Fault Rupture Mechanism and Wave Propagation Characteristics in Near Field Considering Asperity by Modified DEM

Nemat Hassani [1] ・ Shiro Takada [2] ・ Keiji Nishikawa [3] ・ Kenji Nakajima [4]

[1]正会員　工博　神戸大学助手　工学部建設学科（〒657-8501 兵庫県神戸市灘区六甲台町 1-1）
[2]正会員　工博　神戸大学教授　工学部建設学科（〒657-8501 兵庫県神戸市灘区六甲台町 1-1）
[3]学生員　大学院学生　神戸大学大学院自然科学研究科（〒657-8501 兵庫県神戸市灘区六甲台町 1-1）
[4]学生員　大学院学生　神戸大学大学院自然科学研究科（〒657-8501 兵庫県神戸市灘区六甲台町 1-1）

A fault rupture mechanism is simulated and the relevant ground failure mode and wave propagation, are investigated. A distinct element code for fracture and failure analysis (DEFA) developed by the authors is used. The Haskell Model is considered for modeling the input displacement in the model. The results show that the crack propagation has an angle of 30-45 degrees with the direction of rupture progress. There are also cracks propagating just beside and parallel to the rupture direction. The vertical component of acceleration is larger in the fault direction, while the horizontal one is larger in the direction of crack propagation . Considering the asperity make a little greater maximum acceleration with higher frequency will be obtained while there is not so much difference in the Fourier spectra.

Key Words **:** *Fault Rupture, Asperity, DEM*

1. Introduction

To analyze the fracture process and to monitor the failure mechanism of structural media, there are some shortcomings in current numerical methods (such as difficulties in geometrical non-linearity, sliding, separation and new contact modeling) which make them unable to monitor the behavior of the system up to the complete collapse. There are also some shortcomings in experimental methods such as: almost impossibility to repeat the same test, difficulties in monitoring the behavior in all parts, specially internal parts and time-money consumption.

Therefore, there is a need for a numerical simulation method which is able to simulate more realistic post fracture behavior of structural media under dynamic loads (specially earthquakes) up to the complete collapse.

The authors [1,2] have already developed a computer code (DEFA) based on distinct element algorithm for fracture analysis and failure monitoring of structural media.

In the developed numerical simulation the medium is modeled as an assembly of circular (disk) particles [3] which are connected to each other through a system of normal and tangential springs and dash-pots (Voigt-Kelvin visco-elastic model). The force is transferring due to the springs and dash-pots between those elements that are within a specified distance from each other. The general idea for using pore springs (regarding the contact springs in original DEM) in continuous (or cohesive) media was introduced by Iwashita[4, 5] as the winkler types springs for modeling the cohesion in granular media. There is also a mathematical type of damping known as global damping[3] for stabilizing the central finite difference scheme which is used for solving the equation of motion of the elements.

The basics of the program are as followings:

- Newton double integration scheme for tracing the movement of elements.

- Computing the inter-element forces due to the visco-elasticity theory in continuum mechanics.
- Crack modeling by breakage in pore connection between the elements.
  - A modified Coulomb criterion for shear failure for dynamic fracture.
  - Tension cut-off for tension failure in pore medium.
  - Periodical connection updating between the elements for new contacts.

During the Kobe Earthquake, the structures in near field suffered more damage comparing to those in far field. This is study is a part of more comprehensive research on ground motion characteristics at near field and its effects on buried lifelines. In this study we have used the developed program for analysis of fault rupture and ground response in near field. The main object of this paper is to find the effect of asperity on fault rupture and ground response.

2. Analytical model

The fault model, which is used in this study as shown in Fig.1 is an assembly of 4279 circular elements (disks) with a radius of 200m in a section of 15km by 40km of ground (rock).

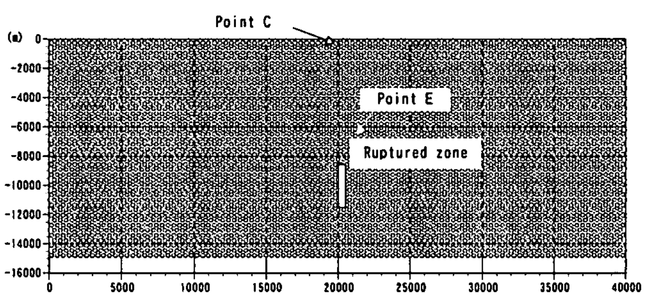


Fig. 1 Analytical model

For mitigating the effect of the boundaries on the ground response, the left and right of the model are supported by viscous dash-pots with a damping ratio of 12 percent.

