ESTIMATION OF RESPONSE OF STRUCTURES UNDER NEAR FIELD GROUND MOTIONS CONSIDERING INHOMOGENEOUS FAULTING

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SUMMARY

This paper shows a way to estimate the response of structures under near field ground motions. It is well known that the high frequency components of the near-field ground motion records are strongly influenced by the inhomogeneous failure process of the earthquake. It is extremely difficult, however, to predict the inhomogeneous faulting process in detail. To study the effects of asperities on the near-field ground motions, the asperity was modeled simply and the acceleration ground motions that were generated by an asperity were discussed. An asperity radiates a pulse-like ground motion that approximate one pulse of sine wave. Elastic response analyses of Single Degree of Freedom systems under the pulse-like ground motion were carried out and the amplitudes and the periods of the pulses were investigated. For a strike slip asperity, the amplitudes of the response spectra are very sensitive to the depth of the asperity. The predominant periods of the response spectra in the region where the amplitude of the pulse is large can be simply estimated

INTRODUCTION

Most of the recent earthquakes that brought severe damage to big cities, for instance, the 1994 Northridge earthquake or the 1995 Hyogoken-Nanbu earthquake, are shallow inland earthquakes. It is very important for the earthquake resistant design of structures to understand the basic characteristics of near-field ground motions and to investigate the earthquake load considering the near-field ground motions. There are many studies for estimating near field ground motions using detailed information of source faults and geometry. However, it is impossible to apply the complicated method to the practical earthquake design for structures.

The purpose of this study is to develop a simple method to roughly estimate the near field ground motions that are most dangerous for the earthquake resistant design of general structures. It is well known that the high frequency components of the near field ground motion records are strongly influenced by the inhomogeneous failure process of the earthquake. In this paper, the asperity is modeled simply and the basic characteristics of the asperity are investigated.

WAVEFORM SYNTHESIZING METHOD

An asperity is divided into small areas with the elements are considered as point sources. The double-couple solutions in an infinite homogeneous medium [Aki and Richards, 1980] for the elements are summed taking into account the time lags of the failure start of the elements and the travel time of the seismic wave. The Q value

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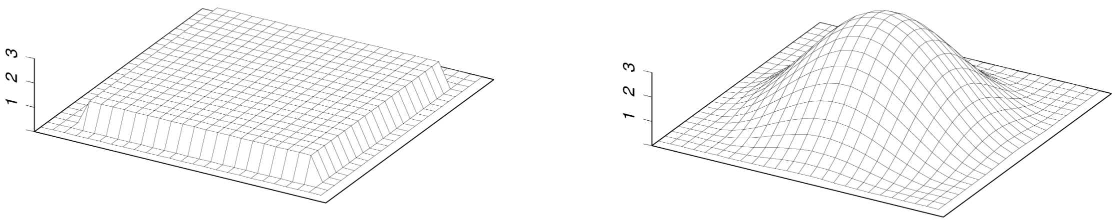
attenuation and the surface layer amplification are not considered. The synthesized waveforms are doubled considering the effect of the open surface.

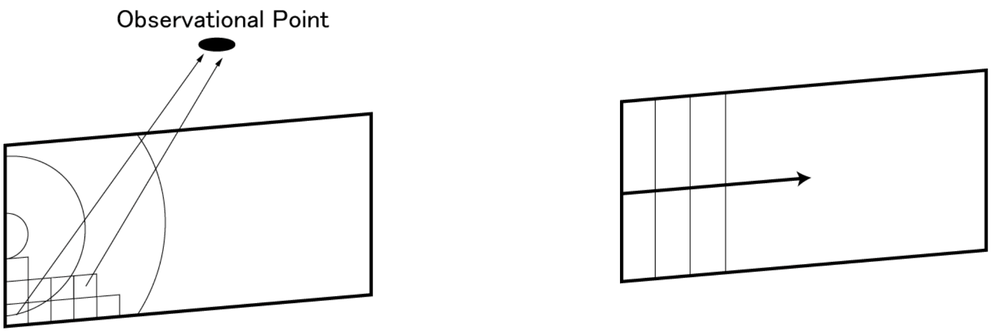
MODELING OF THE ASPERITY

Slip Distribution:
Figure 1(a) shows a slip distribution model, where the shape of the asperity is square and the slip amount is constant. This model is useful because it is the simplest and requires the least parameters. However, the actual asperities do not have the clear boundaries like this model has, and it is more realistic to assume that the slip amount decreases near the edge of the asperity. Therefore the curved surface slip distribution model with a cosine function (figure 2(b)) is introduced and compared to the flat slip distribution model.



