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Relatively long period ground motions expected in the Tokyo bay region

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ABSTRACT: In the last decade several huge projects on regional developments along the Tokyo bay have been made particularly on the reclaimed land. It became more important then to study the characters of strong ground motions being specific to this region and for which important structures are to be designed. Recently the input ground motions for designing high buildings on specific sites in Tokyo and Yokohama were proposed by the Tokyo metropolitan government and Yokohama city office. We studied the effects of two dimensional ground formation of the Tokyo bay (basin) region on the relatively long period components (several seconds) of the ground motions by using the discrete wave number method that was proposed by Aki and Larner.

1 INTRODUCTION

Many high buildings collapsed downtown Mexico city which was located 400 km far from the epicenter of the 1985 Michoacan earthquake. Timber apartment houses and double-deck free ways were severely damaged in the San Francisco bay area about 100 km away from the epicenter of the 1989 Loma Prieta earthquake. On these occasions valuable records of strong ground motions were obtained, which showed large amplitudes and extremely long durations of the ground shaking. The Tokyo bay area has a similar geological environment to these cases and the deep soil layer formation has been studied in detail by means of the seismic prospecting made by the Tokyo metropolitan government and the multi-channel acoustic emission tests made by the Japan Marine Guard Agency.

To study the possibilities of extraordinarily strong ground shaking in this particular area we made a series of earthquake response analyses on a simple two layer model by the two dimensional Aki-Larner method (Aki and Larner, 1970). A large variation of response amplitudes in space existed, the phenomenon of which did not appear at all for the cases where either one of the superficial layers was ignored. Also, a very long duration ground shaking was observed near the throat of the bay, which may be due to the complex refraction and reflection of incident waves at the two non-horizontal boundaries.

To understand basic properties of the surf phenomenon, we applied a series of Ricker wavelets to a more simple one-layered model. Because of the superposition effects of the response time history for a single wave, time histories of the response became more sinusoidal and the differences in both amplitude and duration time were more emphasized as we applied many successive incident waves. This suggested a possibility of sever ground shaking with large amplitudes and long duration in Tokyo bay area that is similar to those recorded in Mexico city in 1985.

2 GEOLOGICAL INFORMATION AND MODELING OF THE GROUND IN TOKYO BAY AREA

Tokyo bay occupies an area of about 20 km x 50–60 km and its coast is populated by more than thirty million people. Large projects on regional development have been made or being planned in this area, particularly on the reclaimed land, by the national and local governments as well as the private sectors; e.g., the cross-bay bridge and belt highway, Tokyo Disney Land, Makuhari commercial center, development of the Tokyo No. 13 reclaimed island, MM21 exhibition center in Yokohama and so on. The 60 storied Land Mark Tower which will be the highest building in Japan is under construction in the MM21 area. The depth of water in Tokyo bay is 10 - 25 m in general and if the bay is totally reclaimed the predominant periods of filled soils would not exceed 1.0 sec; not affecting the earthquake response of huge structures with longer natural periods. Also, the depth of filled soils is negligibly small as compared to the horizontal dimensions of the bay and its non-horizontal boundaries are not likely to affect the long period components of strong ground motions. Therefore, we ignored the existence of superficial soil layers and modeled a deeper ground formation.

Research group on the seismic bed rock in metropolitan Tokyo made a series of seismic prospecting by exploding dynamite underground at Yumenoshima for more than ten years (Research Group on Ground Formation in Metropolitan Tokyo, 1989). The ground essentially consists of two layers on the bed rock whose density, shear wave velocity, damping constant and thickness at Yumenoshima are listed in Table 1. The contour map in Fig 1 shows the depth of bed rock that was obtained by compiling the results of Yumenoshima seismic prospecting on more than twenty measurement lines. The bedrock is deepest in the east of the bay and becomes shallower in the north-east and south-west along the principal axes of the bay. The contour map in

Fig 2 shows the depth of the upper layer (a Quaternary layer) detected by the multi-channel acoustic emission tests made by the Japan Marine Guard Agency (Kato, 1984). It goes deeper toward the throat of the bay. We know that the depth becomes smaller inland toward north-east from the Yumenoshima seismic prospecting.

