STATIC MODELING OF REVERSE DIP-SLIP FAULTS USING APPLIED ELEMENT METHOD

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1. INTRODUCTION

We have witnessed many great earthquakes in the recent past. Among them, Northridge (1994), Kobe (1995), Turkey (1999) and Taiwan (1999) to name a few. The amount of destruction and death toll they caused to the society is still fresh in our memories. Majority of the death toll because of these earthquakes is mainly due to the failure of structures and buildings. Every earthquake is giving valuable information showing out the deficiencies in our understanding the behavior of nature.

In this study, we focus our discussion on the large surface displacements/upliftment of the unconsolidated soil deposits which commonly overlie the active and potentially active faults. The behavior of such deposits is very important during the planning and construction of critical structures that may be located near the zone of faulting. Carrying out experiments to understand such kind of behavior may be uneconomical sometimes, because many experiments of high precision are to be conducted to obtain results for establishing a relationship between the various parameters such as width of affected zone, soil properties, thickness of deposit and dip angle. Hence there is a need to develop a numerical model which gives quantitative results to establish a relationship between soil parameters and width of affected zone. For this reason, we attempted to develop a new application to Applied Element Method (AEM)[1)] by modelling the fault rupture zone to study the behavior of reverse dip-slip faults (see **Fig. 1**). As this is preliminary stage, the modelling is done in static mode without giving regard to the dynamic aspects such as ground shaking and slip rate of the fault.

2. ELEMENT FORMULATION & BOUNDARY CONDITION

Applied Element Method (AEM), which was developed recently as a general method for structural analysis in both small and large deformation ranges has shown good accuracy in predicting the structural behavior. In AEM, the media is modelled as an assembly of small elements which are made by dividing the structure virtually. Two elements shown in **Fig. 2** are assumed to be connected by pairs of normal and shear springs set at contact locations which are distributed around element edges. Stresses and strains are defined based on the displacements of the spring end points which are located along the axis passing through centroid. Three degrees of freedom are assumed for each element. For other details, please refer to Refs. 1-3. By using the advantage of AEM's simplicity in formulation and accuracy in non-linear range, fault rupture zone which is shown in **Fig. 3** is modeled.

To analyze the mechanism shown in **Fig. 1**, the model shown in **Fig. 3** is prepared. Bottom layer is bedrock of thickness, D, and the top layer is soil deposit of depth, H. As the soil strata and rock extends upto infinity in horizontal direction and the numerical modelling of an unbounded media is a difficult task, we set an approximate boundary condition at some fixed distance from fault zone to take care the effects of continuity. At this boundary, it is assumed that equal amount of pressure is applied from infinity towards the fault zone thus making the horizontal displacement of the elements along the boundary line zero. Since the thickness of the soil deposit is known, all the elements along the boundary are free to move in vertical direction depending of the properties of deposit. Bottom of the bedrock is assumed as fixed boundary.

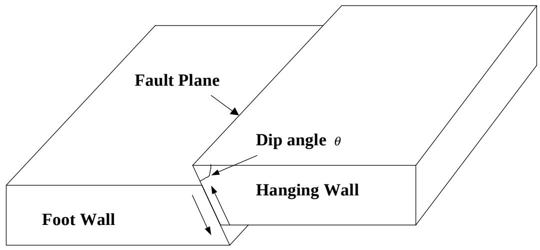

Fig.1 Potential faulting zone near reverse dip-slip fault

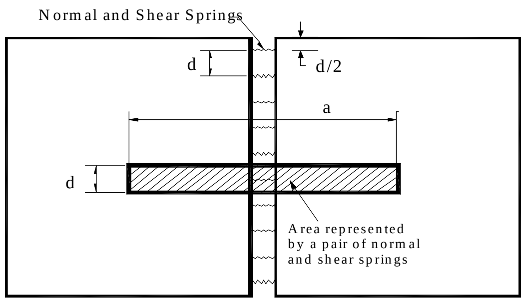

Fig. 2 Spring distribution and area of influence of each pair of springs

3. PARAMETRIC STUDY

A parametric study has been carried out to show the relationship between the thickness of the overlain soil deposit, properties of soil and influence length. As a preliminary stage, we are examining the simple model of dip angle 90 degrees as shown in **Fig. 3**. Thickness of the soil deposit, H, is assumed to vary from 10 m to 150 meters by constant

