clear and the character of an individual earthquake can be considered. Since only a little information is required, the method is adequate enough to predict earthquake ground motions. This method exhibits full play to the examination for earthquake-resistance and the estimation of the response of structures to a hypocetical large earthquake.

ILLUSTRATION OF COMPUTATION

Authors try to reproduce the two components of the record in horizontal acceleration on the highest floor of the 9 story reinforced concrete building at the department of architecture of Touhoku University in Sendai City in the Miyagiken-Oki Earthquake of June, 1978, using the record which has been obtained at the same place in the earthquake of February in the same year. Figures 1 and 2 reveal the location for the fault plane of the mainshock. And Table 1 and 2 show the information about the focuses and the source parameters of both earthquakes (Ref.7 ; Ref.8). Also Table 3 tells the fault geometry necessary for synthesis. In this point, there remains the problem of whether this method is effective or not even if the small earthquake is used which is different from the large one in the focal mechanism. There is no demonstrative research about this problem up to now. But since the structure less than several kirometers in a source region becomes important to short-period components, it is thought that the minute structure is more dominant than the focal mechanism. Next, Figure 3 depicts the result of three-dimensional response analysis about this building (Ref.9). And Figure 4 shows the record of the foreshock. In the NS component, the natural period of the building was suddenly lengthened owing to the damage which occurred in several seconds and the Fourier spectrum has two peaks, and the period in the latter harf represents the natural period just before the mainshock. So Figure 5 represents the wave whose period in the first half is modified with amplitude unchanged. For synthesis about the NS component, both waves are used. First, authors deal with the records in the way of the theory of elasticity although it is thought that this building is

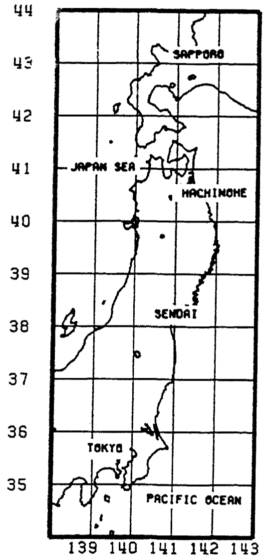

Fig.1 The Map of Northeastern Japan

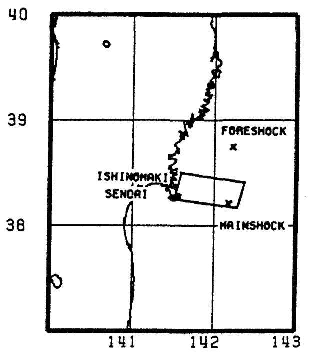

Fig.2 Location of Fault Plane and Focuses

Table 1 Mainshock and Foreshock (after Japanese-Meteorological-Agency)

	MAINSHOCK	FORESHOCK
ORIGINE DATE	JUNE12,1978	FEBRUARY20,1978
ORIGINE TIME	17H14MIN25S	13H36MIN57S
LATITUDE (DEGREE)	38.15N	38.75N
LONGITUDE (DEGREE)	142.17E	142.20E
DEPTH (KM)	40	50
MAGNITUDE (JMA)	7.4	6.7

under the influence of growing plastic. After that, authors try to cope with growing plastic by taking account of the change of the rigidity about a whole structure.

METHOD

First, authors intend to simplify the method as a whole. Since a structure has proper modes of oscillation, they perform synthesis independently of each direction of the structure. They assume the rectangular fault and divide it into the elements of the same shape and size. Here the number of the elements is almost the same in both of the directions of length and width of a fault. The synthetic wave F(t) is represented in the next equation (3).

$$F(t) = \sum_{i=1}^{N} gi \times bi \times fi\left(t - \frac{si}{vi} - \frac{ri}{ui}\right) \quad \cdots\cdots(3)$$

where
- N :the number of synthetic elements
- i :the number of an element
- fi:records to small earthquakes
- t :time
- si:the distance from the initial point of rupture to the center of an element
- ri:the distance from the center of an element to the station
- vi:the rupture velocity of a fault
- ui:the propagation velocity of seismic wave motion
- bi:the function depending upon the difference of the scale of earthquakes

and
- gi:the function depending upon the difference in the location of the focus of a small earthquake to an element

And Figure 6 appeals to the sense of sight for the outline of this method.