Table 1. Physical constants for soil layers in Tokyo metropolitan area

Layer No.	Density (ton/m^3)	S-wave velocity (km/sec)	Damping constant (%)	Depth (km)
1st layer	2.0	0.7	2.5	1.3
2nd layer	2.3	1.5	1.0	1.0
bedrock	2.5	3.0	.025	---

Referring to these test results, we made a simple two dimensional two-layer ground model along the principal axes of the bay as shown in Fig 3 a, in which the boundaries of each layers were represented by a smooth trigonometric function. It is also consistent with the results of gravity observations in the Tokyo metropolitan area. We used the physical constants of Table 1 for each soil layers and applied a plane incident SH wave vertically in the bed rock. For comparison purposes, we also analyzed two additional models (Fig 3 b, c) in which either the upper layer or the bed rock was totally disregarded.

3 AMPLIFICATION ANALYSES BY TWO-LAYERED MODELS

Using the modified Aki-Larner method (Ohori, 1991), we solved for the ground motions on the surface by applying a Ricker wavelet traveling vertically upward in the bed rock as an incident Plane SH wave. We know, from the earthquake records measured by the low-sensitive displacement-type seismographs, that the predominant periods in a relatively long period range in Tokyo are 7 - 8 sec and 13 sec; we adopted 4 sec (half the full wave) as the width of a Ricker wavelet. In the numerical analyses the horizontal size of the ground model was fixed to be 160 km; it was divided by 45 points for discretizing the wave numbers; discrete Fourier integral for determining scattering coefficients was performed at 512 points. The available frequency range then covered from 0.01 Hz to 0.4 Hz with the frequency interval of 0.01 Hz.

Fig 4 a shows time histories of the ground motion at different locations on the principal axes of the bay. Although the incident wave comes vertically, arrivals of direct waves were delayed over the dip of upper layer (G, H) and the wave form was distorted by the succeeding wavelets which lasted several times longer than the length of input Ricker wavelet. Also, the maximum amplitude is 50% greater in this region than those at both ends of the basin. No such phenomena existed in Fig 4 b and c, in which either the upper layer or the bed rock was disregarded. The increase in amplitude and duration time was, therefore, not due to the scattering of incident waves at either one of the two non-horizontal boundaries; it resulted from complex interaction of scattered waves at the both boundaries.

In the later phase of responses we could observe a few groups of waves which travel from the right to left over the dip of upper layer (I to G) with the velocity about 1.3 km/sec. This velocity is much greater than the group velocity of Love waves in the upper layer (about 0.6 km/sec); indicating that they might be a mixture of body waves and surface waves that were generated at the right end of the basin. If this is the case, the vertically traveling incident wave changed their direction at the two non-horizontal boundaries and the situations for total reflection occurrence was attained over the dip of the upper layer. Since the time history of ground responses for a single Ricker wavelet (Fig 3, a) looks sinusoidal and stationary, the amplitudes and duration time would be much increased by the superposition effects particularly at the throat of the bay when a series of Ricker wavelets were applied as the incident waves. The locations over the dip of upper layer (G, H, I) coincide with the region extending from Yokohama, Tokyo to Chiba, the most highly populated area in metropolitan Tokyo: Here, an extraordinarily severe ground shaking with large amplitudes and long duration similar to those observed in Mexico city in 1985 could be expected.

4 SURF-PHENOMENON ANALYSES BY ONE-LAYER MODEL

To study the effects of the so called "surf effects", we calculated ground responses of the simplified one-layer model as shown in Fig 5. The width and depth of the basin were 30 km and 1.0 km; the length of a flat portion being 25 km. Physical constants of each layers are listed in Table 2. An incident Ricker wavelet with the period equal to the fundamental period of the one dimensional SH waves in the alluvial layer (4.0 sec) was applied at the incidence angle of 45 degrees from the left. The locations on the ground was indicated by the non-dimensional distance (x/R), in which R is the half width of basin (R=15 km) and x denotes distance measured from the center. Incident waves travel from negative side to positive side.

