THE EFFECTS OF SOIL THICKNESS ON REVERSE FAULT RUPTURE PROPAGATION

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Keywords: Reverse Fault Rupture, Soil Thickness, Physical Modeling

ABSTRACT

Fault setbacks or avoidance of construction in the proximity to seismically active faults, are usually supposed as the first priority by building codes and regulations. For instance, the well-known Alquist-Priolo Earthquake Fault Zoning Act of the State of California stipulates a setback of 50ft (15.3m) from each side of active fault traces, whereas the Iranian and the European seismic codes forbade any construction within the "immediate vicinity" of active fault traces. In this paper, based on some 1-g physical modeling tests, the effects of soil thickness on reverse fault rupture propagation are presented. It is observed that without consideration of the effects of soil thickness on surface fault rupture propagation, the setback provision does not give generally enough assurance for reverse faults.

INTRODUCTION

During strong earthquakes fault rupture often propagate to the ground surface threatening the safety of existing structures. This could have devastating effects on structures overlying the faults such as what was observed in the Turkey and Taiwan earthquakes in 1999. These observations reminded the profession and researchers to devote more efforts on surface fault rupture hazard mitigation approaches and investigations.

Different approaches have been adopted to investigate the surface fault rupture hazard. These have included field studies (Kelson et al., 2001; Faccioli et al., 2008; Jafari and Moosavi, 2008), physical modeling (Cole and Lade, 1984; Tani et al., 1996; Lee and Hamada, 2005; Bransby et al., 2008; Moosavi et al., 2010), numerical modeling (Bray et al., 1994; Anastasopoulos et al., 2007) and finally analytical approaches (Berill, 1983; Yilmaz and Paolucci, 2007).

Most building codes suggest using setbacks for mitigating damages caused by the effects of surface fault rupture, assuming that when rupture occurs, buildings are far enough away to avoid any damages. The aim of this paper is to investigate how thickness of soil layers can affect surface fault rupturing and to define the relationship between the position of the fault rupture on the surface (as shown in Figure1) and the thickness of soil layer. The conclusions reached in this research are based on physical modeling tests which were performed just under the normal gravity conditions.

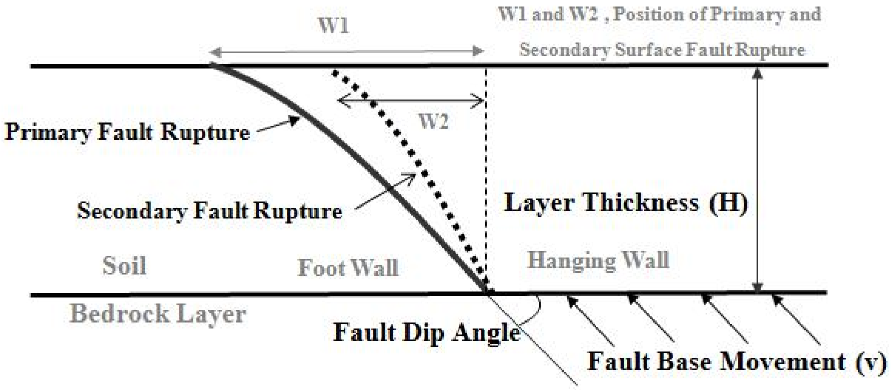

Figure1. The geometry of model on 1-g physical modeling tests to determine the location of the surface fault rupture - the width of the affected zone- in soil layer over reverse faults

APPARATUS AND TEST PROGRAM

The 1-g physical modeling approach was adopted in this study particularly since the 1-g model tests were much more economic and accessible and also 1-g model tests could be reliable for the investigation of surface fault rupture propagation based on Moosavi et al., 2010. The device used for testing was designed in such a way that the reverse fault rupture events could be modeled along different dip angles. Two Plexiglas plates with a thickness of 5 centimeters were installed at each side of the box, perpendicular to the fault strike. to enable digital photography of the vertical section throughout the soil (Figure 2). The testing investigated reverse fault rupture propagation with a dip angle of 45 degree through the bedrock in a quasi-static mode using a hydraulic piston beneath the moving floor.