Source Parameter and Number of Synthetic Element

Authors adopt the source parameters in table 3. They propose the following equation (4), taking account of the relations among seismic moment Mo, surface-wave magnitude Ms and Mj (Ref. 10 ; Ref. 11 ; Ref. 12).

$$\log Mo(N \cdot M) = 1.60Mj + 8.4 \quad \cdots\cdots(4)$$

And the ratio about Mo of the large earthquake to the small one is the number of synthetic elements N. They estimate N by using the equation (4). This time, the synthetic wave is made of only one kind of

Table 2 Source Parameters of Two Earthquakes (after Ref.7 and Ref.8)

	MAINSHOCK	FORESHOCK
DIP ANGLE (DEGREE)	20	85
DIP DIRECTION (DEGREE)	N280E	N270E
SEISMIC MOMENT (N*M)	3.1×10^{20}	8.0×10^{18}
FAULT AREA (KM^2)	80*30	20*10
DISLOCATION (M)	1.8	0.6
STRESS DROP (N/M^2)	7.0×10^5	7.0×10^5

Table 3 Fault Geometry Necessary for Synthesis

LENGTH (KM)	30
WIDTH (KM)	80
DIP ANGLE (DEGREE)	20
DIP DIRECTION (DEGREE)	N280E
MAGNITUDE (JMA)	7.4
LOCATION OF CENTER OF FAULT	
LATITUDE (DEGREE)	38.33N
LONGITUDE (DEGREE)	142.00E
DEPTH (KM)	35

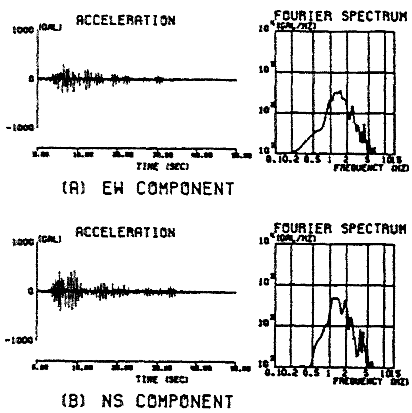

Fig.4 Record of Foreshock

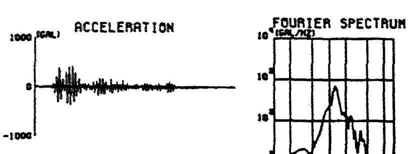

Fig.5 Modified Wave about NS Component of Record of Foreshock

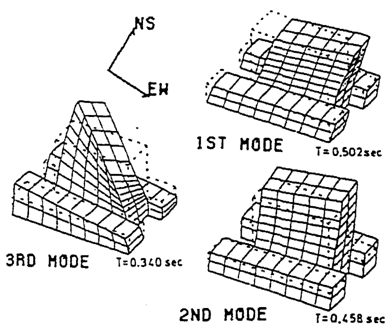

Fig.3 Natural Period and Mode (after Ref.9)

record as shown in the equation (5).

$$fi(t) = f(t) \quad \cdots\cdot(5)$$

Also they suppose that the release of short-period components per unit seismic moment is of the same quantity in spite of earthquakes. The next equation (6) represents this assumption.

$$bi = 1 \quad \cdots\cdot(6)$$

Rupture of Fault

To make the phases of elemental waves dispersed, authors assume the rupture front to spread irregularly in a concentric circle. The model of the rupture front is depicted in Figure 7. The velocity of normal distribution is expressed in the equation (7).

$$vi = vi(mi, \sigma i, ji) \quad \cdots\cdot(7)$$

Here, m, σ and j are the average, the standard deviation and the initial value of rupture respectively. They suppose mi=2.0 or 2.5(km/sec), σi=0.5mi. The initial point of rupture is assumed to be the focus atthe southeast end of the fault.

Propagation of Wave Motion

Authors disregard the effects of the radiation pattern, the difference in pathes and the direction of sources when they deal with the function gi. They take only the hypocentral distance into account and multiply each elemental wave by the constant ratio of the P in a large earthquake to the P in a small one in the time domain, applying the next equation (8).

