NEAR-FIELD STRONG GROUND MOTION CHARACTERISTICS BASED UPON THE DISTRIBUTION OF THE WOODEN HOUSE DAMAGES IN JAPAN

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Abstract

The damages of the past great earthquakes have been usually recorded in detail in Japan. This paper describes a method to estimate the intensity of base rock motion based upon the damage ratio of wooden houses and the subsurface geological structure at the site assuming a spectral characteristic of earthquake source based upon the present knowledge of seismology. Four cases were analysed and the maximum acceleration and velocity at the epicenter were estimated and the attenuation characteristics away from the fault area were also reduced and compared with recorded amplitudes with good correspondence.

1. INTRODUCTION

Earthquake with large magnitude often causes drastic damages at the epicentral area. At present few instrumental data of near field strong ground motions are available. Among many damage earthquakes occured in Japanese history it was since 1881 that the qualitative descriptions of damages were begun to be recorded in detail.These damages are given in terms of damage ratio which is considered to reflect the ground motion intensity. The authors describe a method to reduce the distribution of intensity of near-field ground motion at epicentral area based upon those of damage ratio and further show the attenuation characteristics away from the fault expected by the analysed results.

2. EARTHQUAKES AND DAMAGES

Four in-land type large earthquakes with magnitude greater than 7 listed in Tab-1 were selected to study in this research and their locations are shown in Fig.1. The failure of wooden houses by these earthquakes whose distribution covers wide area near the epicentral faults and the number of wooden houses is thought large enough to describe the degree of damages statistically. Damages of wooden houses are shown in Fig.2-5 in terms of damage ratio Rd. Damage ratio is defined as a sum of the number of completely collapsed houses Ncc and a half of the number of partially collapsed ones Npc devided by the total number of houses Nt at the specified site. i.e.,

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Rd = (Ncc+0.5 Npc)/Nt

These four earthquakes are identified as to be caused by strike-slip type fault movement in-land Japan. Damage ratio shows its maximum near the fault and to decrease with the distance away from the faults.

3. DAMAGE OF WOODEN HOUSES

Dynamic characteristics of Japanese wooden houses are known to vary with several factors such as age after construction size of the structure as well as locality. The past experimental studies show that natural period of those wooden houses lies in a range from 0.1 to 0.5 sec. with damping ratio from 0.05 to 0.2. It is also pointed out that under strong cyclic loading condition wooden structure undergoes large deformation which results in longer natural period of the order of 1.5 times than that for small amplitude and increases damping ratio as well. Failure of Japanese wooden house has been found to depend upon the excessive horizontal deformation during earthquake. Based upon the past study summarized by Umemura(1) the relationship among the degree of damage the horizontal displacement of the structure and the damage ratio are estimated and listed in Tab. 2. In addition to vibrational failure soil liquefaction might have caused some damages to the wooden structures. However since the liquefaction initially causes ground failure leading to the damages of foundation this type of failure was estimated to give only partial damage to the structures. Except a case under occurrence of liquefaction in large area like Niigata Earthquake of 1964 the damages reported could be recognized due to vibration in the first order approximation.

4. NEAR-FIELD STRONG GROUND MOTION CHARACTERISTICS

The present knowledge on source mechanism by dislocation theory as well as observation shows several important characteristics on near-field strong ground motion. Spectral characteristics on source model have been reduced called as scaling law(Aki(2), Haskel(3)) which states the shape of displacement spectral intensity keeps similarity for different magnitude earthquake. The shape is characterized by a straight level of the intensity in a frequency range up to corner frequency $f\ell$ at which the spectral amplitude begins to decrease with square or cubic of the frequency(squqre or cubic model). The frequency $f\ell$ is related with the running time required by rupture from start to stop on the fault plane. Recent study of spectral analysis of recorded acceleration on rock shows that the shape of the spectrum has two corner frequencies($fa\ell$ and fah) between which the intensity of the spectrum isconstant as shown in Fig.6. Since the spectral intensity of accel eration is found to decrease when frequency decreases in the range lower than $fa\ell$ with tangent of negative square of frequency the lower frequency is considered to correspond to $f\ell$ in the displacement spectrum i.e.,

