EXPECTED LONG PERIOD GROUND MOTIONS DUE TO THE HYPOTHETICAL TOKAI EARTHQUAKE

E. Shima

SUMMARY

Synthetic seismograms, the sum of Love and Rayleigh waves, expected in Tokyo due to the hypothetical Tokai earthquake were computed taking the fault parameters and the underground structure into consideration. Fault parameters were assumed from the published empirical formulae, and the maximum amplitude in Tokyo was found to be around 15 cm. Since there still remains a lot of ambiguity in determining the parameters, we tried to estimate the range of expected ground motions. Depending upon the combination of parameters, it was found that the expected maximum amplitudes of ground motions varies from 8 to 40 cm.

INTRODUCTION

Japan is an earthquake-ridden country. It is said that almost 15% of the total energy of earthquakes occurring all over the world is released from Japan and its vicinity. So, from the ancient time, Japan has suffered from the severe damage due to the earthquakes. Ancient people believed that the earthquake phenomena were due to the wrath of God, many documents not only from the official ones but also from the private ones such as diaries describing the degree of damage were left as the reference for the descendants. Late Professor H. Kawasumi discussed the seismic intensities of the historical earthquakes utilizing the information deduced from the above-mentioned old documents. And now, his effort enabled us to discuss the magnitudes of historical earthquakes since 5th Century.

Through the study of historical earthquakes it was revealed that the large scale earthquakes originated from off the Pacific coast of Japan hitted repeatedly. From the view of plate tectonics, these earthquakes are said to be interplate earthquakes. The recurrence time of such earthquakes is 100 to 150 years.

Among these earthquakes, if we talk about the focal regions of Nankai and Tokai areas, there are 5 regions. They are ABCDE regions. 1854 Ansei Tokai earthquake was one of the severest earthquakes occurred in Japan. Its focal region covered CDE regions. Ansei Nankai earthquake occurred next day in AB regions. Recent Tokai earthquake occurred in 1944 released the energy from CD regions. This earthquake is called Tonankai

---

Director, Earthquake Research Institute, University of Tokyo, Tokyo, Japan.

earthquaks. Two years later, in 1946, Nankai earthquake hitted Japan. This was originated from the focal regions AB. Thus the focal region E is said to be a seismicity gap which may become the focal region of the future earthquake. Numerous instrumental observations data also shows the indication of the accumulation of strain energy in this region. Future Tokai earthquake is thus predicted in the sense of long term prediction.

In response to the prediction, Japanese Government is now conducting the continuous watching system in this area for the purpose of short term prediction. The Land Agency of Japan also announced officially the Large-Scale Earthquake Countermeasure Act to reduce the disaster and designated an area under intensified measure against the earthquake disaster based mainly upon the estimated short period ground motions. However, the estimation of damage due to the long period seismic waves was left for the future study, since our knowledge on the characteristics of long period seismic waves is not enough to discuss the matter.

Although it might be difficult, the estimation of the long period ground motions is extremely important, since we have many structures having long natural periods, such as high-rise buildings, huge oil tanks etc. in Tokyo Metropolitan area. These structures experienced no severe earthquake. Although Tokyo is apart more than 100 km from the focal region, and the seismic intensity is estimated to be V or less in JMA Intensity scale, the amplitude of long period surface waves excited by around 2.5 km thick sedimentary layers may be very large. Although the acceleration itself may be small, the displacement amplitude may be as large as of the order of ten cm. In such a case, the sloshing amplitude of the oil may be very large, and it may suffer the damage to the structure. One example is the recent M7.7 Nihonkaichubu earthquake that brough the heavy damge in Akita and Aomori Prefectures and took 102 human lives. During the earthquake, overflow of oil from the oil tanks(10 out of 34) due to the sloshing was observed in Niigata city. The maximum acceleration was believed to be less than 5 gals, since no strong motion seismograph, SMAC, was triggered. That is quite natural, since Niigata city is apart more than 300 km from the origin. However, ground displacement was larger than 3 cm. Accurate amplitude is unknown, since JMA strong motion displacement seismograph cound not record the maximum amplitude. It was out of scale.

In the following, we will try to estimate the long period ground motions from the hypothetical Tokai earthquake. We will synthesize the surface waves excited by the thick sedimentary layers of Tokyo Metropolitan area taking the fault parameters and the underground structure into consideration.

