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SYNOPSIS The initial stress is first calculated quasi-statically under various loading conditions by using 3-dimensional finite element model with double nodes to simulate the locked Tangshan fault. Once the shear stress at the front of fault tip reaches rupture criterion, the accumulated stress is suddenly released accompanying with frictional slip along the fault plane, the new state of stress imposed during faulting is re-calculated by reducing the shearing resistence of the hypocenter with the same boundary condition. Then the stress difference before and during shock is regarded as the driving force to generate ground motion. Numerical results show that both the fault mode and the loading system play an important role on the behavior of ground motion. To cause a greater damage and a tremendous depression on the seaward side of the fault, there must be a pre-existing oblique fault and the body force should be considered in addition to the horizontal stressing.

INTRODUCTION

In China, there are mainly two types of faulting, one is strike-slip with negligible dipping component occurring in the southwestern mountain ranges where the horizontal compression is predominant, the other is strike-slip with strong dipping component occurring mainly around and occasionaly within the faulted basins where the diffusive tectonics are very evident (Loo et al, 1989). As shown in Figs. 1 and 2, there are tremendous relative movements between the hanging wall and the foot-wall sides of the seismogenic fault during and after the 1976 Tangshan earthquake of magnitude 7.8. It seems that the behavior of ground motion during faulting is controlled by both the geometrical mode of the pre-existing fault and the nature of driving force (Loo et al., 1990) as well as the variation in mechanical properties along the fault.

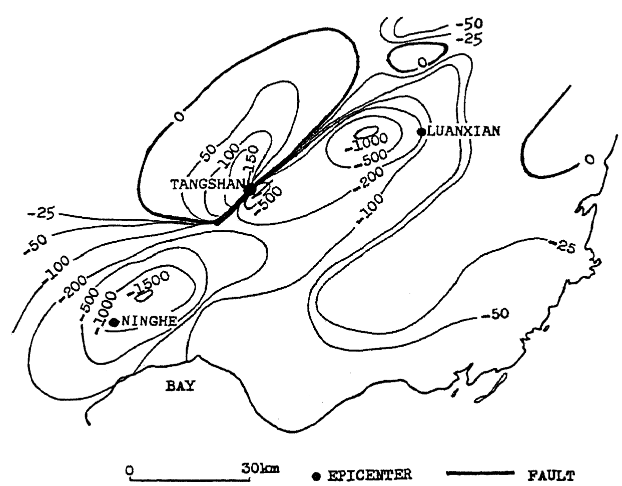

Fig. 1 Vertical Ground Deformation(mm) Observed after Tangshan Earthquake (after Mei et al.,1982)

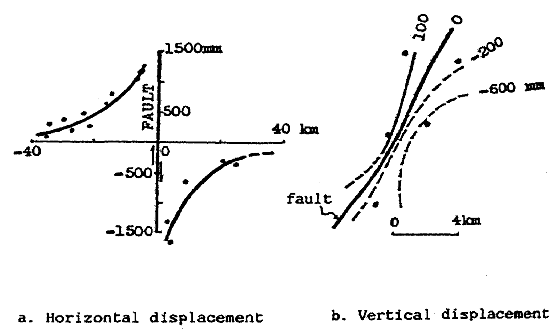

Fig. 2 Coseismic Ground Deformation at Epicenter (after Mei et al., 1982)

Recent progress in computer-simulation has significantly changed the statistical and empirical methodology(Kanamori, 1975) in ground motion prediction. Two kinds of theoretical models were developed in the past decade, the kinematic one (McGarr, 1977) is based on an arbitrarily assigning a slippage along the fault plane, and the dynamic one is based on the solution of stress relaxation problems (Madariaga, 1980). Diterich (1973), Archuleta (1978), Toki (1985) Mikumo (1986) have simulated the source rupture process how to be related to the near-field ground motion by 3-dimensional models, they have only taken the strike-slip as the driving force without consideration of the dipping component, such a simplification would cause serious shortcomings for practical use.

We are aimimg at evaluating potentially the ground motion of the Tangshan earthquake using a 3-dimensional finite element model with locked fault.

MODELS AND COMPUTATION PROCEDURES

To simulate both the ground deformation and the near-field ground motion of the Tangshan shock, a 6-layered model of 50x50x30 km in dimension with uniform thickness, 5 km for each layer is considered. A finite length, 25 km fault penetrating down to a depth of 20 km and varying in dipping angle is simulated by double nodes with assigned tangential and normal stiffness (Goodman, 1968). Altogether there are 594 elements and 840 nodes.

In order to determine the failure stress of the locked fault and the dynamic stress-drop in hypocenter, the initial stress is first calculated quasi-statically by varying the geometrical mode of the fault under the action of body force or horizontal stressing or both, the magnitude of the horizontal force is limited to such an extent that the ground deformation will match approximately the geodetical survey (Loo et al., 1990). Once the stress at the fault tip reaches rupture criterion, its shear modulus is arbitrarily reduced to one-tenth, which can be adjusted of the original value, and the frictional slip along the fault plane happens simutaneously. The new state of stress is then re-calculated using these revised parameters under the same boundary conditions. The stress difference before and during faulting is regarded as a driving force applied at the faulted zone to calculate the ground motion with viscous boundary condition (Bathe et al., 1976; Lysmer, 1972; Robinson, 1972 and Loo et al., 1985) in order to avoid the reflection problem at the fictitious edge of the model. The dynamic stress-drop, which is different from the static one as described by Kasahara (1981), acts as a triangular pulse simutaneously at all the faulted nodes, having a time duration of 0.3 sec. with a time-step 0.1 sec. The rupture process along a heterogeneous fault is not included in this study.