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interval of 20m. Thickness of bedrock, D is kept constant at 50m and total length of the model, L is 500m. Properties of bedrock are assumed as follows: density, γ = 26.5 kN/m^3, modulus of elasticity E_b=66x10^6 kN/m^2, tensile strength, ft=2.5x10^4 kN/m^2 and compressive strength, fc=2.5x10^5 kN/m^2. Vertical displacement of 5m is given to bedrock in 50 increments and displacement at the surface is observed. Behaviour of three cases with varying soil properties as shown in the **Table 1** is studied. From the graph shown in **Fig. 4**, it is clear that the displacement at the zone of fault is large in case 2 than in cases 1 and 3 and this is because of the elasticity property of the soil which directly reflects in surface deformation. However, on the contrary, if the compressive strength is halved, we observed that the surface displaces only little because of the failure of soil due to crushing. We also observed the effect of thickness of soil deposit on surface displacement. It was found from the results that the surface displaces more when the fault is nearer to the surface. When the thickness of the deposit is more, it is found that the large amount of deformation is getting absorbed in the soil deposit. Other details will be discussed with the aid of graphs while presentation.

Table 1 Material Properties of soil deposit

Deposit Soil	E_s (kN/m^2)	f_t (kN/m^2)	f_c (kN/m^2)
Case 1	20x10^5	1.5x10^3	1.86x10^4
Case 2	10x10^5	1.5x10^3	1.86x10^4
Case 3	20x10^5	1.5x10^3	0.93x10^4

This kind of study is necessary to establish the possible locations of the faults appearing on the surface due to future earthquakes because engineers are more concerned about the damage that will be caused when the structures are located on the vulnerable area. According to seismological point of view, a small difference between the real fault and the expected fault line is acceptable but for the engineers this difference might be sometimes of a major concern. Moreover, from the recent earthquakes, it was observed that the structures which are located very near to the zone of faulting have survived and the structures which are far have experienced major damage[4)]. This shows that there is strong relation between site conditions and the dynamic characteristics of wave motion. Hence it is important to study the surface behavior based on the local soil conditions and fault characteristics. This kind of study is difficult to perform experimentally because it is difficult to model the soil similar to actual case. On the other hand, numerical models which can predict the behavior of the media accurately in small and large deformation range and in non-linear range have the advantage of modelling any kind of soil and flexibility to change the parameters such as strength of soil, thickness of the deposit and dip angle.

4. SUMMARY

A new application to Applied Element Method is proposed in this paper. The relation between influence length on the surface and parameters like, depth of soil deposit and soil properties and dip angle of the fault are discussed. Since this is preliminary model, dynamic aspects such as ground motion, slip rate of fault movement are not taken into consideration. The boundary condition discussed here is not appropriate for qualitative discussion since there will be some movement in the horizontal direction along the boundary. Although the discussion done here is for the static case, the method can be extended to dynamic case such as modelling of the unbounded media for studying more realistic phenomenon like wave propagation, radiation condition and dependence on soil parameters.

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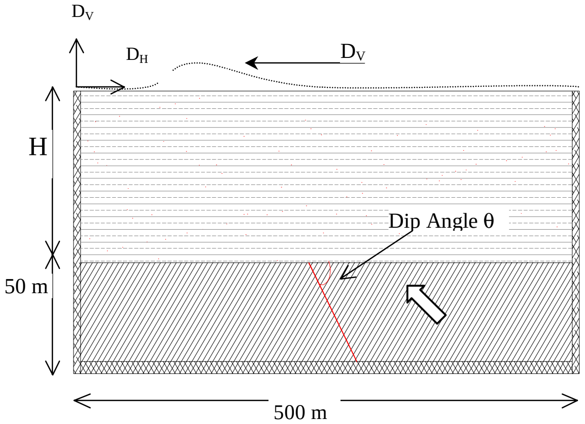

Fig. 3 Soil deposit over dip-slip fault

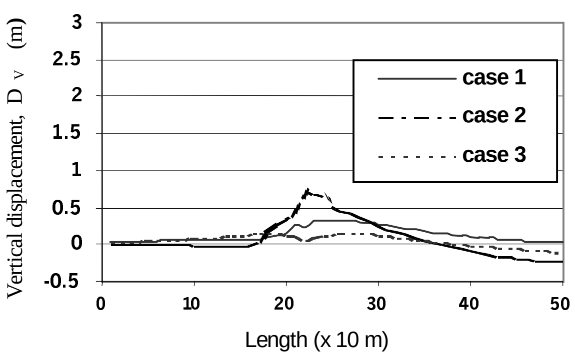

Fig. 4 Surface displacement for different material properties