SEISMIC RESPONSE OF THE GROUND AND EARTHQUAKE DAMAGE IN NAGOYA AREA, JAPAN

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SYNOPSIS

The relation of earthquake damages to seismic response amplitudes of the ground in Nagoya area located in the central part of Japan was studied by the following method.

Shear wave-velocity, soil density, N value of the standard penetration test and other geological data at 35 boring sites were obtained by means of measurements of P and S wave-velocity up to 100 m in depth. Analizing these underground geological data, the empirical equations for estimating shear wave-velocity and soil density in any underground depth were derived. By using the above equations, shear wave-velocities and densities in depth at about 380 ground mesh points in Nagoya area were estimated and seismic responses cf each mesh point were calculated by means of the shear wave milti-reflection method by I. Herrera and E. Rosenblueth.

Amplification factor was related to the damage ratio to wooden houses in the three destructive earthquakes in Nagoya area, and it was shown that earthquake damage became great in the place where amplification factor was large.

INTRODUCTION

Nagoya area for the present investigation is located in the central part of Honshu, Japan and suffered damages from three destructive earthquakes during the last hundred years, such as the earthquakes of the 1891 Nobi, the 1944 Tonankai, and the 1945 Mikawa. It appeared that the damages to wooden houses were different not only from each earthquake but from place to place even at a very short distance. This may be resulted from the differences of geological and dynamical characteristics of the ground. It is, therefore, important to elucidate the geological and dynamical properties of the ground for obtaining the seismic risk in Nagoya area.

To obtain the seismic characteristics of the ground, P- and S-wave velocity measurements have been carried out at thirty-five sites in Nagoya area. The data of the shear wave-velocity measured are, however, not enough to fully understand the seismic characteristics of the ground over the whole wide area in Nagoya, and further to make the microzoning map for the estimation of earthquake damages. Then we tried to calculate the distribution of shear wave-velocities and the densities at their unknown places from the geological data and standard penetration test values measured in situ, which have been obtained well by some thousands of test borings carried out in Nagoya area. The empirical equation for the estimation of shear wave-velocities is presented in a similar way as developed by Y. Ohta and N. Goto (1976). In the present paper, the empirical equation for the estimation of density in depth is also developed on the basis of our experimental field data together with the equation for the shear wave-velocity.

By using these equations, shear wave-velocities and bulk densities in any depth are estimated. Thus seismic response spectra of about 380 points in Nagoya area are calculated by means of the shear wave multi-reflection

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method by I. Herrera and E. Rosenblueth (1965).

GEOLOGICAL PROFILE OF NAGOYA AREA

Geological profile of Nagoya area located in the south-east part of the Nobi plain, central Japan, is shown in Fig. 1. The tectonic stratifications were formed by a westward dipping sedimentary sequence, and sediments are deep in the western part of the area but thin its eastern part. The uppermost layer is alluvial deposit of less 20 m in thickness. The lower layer is composed of diluvial sediments of clay, sand and gravel. Tertiary base of 200 m in depth at the west region, which is exposed at the eastern hill side of the area. Geological profile of the ground up to 50 m in depth is well studied by thousands of boring surveys and many data of soil are obtained.

ESTIMATION OF SHEAR WAVE-VELOCITY AND BULK DENSITY

Shear wave-velocity and bulk density of soils are neccessary for calculating the seismic response of the ground, but it is not so easy to know such constants in every site of the area because of technical and economical stand points. Then the available method for estimating such constants is expected. The authors tried to derive an empirical equation for estimating shear wave-velocity and bulk density in the following device.

Boring surveys ranging up to about 100 m in depth were carried out at 35 sites in Nagoya area. Shear wave-velocities were measured by means of P and S wave-velocity logging, and bulk densities were also measured by the ratio of weight to volume of sample cores obtained by the standard penetration test of soil.

The relations between shear wave-velocities and N values of standard penetration test were obtained in the cases of alluvium and diluvium, or of clay, silt, sand and gravel as shown in Fig. 2. However, the curves representing these relations were somewhat different in soil facies and its geological ages. Therefore, shear wave-velocity may be expressed by the following equation.

$$Vs = Co \cdot N^{\alpha 1} \cdot H^{\alpha 2} \cdot C_E \cdot C_F \qquad (1)$$

Here, Co, α_1 , and α_2 are constants, and H means depth. Soil facies and geological ages are qualitative items essentially, but in the above equation they are expressed as the numerical constants C_E and C_F. Geological ages are classified into three categolies: alluvium, diluvium, and tertiary. Soil facies are classified by the grain size into four: clay, silt, sand, and gravel. Numerical constants which express each categoly are derived so as that the measured velocity well agrees with the estimated one by Eq. 1, on the analysis of about 450 data of shear wave-velocities measured at 35 boring sites.

