Large Variation in PGA due to Presence of Heterogeneities in the Surface Soil

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ABSTRACT

In the proximity of an active fault, spatial variation of peak ground motion is significantly affected by the faulting mechanism. It has been observed that near fault ground motions consists of different characteristics compared to the far fault ground motions. Near fault records, in the distance range of less than 100 m from the faults are not available except for few cases. Therefore numerical simulation of ground motions for such near-fault situations is necessary. There is a need to enhance our understanding of the possible potential hazard that can be caused due to the future rupture activity by understanding the phenomenon of surface faulting. In this paper we propose numerical simulation based on discrete modeling to investigate the fault rupture propagation. Initially a two dimensional study is done for understanding the crack propagation due to various types of bedrock movement. A model of size 1000x150 m is selected for this purpose. It is observed as the stiffness of the media is decreasing, the affected surface is decreasing and also width of the shear crack zone is decreasing. However in the dynamic analysis we can observe the significant increase in amplification in soft media. Secondly, we attempted to study the presence of boulders. Surface faulting has been examined by keeping the boulder at different positions. We find that there is an increase in the shear zone as well as the PGA on the surface when the boulder is present on the foot wall. Finally, we performed the analysis using layered media and studied the affect of crack propagation and also the variation of peak accelerations Findings from the study can be utilized to assess the damage potential of the near fault areas.

INTRODUCTION

In the past decade several earthquakes near large urban areas have caused considerable damage, including the 1994 Northridge, California, the 1995 Hyogo-Ken Nanbu (Kobe), Japan, the 1999 Izmit and Duzce, Turkey, and the 1999 Chi-Chi, Taiwan, earthquakes. These earthquakes and their associated ground motion records have increased the awareness of the destructive capability and characteristics of near-source ground motions in the vicinity of faults. The primary factor controlling the size of near-source ground motions is not simply the distance the rupture propagates, but the distance the rupture propagates in the direction of slip. The ability to capture pulse-type ground motions in the near-fault region is of recent development and records of this type are few. In addition to the near source ground motion it is necessary to understand the possible location of the fault appearing on the surface due to future rupture activity. The study of fault rupture propagation is necessary because engineers are more concerned about the damage that will be caused when structures are located on the vulnerable area.

Many researchers have studied the phenomenon of fault rupture propagation by experimental models. Sanford (1959) investigated the pattern of cracks using a sandbox models. Belousov (1961) conducted experiment to illustrate how soft clay responded to vertical thrust and normal faults. Cole and Lade (1954) have tried to determine the location of surface fault rupture and width of the affected zone in alluvium over dip-slip fault using fault test box. Lade et al. (1954) studied to determine the multiple failure surfaces by conducting the experiments on sand using fault test box. The results of the sand box model tests concluded that the observed displacement fields were largely the same for the different materials. Bray (1990) investigated the pattern of ruptures in clay models under 1-g subjected to dip-slip faulting. The range of bedrock's dip angle varied from 60º to 90º for both normal and reverse faults. Results from all these tests indicated that the base offset necessary for the rupture to propagate to the ground surface varied with fault orientation and the rate of slip. Using the above experimental methods, we can find the affected length on the surface. However, replicating the actual field conditions using experiments is very difficult, especially, controlling the material properties and modeling the boundary conditions. On the other hand, studying this phenomenon using numerical model has the advantage of controlling the parameters. Numerical model allow us to investigate a number of aspects of the fault rupture propagation phenomenon, which are difficult to study from the examination of case histories or the conduct of physical model tests. Many researchers have studied the fault rupture problem using finite element method. FEM can be applied to study this problem provided that the soil's nonlinear stress-dependant stress strain relation is properly modeled. Nonlinear stress-deformation behavioral models provided significantly better predictions of observed behavior of shear and tension zones. However once a shear tension crack i.e. a discontinuity develops within the soil mass it typically becomes difficult to reliably apply the numerical approach based on the continuum mechanics. Scott (1987) identified a number of limitations of FEM in the analysis of failure. Hence a suitable numerical approach must be chosen to study this problem. Pradeep (2001) has used Applied Element method based on discrete modeling for studying the effects on the ground surface due to seismic base fault movement.