Table 2. Physical constants of one-layer model

Soil type	Density (ton/m^3)	S-wave velocity (km/sec)	Damping constant (%)
Alluvial	2.0	1.0	1.0
Bedrock	2.3	2.6	0.5

Fig 6 a shows ground responses at different locations; the location denoted by x/R = -1.0 - 1.0 lies within the basin. Long trains of wavelets followed the directly arriving waves within the basin. We could clearly observe several types of waves which travel from the left edge of basin with different speeds (1.3 km/sec - 2.9 km/sec). The group velocity of Love wave for the flat portion of the basin was calculated to be 0.8 km/sec which is much smaller than the lowest velocity observed in the figure.

tion time of ground responses became extremely long especially on the opposite side of incidence.

The maximum amplitude was 50 % greater at the left edge (over the corner of sloping and flat boundaries) than elsewhere in the basin. The displacements outside the basin were smaller on the opposite side of incidence because of the shadow effects. The maximum responses were marked, in general, in an early phase of response for the cases of a single wave incidence.

Since the response time histories of Fig 6 a, again look sinusoidal, a series of 10 successive Ricker wavelets were applied next to see the superposing effects of ground responses to a single wave incidence. The calculated response time histories shown in Fig 6 b showed more clearly the refracted and reflected wavelets at the both sides of the boundaries than those for a single wave incidence. The incident wavelets proceeded keeping their original configurations up to x/R = –0.4; then the velocity of wave propagation for the later waves changed suddenly and duration time of wavelets became longer as they proceeded to the right edge of the basin; the reflected waves interacted with the proceeding waves near the right edge and produced large responses with longer duration; the reflected waves traveled to the left until they were reflected again at the left edge; they went back to the right, increasing their amplitude; at the right edge no significant reflection was observed any more. As a whole, the duration of response became extremely long on the opposite side of incidence as compared to that of incident wavelets. This phenomenon (surf–phenomenon) was not observed for narrow or deep valleys which have no flat portion on the boundaries. The apparent velocity of reflected waves was again about 1.3 km/sec which was greater than the calculated group velocity of Love waves, 0.8 km/sec.

Large maximum response amplitudes were recorded at the center of the basin as well as over the edge on both sides. The largest maximum amplitude (12.5 as compared to the incident amplitude, 1.8) was marked at x/R = 0.75; exactly on the corner of sloping and flat boundaries. It is evident from this example that the sever ground shaking with large amplitudes and extremely long duration which is similar to those recorded in Mexico city in 1985 could occur in a relatively shallow basin.

5 CONCLUDING REMARKS

From the numerical analyses of the two layer model for Tokyo bay area with non–horizontal boundaries represented by a trigonometric function, we found large ground responses with long duration over the dip of upper layer although we applied a single Ricker wavelet traveling vertically as the plane incident waves; they did not appear for the models in which either one of the non–horizontal boundaries was disregarded. This phenomenon, therefore, resulted from complex interaction of the refracted and reflected waves on both boundaries. The locations of large ground response coincided with the most highly populated area in metropolitan Tokyo.

We next analyzed the surf phenomena using the simplified one–layer model with a wide flat base and a series of Ricker wavelets as the plane incident waves with the 45 degree incident angle. The ground response was much amplified over the edge on both sides as well as at the center of the basin. The train of incident waves traveled horizontally with repeated reflections at the slope on both sides of the basin; thus making the duration time of ground shaking several times longer than that of incident waves. These "surf pheonomena" were not observed for a deep or narrow valley which does not have a flat portion on the boundaries.

From the two kinds of analyses mentioned above, we concluded that the severe ground motions with large amplitudes and extremely long duration, which are similar to those observed in Mexico city on the occasion of the 1985 Michoacan earthquake, could occur in Tokyo bay region, particularly in the most highly populated area.