The empirical equation thus obtained is,

$$Vs\ (m/s) = 100N^{0.15}H^{0.10} \begin{Bmatrix} 1.00\ (\text{allivium}) \\ 1.33\ (\text{diluvium}) \\ 1.73\ (\text{tertiary}) \end{Bmatrix} \begin{Bmatrix} 1.00\ (\text{clay}) \\ 0.87\ (\text{silt}) \\ 0.86\ (\text{sand}) \\ 0.99\ (\text{gravel}) \end{Bmatrix} \qquad (2)$$

The correlation coefficient between measured and estimated velocities is 0.86 as shown in Fig. 4.

The same analysis was carried out in the case of bulk density. The equation derived by use of 370 data of measured bulk densities is,

$$\rho(g/cc) = 1.66N^{0.33}H^{-0.01} \begin{Bmatrix} 1.00 \text{ (alluvium)} \\ 1.01 \text{ (diluvium)} \\ 1.01 \text{ (tertiary)} \end{Bmatrix} \begin{Bmatrix} 1.00 \text{ (clay)} \\ 1.01 \text{ (silt)} \\ 1.04 \text{ (sand)} \\ 1.06 \text{ (gravel)} \end{Bmatrix} \tag{3}$$

and its correlation coefficient is 0.64 as shown in Fig. 5.

SEISMIC RESPONSE ANALYSIS

Seismic response of the ground is calculated by means of the shear wave multi-reflection method by I. Herrera and E. Rosenblueth (1965).

The equation of motion

$$\rho_n \frac{\partial^2 u_n}{\partial t^2} = \left(\mu_n + \xi_n \frac{\partial}{\partial t} \right) \frac{\partial^2 u_n}{\partial z^2} \tag{4}$$

where ρ_n, μ_n, and ξ_n are bulk density, regidity and viscosity of the n-th layer respectively, is solved under the assumptions;

1) Ground is horizonyally multi-layered half-space.
2) Only shear waves come in perpendicular to the layers and transmit or reflect at the layer bounderies.

and on the boundary conditions;

a) Shear stress on the ground surface is zero.
b) Shear stress and displacement are continuous at the boundaries.

Abbreviating the development of the equation, only the result is shown. The response $A(\omega)$ is given finally as

$$A(\omega) = \frac{2}{|S_2 + iS_1|} \tag{5}$$

$$\begin{Bmatrix} S_1 \\ S_2 \end{Bmatrix} = T_{n-1} \cdot T_{n-2} \cdot \ldots \cdot T_1 \cdot \begin{Bmatrix} 1 \\ 0 \end{Bmatrix} \tag{6}$$

$$T_{n-1} = \begin{bmatrix} \cos\lambda_{n-1} & \sin\lambda_{n-1} \\ -\gamma_{n-1} \cdot \sin\lambda_{n-1} & \gamma_{n-1} \cdot \cos\lambda_{n-1} \end{bmatrix} \tag{7}$$

$$\gamma_{n-1} = \frac{\rho_{n-1} \cdot V_{n-1}}{\rho_n \cdot V_n} \left[\frac{1 + i\alpha_{n-1}}{1 + i\alpha_n} \right]^{\frac{1}{2}} \tag{8}$$

$$\lambda_{n-1} = \frac{\omega}{(1 + i\alpha_n)^{\frac{1}{2}} \cdot V_{n-1}} \cdot h_{n-1} \tag{9}$$

$$\alpha_n = \frac{\xi_n \cdot \omega}{\mu_n} \tag{10}$$

When the soil is assumed to be Voigt body, α_n means the specific attenuation factor Q_n^{-1}. Therefore, the response $A(\omega)$ can be calculated when the thickness h_n, shear wave-velocity V_n, bulk density ρ_n, and Q_n value in the n-th layer are given.

Shear wave-velocity V_n and bulk density ρ_n are estimated by the Eq. 2 and Eq. 3. Q is assumed to be constant, 20. The number of layers varies six to fifteen depending on ground conditions.