The data, which have been used for the analysis are shown in Table 1.

For modeling the rupture in the fault, it is assumed that a narrow zone in the middle of the model (Fig. 1) is displacing with a rupture propagation velocity of V_r =2.5 km/sec in average. The forced displaced elements in this zone are shown in Fig. 2. The rupture time in the focus is assumed about 2.0 seconds and the total ruptured displacement

Table-1 Main data used in the analysis

Element Type	Internal elements	Loading elements
Young modulus E(tf/m^2)	5.4×10^6	3.5×10^6
Poisson ratio (ν)	0.15	0.23
Unit weight γ (tf/m^3)	2.45	2.25
Friction coefficient (μ)	0.70	0.40
Cohesion c(tf/m^2)	300.0	100.0

in the ruptured zone is 2.0m. This mechanism of rupture is done according to the Haskell model which is mainly based on the sequence displacements of the elements from bottom to the top in the ruptured zone.

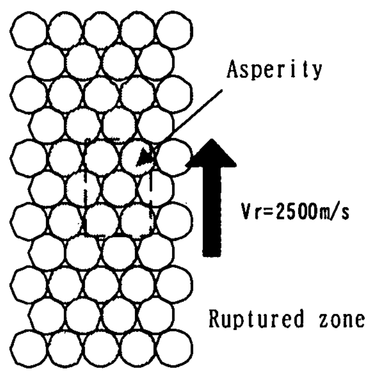


Fig. 2 Fault rupture model

In this study for investigating the effect of asperity on the ground response, as depicted in Fig. 2 we have assumed that 5 elements among the 28 elements, which are under forced displacements, are moving more than the other ones. However, the average displacement of whole 28 elements is 2.0m.

Here, 4 cases are considered for the effect of the asperity. In case 1, there is no asperity and all the 28 elements are moving with the same amount of displacements.

In other 3 cases asperity is considered in such way that in case 2, the 5 elements, with more displacements are in the middle, while in the cases 3 and 4, these 5 elements are selected in the lower and upper parts of the ruptured zone, respectively.

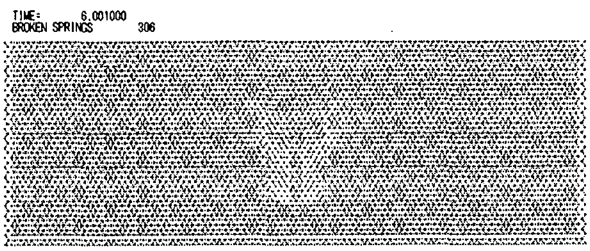
3. Results of analysis

Crack pattern for different cases of analysis are shown in

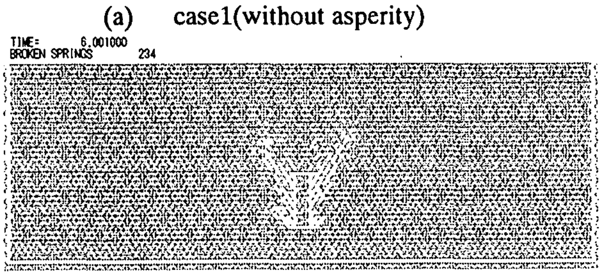
Fig. 3. The cracks are depicted as the broken springs between the elements. These crack patterns are obtained after 6 seconds of the start of the simulation analysis. As a general view it is seen that the cracks are propagated in the vertical and inclined direction in all cases.

Since there is no asperity in case 1 (Fig.3-a) and all the elements in ruptured zone are moving with same amount, the crack pattern is symmetrical. But, in the cases with asperity (Fig.3-b,c,d), it is seen that the cracks in right side of the ruptured zone are different from the cracks in the left side. In case 3, in which the upper 5 elements of ruptured zones are displaced more than the others, the crack pattern is more wider than the other cases and is mainly propagated up to the near of the ground surface.

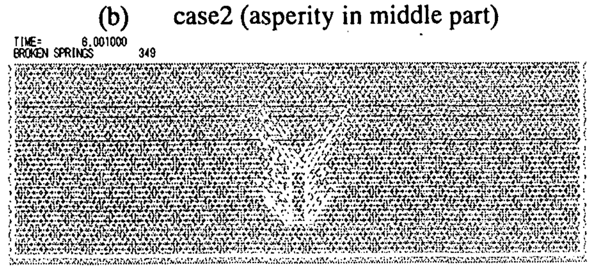
Cases 2 and 4, show the crack patterns with more inclined propagation but mainly in vertical direction.