SIMULATION METHOD

The method used here is the Applied Element Method which was developed by Hatem et al. (1998). With the AEM, structure is modeled as an assembly of small elements that are made by dividing of the structure virtually, as shown in Fig.1. The two elements shown in Fig. 1 are assumed to be connected by pairs of normal and shear springs located at contact locations that are distributed around the element edges. Each pair of springs totally represents stresses and deformations of a certain area of the studied elements.

$$k_n = \frac{ExdxT}{a} \qquad\qquad k_s = \frac{GxdxT}{a} \qquad (1)$$

where, d is the distance between springs, T is the thickness of the element and "a" is the length of the representative area, E and G are the Young's and shear modulus of the material, respectively.

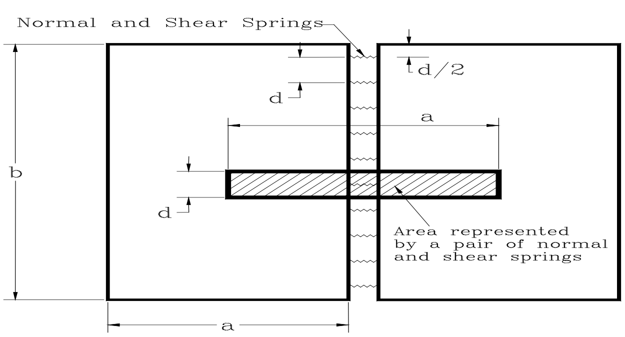


Fig.1 Element formulation

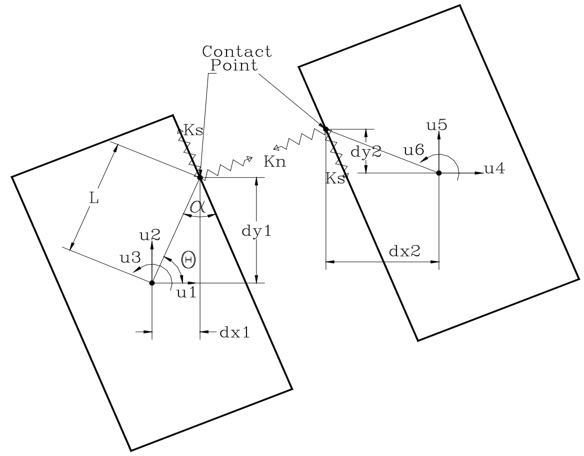


Fig.2 spring connectivity

The spring stiffness is determined as shown in Eq. (1). The above equation indicates that each spring represents the stiffness of an area (d x T) with length "a" of the studied material. In case of reinforcement, this area is replaced by that of the reinforcement bar. The above equation (1) indicates that the spring stiffness is calculated as if the spring connects the element centerlines.

Model parameters

The mechanism shown in Fig. 3 is called Reverse Dip-Slip Faulting. This is one of the types of fault where the hanging wall moves upward relative to the footwall. If the direction of the movement of the hanging wall is downward then it is called normal faulting. To analyse the mechanism of fault rupture zone near dip-slip faults, the numerical model shown in Fig. 4 is prepared. Length of the model is assumed as 1 km and depth is 150 m. The location of the base fault is assumed to lie exactly at the centre of the model