As shown in Fig. 1, there is a lack of alluvial deposit in the eastern region of Nagoya area and diluvial sediment is exposed on the ground surface. Most of the boring surveys are digged into diluvial layers, but some into tertiary ones. Thus, the seismic base is assumed as the upper-most surface of the tertiary layer for the present investigation.

Nagoya area was divided into 381 meshes of about 1 * 1 km squares, and response spectra of the surface motion were calculated in each mesh in the seismic frequency range of 0 - 10 Hz. Amplification factor was defined as the maximum amplitude of the response spectrum.

Distribution of the amplification factors are shown in Fig. 6 and Fig. 7, the former is for the non-attenuation and the latter for Q = 20. It is found that amplification factors are large in the western, especially in the southwestern region of the area. This distribution will be compared with the distribution of damage to wooden-house in the earthquake in next section.

EARTHQUAKE DAMAGE

Earthquake damages in the following three destructive earthquakes were studied.

1) The Nobi Earthquake of 1891. Earthquake magnitude M is 8.4 and epicentral distance Δ is 60 km. The Neo-Valley fault of about 80 km in length was formed, its southern end being about 30 km apart from the north-western part of Nagoya area where about 350 persons were killed and about 7,900 houses were completely destroyed.

2) The Tonankai Earthquake of 1944. M = 8.0, Δ = 180, 121 persons were killed and about 7,560 houses were destroyed.

3) The Mikawa Earthquake of 1945. M = 7.1, Δ = 50 km, the epicenter was in the shallow bottom in the south eastern direction of Nagoya where 8 persons were killed and 531 houses were destroyed.

Damage ratio to wooden houses defined as

$$\text{Damage ratio} \quad (\%) = \frac{X_1 + 0.5\, X_2}{X} 100$$

$$\begin{cases} X_1 & : \text{completely destroyed houses,} \\ X_2 & : \text{partially destroyed houses,} \\ X & : \text{total number of houses,} \end{cases}$$

is calculated in each district, and is rearranged in each mesh. The distribution of damage ratio is shown in Fig.8. Damage ratios in the Nobi Earthquake are large in the north-western region of Nagoya area. On the other hand, those in the Tonankai and Mikawa Earthquake are large in the south region faced to the Ise Bay.

Comparing Fig. 8 with Fig. 6 or Fig. 7, it is found that damage ratios are large in the meshes whose amplification factor is large. Large damage ratios in the north-western region, however, may be originated in the fact that the region is close to the Neo-Valley fault as mentioned above.

The relation between amplification factors and damage ratios is illustrated in Fig. 9 in which the damage ratios in the Nobi Earthquake are plotted against the amplification factors of 14 boring sites. As will be seen from Fig. 9, damage ratio increases with the increase of the amplification factor.

CONCLUSION

The empirical equations for estimating shear wave-velocity and bulk density of soil in terms of its geological characteristic indices such as N values of the standard penetration test, depth where the soil is, soil age and facies were derived from the systematic analysis of about 800 soil data obtained by means of P and S-wave velocity logging up to about 100 m in depth at 35 boring sites in Nagoya area.

By using the shear wave-velocities and bulk densities estimated by our empirical equations, seismic resposes at about 380 mesh points in Nagoya area were calculated by the shear wave multi-reflection method by I. Herrera and E. Rosenblueth.

Amplification factor was related to the damage ratio to wooden houses in the three destructive earthquakes in Nagoya area, and it was shown that earthquake damage became great in the place where amplification factor was large.