$$f\ell = fa\ell$$

The existance of the constant part of the acceleration spectrum implies to support rather the square model of the displacement spectrum than the cubic one. The higher corner frequency fah has been interpreted by Papageorgiou & Aki(4) recognizing the maximum frequency limitted by dull stopping phase of the rupture at the end of the fault. Some of the example of the $fa\ell$ and fah are shown in Tab. 3. The average velocity response spectra based upon 18 records on hard and soft rock ground reported by Ohsaki et al.(5) is shown as in Fig.7. Since the response velocity spectrum coincides with acceleration spectrum the corner frequency in Fig.7 may be considered as f_{al} and listed in Tab.3.

It is also found in Fig.7 that the hard rock gives only one half of the spectral intensity than that of soft rock. On the other hand particle velocity near the fault is supposed to be limitted by the maximum shear strain at failure. As is well known the particle velocity is expressed by the following relationship.

$$v = \gamma \times c$$

where v:particle velocity
γ:shear strain
c:velocity of shear wave propagation

The particle velocity at and near the fault plane is expected to correspond to the shear strain at failure because the rupture itself is the shear failure of the fault. The above faulting characteristics of constant particle velocity corresponds to the si mple dislocation model of the constant slip velocity(dislocation velocity) which satisfies square model. Based upon the above mentioned present knowledge on the characteristics of seismic source it seems reasoble to assume the constant particle velocity or the constant intensity of the acceleration spectrum between two frequencies of f_{al} and f_{ah} Three acceleration records of El Centro(1940) Taft(1952) and Lake Hughes No.4(1972) were modified to have a constant intensity of acceleration spectrum from f_{al}=0.5Hz to f_{ah}=5Hz and shown in Fig.7.

5. GROUND MOTION COMPATIBLE WITH THE DAMAGE RATIO OF THE WOODEN STRUCTURE

The frequency characteristics of the base rock motion at the epicentral area could be assumed as discussed in the preceding section. The present problem is to estimate probable level of the input base rock motion from which the surface motion compatible with the observed damage ratio could be reduced. Denoting Gb(f) as the spectrum of input acceleration time history, that of ground motion at surface Gs(f) may be expressed as

$$Gs(f)=T(f)\times Gb(f)$$

where T(f) is tranfer function of the subsurface layer. T(f) was evaluated by multi-reflection analysis by assuming horizontal layer structure which was estimated by many boring data as well as geophysical survey. The damage ratio may be converted into evaluation of equivalent quantity of response displacement. Since T(f) is non linear function against level of the input Gb(f) several iteration is required to obtain the level of the intensity of Gb(f) giving a surface response Gs(f) whose maximum displacement spectral reaches the required value in a range from 1Hz to 5Hz. To obtain response spectra the structural damping was assumed as 0.15 as average.

6. SUBSURFACE GEOLOGICAL STRUCTURE IN THE CAMAGED AREA AT EPICENTER

The geological conditions of the damaged area were studied by gathering boring data to make geological sections and carring out PS-logging and refraction seismic survey using P and S waves to obtain dynamic characteristics of the geological formation. Geo logical sections are shown in the middle part of Figs.9 -12 for the selected sections for the studied earthquakes. In Nohbi area the Quaternary formation dips westwards and the thickness of the subsurface formation varies 30 to 200m. The base rock is assumed as Yagoto formation of tertiary age. Kita-Tango area covered by recently deposited alluvial formation with maximum thickness of about 25m followed by granitic base rock. Tottori area lacks boring data deep enough to identify base rock formation. For basic formation in this area the diluvium of Quarternary age was tentatively selected which exists 20 to 50m in depth. Fukui area is covered by thick recently deposited alluvium of 20-50m followed by diluvium and Tertiary formation. The shear wave velocities of the geological formations in general are listed in Tab.4. The base rock assumed in this study has shear wave velocity of 1,000m/sec which may be considered as rather soft rock. Fig.13 shows strain dependent dynamic characteristics of soil layers assumed in the response analysis by the program SHAKE.