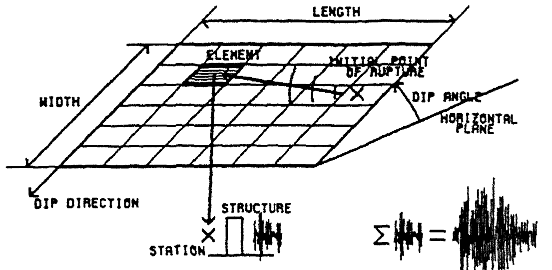

Fig.6 Outline of Method

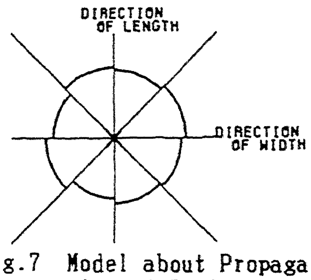

Fig.7 Model about Propagation of Rupture Front

$$\log P = 0.508 + 0.575M_j - 1.307\log_{10}\left(\sqrt{\Delta^2 + d^2}\right) \quad \cdots\cdots(8)$$

Here, Δ and d are the epicentral distance (km) and the depth (km) respectively. The equation (8) is the empirical formula obtained from the seismic records in this region. Moreover, they look upon the whole wave motion as a shear wave and assume $u_i = V_s$(shear wave velocity)= 4.0(km/sec).

Result

Authors have simulated several cases by changing the initial value of rupture. They show one case in Figures 8 and 9. In the EW component, the amplitude in the synthetic waves is about twice as much as that in the records. A lot of short-period components cause the increase in amplitude. In the NS, the synthetic waves aren't similar to the records as the component of 2Hz disturbs wave form. Besides, in the modified NS, the synthetic waves are in good agreement with the records. The results seem relatively well.

IMPROVEMENT IN METHOD

Authors try to examine the above result and improve the method to ascertain the propriety of this study. In this section, they concentrate on the rupture of a fault and the propagation of the wave motion.

Rupture of Fault and Propagation of Wave Motion

In this part, the attenuation through a path is revised at each period. Now authors regard the whole wave motion as a shear wave and take account of the spreading of a wave front and the internal damping. And as the rupture velocity was a little slow in the previous calculation, this value is treated as a parameter next time. And these contents are expressed in the following equations (9) (10) (11) and (12).

$$y_i = g_i \times x_i = g_i \times f\left(t - \frac{s_i}{v_i} - \frac{r_i}{V_s}\right) \quad \cdots\cdots(9)$$

$$y_i(t) = \int_{-\infty}^{\infty} \exp(D_i f + I2\pi f t) \times W_i(f)\, df \quad \cdots\cdots(10)$$

$$W(f) = \int_{-\infty}^{\infty} x(t) \times \frac{r}{r_i} \times \exp(-I2\pi f t)\, dt \quad \cdots\cdots(11)$$

$$D_i = \frac{\pi}{V_s} \times \left(\frac{r}{Q_{ss}} - \frac{r_i}{Q_{si}}\right) \quad \cdots\cdots(12)$$

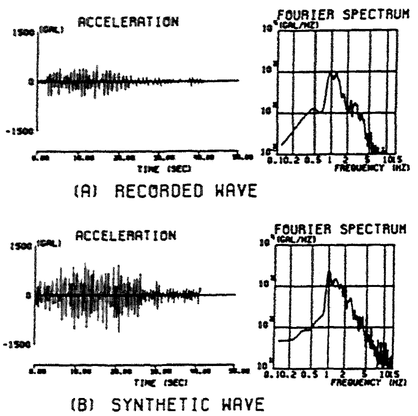

Fig.8 EW Component (1)

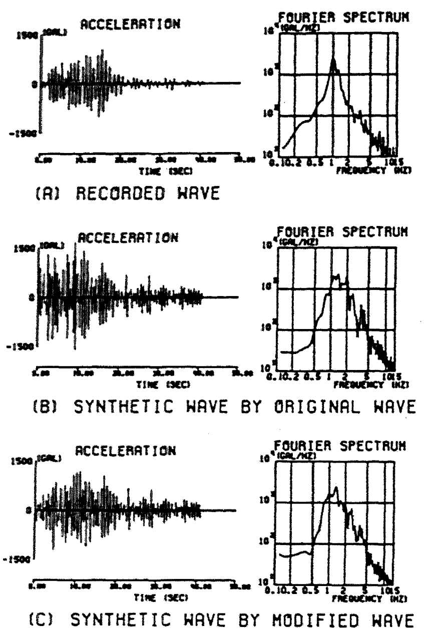

Fig.9 NS Component (1)

where Qss: the quality factor of a shear wave through the path of a small earthquake

Qsi: the quality factor of a shear wave through the path of an element

r : the hypocentral distance of a small earthquake

I : $I^2 = -1$

and f : frequency

Here, Qsi=1000 and Qss=600 are adopted. Also, mi=0.1 αVs (α= 6, 7, 8, 9) is assumed as the rupture velocity. The items which aren't mentioned in this section remain as they are.