The material used to model the soil was the well-known Firoozkooh sand (No. 161) that is similar to Toyoura sand, commercially available from the Firoozkooh mine in northeast of Tehran. It has a uniformly graded (SP) size distribution as well as a mean grain size (D50) of 0.25 mm and the Gs, emax, emin are equal to 2.64, 0.83, and 0.52. The sand layering in the box had a length and width of 150, 50cm, respectively, approximately modeling the plane strain condition. The pluviation technique had a pre-defined height and velocity deposited by a sand rainer into the test box (Figure 2). The relative density of the sand was approximately 80%.

The propagation of the reverse faulting was conducted in absence of a footing (“free field test”). The tests were modeled for soil thicknesses of 10 centimeters (the test identifier is 10R), 20 cm (20R), 30 cm (30R), and 40 cm (40R) to compare where the free field fault would emerge at the ground surface.

Figure 2. The 1-g model tests apparatus (left) and the pluviation technique with an electric sand rainer (right)

TEST RESULTS

After performing the four soil model experiments, both the effect of model height on the propagation procedure and the position of the fault rupture at the surface were scrutinized.

As it can be seen on figure 3 in a free field situation, the 10 cm (10R experiment) soil model required a base movement of 10.7 mm for the primary surface rupture to initiate. The 20 cm soil height model (20R experiment) required a base movement of 11.6 mm. the 30 cm soil model (30R experiment) required a base movement of 13.4 mm and the 40 cm soil model required a base movement need of 17 mm. This reveals that by increasing the thickness of the soil, the base movement required for the surface rupture to manifest also increases. Also in all of the experiments, the reverse fault rupture has an angle of 45 degrees in the base point and as the rupture propagates, the angle consistently decrease upwards toward the surface and the position directly below the surface shows to the least amount movement. Finally, it was noted that after increasing the base movement in all experiments, a secondary rupture occurred. The rupture procedure is shown in figures 4 to 7.