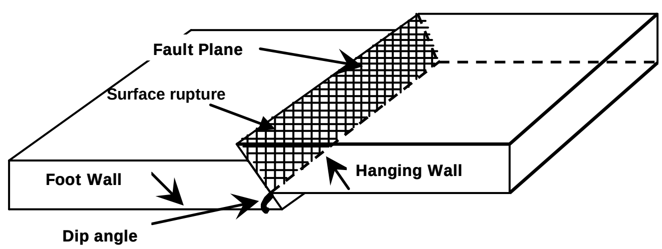


Fig. 3 Mechanism of reverse fault

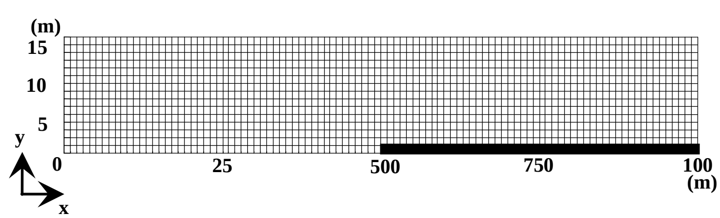


Fig. 4 Numerical model

Generally, soil strata and bedrock extend upto tens of kilometers in horizontal direction. Numerical modeling of such a large media is a difficult task and moreover, for studying the surface behavior near the active fault region, it is necessary to model the small portion of the region that includes all the effects when the bedrock moves. For studying the selected region numerically, we assumed the boundary on left side as an absorbing boundary. These absorbing boundaries prevent waves from reflecting and contaminating the solution In order to avoid the interference of boundary condition on numerical results, boundary is kept at sufficient distance from the fault zone

Slip function

For comparing the results with real near field records with large displacement, closed form approximation of static displacement is assumed. Pulse-like displacement time history that represents the base motion is considered (Fig. 5) referring to Mladen (2000). As an approximation, the corresponding displacement pulse can be assumed as Gaussian-type function given by Eq. 2.

$$d_{sp}(t) = \frac{\sqrt{2\Pi}}{n} V_{sp} T_p \Phi\left[\frac{(t-t_c)}{T_p/n}\right] \qquad (2)$$

Where V_{sp} is the amplitude of static velocity pulse, T_p Velocity pulse duration, tc time instant, at which the pulse is centered, n constant equal to 6 and t is the time. The term T_p/n has the meaning of standard deviation and controls the actual spread of the pulse with respect to the given pulse duration and Φ is the normal probability function.

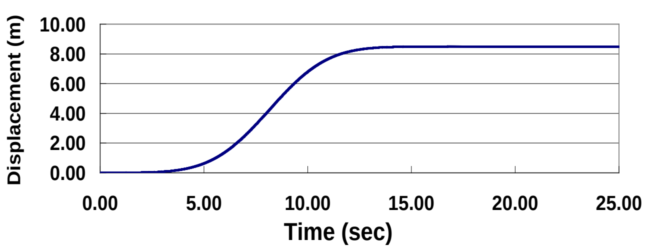
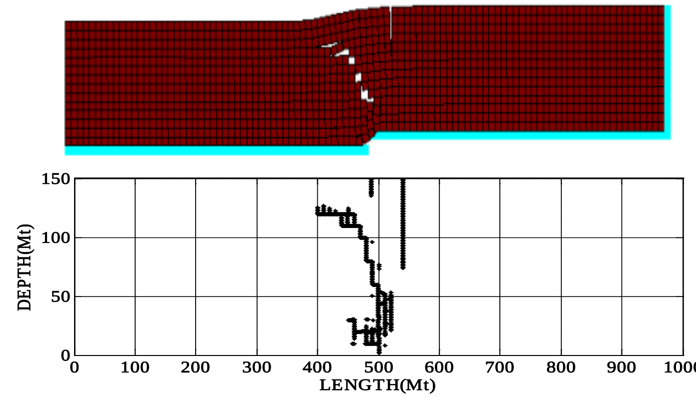
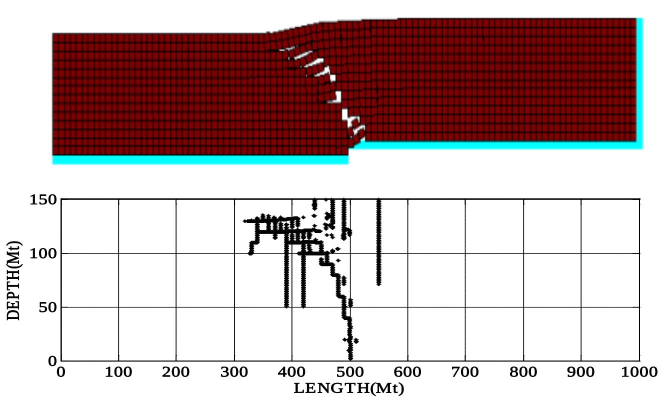