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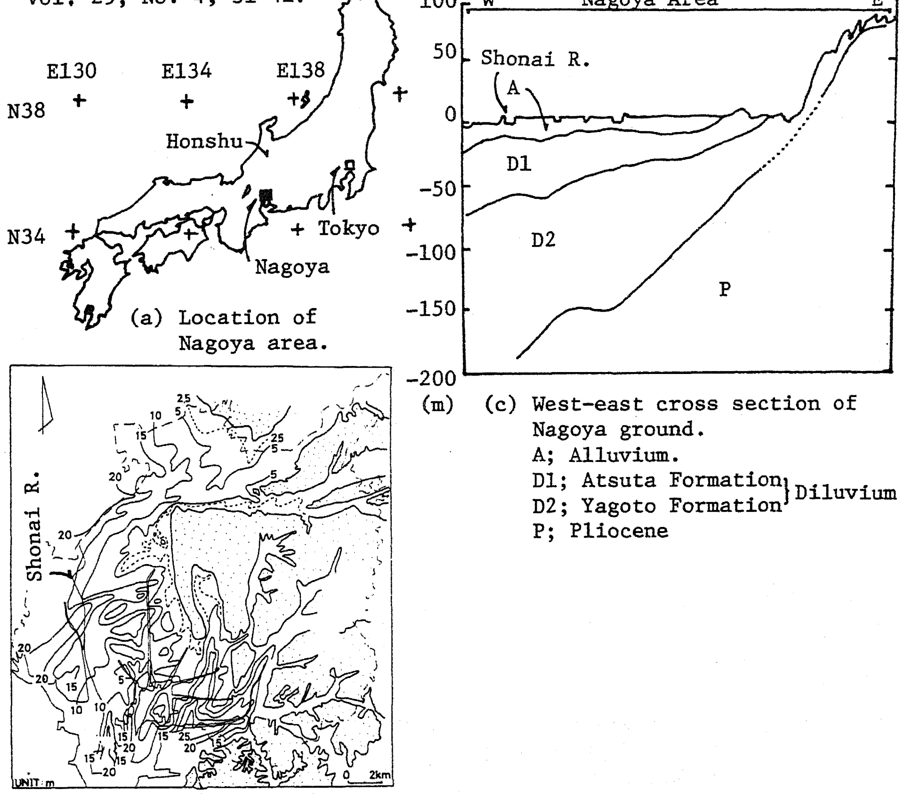
1) Herrera, I. and Rosenblueth, E., 1965, Response Spectum on Stratified Soil, Proc. III. W.C.E.E., Vol.1, I-44 - I-60.
2) Ohta, Y. and Goto, N., 1976, Estimation of S-Wave Velocity in Terms of Characteristic Indices of Soil,Butsuri-Tanko(Geophysical Exploration), Vol. 29, No. 4, 31-41.



(a) Location of Nagoya area.

(c) West-east cross section of Nagoya ground.
A; Alluvium.
D1; Atsuta Formation } Diluvium
D2; Yagoto Formation } Diluvium
P; Pliocene

(b) Thickness of alluvium deposit.

Fig. 1 Location and geological profile of Nagoya area.

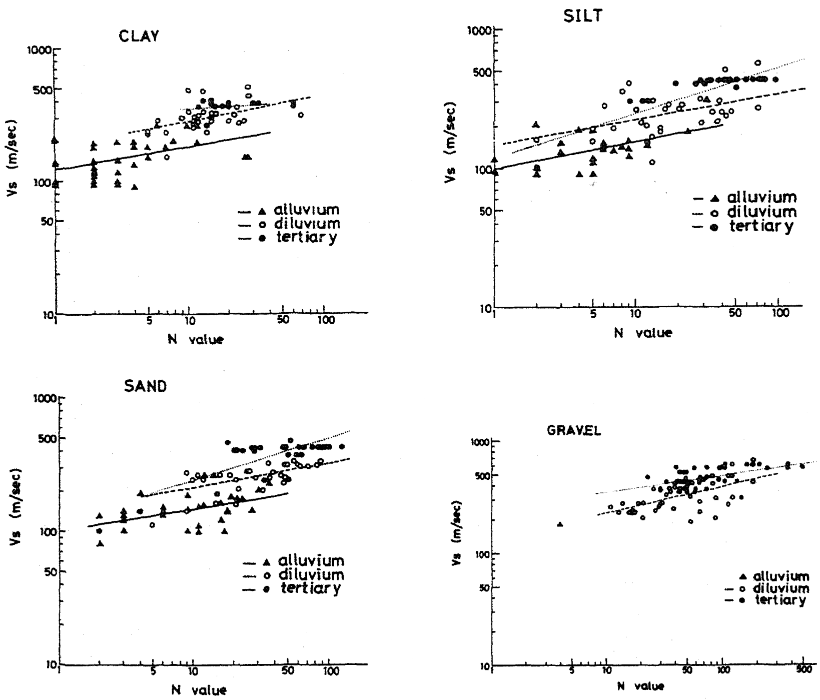


Fig. 2 Relation between shear wave-velocity Vs (m/sec) and N value of standard penetration test.