Result

Figures 10 and 11 show the results of simulation (The best agreement is obtained when α = 7). The impression of wave form gets much better though the amplitude is a little large. Both waves are perfectly agreed on the envelop and duration of wave motion. Moreover, they are roughly in good agreement at the wide frequency band. Next Figures 12 and 13 represent the state of the development of the response. It is similar between the synthetic waves and the records. That is due to taking the rupture of a fault and the propagation of wave motion into consideration. But it is admitted that the synthetic waves contain more short-period components and they have shorter predominant periods. And the wave motion seems very sensitive in the time domain.

CONSIDERATION OF GROWING PLASTIC

In this section, authors take account of the influence of growing plastic of the building in a mainshock. They regard the building as one degree of freedom and express the frequuency characteristic using a frequency transfer function. So the response to the mainshock is represented by the next equations (13) and (14).

$$\ddot{Z}m = \frac{H(i\omega)r}{H(i\omega)s} \times \ddot{Z}y \quad \cdots\cdots(13)$$

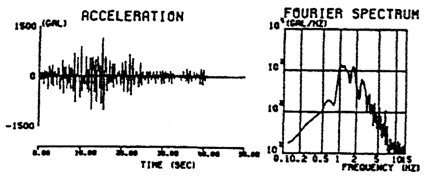

Fig.10 EW Component (2)

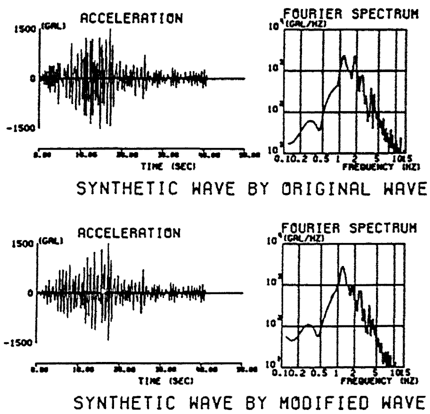

Fig.11 NS Component (2)

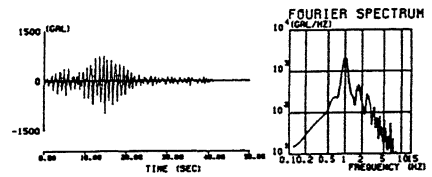

Fig.14 EW Component (3)

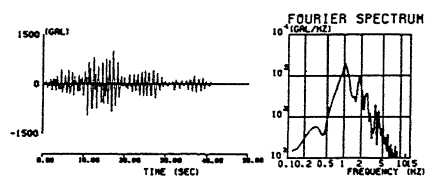

Fig.15 NS Component (3)

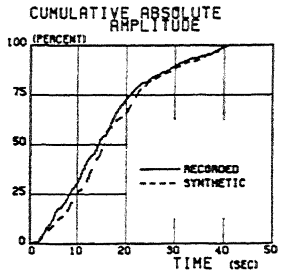

Fig.12 Development of Response about EW Component

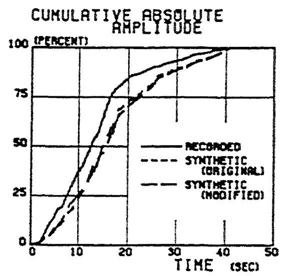

Fig.13 Development of Response about NS Component

$$H(i\omega) = \frac{1+\ i2h\omega/n}{(1-\omega^2/n^2)\ +\ i2h\omega/n} \quad \cdots\cdot(14)$$

where H: frequency transfer function
Z: the absolute accerelation of a structure
ω: frequency
n: the natural frequency of a structure
and h: damping constant

Here, small affixed symbols s, m, y show the foreshock, the mainshock and the synthetic waves respectively. And h=0.03, n=1/0.54Hz(EW) and n=1/0.55Hz (NS) in the foreshock and h=0.05, n=1/1.03Hz(EW) and n=1/1.00Hz(NS) in the mainshock are assumed. Simulated results are shown in Figures 14 and 15. The natural frequency and the ratio of frequency components are in good agreement between the records and the synthesized waves. Besides, the level in amplitude is improved a great deal and the envelop of wave motion is proper. It is thought that the results on the whole are excellent.

CONCLUSION

Authors have reproduced the response in acceleration on the highest floor of a building with quite a new method which is based upon the scaling law of a fault and the record on the building. It is thought that the results have been extremely good. We can estimate the response of a building to a considerable extent by this method even if the structural analysis isn't executed at all. Since the prediction of source parameters in a large earthquake is becoming probable in recent years, it is expected that the method can be applied practically.

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