Fig.5 Assumed input displacement at the bedrock



(a) *For shear wave velocity Vs=527m/s*



(b) *For shear wave velocity Vs=265m/s*

. Fig 6. Propagation of cracks and the element location

CASE STUDY

To analyse the surface fault rupture zone materials having shear wave velocity Vs=527m/s and Vs=265m/s have been taken respectively. In order to find the attenuation of the of the peak ground acceleration along the surface due to the input displacement at the bed rock as shown in fig 5, only soil mass has been considered. Young's modulus of elasticity of the soil has been considered as $10x10^5$ kN/m^2, and the shear wave velocity considered as 527 m/s. Figure 6 shows the propagation of shear and tension cracks in the material. From these figures it can be said that the thickness of the shear band reduces with the reduction in the shear wave velocity because in the softer material shear cracks gets localized. Attenuation of the peak ground acceleration on the surface has been plotted in fig 7. From the figure it is seen that ground acceleration (PGA) attains a maximum value in the hanging wall side and then decreases with distance. Pradeep (2001a) suggested the reason as, near the surface fault rupture, the material becomes highly nonlinear and the response of this region becomes low compared to the adjacent areas of response. Response time history of the element at which peak response is observed has been plotted in fig 8(a) & 8(b). From the response history it can be seen that the peak value attained is only for a small instant of time and then it is reduced because of high nonlinearity of soil.

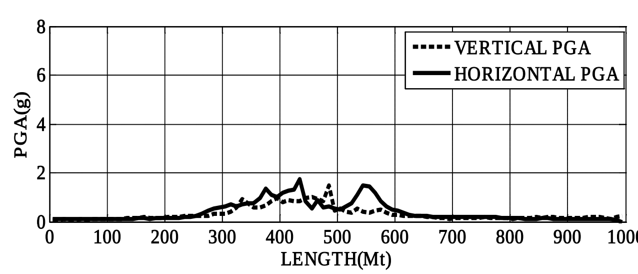
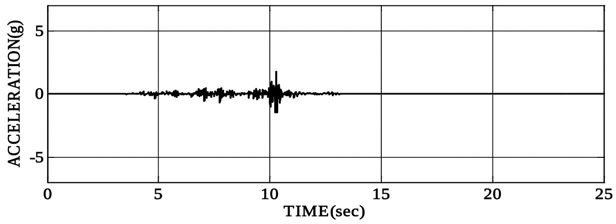
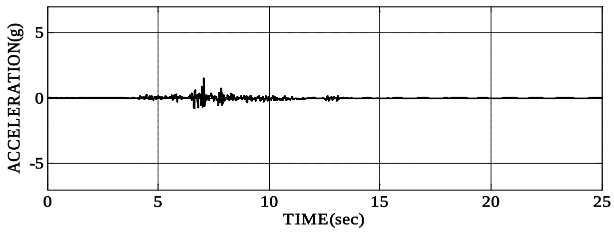


Fig 7. Attenuation of PGA on the surface



(a) Horizontal time history at the maximum PGA



(b) Vertical time history at the maximum PGA

Fig 8. Acceleration Time history at maximum ground motion

It is well known that the soil is not a homogenous strata. It is filled with heterogeneities. Case study has been done to study the effect of the presence of boulders in the soil on the ground surface. The analysis is carried for two cases to study the response on the surface in presence of boulders in the soil medium. In Case.1 the boulder is placed in foot wall andin case.2 the boulder is placed in hanging wall. In case.1 the boulder with young's modulus $66x10^6$ kN/m^2,and the shear wave velocity considered as 3496 m/s has been placed in the footwall and the analysis has been performed to find the the response on the surface. Material properties of the rock and the soil deposit have been shown in Table 1. Figure 9 shows the attenuation of peak ground acceleration on the surface and the crack propagation in presence of a boulder in the foot wall. Large variation in the ground motion has been observed when compared to results of without boulder condition(Fig 7).