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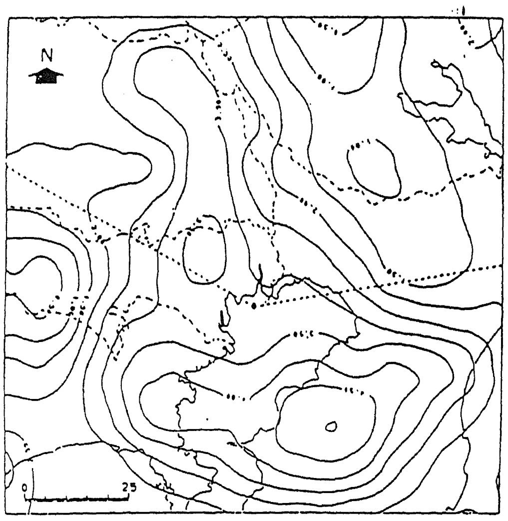


Figure 1 Depth of bedrock in Tokyo bay region compiled from the series of Yumenoshima seismic prospecting

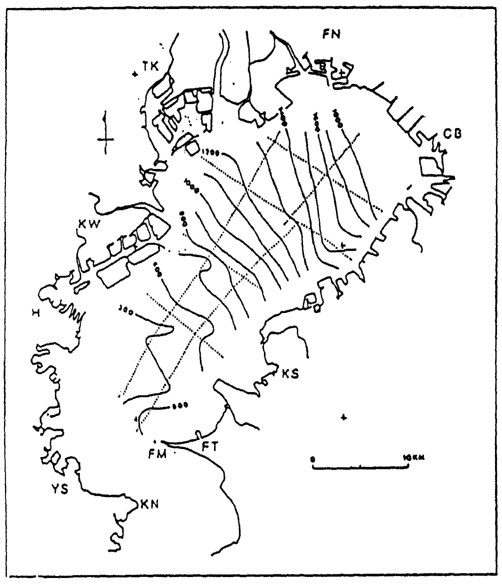
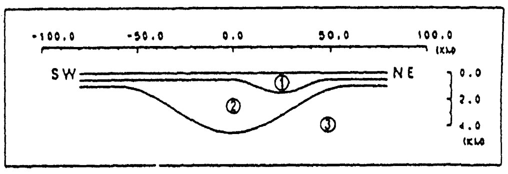
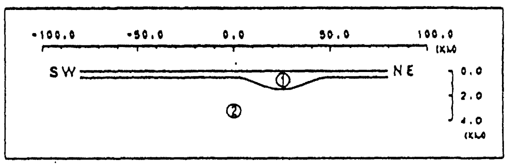


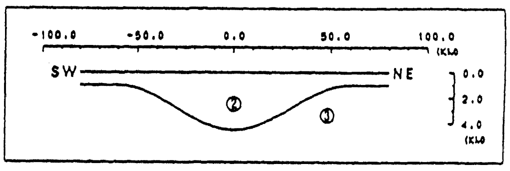
Figure 2 Depth of quaternary in Tokyo bay region detected by multi-channel acoustic emission tests



