STRONG EARTHQUAKE GROUND MOTIONS DUE TO A PROPAGATING FAULT MODEL CONSIDERING THE CHANGE OF DISLOCATION VELOCITY - PARKFIELD EARTHQUAKE OF 1966 -

by

Katsuhiko Ishida[I] and Yutaka Osawa[II]

SYNOPSIS

Among factors exerting influence on short-period ground shaking, the source mechanism of the fault seems to be one of the most important problems. From this point of view, authors proposed the formulation of source function taking account of the change of dislocation velocity in order to explain the short-period component of ground shaking which exert an important effect of earthquakes on the majority of buildings. To compare the theoretical ground motion calculated from this source function with the observed one, the Parkfield earthquake of 1966 was analyzed. From this comparative study, it was found that the theoretical ground motions were able to well represent the feature of observed displacement, velocity and acceleration.

INTRODUCTION

The most important effect of earthquakes on the majority of building structures is exerted by the short-period component of ground shaking. Among factors exerting influence on short-period ground shaking, the source mechanism of the fault seems to be one of the most important problems. But this problem remains unsolved yet. Recent fault studies show that a relatively simple elastic dislocation model of faulting can explain the long-period portion (longer than several seconds) of observed seismograms. So far as the simple dislocation model of faulting is adopted, however, it is very difficult to explain the short-period portion (shorter than several seconds) of them.

It is intended in this paper first to propose the source function taking account of the change of dislocation velocity for the purpose of explaining the short-period component of seismograms recorded in the near-field of the fault and second to compare the theoretical earthquake ground motion calculated by the use of this equation of source function with observed one of Parkfield earthquake of 1966.

The elastodynamic representation theorem in the form given by de Hoop (1958) provides the mathematical basis for such a calculation. A form of this theorem appropriate for the representation of faulting source in an infinite homogeneous medium has been given by Haskell (1964, 1969) as follows;

[I] Research Fellow, Earthquake Res. Inst., University of Tokyo

[II] Professor, Earthquake Res. Inst., University of Tokyo.

$$U_i(\mathbf{x},t) = -\iint_S \{\rho(\alpha^2 - 2\beta^2)\, n_j M_{iq,q}[D_j] + \rho\beta^2 (n_q M_{ij,q}[D_j] + n_p M_{ip,q}[D_q])\}\, dS \quad \text{--- (1)}$$

The notations in eq. (1) are

S = fault plane area.

$\mathbf{U}$ = (U_1, U_2, U_3) = cartesian components of displacement measured from the initial state.

$\mathbf{x}$ = (x_1, x_2, x_3) = cartesian coordinates of point at which is to be evaluated.

ρ = density.

α = P - wave velocity.

β = S - wave velocity.

$\mathbf{n}$ = (n_1, n_2, n_3) = unit normal on S.

$\mathbf{D}$ = (D_1, D_2, D_3) = displacement discontinuity across S.

$M_{ij,q}$ is an operator appeared in Haskell's paper of 1966.

As these expressions are exact for a homogeneous and unbounded medium, the results can not be applied directly to the observed data obtained at the free surface. We may anticipate, however, that (1) the amplitude of the displacements measured at the free surface will be approximately twice those calculated for the same point in the absence of a free surface,and (2) the later parts of the wave forms measured at the free surface will show additional oscillations due to surface waves that will have no counterpart in the wave forms calculated for the unbounded medium.

ASSUMED SOURCE FUNCTION CONSIDERING THE CHANGE OF DISLOCATION VELOCITY

In general the simple ramp function is adopted for the dislocation function, so, at any fixed point on the fault plane, the relative displacement increases at constant velocity from 0 at $t = \xi_1/v$ to a final value, D_0, at $t = T + \xi_1/v$. But the real process of dislocation is supposed to be more complex as illustrated in Figure 1. Because it must be unrealistic to consider that the stress field around the fault in the crust will be homogeneous, the relative displacement at any fixed point on the fault must increase at changing velocity rather than at constant velocity. This phenomena of changing velocity of dislocation gives some significant effects on the short-period component of seismograms. So authors assumed the source function considering the change of dislocation velocity as indicated below.

$$D(\xi_1, \xi_2, t) = \begin{cases} 0 & \text{---}\ \ t - \xi_1/v < 0 \\ (D_0/T)(t - \xi_1/v) + \sum_{n=1}^{\infty} a_n \sin \omega_n (t - \xi_1/v) & \text{---}\ \ 0 < t - \xi_1/v < T \\ D_0 & \text{---}\ \ T < t - \xi_1/v \end{cases} \quad \text{--- (2)}$$

In eq. (2); the 2nd term of 2nd equation represents the change of dislocation velocity. Although Haskell (1969) attempted to express this process using two-stage ramp function, authors considered to use the superposition of sine-waves having some amplitudes and periods. The formulation of eq. (2) is so simple that the relatively complex dislocation can be expressed with ease.