FAULT PARAMETERS OF HYPOTHETICAL TOKAI EARTHQUAKE

National Committee on Disaster Prevention proposed the rectangular fault as shown in Fig. 1. Parameters are as follows:

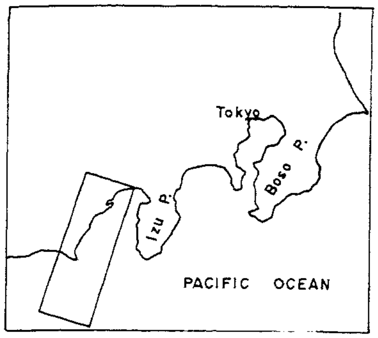


Fig. 1

Fault Length	L	120 km
Fault Width	W	50 km
Dip Angle		20 °
Dip Direction		77 °
Magnitude		M8
Dislocation	$\bar{U}$	3-4 m

For simplicity, we will fix the above parameters. To synthesize the seismograms of hypothetical Tokai earthquake, additional parameters are inevitable. They are seismic moment M_o, rise time τ and rupture velocity Vr. These parameters may be estimated through the published empirical formulae to some extent although there still remains a lot of ambiguity. For simplicity, we will assume the circular uniform rupture starting from the southwest end of the assumed fault.

1) Seismic Moment Mo

Aki(Ref.1) defined the seismic moment Mo as follows,

$$Mo = \mu \bar{U} S \qquad (1)$$

where μ is the rigidity, $\bar{U}$ is the mean dislocation of fault and S=LW is the area of fault. Since $\mu = \rho Vs^2$, where ρ is the density and Vs is the shear wave velocity, we can estimate μ correctly provided that we know the underground structure of Tokai area. Kubota and Hayakawa(Ref.2) proposed the three-layered underground structure of this area. According to them, the thickness of the topmost layer is 5 km. Then follows the intermediate layer, having the P-wave velocity of 6 km/sec, with 15 km thickness, then 6.6 km/sec layer having 10 km thickness follows. Murauchi et al.(Ref.3) also claim that the thickness of the topmost layer is 6 km, and then 6 km/sec layer follows. From the observations of the natural earthquakes in Izu Peninsula, Kudo et al.(Ref.4) found a layer having the shear wave velocity of 3.7 km/sec which corresponds to the 6 km/sec layer. If we assume that the depth of the top of fault be 5 km, then the bottom of the fault becomes around 22 km. So, we may consider that the assumed fault lies in the 6 km/sec layer. ρ is approximately equal to 2.8 g/cm^3. So the rigidity is calculated to be 3.8×10^{11} dyne.cm. The relation between the fault area S(km^2) and the earthquake magnitude M is given by Sato(Ref.5) as follows:

$$\log S = M - 4.07 \qquad (2)$$

From this formula M is calculated to be 7.85. Sato(Ref.5) also obtained empirical formula between the dislocation $\bar{U}$(cm) and the earthquake magnitude M as

$$\log \bar{U} = 0.5M - 1.40 \qquad (3)$$

From equations (2) and (3), $\bar{U}$ becomes 3.35 m. The seismic moment Mo is then 7.6×10^{27} dyn.cm. In equation (3), if we put M = 8, then we have $\bar{U}$ = 4 m. In this case, M_o becomes 9.1×10^{27} dyne. cm. Associated with the relation between Mo and M, we have following empirical formulae.

$$\log Mo = 1.5M + 16.2 \qquad \text{(Sato,Ref.5)} \quad (4)$$

$$\log Mo = 1.5M + 16.0 \qquad \text{(Aki,Ref.1)} \quad (5)$$

$$\log M = M_S + 19.9 \quad M_S > 7.5 \quad \text{(Brune,Ref.6)} \quad (6)$$

where Ms is the surface wave magnitude. If we put M = Ms = 8, then we have 1.6×10^{28}, 1.0×10^{28} and 0.8×10^{28} dyne.cm from equations (4),(5)and(6) respectively. In the same way, if we put M = Ms = 7.85 then we have 0.94×10^{28}, 0.6×10^{28} and 0.56×10^{28} dyne.cm respectively. Therefore estimated seismic moment lies between 0.6 to 1.6×10^{28} dyne.cm. Incidentally, seismic moments of both 1944 Tonankai and 1946 Nankai earthquakes, which occurred in the adjacent region of Tokai area, were estimated to be 1.5×10^{28} dyne. cm from the observations of long period seismic waves. Comparing the assumed fault area with the ones of mentioned earthquakes, the seismic moment of the hypothetical Tokai earthquake must be smaller than the others. So, for simplicity, we will fix the seismic moment of the interested hypothetical earthquake to be 0.9×10^{28} dnye.cm.