RESULTS AND DISCUSSION

Quasi-statical analysis

Case 1: Strike-slip of a vertical fault caused by horizontal stressing

Assuming the dip-angle of a vertical fault is 90^{o}, the ground deformation caused only by a horizontal stressing is calculated quasi-statically. The pattern of vertical grond displacement as shown in Fig. 3(a) is symmetrical around the fault with a four-quadrant distribution which is inconsistent with the field data as shown in Fig. 1. However, the distribution of the horizontal displacements has skew pattern showing a similarity with the field measurements as shown in Fig. 2(a). On the other hand, these numerical results are very similar to that of the dislocation model (Kasahara, 1981), indicating the validity of our modeling programme.

Case 2: Dipping-slip of an oblique fault due to body force

If the dip-angle of the fault is changed from 90^{o} to 60^{o}, the calculated uplifts on the footwall side is rather small, about one-half of the depressions on the hanging wall side, resulting in an asymmetrical pattern as shown in Fig. 4. It is evident that a combination of Fig. 3 with Fig. 4 will match easily with a strike-slip accompanied by a normal component as evidenced by both the co-seismic and post-seismic field measurements as shown in Figs. 1 and 2.

Dynamic analysis

If both the tectonic stressing and the body force are taken into consideration, and the dip-angle of a pre-existing fault is 60 degree, the calculated pattern of x, y and z components of the peak accelerations along a line passing through the center of the fault is not bilateral symmetry as shown in Fig. 5, both y and z components on the foot-wall side decay faster than that on the hanging wall side, and the strengthening of z component on the hanging wall side induces a weakening of x component nearby the fault on the same side. This means that the damage on the hanging wall side will be more serious than that on the foot-wall side, this is consistent with the damage distribution of the Tangshan faulting.

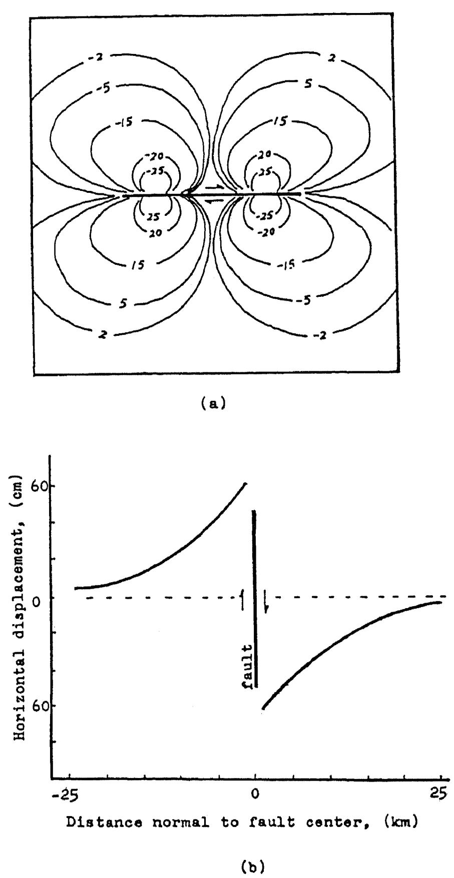

Fig. 3 Ground Displacements(cm) Due to strike-Slip of a Vertical Fault. (a) Vertical, (b) Horizontal

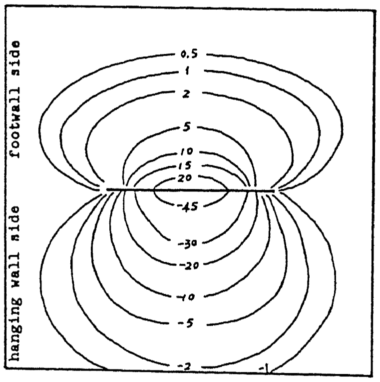

Fig. 4 Vertical Ground Displacements (cm) of an Oblique Fault Due to Self-Gravity

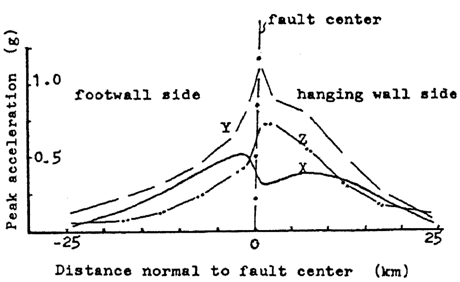

Fig. 5 Peak Acceleration (g) of x, y and z Components along a Line Passing through the Center of an Oblique Fault with Normal Dipping Equivalent to Body Force

CONCLUSION

In nature any fault has a certain dip-angle, the normal dipping of the faulting plane is then not negligible in near-field ground motion prediction and damage zonation evaluation, especially in faulted basins such as in North-China plain area, the normal faulting due to self-gravity is very pre-dominant. The dislocation model assigning arbitrarily a horizontal displacement along a fault plane will overestimate the damage on the foot-wall side on one hand and underestimate the damage on the hanging wall side on the other.

By geodetical survey crossing over a potentially seismogenic fault, it is plausible to judge the mode of the pre-existing fault and the nature of driving force in earthquake development. However, the behavior of the near-field ground motion is also influenced by the variation of the stress-drop along the faulting plane and the heterogeneous faulting process, the thrust of future research will be first to use the horizontal record of ground motion to infer inversely the mechanical properties along the faulted plane by using a more realistic and refined 3-dimensional finite element model before predicting numerically the near-field ground motion.

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