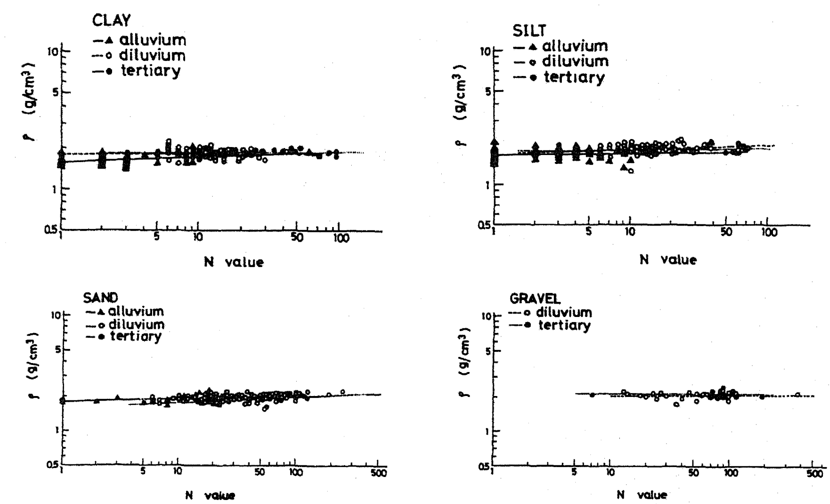
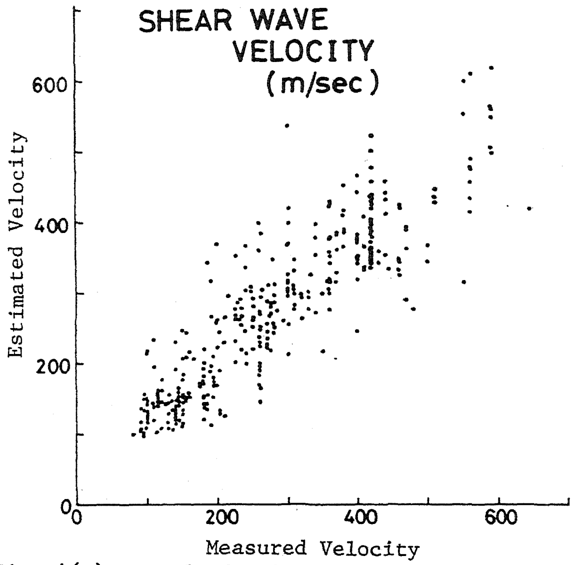


Fig. 3 Relation between bulk density ρ (gr/cm^3) and N value of standard penetration test.



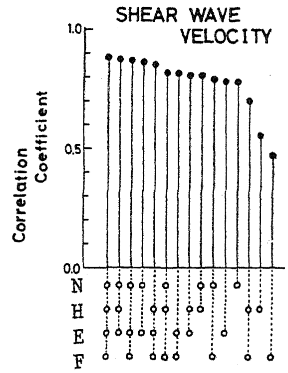
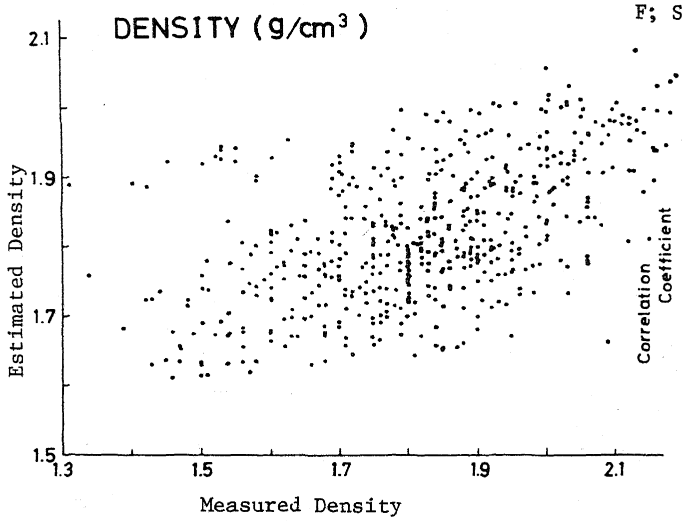


Fig. 4(a) Correlation between measured and estimated shear wave velocity.

Fig. 4(b) Correlation coefficient.
N; N value of standard penetration test.
H; Depth in situ.
E; Soil age.
F; Soil facies.