THE OBSERVED STRONG MOTION ACCELEROGRAM INTEGRATED VELOCITY AND DISPLACEMENT

The ground motion of the magnitude 5.6 Parkfield earthquake of June 27, 1966 was recorded by an array of five strong-motion accelerographs. Especially, one of them, Cholame Station No. 2, was located about 80 m far from the San Andreas Fault. (see Figuare 2). The ground motion acceleration perpendicular to fault strike was recorded at this station. As shown in Figure 3, the maximum ground velocity and acceleration are about 80 cm/sec. and 500 gals, respectively. It is also shown in that the integrated ground displacement is essentially a single pulse of approximately 25 cm amplitude. But this ground displacement is apparently separated to two parts at its peak. For the long-period component of seismogram, it seems to be adequate to consider the integrated displacement as a simple pulse by neglecting the existence of separated two peaks. But for the short-period component of seismogram it can not be neglected. The Fourier spectrum density function of observed accelerogram is indicated in Figure 4. As shown in Figure 4 the predominant period appears about 0.7 sec. and 1.4 sec.

The crustal model of P-wave velocity along the San Andreas Fault in the Parkfield region was obtained by Eaton et al. (1970). A modified simple crustal model of S-wave velocity shown in Figure 5 was assumed approximately based on the equation; $V_s = V_p/\sqrt{3}$. The fundamental period of this modified simple crustal model estimated from eq. $T = 4H/V_s$ appeared to be about 1.1 sec. For the first-order approximation this crustal model seems to be applicable to estimate the fundamental effect of the crust. For the feature of observed seismogram, as the effect of the crust is considered to be small.

THE THEORETICAL GROUND MOTION

The comparison of the theoretical and observed ground motion perpendicular to fault strike recorded at Cholame station No. 2 was indicated in Figures 6 - 8 . The geometrical fault parameters estimated by K. Aki (1968) were used to calculate the theoretical ground motions. (Table 1) Figure 6 shows the comparison of the theoretical ground displacement by using the source function (ramp function) as indicated in eq. (3)

$$D(\xi_1, \xi_2, t) = \begin{cases} 0 & \cdots\ t - \xi_1/v < 0 \\ (D_0/T)(t - \xi_1/v) & \cdots\ 0 < t - \xi_1/v < T \\ D_0 & \cdots\ T < t - \xi_1/v \end{cases} \qquad \cdots (3)$$

This source function has been generally adopted to study the average source mechanism, and has succeeded to explain the long-period portion of observed seismogram. But apparently, the theoretical seismogram obtained from the source function taking no account of the change of dislocation velocity (ramp function) was not too adequate to explain the observed seismogram perpendicular to fault strike, especially for short-period component of it. The calculated theoretical seismogram can not explain the two separating parts of observed one. (Figure 6)

Figures 7 and 8 show the comparison of observed ground motions; displacement, velocity and acceleration, and the theoretical ones taking account of the change of dislocation velocity indicated in eq. (2). As shown in Figures 7 and 8, the theoretical ground motion (displacement, velocity and acceleration) calculated from the source function proposed in this paper well represented the feature of seismograms. From the comparative analysis, parameters which defined the degree of changing dislocation velocity in eq. (2) were estimated approximately to be $T_n = (2\pi/\omega_n) = 0.5$ sec., 0.6 sec., and $a_n = 0.05\ D_0$, $0.03\ D_0$ and $0.01\ D_0$ for the rise time 0.5 sec. and 0.6 sec., respectively. The parameters defined the degree of changing dislocation velocity have little effects upon displacement, but have significant effects upon velocity and acceleration.

The Fourier spectrum density function of the theoretical acceleration ($T_n = 0.6$ sec., $a_n = 0.01\ D_0$, rise time = 0.6 sec.) is shown in Figure 9. According to comparison of Figures 5 and 9, it was considered that the predominant period of 0.7 sec. was caused by the source mechanism and that of 1.4 sec. the site characteristics at station No. 2, respectively.