(a) Flat Distribution **(b) Curved Surface Distribution**

Figure 1: Slip Distribution Models



(a) Circular faulting **(b) Uni-Lateral Faulting**

Figure 2: Rupture Patterns

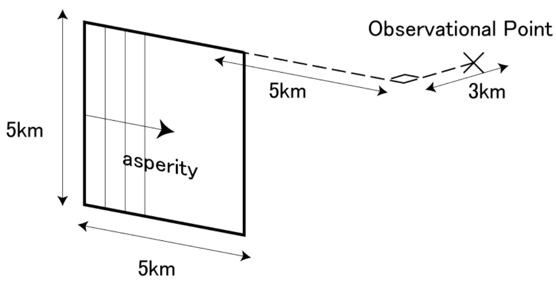


Figure 3: Location of the Observational Point

The diameter of the curved surface model equals the length of the side of the square model and the average slip amount equals that of the flat model. The Kostrov type function described in the next section is used as the source time function. Two patterns of asperity failure are compared, the uni-lateral faulting and the circular faulting **Figure 2**. The asperity is vertical strike slip, the side length or the diameter of which is 5km. The observational point is as shown in **Figure 3**, at a distance of 3km from the fault surface, 5km along the fault strike from the side edge and 2.5km above the center of the asperity.

The acceleration ground motions due to the two types of failure radiated from the asperity described above are shown in Error! Reference source not found.. For the flat distribution model in uni-lateral failure, two pulses appear. These pulses are reported in observation records as starting and stopping phase. The periods of these pulses are related to the model parameter t_d of the source time function (described in the next section). In case of the circular faulting, the starting phase is not clear. For the curved surface distribution model, the acceleration ground motion consist of only one pulse in both failure cases. The period of this pulse is related to the rupture time of the asperity. These results show that the failure pattern does not have a strong influence on the generated ground motions; so the simpler uni-lateral pattern is adopted. The response acceleration spectra are shown in Error! Reference source not found.**5**. In the flat distribution model, the shape of the spectrum is not simple and the predominant period is very short. In the curved surface distribution model, the shape of the spectrum is similar to that of sine wave (shown in Error! Reference source not found.**5** with gray line). Error! Reference source not found.**6** shows the required base shear coefficient spectra. The periods of starting, stopping phases are so short that they have little influence on the nonlinear response of buildings. Therefore the curved surface distribution model is used to investigate the basic characteristics of asperities.

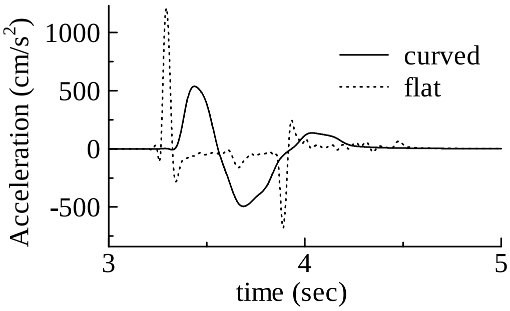


Figure 4: Acceleration Spectra

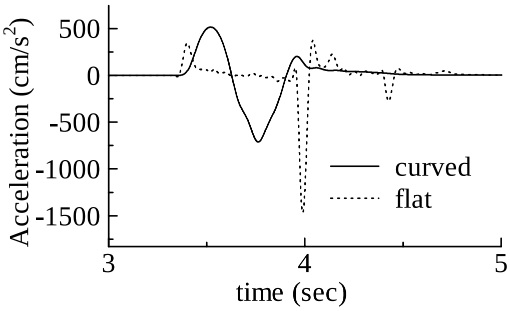
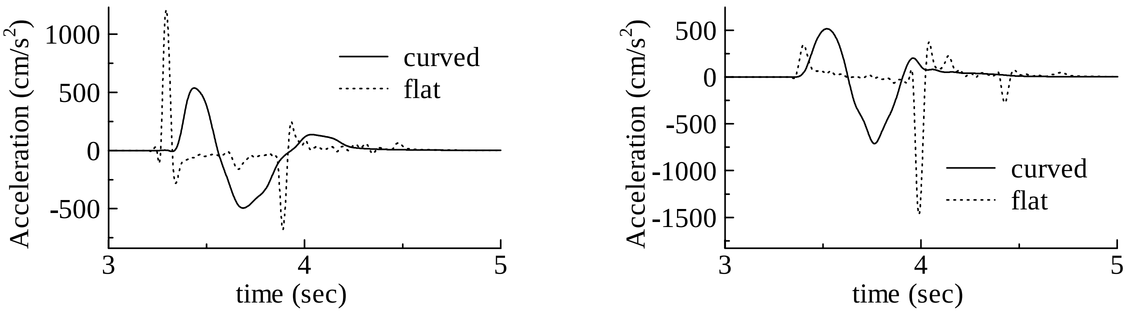