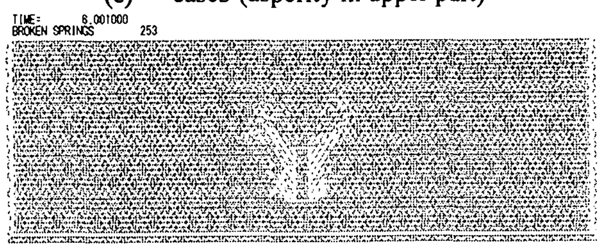
(a) case1(without asperity)



(b) case2 (asperity in middle part)



(c) case3 (asperity in upper part)



(d) case4 (asperity in lower part)

Fig. 3 Crack pattern after 6 seconds

The Time-history of horizontal and vertical acceleration at point E (Fig.1), which is located inside ground and very near to the ruptured zone for cases 1 and 3 are shown in Fig.4.

Also the time-history of acceleration response in vertical direction at point C (Fig.1), which is located directly above the ruptured zone and on the ground surface are depicted in Fig. 5 for cases 1 and 3. A comparison between the Fourier Spectra of accelerations for cases 1 and 3 in horizontal and vertical direction are shown in Fig. 6.

Figs. 4 and 5 show that the maximum acceleration in case 3 both in horizontal and vertical directions are greater than the ones of case 1. They also show short period pulses in this case. However, the Fig. 6 shows that in both cases the short period components are predominant.