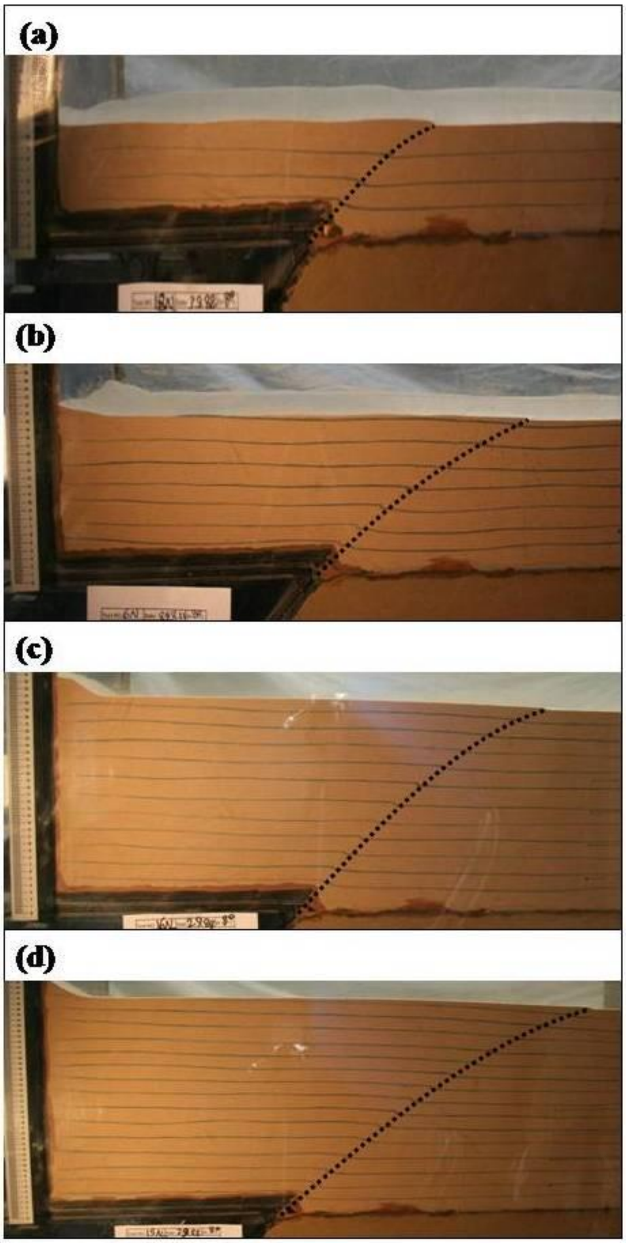

Figure 3. Propagation procedure of surface fault rupture (reverse fault) in a free field situation (primary rupture). a- Thickness of 10 cm needs a base movement of 10.7 mm (10R experiment). b- Thickness of 20 cm needs a base movement of 11.6 mm (20R experiment). c- Thickness of 30 cm needs a base movement of 13.4 mm (30R experiment). d- Thickness of 10 cm needs a base movement of 17 mm (40R experiment)

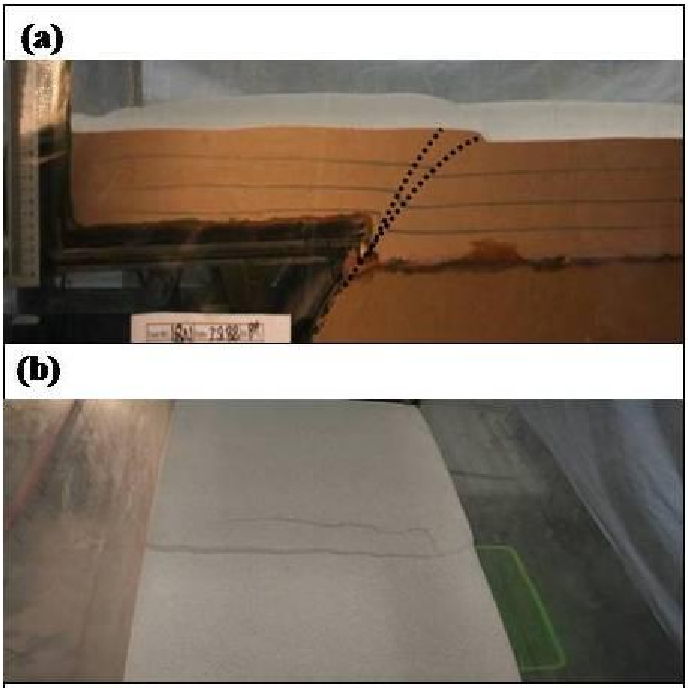

Figure 4. Propagation procedure of surface fault rupture in a 10 cm thick model (10R experiment). a- The occurrence of the secondary rupture with a 20.3 mm base movement. b- The top view of this model