Figure 5: Required base shear coefficient spectra



(a) uni-lateral failure **(b) circular failure**

Figure 6: Ground Motion Radiated from Two Asperity Models

Source time function:

The ramp function (boxcar function for slip velocity) is often used as the simplest source time function. On the other hand, rupture dynamics says that the slip velocity is concentrated in the beginning of the rupture. In this section, Kostrov type source time function with fraction constitution law and slip interruption [Miyatake, 1998] is introduced and compared with the ramp function. Although it is pointed out in previous studies that the source time function is not uniform over the fault plain, a uniform function is used because the object of this study is only one asperity.

Figure 7 shows the appearance of the Kostrov type function. The model parameters are determined by the following expressions.

$$V_m = (\Delta\sigma / \mu)\sqrt{2WV_r / f_{\max}} \qquad \text{[Day, 1982]} \qquad (1)$$

$$t_d = 1/(\pi f_{\max}) \qquad (2)$$

$$t_r = W_T / (2V_r) \qquad \text{[Ohnaka and Yamashita, 1989]} \qquad (3)$$

where $\Delta\sigma$ is the stress drop, μ is the modulus of rigidity, W is the width of the asperity, $f_{\max}$ if the cut-off frequency, W_T is the width of the entire fault and V_r is the rupture velocity. The ground motions radiated from the asperity due to the two types of source time function are shown in **Figure 8**. The asperity size and the location of the observational point are the same as that of the previous section. For the ramp function, the period of the velocity pulse is determined by the rupture time, the wave velocity and the rise time, and much longer than that by the Kostrov type function. Two symmetric pulses are seen in acceleration ground motion by the ramp function while only one pulse is seen in that by the Kostrov function. Although the ramp function is convenient because it requires the least parameters, the difference from the theoretical model is quite large. Therefore the Kostrov type function is used in following section.

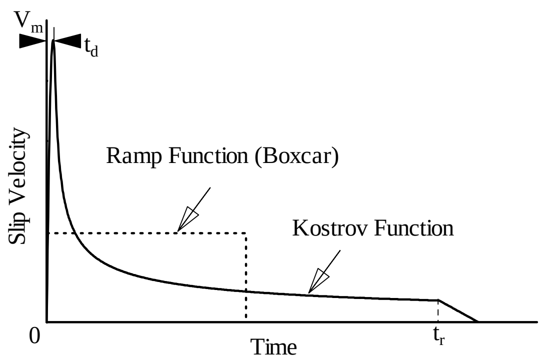
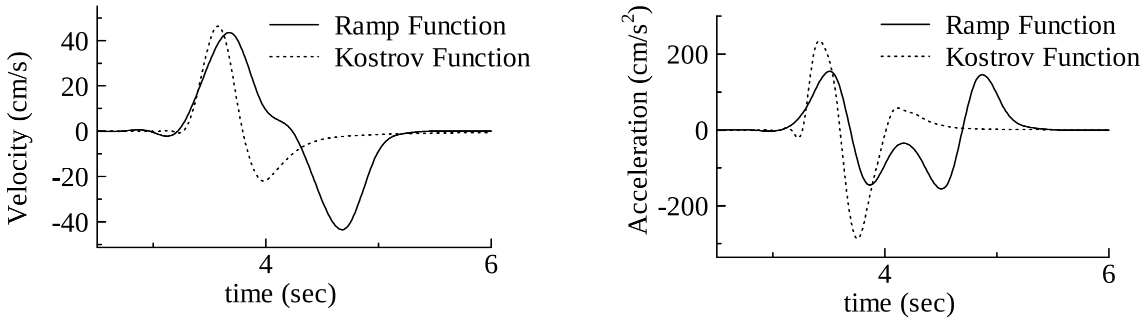