2) Rise time

Geller's formula(Ref.7) $Vr = 16\sqrt{S}/(7\pi^{\frac{3}{2}}Vs)$ may be used to estimate the rise time. He assumed that L = 2W and Vs = 4.0 km/ sec. Substituting these values into his formula he obtained the simple relation, namely Vr = 0.0726L. In our case, L = 120 km, so, Vr becomes 8.7 sec. While, Kanamori and Anderson(Ref.8) claim that $Vr\tau/L$ is constant. This value is nearly equal to 0.2.If Vr = 2.7 km/sec, then τ becomes 8.9 sec. Kanamori(Ref.9) expressed approximately the effective stress σ be

$$\sigma = \frac{\mu}{2Vs} \left(1 + Vs / Vr \right) V, \qquad (7)$$

where V is the dislocation velocity. From the observational data we know that the effective stress and stress drop are almost the same. The stress drop of Tonankai and Nankai earthquakes are estimated to be 39 bar. So in case of the hypothetical Tokai earthquake, we may assume the same amount of stress drop, since these earthquakes are supposed to be similar ones. We will assume thus stress drop of 40 bar. V will be 33 cm/sec, provided that Vr = 0.72Vs(Ref.7). From this τ = 335/33 = 10.1 (sec). If we assume Vs = Vr, then V becomes 39 cm/sec and τ becomes 8.6 sec. While, Sato(Ref.5) estimated the rise time of

M8 earthquake to be 5 sec, assuming that the dislocation velocity of 80 cm/sec and 4 m dislocation. The estimated values are thus lie between 5 to 10.1 sec.

3) Rupture velocity Vr

One may claim that the assumption of uniform rupture is too optimistic. But we are forced to use the empirical formula since other parameters are also nondeterministic. Geller(Ref.7) obtained the following relationship from the statistics of reported earthquakes.