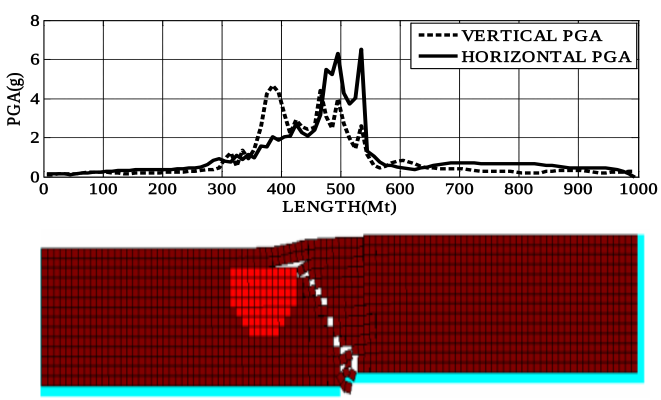
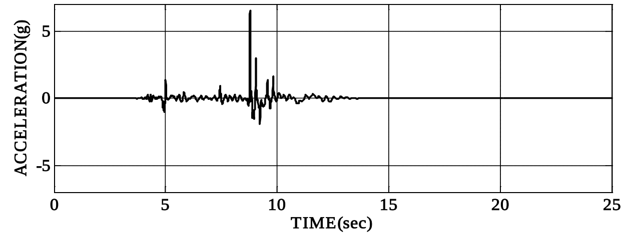
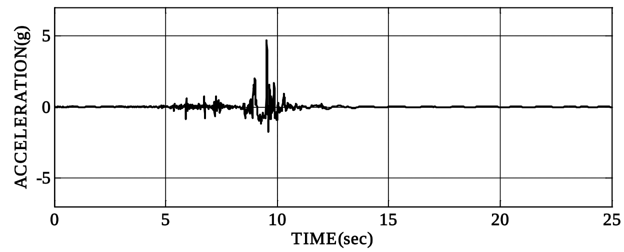


Fig 9. Attenuation of PGA on the surface in presence of boulder in foot wall.



(a) Horizontal time history at the maximum PGA



(b) Vertical time history at the maximum PGA

Fig 10. Acceleration Time history at maximum ground motion

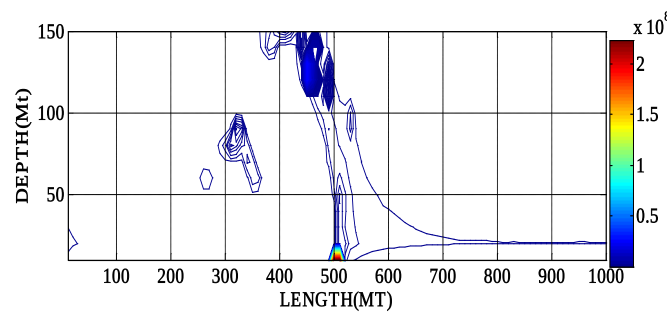


Fig. 11 Energy distribution in the system at time 8.57 sec

Table 1. Material Properties

	Young's modulus kN/m^2	Unit weight kN/m^3	Comp. Strength kN/m^2	Tensile Strength kN/m^2
Soil deposit	10 x 10^5	18	10 x 10^3	10 x 10^2
boulder	66 x 10^6	26.5	10 x 10^5	10 x 10^4

The reason for this is in the beginning of the analysis i.e in linear state the energy gets concentrated around the boulder and when the stresses exceeds the competance of the soil material this energy is suddenly released after cracking. Multiple reflections of the body waves after interacting with the rock medium are reflected back on to the hanging wall side with greater intensity. Peak acceleration response on the surface is increasing from 2 to 6 m/sec^2. Though this much value is not actual seen in the real field situations but since this is an hypothetical value there is that much variation. Response histories of the acceleration at the peak have been plotted in fig 10 (a) & 10(b). In figure 11 the energy distribution at the time when peak is been reached has been plotted. nergy being concentrated can be seen on the surface at hanging wall side because of the presence of the boulder.