Figure 7: Source Time Function



(a) Velocity **(b) Acceleration**

Figure 8: Comparison between Ramp Function and Kostrov Type Function

CHARACTERISTICS OF THE PULSE

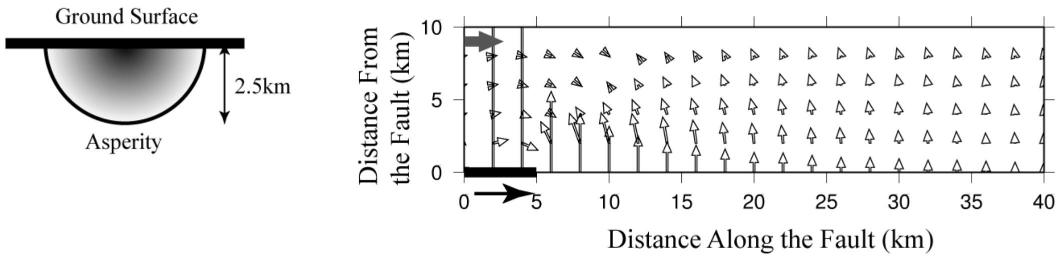
An asperity generates one pulse-like ground motion to the direction of the failure. If the large amplitude pulse could be modeled simply, the most dangerous location and size of an asperity can be determined for earthquake resistant design of structure. In this section, ground motions of some cases are synthesized and the relations between the period of the pulse and the location of an asperity are discussed.

To discuss the spatial pattern of the ground motions radiated from a perpendicular strike slip asperity, ground motions at many points near the asperity are synthesized. The depths of the asperities are varied in three models. Model A: the depth of the center of the asperity is 0km; the asperity intersects the ground surface. Model B: the depth of the asperity is 2.5km; the asperity is just buried. Model C: the depth of the asperity is 5km. All the other parameters are the same in each model (Shown in Table 1.) In previous inversion studies, the average slip amounts of asperities are distributed between 1.5 and 3.0 times as large as the average slip amount of the entire fault [Somerville et al, 1998]. Here, considering that the average slip of the entire fault is 150cm, the slip amount (the cosine function type distribution) is set with the average slip amount of asperities at 450cm. The near field and intermediate term are neglected to reduce the computation time.

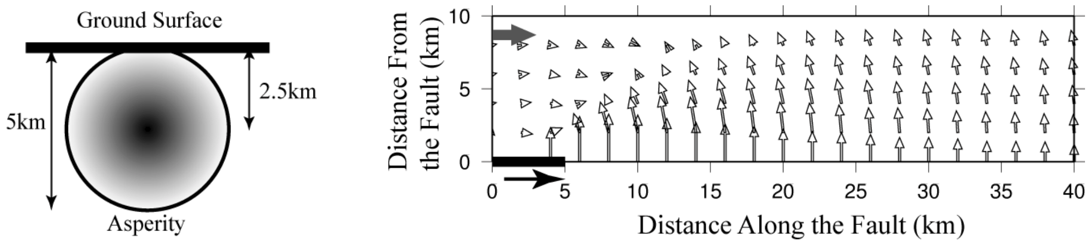
Table 1: General Parameters

Shear wave velocity	**Rupture velocity**	**Average Stress drop**	**Average slip amount**	**fmax**	**Radius of asperity**
3.2km/s	2.6km/s	30MPa	450cm	10Hz	2.5km

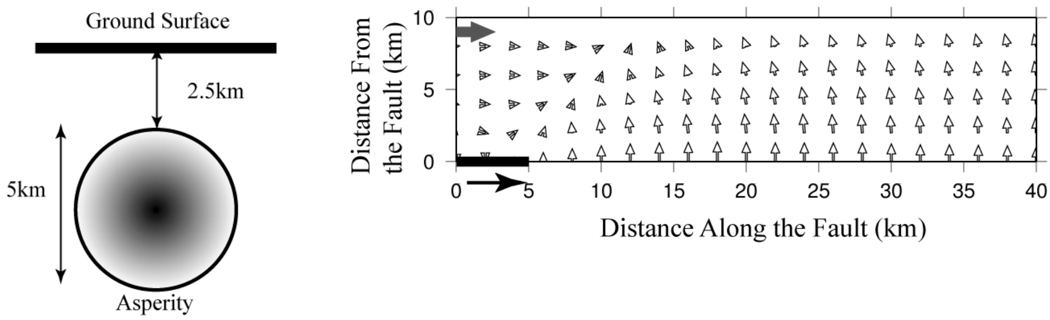
The vectors of maximum ground velocity are shown in Figure 9. The asperity projection is drawn as the thick line. The length of the upper -left arrow represents 100cm/s. The lower-left arrow represents the rupture direction. On the left side region of the asperity, the ground motions are not strong because of the backward directivity, and the amplitudes of the ground motions are symmetrical with the strike axis, so only the upper-right region is shown. Extremely large ground velocity appears at the point where the asperity intersects the ground surface. However the large velocity region is very narrow and it is a peculiar case that the fault is just below a building and an asperity intersects the ground surface. The transverse component is predominant on a wide region by the forward directivity effect.