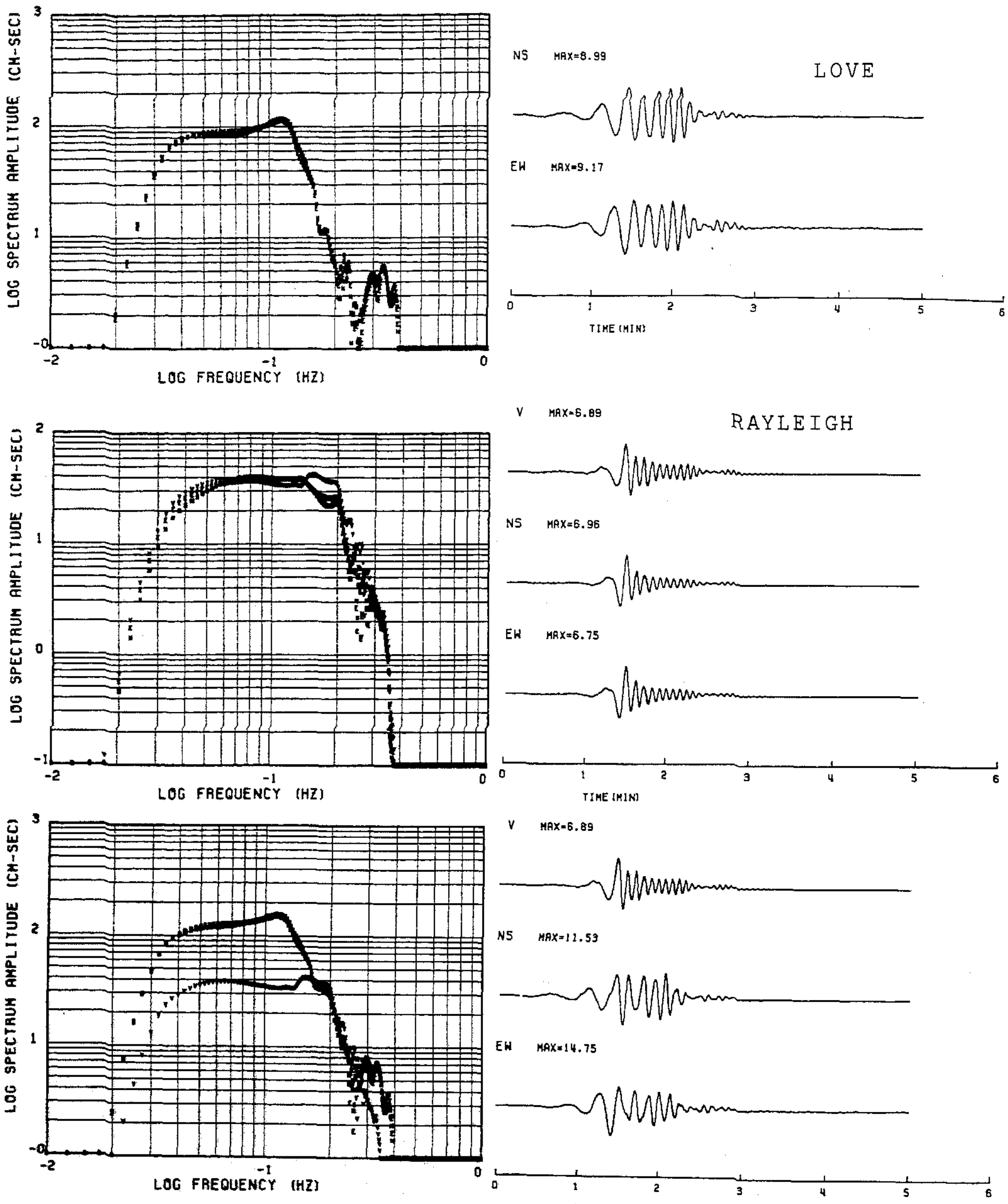
$$Vr = 0.72Vs \tag{8}$$

Putting Vs = 3.7 km/sec into equation (8), we have Vr = 2.7 km/sec. We will consider this as the standard value. However, it seems to the author that the fluctuation of Vr is depend upon the proposed model. We will assume that the rupture velocity is between 2.3 - 3.1 km/sec.

SYNTHESIS OF LONG PERIOD GROUND MOTIONS

Following the method proposed by Kudo(Ref.10), the long period ground motions were synthesized. We will assume the fault parameters discussed in the former section. For convenience' sake, we divided the fault into 6x5 meshes. Then computed the Love and Rayleigh waveforms as the superposition of normal modes up to 2nd higher modes for each mesh. Then the contribution of every meshes were integrated in the time domain taking the uniform rupture velocity into consideration. Since Tokyo is far from the source region, far field solution may be used. We checked if the number of meshes alters the waveforms significantly. It was found that the abovementioned number of meshes was sufficient. However, at the sites of shorter distances the number of meshes should be increased.

The underground structure model assumed in this study was the modified one suggested by Kudo(Ref.10). Originally Kudo's model was the slight modification of the one deduced from the observations of Yumenoshima Explosions(Ref.11). The model consists of 5 layers. From the surface to upper mantle, shear wave velocities are 1.3, 2, 3.54, 3.7, 4.3 km/sec and densities are 2.1, 2.4, 2.7, 2.8 and 3.1 respectively. The thicknesses are 1.2, 2.8, 8 and 10 km respectively. Kudo used his model to verify if the seismograms of Tokyo due to 1931 Kita-Izu and 1974 Izu-Hanto-Oki earthquakes could be reproduced by the method mentioned before using the published fault parameters. His trial was quite successful. The wave path to Tokyo in case of the hypothetical Tokai earthquake, the underground structure is common from Izu to Tokyo. But we have to consider the additional path. The underground structure of Izu Peninsula is so to say harder compared with the remainder part. That is why we had to change Kudo's model slightly.



SURFACE WAVES FROM THE TOKAI EARTHQ. AT HON

F. LENGTH (KM)	120.0	DISTANCE (KM)	116.0
F. WIDTH (KM)	50.0	AZIMUTH (DEG)	138.0
SLIP-ANGLE (DEG)	77.0	MESH (L & W)	6 5
DIP-ANGLE (DEG)	20.0	INIT. BREAK	6 5
MOMENT (D-CM)*E25	900.0	CIRCULAR PROPAGATION	
DEPTH (KM)	5.0		
RUP. V. (KM/S)	2.7		
RISE TIME (S)	0.6		
STRIKE (DEG)	192.5		

Fig. 2.

Fig. 2 shows an example of computation. In this example we assumed Vr = 2.7 km/sec, τ = 8.6 sec. In actual case, we will observe Love and Rayleigh Waves simultaneously. Therefore, Love and Rayleigh waveforms were added in the time domain and shown in the figure. The maximum amplitude is around 15 cm in EW-component. This value will be the most probable one from the engineering judgement. However, since there remains a lot of ambiguity in determining the fault parameters, we tried to estimate the range of expected amplitudes. For that purpose, we fixed the rupture velocity and computed the maximum amplitudes of ground motions for various rise times. This is shown in Fig. 3. The shorter the rise time the larger will be the maximum amplitudes. In the former section, the estimated rise time was between 5 to 10 seconds. When τ = 5 sec, the maximum amplitude will be 23 cm, while in case of τ = 10 sec, the maximum amplitude will be 13 cm. In the same way, we fixed the rise time as 8.0 sec and computed the maximum amplitude for different rupture velocities as shown in Fig. 4.