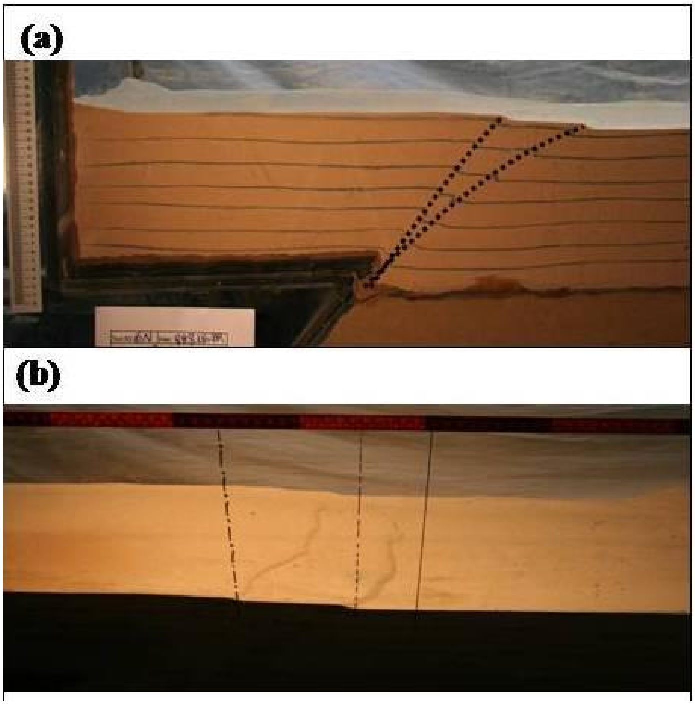

Figure 5. Propagation procedure of surface fault rupture in a 20 cm thick model (20R experiment). a- The occurrence of the secondary rupture with a 31 mm base movement. b- The top view of this model

DISCUSSION

After measuring the position of the primary fault rupture on the surface (shown with W1 in figure 1), it was observed that by thickening the soil in the model, an increase in base movement is required for surface rupture to occur, in a normalized situation the two factors, position of the fault rupture on the surface and the base movement required for surface fault rupture occurring has a different process and as it can be seen in figure 8, it decreases similar to Tani et al., 1996.

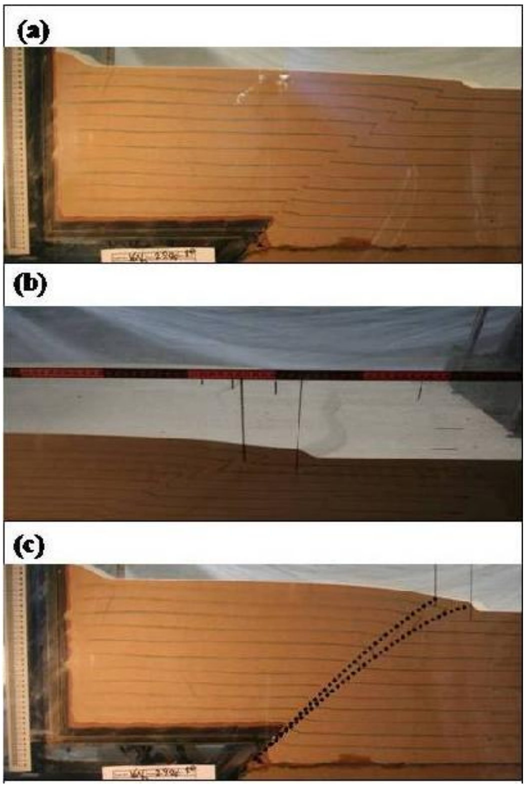

Figure 6. Propagation procedure of surface fault rupture in a 30 cm thick model (30R experiment). a- The occurrence of the secondary rupture with a 39.9 mm base offset. b- The top view of this model.
c- The status of the primary and secondary rupture

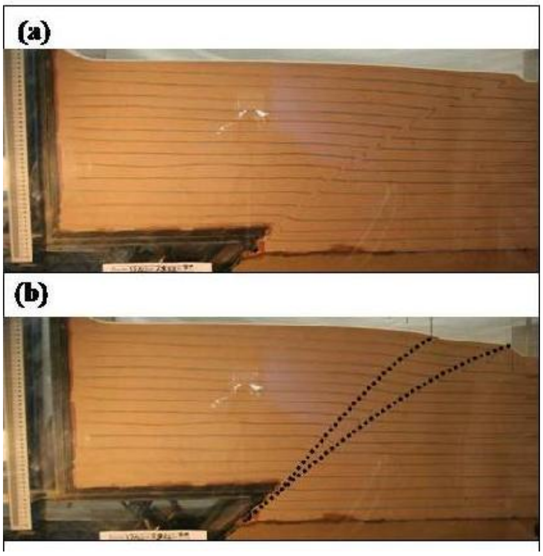

Figure 7. Propagation procedure of surface fault rupturing in a 40 cm thick model (40R experiment).
a- The occurrence of the secondary rupture with a 50.8 mm base movement. b- The status of the primary and secondary rupture with a base movement of 96.1 mm

The results of the positioning of the secondary fault rupture are depicted in figure 9. In this graph the relation between W/H (W is refer to W1 and W2 that is the position of primary and secondary fault rupture and H is the height or thickness of the model) and the increase of the model height in the primary and secondary ruptures has been demonstrated. This graph assumes shows that when the soil thickness increases in a normalized situation the distance of the fault rupture in the surface diminishes, in both primary and secondary fault ruptures.