a) Model A
Two-layer standard model



b) Model B
Simplified one-layer model;
bedrock being disregarded



c) Model C
One-layer model; top layer
being disregarded

Figure 3 Soil layer model for tokyo bay region

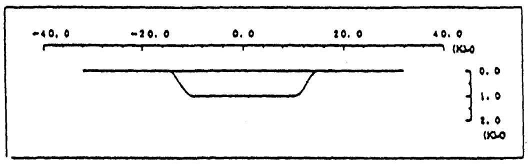
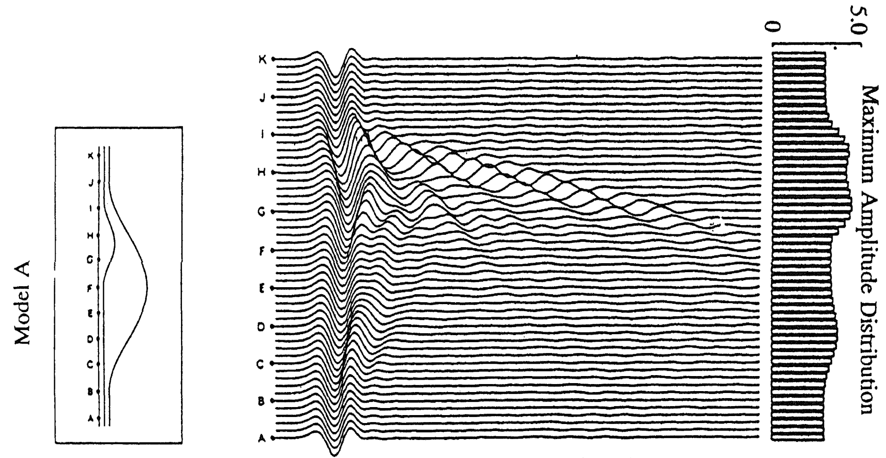
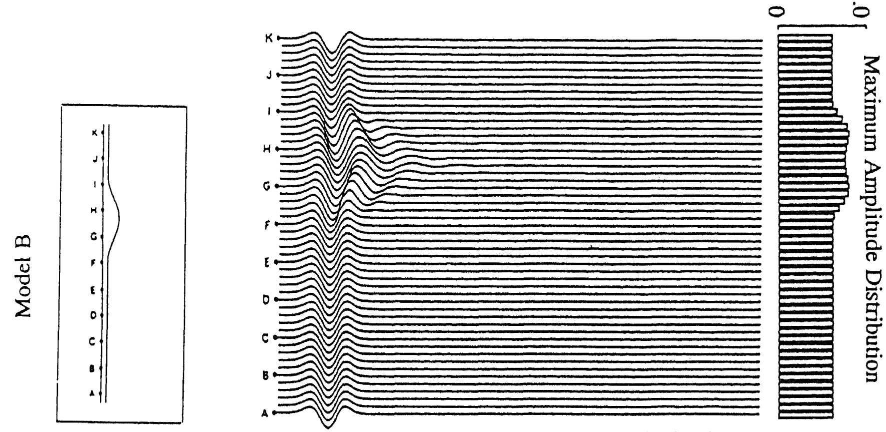


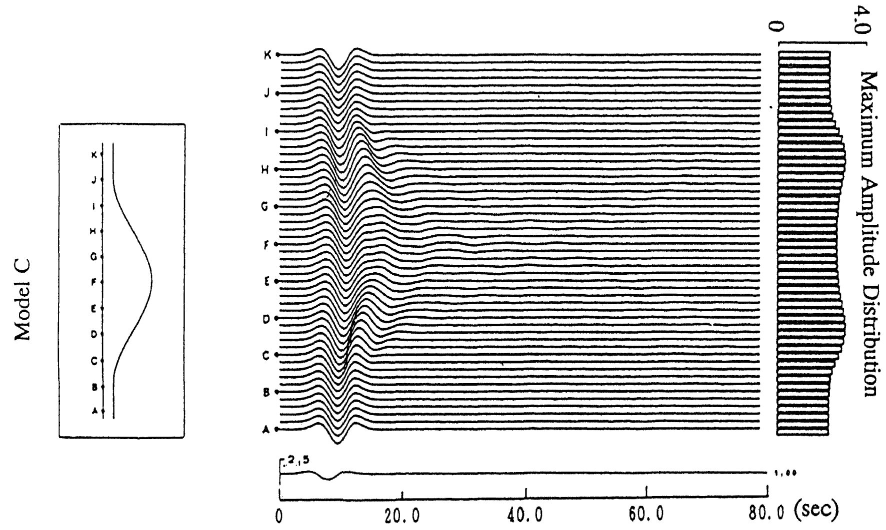
Figure 5 One layer model with flat bed for surf phenomenon analyses