7. ACCELERATION AND VELOCITY ON THE BASE ROCK COMPATIBLE WITH WOODEN HOUSE DAMAGE RATIO ON THE SURFACE

The results of the present study are shown in Figs.9-12 which show the expected response displacement reduced by the damage ratio distribution the computed maximum acceleration on the ground surface and the computed maximum acceleration and particle velocity in the base rock formation. The variation of the maximum acceleration and velocity is due to using three earthquake acceleration records. Even though large scattering of the estimated ground motions the general trend is found as follows,

a. The maximum intensity is found at or near the fault line with acceleration value of 0.5-1.2g and velocity value of 20-50kine. b. spatial distributions of the particle velocity on the base rock near the fault in the area for Nohbi, Kita-Tango and Fukui earthquakes are shown in Figs.13-15. In Kita-Tango earthquake the estimated fault line was expected northwards into Japan sea with the same length as that in the land based upon the distribution of the observed after-shocks. The pattern of the equi-velocity lines in the above cases shows that equi-intensity line constitutes ellipsoid with the fault line as its long axis. It should be pointed out the above cases analysed are due to the earthquake fault of horizontal strike-slip movement. If the fault is dip-slip reverse movement type, the intensity is expected as one sided distribution stronger on the upper part of the fault(Yoshikawa et al.(6)). Tab. 5 shows comparison of the maximum particle velocity near the faults and the slip velocity obtained by fault model analysis(Usami T.(7)). Slip velocity is given as one half of the displacement divided by rise the time for each case and is considered to give average particle velocity on the fault. Slip velocities are found to have a good correspondence with the particle velocity obtained by the damage ratio analysis.

8. ATTENUATION CHARACTERISTICS OF GROUND MOTION INTENSITY

The average of the maximum acceleration and velocity on the base rock obtained are plotted in Fig.16 and 17 against the distance from the fault. In these Figures the maximum observed values are also plotted as comparison. It should be pointed out that the maximum acceleration and velocity distribution are found to be continuous between observed and estimated from the wooden house damage ratio. The maximum intensity of the acceleration at the fault is found about 1.0g and the maximum velocity about 50kine under earthquakes of Mag.7.3-7.9. The maximum intensity is found constant along the distance away from the fault upto some distance of 5-10km which may be turmed as the corner distance in the attenuation curve. At the distance longer than the corner distance the ground motion intensity is shown as decreasing drastically against distance with a tangent of -1 in log.-log. scale for both the maximum acceleration and velocity. The base rock assumed in this study is thought to be rather soft rock than hard base rock which usually shows shear wave velocity as high as 3.5km/sec. As shown in Fig.7 by Ohsaki,Y.et al.(5) accelerations on the hard rock may be smaller than those on the soft rock by decreasing about 50% of the maximum amplitude.

9. CONCLUSIONS

Based upon the estimated maximum intensity of acceleration and velocity on the base rock which is expected to produce the surface ground motion reasonably compatible with the damage ratio of the wooden house in the epicentral area near fault several conclusions have been obtained as follows,

1.The maximum base rock motion varies 0.5-1.0g for acceleration and 20-80kines for particle velocity at epicentral area for earthquake with Mag.7.3-7.9 under analysis.
2.The maximum values keep rather constant within a critical distance of 5-10km from the faults followed by rapid attenuation beyond the critical distance.
3.The maximum values of the estimated base rock motion in near-field were found to be continuous with those recorded at intermediate and far-field sites.
4.The estimated maximum particle velocity were also found to correspond well with slip velocity given by the fault model analysis for each case.
5.The obtained maximum strong ground motions and its attenuation characteristics which shows good continuity with recorded ones and well correspondence of particle velocity with fault models may be considered to give reliable results presented in this work.