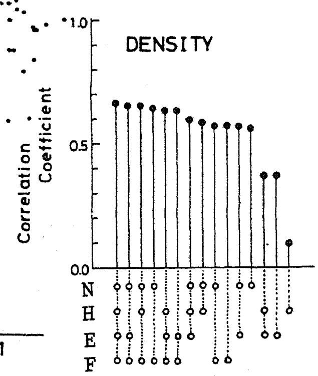


Fig. 5(a) Correlation between measured and estimated bulk density.

Fig. 5(b) Correlation coefficient.
N; N value.
H; Depth in situ.
E; Soil age.
F; Soil facies.

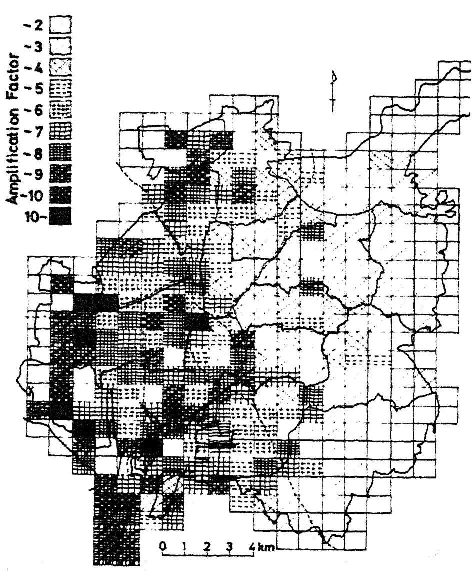


Fig. 6 Distribution of amplification factors in Nagoya area (non-attenuation).

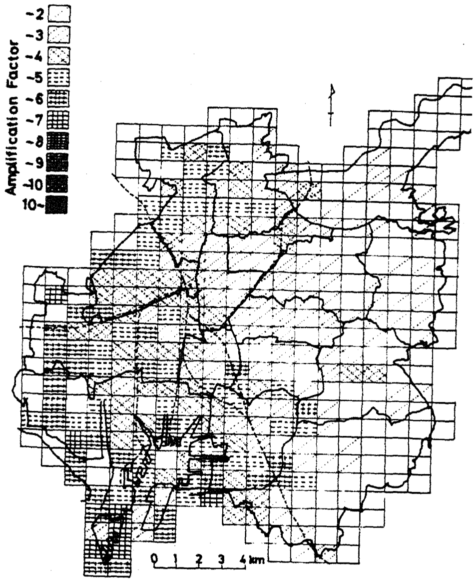


Fig. 7 Distribution of amplification factors in Nagoya area (specific attenuation factor Q is 20).

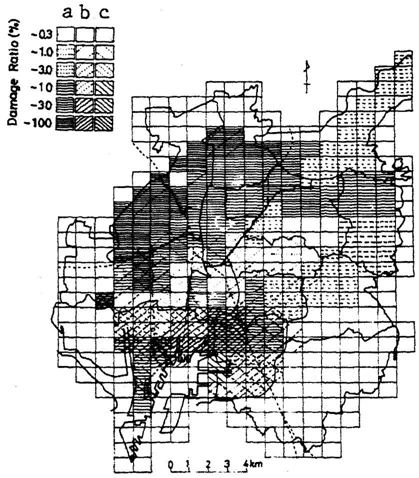


Fig. 8 Distribution of damage ratios of destroyed wooden houses in Nagoya area.
a; The Nobi Earthq. of 1891.
b; The Tonankai Earthq. of 1944.
c; The Mikawa Earthq. of 1945.

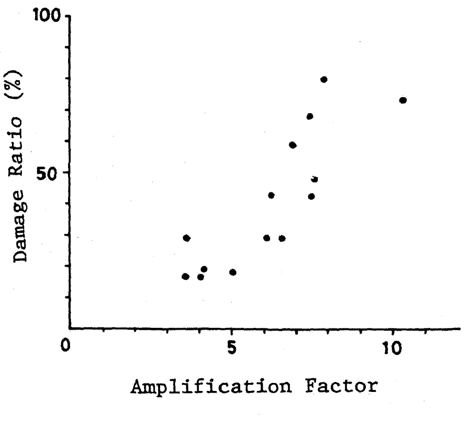


Fig. 9 Relation between damage ratios of the Nobi Earthq. and amplification factors.