A STUDY ON GROUND SURFACE DEFORMATION OVER DIP-SLIP FAULTS USING APPLIED ELEMENT METHOD

Pradeep Kr. Ramancharla, Student Member, The University of Tokyo
Kimiro Meguro, Regular Member, The University of Tokyo

1. INTRODUCTION

The recent strong earthquakes that have occurred in Turkey (M.7.4, 1999.8.17) and Taiwan (M.7.3, 1999.9.21), evidenced the effect of differential ground displacement on structural failure. Numerous researchers have attempted to study this phenomenon through experiments for understanding the effects of seismic fault mechanism and soil deposit parameters on surface deformation characteristics. However, from the wide spread damage caused by the recent events, it is now clear that the earthquakes in different geological regions show drastic variations in their effects such as, large surface upliftment/displacements of unconsolidated soil deposits, commonly lying over the active faults.

In this study, we focus our discussion on the large surface displacements/upliftment of the unconsolidated soil deposits that commonly overlie the 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. 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 dip-slip faults (see **Fig. 1**).

2. PROBLEM FORMULATION

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. 1** are assumed to be connected by pairs of normal and shear springs set at contact locations that 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. 2** is modeled.

In **Fig. 2**, bottom layer is bedrock of thickness, d (=10 m), and the top layer is soil deposit of depth, H (= 140 m). As the soil strata and rock extends upto larger distances 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. Bottom of the bedrock is assumed as fixed boundary. Analysis is carried out by giving the displacement to the hanging wall along the direction of dip angle and measuring the surface displacement. L1 and L2 are indicating the influence length on the right side and left side of the point exactly above the location of the seismic fault.

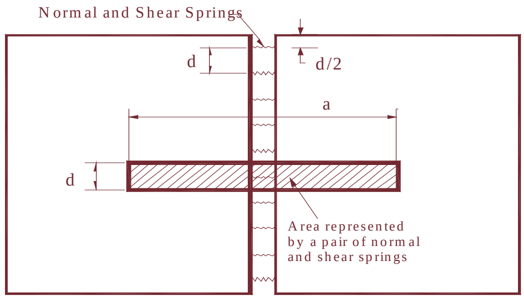

Fig. 1 Spring distribution and area of influence of each pair of springs

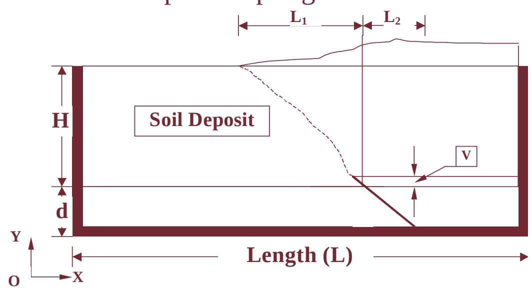

Fig. 2 Potential faulting zone near dip-slip fault

Table 2. Material Properties

	E (kN/m^2)	γ (kN/m^3)	f_c (kN/m^2)	f_t (kN/m^2)
Bedrock	66x10^6	26.5	2.5x10^5	2.5x10^4
Soil deposit	20x10^5	18.0	1.5x10^4	1.5x10^3

3. RESULTS

To verify the proposed model, analysis is carried out in linear and non-linear cases and the results are compared with experimental results of Onizuka et. al. (refer Ref. 5) and with the analytical expressions given by Okada (refer Ref. 6). Some of the illustrative results of non-linear case are shown in this paper.

The case shown in **Figs. 3** and **4** is reverse faulting where hanging wall is moving in the upward direction and the stresses in the soil deposit are compressive. The displacement on the surface is plotted for every 1-m displacement of the hanging wall along the direction of dip angle. Material properties for bedrock and soil deposit in case of non-linear analysis are shown in **Table 1**. From the **Fig. 3**, it can be observed that the displacement on the hanging wall side is in

---

Key words: Applied Element Method, surface displacements/upliftment, active fault, Kocaeli earthquake, Chi-Chi earthquake
Institute of Industrial Science, The University of Tokyo, 4-6-1 Komaba, Meguro-Ku, Tokyo 153-8505, Japan
(Tel: 03-5452-6437, Fax: 03-5452-6438)

proportion to the movement of the hanging wall and the affected zone is concentrated near the fault region only. From **Fig. 4,** it can be seen that the stresses near the zone of rupture are high and these stresses are reducing when we move towards the surface.