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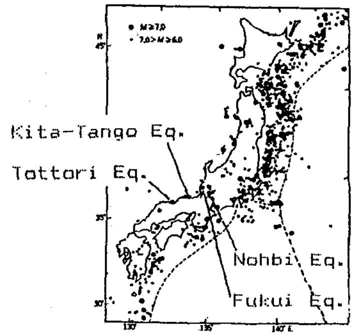


Fig.1 Site Map of the Damaged Area by Four Earthquake under Study

Table.1 Earthquake Analysed

Earthquake	Date	Mag.	Total No. of Collapsed Houses
Nohbi Eq.	Oct. 28,1891	7.9	142,177
Kita-Tango Eq.	March 7,1927	7.5	12,584
Tottori Eq.	Sept.10,1943	7.4	7,485
Fukui Eq.	June 28,1948	7.3	35,420

Table.2 Horizontal Deformation vs. Degree of Damage and Damage Ratio

horizontal displacement	damage	damage ratio
0 - 5 cm	little	0 %
5 -10	medium	0 - 33
10 -20	heavy	33 -100
20 -	collapsed	100

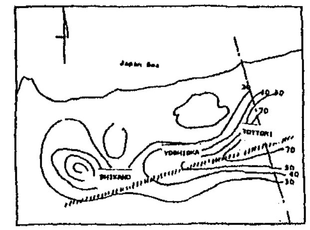


Fig.4 Damage Distribution by Tottori Earthquake

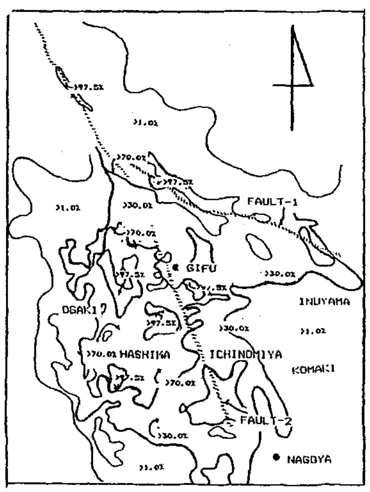


Fig.2 Damage Distribution by Nohbi Earthquake

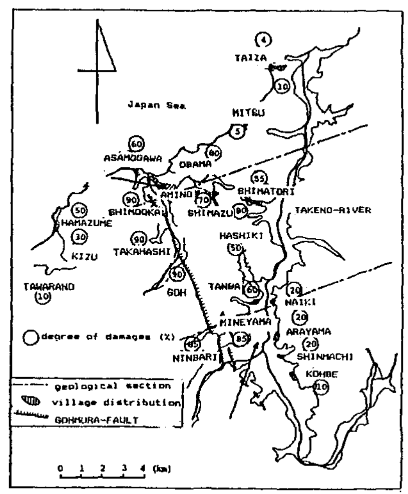


Fig.3 Damage Distribution by Kita-Tango Earthquake

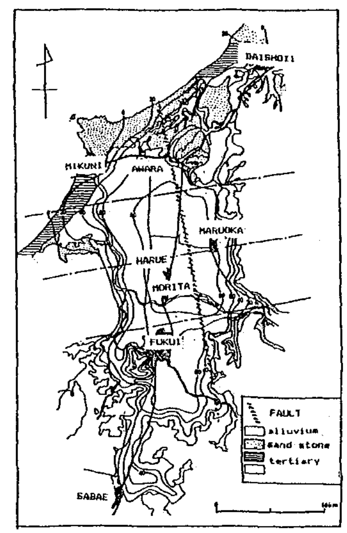


Fig.5 Dameqe Distribution by Fukui Earthquake

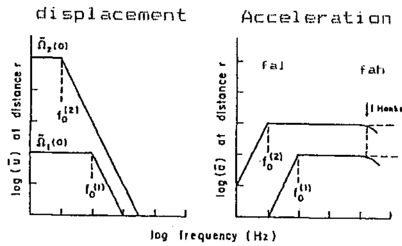


Fig.6 Spectral Characteristics of Acceleration Recorded on Rock(Aki)