CONCLUDING REMARKS

The results obtained in this study are as follows;

(1) The theoretical seismogram obtained from the source function taking account of the change of dislocation velocity proposed in this paper well represented the feature of seismograms (displacement, velocity and acceleration) at the Cholame station No. 2.

The parameters which defined the degree of changing dislocation velocity in eq. (2) were estimated to be $T_n = 0.5$ sec. ~ 0.6 sec. and $a_n = 0.05\ D_0 \sim 0.01\ D_0$, $D_0 = 100$ cm ~ 140 cm.

(2) Predominant periods of the observed acceleration spectrum appeard about 0.7 sec. and 1.4 sec. It was considered that the former was caused by the source mechanism and the latter the site characteristics at station No. 2, respectively.

Although the short-period component of Parkfield earthquake of 1966 was well explained by the use of proposed source function as an illustrative example, further investigation is necessary to establish reasonable way of anticipating the source function for future earthquakes.

ACKNOWLEDGMENTS

The authors should like to express their sincere thanks to Prof. K. Kasahara and Prof. K. Mogi, Earthquake Res. Inst., University of Tokyo and Associate Prof. K. Abe, Hokkaido University and Dr. M. Ishida, the National Res. Center for Disaster Prevention Science and Technology Agency for the helpful discussions.

REFERENCE

(1) AKI, K., Seismic Displacement near Fault, J. Geophys. Res., 1968

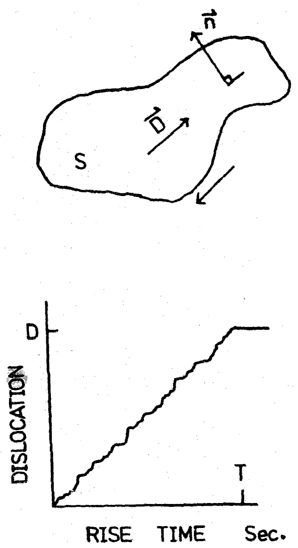

Fig. 1 Shematic fault model and dislocation function.

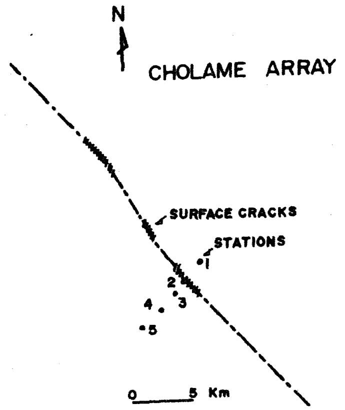

Fig.2 Map of fracture zone.

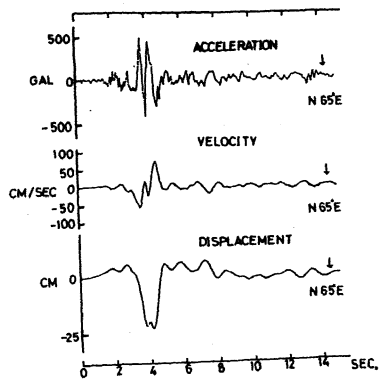

Fig.3 Observed ground motions perpendicular to fault strike.

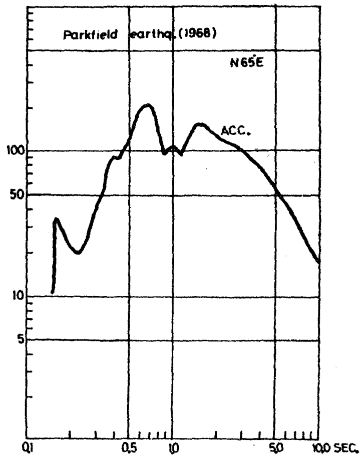

Fig. 4 Fourier spectrum of accelerogram of Parkfield earthquake.

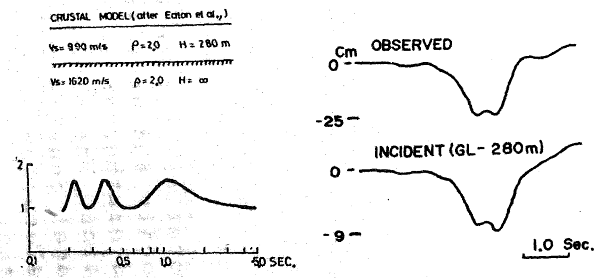

Fig. 5 Crustal model at Cholame station NO.2 and its midium response.