(a) Model A



(b) Model B



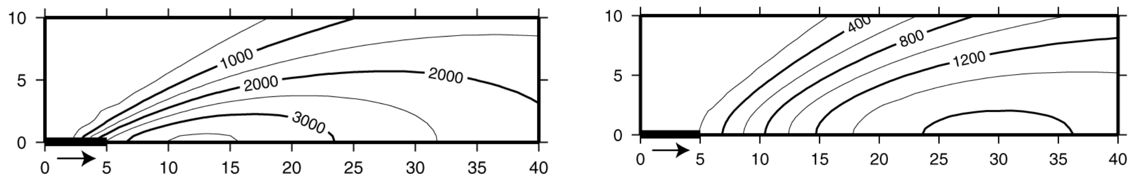
(c) Model C

Figure 9: Maximum Velocity Vectors

As shown in the section 3, the ground motion generated by an asperity is similar to one pulse of sine wave. Therefore the response acceleration spectra have clear peaks at the periods of the equivalent sine waves. **Figure 10** shows the distribution of the maximum values of the h=5% response acceleration spectra. For the model C, the values are much smaller than that by the model B. In most cases, asperities are buried in the ground and the amplitude of ground motion is very sensitive to the depth of asperities. Therefore, for the depth of the asperity, it is not good to assign the most dangerous case for the structural design. **Figure 11** shows the period at which the response spectra take the maximum values. Though the values are a little scattered because of the numerical errors, the periods are almost uniform on the region where the response spectra take large values. The periods can be estimated from the duration of the wave because the acceleration waveforms approximate sine functions.

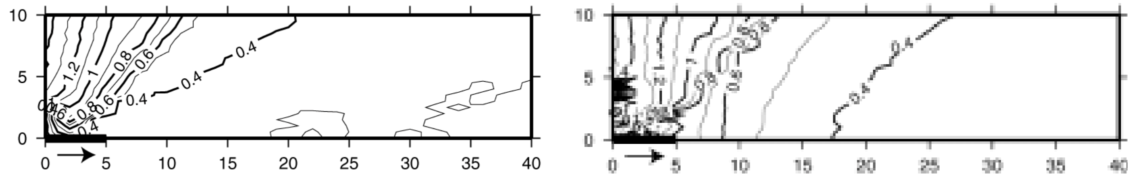
$$T_e = r_a / v_r + r_2 / v_s - r_1 / v_s \quad (4)$$

where r_a is the diameter of the asperity, V_r is the rupture velocity, r_1 and r_2 are the distances from the observation point to the rupture starting and ending point and V_s is the shear wave velocity. The periods estimated by the equation (4) are shown in **Figure 12**. The periods cannot be estimated in the region where the forward directivity effect is not clear because the acceleration waveforms do not approximate sine waves in such region. However in the region where the acceleration response spectra take large value, the periods are well estimated.



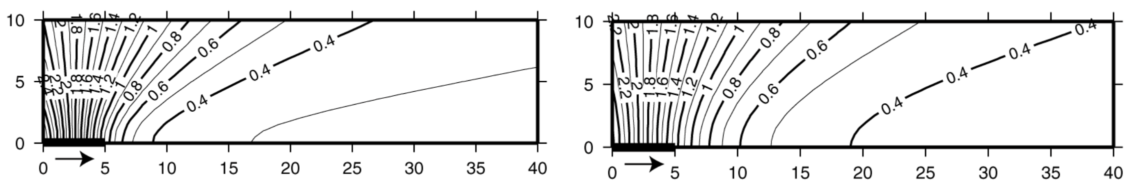
(a) Model B **(b) Model C**

Figure 10: Maximum Values of the h=5% Acceleration Response Spectra (cm/s^2)



(a) Model B **(b) Model C**

Figure 11: Predominant Periods (sec)



(a) Model B **(b) Model C**

Figure 12: Estimated Predominant Periods (sec)

CONCLUSIONS

1. Neither starting nor stopping phase appears by the curved surface slip distribution model in which the slip amount decrease near the edge of the asperity.
2. The ramp function is not proper as a source time function to discuss the periods of ground motions.
3. The ground motion radiated from an asperity with a cosine function type slip distribution approximate one pulse of sine wave.
4. Extremely large ground motions appear in a narrow region when the asperity intersects the ground surface.
5. The waveform amplitude is very sensitive to the depth of the asperity.
6. In the region where the acceleration response spectra take large value, the predominant period can be estimated from the asperity size, the rupture velocity and the shear wave velocity.

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