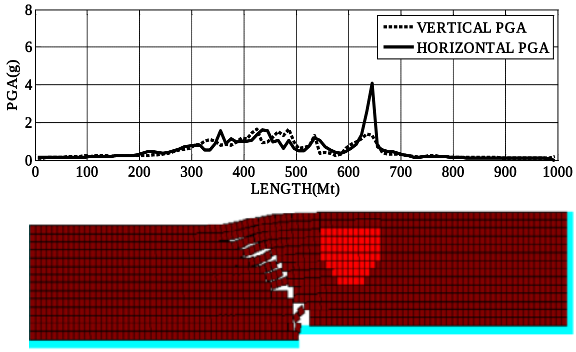
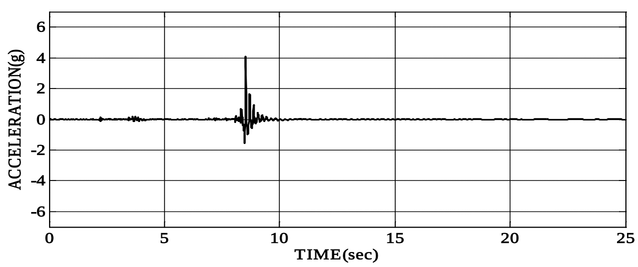
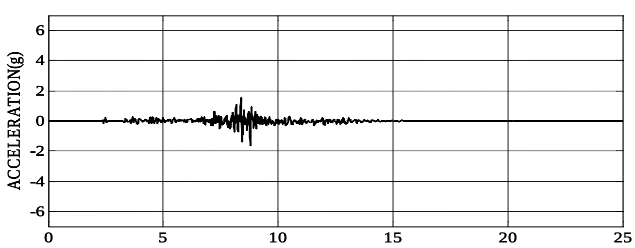


Fig 12. Attenuation of PGA on the surface in presence of boulder in hanging wall.

In Case.2 the boulder is placed in hanging wall and the analysis has been performed to find the the response on the surface. Figure 12 shows the attenuation of peak ground acceleration on the surface and the crack propagation in presence of a boulder in the hanging wall. There is not much effect of the presence of boulders in hanging wall, except just above the boulder there is some amount of amplification in the ground motion for a very short interval of time which can be seen in Fig 13(a) & 13(b).Figure14 shows the energy distribution in the system at the peak response time.



(a) Horizontal time history at the maximum PGA



(b) Horizontal time history at the maximum PGA

Fig 13. Acceleration Time history at maximum ground motion

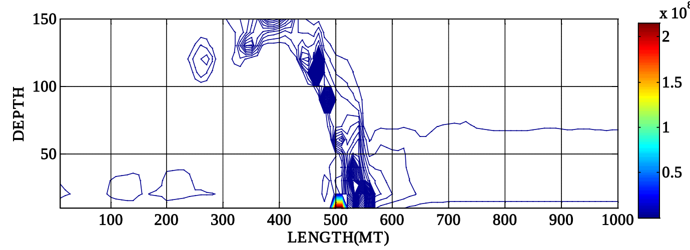


Fig. 14 Energy distribution in the system at time 8.58 sec

In Case.3 the boulder is placed in foot wall but some distance away from the rupture zone. From the plot of peak ground acceleration on the surface as shown in fig. 15 it can seen that there is not much increase in PGA value compared to without boulder condition except at place just besides the boulder. From the above cases studied it can be said that the increase in ground acceleration on the surface is for the case when the boulder is present in foot wall and in proximity of the rupture zone.

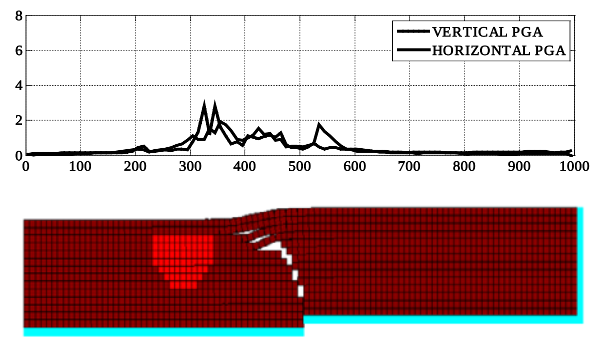


Fig. 15 Attenuation of PGA on the surface in presence of boulder in foot wall away from rupture zone.