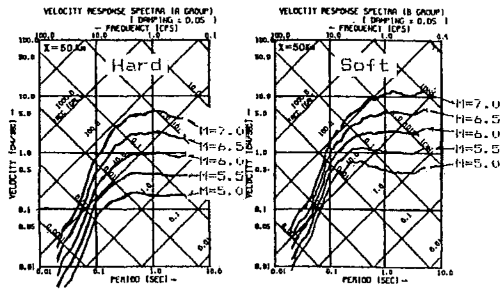


Fig.7 Average Velocity Response Spectra of Acceleration Record on Hard and Soft Rock(Ohsaki)

Table-3 Examples of Corner Frequency

Earthquake	Ms	fah (Hz)
Kern Country(1952)	7.7	2.5
San Fernando(1971)	6.6	5.0
Borrego Mountain(1968)	6.7	4.0
Long Beach(1933)	6.25	4.0
Parkfield(1966)	6.5	5.0
Izu-Toho-Oki(1980)	6.7	4.7

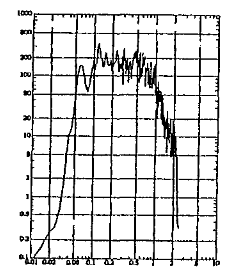
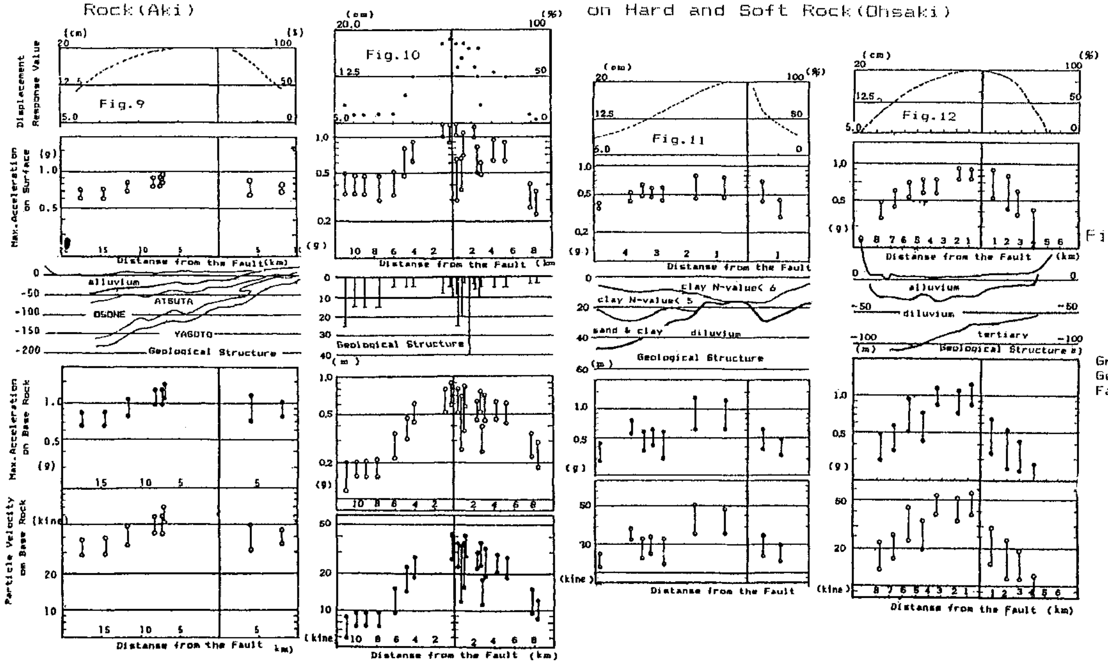


Fig.8 Fourier Spectrum on Assumed Base Rock Acceleration



Damage Ratio,Sd and Estimated Ground Motion on Base Rock with Geological Structure crossing Fault (Kita-Tango Earthquake)

Fig.9 (Nohbi Earthquake)

Fig.10 (Kita-Tango Earthquake)

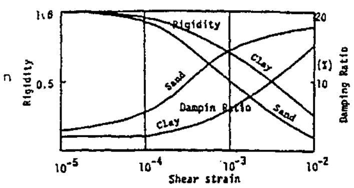
Fig.11 (Tottori Earthquake)

Fig.12 (Fukui Earthquake)