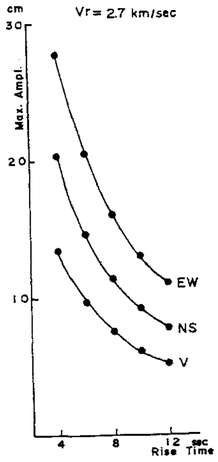


Fig. 3.

If Vr = 2.3 km/sec, then the maximum amplitude will be 14 cm. While, when Vr = 3.1 km/sec, the maximum amplitude becomes 28.4 cm. So, if τ = 5 sec and Vr = 3.1 km/sec, this may be the worst case, the estimated maximum amplitude will be around 40 cm. In the same way, if τ = 10 sec and Vr = 2.3 km/sec, the maximum amplitude will be around 8 cm. Therefore, the expected amplitude varies from 8 to 40 cm, half and twice of the standard value.

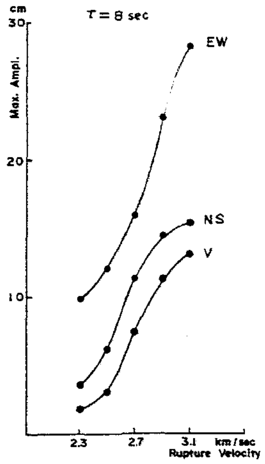


Fig. 4.

CONCLUDING REMARKS

An effort to estimate the long period ground motions expected in Tokyo due to the hypothetical Tokai earthquake is introduced. For this purpose, we computed the synthetic seismograms of surfacewaves which may be excited by the around 2.5 km thick sedimentary layers in Tokyo Metropolis. Although we may predict the earthquake in the sense of long term prediction, its fault parameters are nondeterministic. Thus we assumed the parameters through the published empirical formulae. The maximum amplitude expected in Tokyo thus computed was found to be around 15 cm as the most probable one. We also computed the synthetic seismograms assuming the various combinations of parameters, and found that the expected maximum amplitude varies between 8 to 40 cm.

The author is indebted to Dr. K. Kudo in the computation. Financial support was granted by Science Research Fund, Ministry of Education of Japan.

REFERENCES

1. Aki, K., Generation and Propagation of G Waves from the Niigata Earthquake, Bull. Earthq. Res. Inst., 44, 1966, 73.
2. Kubota, R. and M. Hayakawa, Structure of the Crust and Upper Mantle of Tokai Area(Part 2), Abstract of Annual Meeting of Seism. Soc. of Japan, 1980, C33.
3. Murauchi, S. et al., Seismic Exploration of Suruga Bay by means of OBH(Ocean Bottom Hydrophone), Abstract of Annual Meeting of Seism. Soc. of Japan, 1981, B09.
4. Kudo, K. et al., On the Shear Wave Underground Structure of Izu Peninsula, Bull. Earthq. Res. Inst., 53, 1978, 779.
5. Sato, R., Theoretical Basis on Relationships between Focal Parameters and Earthquake Magnitude, J. Phys. Earth, 27, 1979,353.
6. Brune, J., Seismic Moment, Seismicity and Rate of Slip along Major Fault Zones, J. Geophys. Res., 73, 1968, 777.
7. Geller, R., Scaling Relations for Earthquake Source Parameters and Magnitudes, Bull. Seism. Soc. Amer., 66, 1976, 1501.
8. Kanamori, H. and D. L. Anderson, Theoretical Basis of Some Empirical Relations in Seismology, Bull. Seism. Soc. Amer., 65, 1975, 1073.
9. Kanamori, H., Synthesis of Long-period Surface Waves and its Application to Earthquake Source Studies-Kuril Islands Earthquake of October 13, 1963, J. Geophs., 75, 1970, 5011.
10. Kudo, K., The Contribution of Love Waves to Strong Ground Motions, Proc. 2nd Int. Conf. on Microzonation, 1978, 765.
11. Shima, E. et al., On the Base Rock of Tokyo. I; II, III, IV, V, Bull. Earthq. Res. Inst., 51, 1976, 1; 51, 1976, 45; 53, 1978, 305; 53, 1978, 1245; 56, 1981, 265.