Finally rupture propagation in the soil has been studied in the layered media. A layered media consisting of 5 layers with shear wave velocity from bottom to the surface are 527, 471, 408, 333 and 235 m/s respectively (Fig 16) have been taken. From fig. 17 & 18 it can be seen that the vertical surface deformation is less and the horizontal surface deformation is more in the layered media when compared to the homogeneous media. The reason for this is that in the layered media waves get reflected and the bad rock deformation is absorbed by the soil deposit due to the dispersion of the waves.

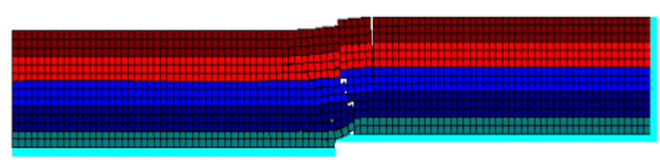


Fig. 16 Rupture propagation in layered media

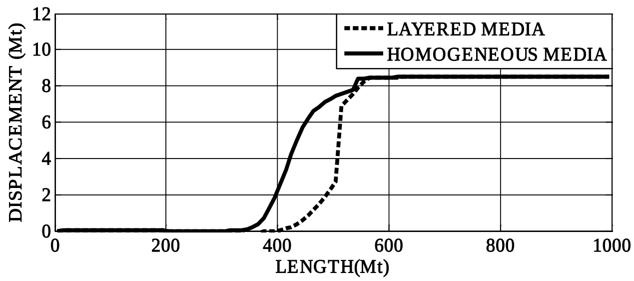


Fig. 16 Comparison of vertical surface deformation

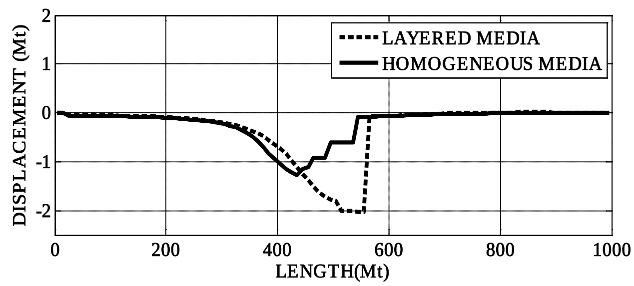


Fig. 17 Comparison of horizontal surface deformation

Over the past few decades, significant efforts have been made to understand the problem of ground-shaking. Accordingly, numerous design and construction procedures have been developed to minimize damage due to strong ground motion. Hence, it is proposed here to study the response of soil deposits to underlying bedrock fault displacement. Although the complete understanding of the fault rupture phenomenon in soil is not so easy, since the factors governing the phenomenon is highly variable. Soil is consisting of different geological and geotechnical properties. Existing planes of weakness or rigid inclusions within a weaker soil mass will certainly cause the fault rupture pattern observed in the field to deviate from any fault rupture pattern predicted by the theories based on the assumptions of homogeneous soil masses. Earthquake shaking, in conjunction with the movement across the fault, may alter the response of the overlying soil deposit. The repetitive nature of faulting gives us an important basis for predicting future activity of faults by using geological information. And hence, the study on the fault rupture propagation is necessary to establish the possible locations of the faults appearing on the surface due to future earthquakes. The hazard of surface faulting is an important problem because of the potentially adverse consequences of ground breakage. From a seismological point of view, some difference between the real fault and the expected fault line is acceptable; but for engineers this difference sometimes might be a major concern. This understanding would also assist engineers in siting and designing critical buildings, utility and transportation systems, and other types of facilities constructed in regions where soils overlie potentially active faults.

CONCLUSIONS

Numerical modeling of fault rupture propagation in dynamic condition is done using 2D AEM. Rupture phenomenon and the response on the surface in presence of heterogeneities like rock boulders in the soil medium has been studied using hypothetical model. Presence of boulders in the footwall and in proximity of the rupture zone increases the PGA value in the hanging wall to a large extent, whereas the presence of boulder in hanging wall does not affect much on the surface ground motion. It has been seen that there is a considerable change in the rupture pattern between layered media and homogenous media. Findings from the study can be utilized to assess the damage potential of the near fault areas when we to the analysis considering the actual field conditions.

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