Table.4 Shear Wave Velocity of Geological Formation used as to obtain the Shear Modulus at Small Strain

alluvium clay layer	130–150 m/sec
alluvium sand layer	140–250
diluvium clay layer	200–300
diluvium sand &clay	400–500
diluvium -tertiary	-1000

Fig.13 Shear Modulus and Damping Ratio with Induced Strain



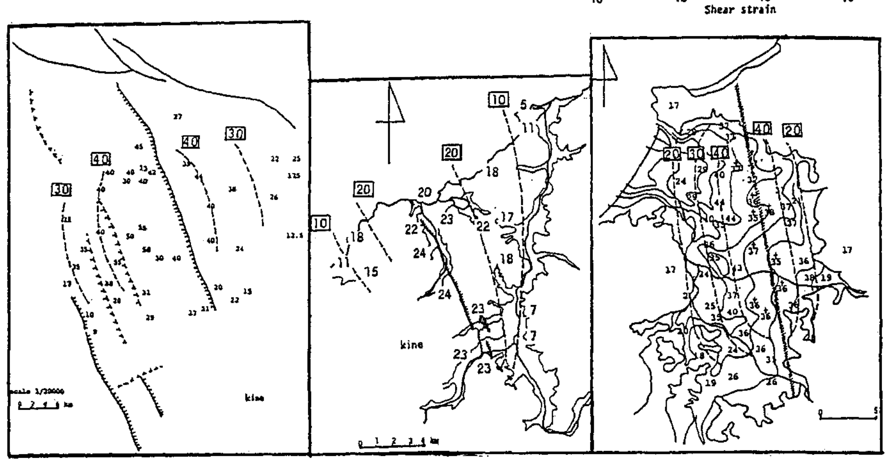


Fig.14 Distribution of Intensity of Particle Velocity on Base Rock

Table.5 Parameter of Fault Model and Comparison of Slip Velocity and estimated Particle Velocity

Earthquake	Dimension.	Rise Time	Dislocation	Slip Vel.	Estimated Particle Vel.
Nohbi Eq.	20-35x15 km2	4.0 sec	7.0 m	87.5 kine	60.–80. kine
Kita-Tango Eq.	35 x13	6.0	3.0	25.	28.
Tottori Eq.	33 x13	3.0	2.5	42.	40.
Fukui Eq.	35 x15	2.0	2.0	50.	52.

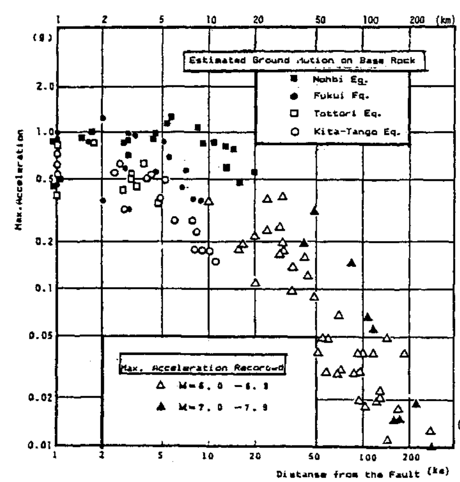


Fig.15 Attenuation of Max.Acceleration on Base Rock against Distanse away from Fault

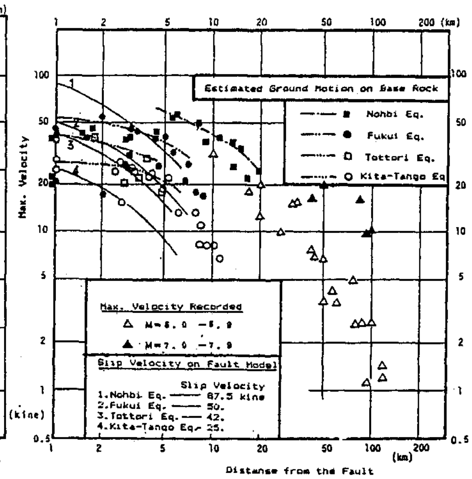


Fig.16 Attenuation of Max. Velocity on Base Rock against Distanse away from Fault