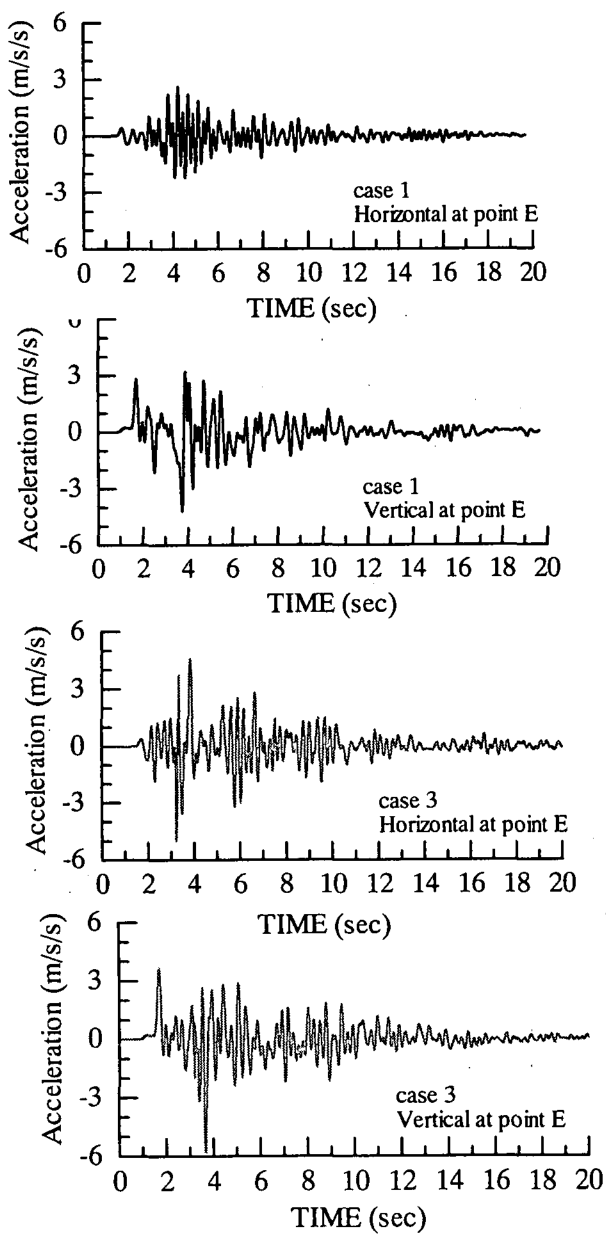


Fig. 4 Time-history of acceleration response at point E

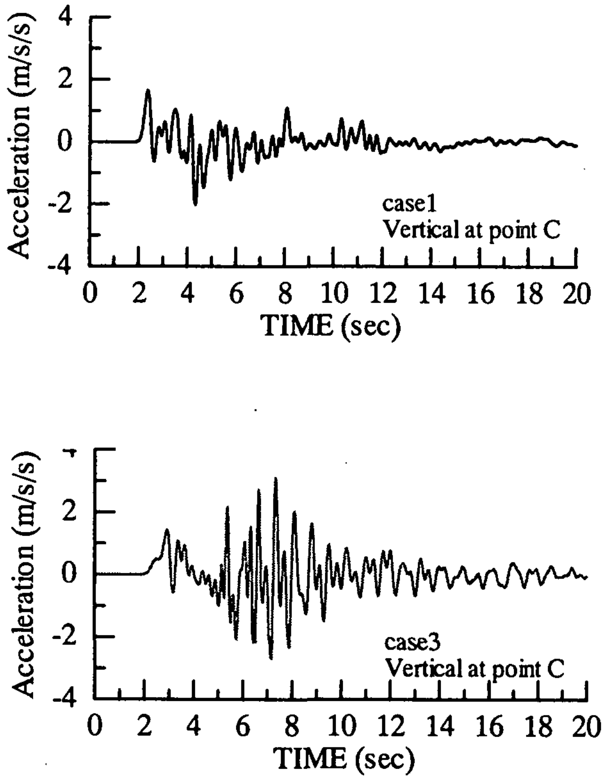
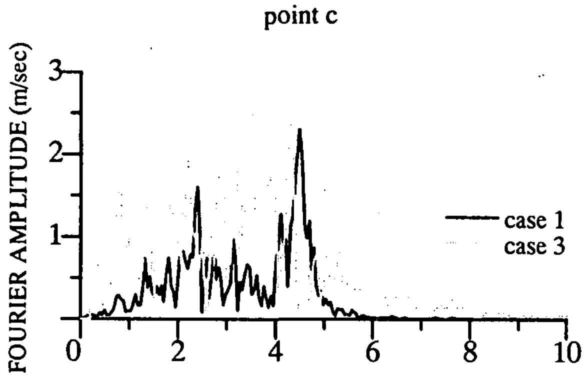
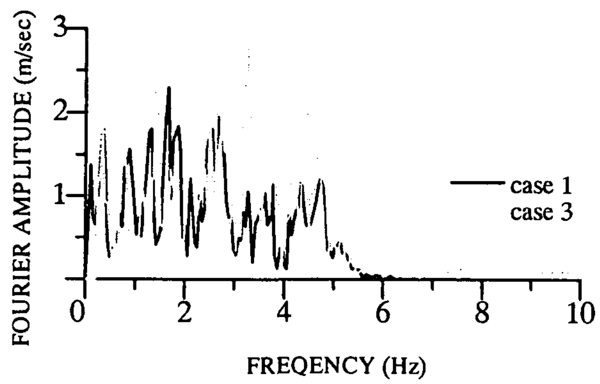


Fig. 5 Time-history of vertical acceleration response at point c



(a) Horizontal direction



(b) Vertical direction

Fig.6 Fourier spectrum of acceleration response at point E

4. Conclusions

This study is a part of more wider research about the ground motion characteristics at near field. In the study in this paper, we have tried to model the effect of asperity on fault rupture and investigate the rupture propagation and ground motion by using a modified distinct element code developed by the authors. The main conclusions can be summarized as followings:

- When the upper part of ruptured zones is displaced more than the other parts, the crack pattern is more wider than the other cases and is mainly propagated up to the near of the ground surface.
- When the asperity is in the middle or the lower parts of the ruptured zone the crack patterns have more inclined propagation but mainly in vertical direction.
- Due to the effect of asperity high frequency pulse waves with a little more maximum acceleration were obtained.

References

1. Hassani, N., " A Study on Development of Distinct Element Algorithm for Fracture Analysis and Failure Monitoring of Structural Media under Dynamic Loads", Doctoral dissertation, Department of Science & Technology, Kobe University, Kobe, Japan, March 1997.
2. Takada et al, "Simulation of ground motion and rupture propagation using DEM", Construction Engineering Research Foundation, Vol. 40-B, Special issue for Hanshin-Awaji Great Earthquake, pp.41-58, 1998 (in Japanese).
3. Cundall P. A. & Strack O.D.L. " A discrete numerical model for granular assemblies", Geotechnique, 29, pp. 439-446, 1979.
4. Meguro, K. & Hakuno, M. " Fracture analysis of concrete structures by the modified distinct element method" , Proc. of JSCE, No. 410/I-12, Struc. Eng./Earthquake Eng. Vol.6, No.2, pp. 283s-294s, October 1989.
5. Iwashita, K. " Dynamic fracture analysis of ground by granular assembly simulation I", Bulletin of the Earthquake Research Institute, University of Tokyo, Vol.63, pp. 201-235, 1988.