a) Two-layer standard model

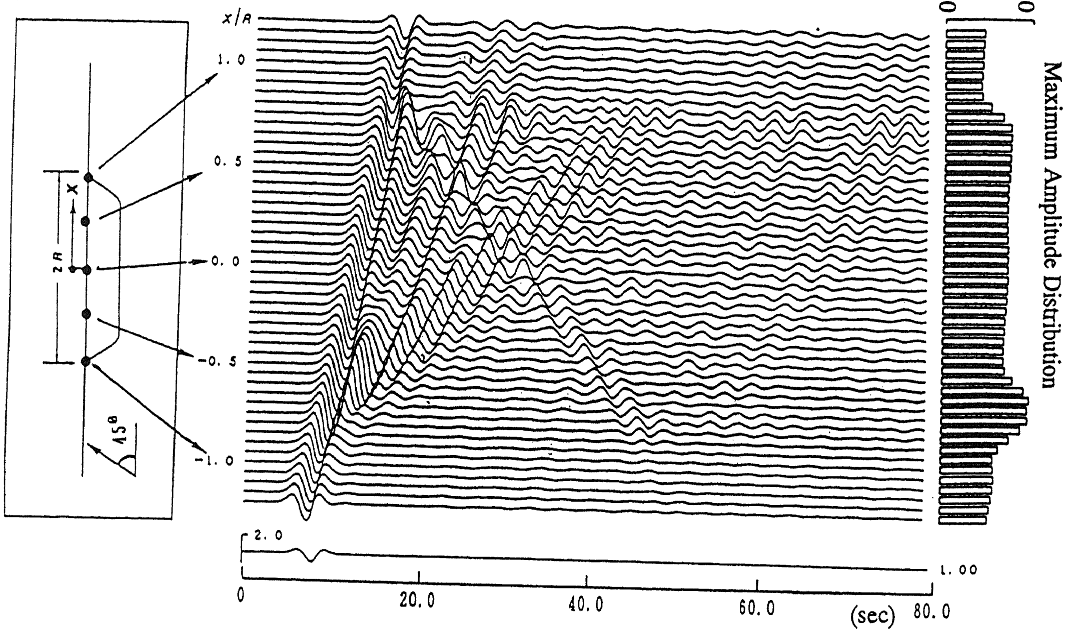


b) One-layer model without bedrock

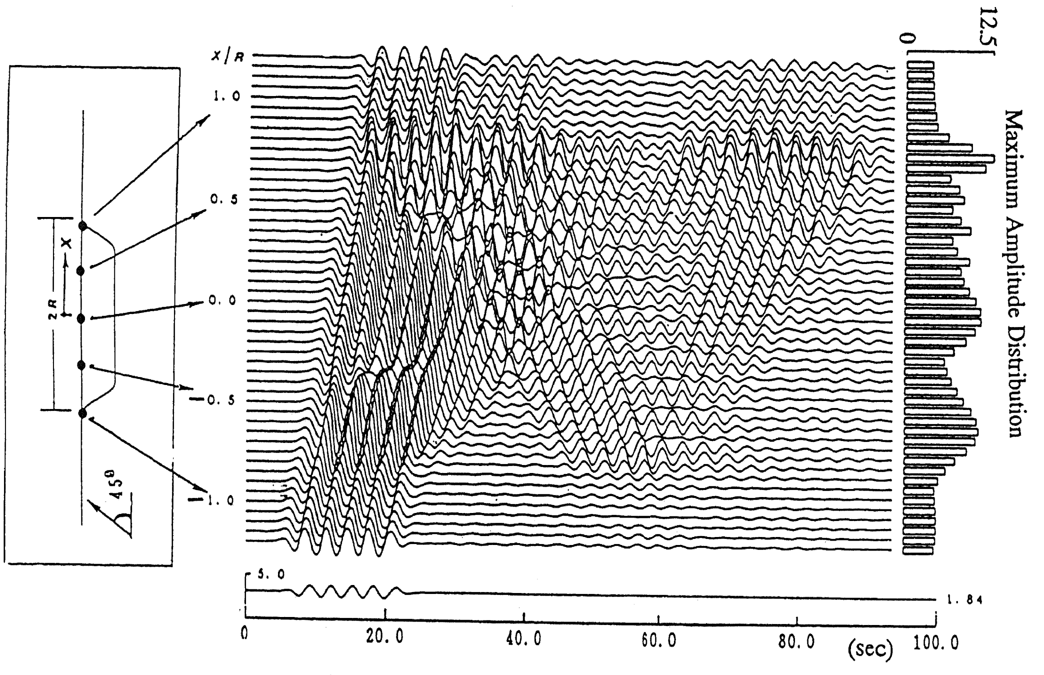


c) One-layer model with top layer totally disregarded

Figure 4 Response time histories calculated on the ground surface for tokyo bay region modelling



a) Incidence of single Ricker wavelet



b) Incidence of ten successive Ricker wavelet

Figure 6 Response time histories calculated on the ground surface for surf phenomenon analyses