A parametric study has been carried out to show the relationship between the surface displacement and the hanging wall displacement. Vertical displacement of 5m is given to the bedrock along the direction of dip angle and the displacement at the surface is observed. Figure 5, shows the influence length on the surface towards the left side and the right side normalized with the thickness of the soil deposit. In this figure, the solid lines are indicating the normalized surface displacement of reverse fault case and the dashed lines show the normal fault case. It is clear from the figure that the influence length on the hanging wall is increasing in case of normal fault and decreasing in case of reverse fault. And the influence length on the footwall side is decreasing in case of normal fault and increasing in case of reverse faulting. We also observed the effect of thickness of soil deposit on surface displacement. It was found from the results that the surface displacement become more when the fault is nearer to the surface. Figure 6 shows the element location after the final displacement. Other details will be discussed with the aid of graphs while presentation.

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 can 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 and the boundary conditions 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 such as depth of soil deposit, soil properties and dip angle of the fault, etc. are discussed. Since this is preliminary model, dynamic aspects like ground motion and 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.

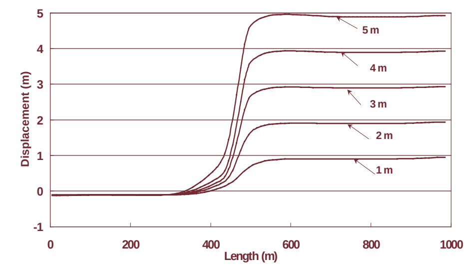

Fig. 3 Surface displacement

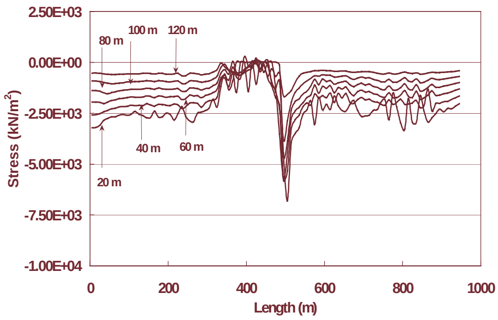

Fig. 4 Normal stresses

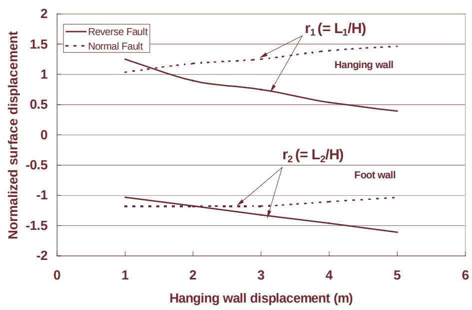

Fig. 5 Normalized surface displacement

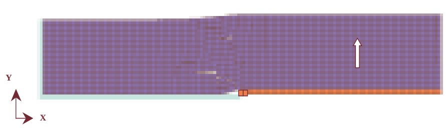

Fig. 6. Element location after displacement

REFERENCES

1. Meguro K. and Tagel-Din H: Applied element method for structural analysis: Theory and application for linear materials, Structural Eng./Earthquake Eng., Vol. I-50 No. 640, Japan Society of Civil Engineers, 2000-04.
2. Tagel-Din H.: A new efficient method for nonlinear, large deformation and collapse analysis of structures, Ph.D. thesis, Civil Eng. Dept., The University of Tokyo, Sept. 1998.
3. Meguro K. and Tagel-Din H: A new efficient technique for fracture analysis of structures, Bulletin of Earthquake Resistant Structure, No. 30, 1997.
4. The 1999 Ji-Ji Earthquake, Taiwan - Investigation into the damage to civil engineering structures, Japan Society of Civil Engineers, December, 1999.
5. Onizuka, N., Hakuno, M., Iwashita, K. and Suzuki, T., Deformation in grounds and bedrock stress induced by reverse dip-slip faults, Journal of Applied Mechanics, JSCE, Vol. 2, pp. 533-542, 1999.
6. Okada, Y., Surface deformation due to shear and tensile faults in half-space, Bulletin of the Seismological Society of America, Vol. 75, No. 4, pp. 1135-1154, August 1985.