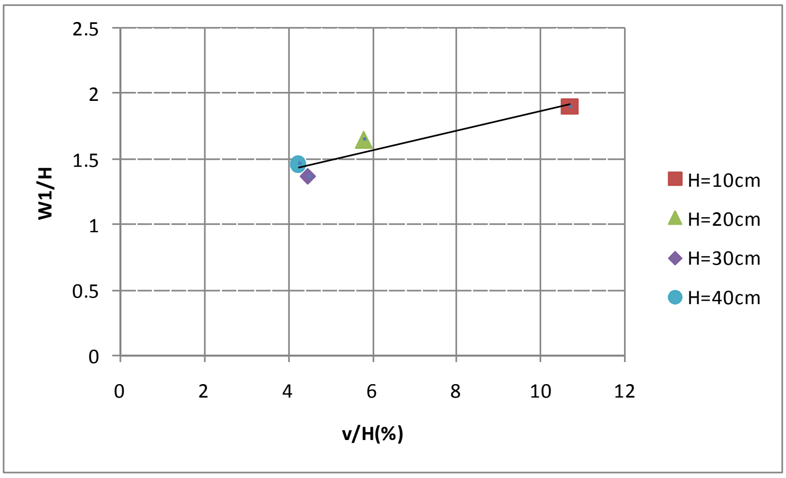

Figure 8. The relation between the position of the primary fault rupture on the surface (W1) and the required base movement (v)

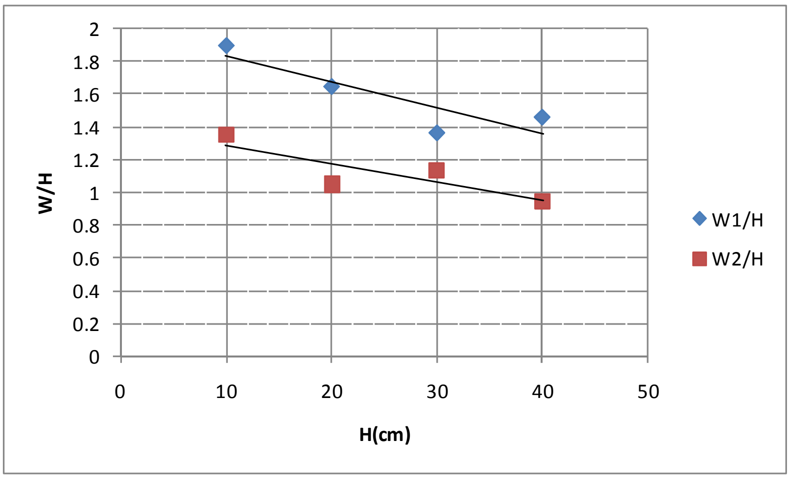

Figure 9. The relationship of the location of the shear rupture at the ground surface (W) and the model height (H) in the primary and secondary ruptures

CONCLUSIONS

When using setbacks and avoidance of construction near fault areas in order to stay safe against surface fault rupture we have to put in mind that thickness of soil may affect the position of the rupture on the surface, making the ground crack in areas that may cause devastation. When thickening the soil layer, the base movement required for surface fault rupture to occurring has an increasing process but in a normalized situation, the position of the fault rupture on the surface and the base movement required for surface fault rupture occurring has a reverse relation. If soil thickness increases, in a normalized situation the distance of the fault rupture on the surface decreases, in both primary and secondary fault ruptures.

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