Table 1 Parameters of the fault of Parkfield earthquake.

Dip angle	= 90°	
Dip direction	= 65°	
P wave velocity	= 6.0	km/sec.
S wave velocity	= 3.5	km/sec.
Rupture velocity	= 2.2	km/sec.
Fault length	= 2.0	km.
Fault width	= 3.0	km.

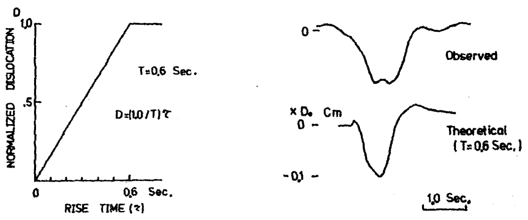

Fig.6 Theoretical ground displacement and its source function.(ramp function)

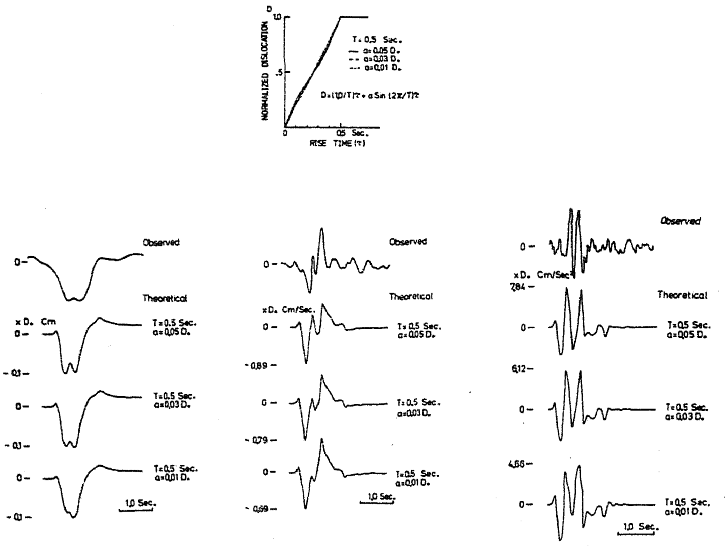

Fig. 8 Theoretical ground displacement,velocity and acceleration of Parkfield earthquake at Cholame NO.2 station. The source function is the model considring the change of dislocation velocity.(rise time=0.6sec.)

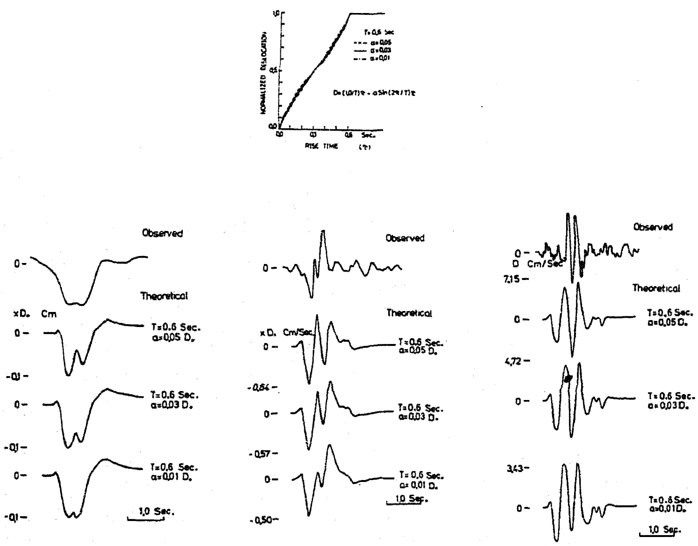

Fig.7 Theoretical ground displacement,velocity and acceleration of Parkfield earthquake at Cholame NO.2 station. The source function is the model considering the change of dislocation velocity.(rise time=0.5sec.)

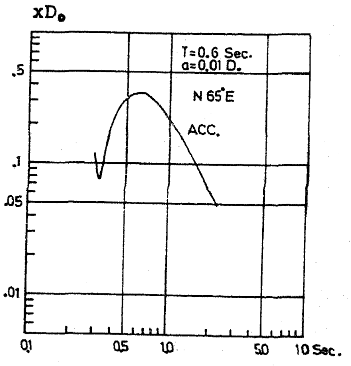

Fig.9 Fourier spectrum of theoretical earthquake accelerogram.(rise time= 0.6sec)