A Study On fault Rupture Mitigation by Slurry Wall

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Abstract: ***Surface fault rupture has caused damages to structures during past earthquakes. Seismic design codes avoid construction across, or in the immediate vicinity of seismically active faults. Protection of structures in these areas is very essential. Retrofitting of existing structures is not simple, especially for historic buildings and monuments.. To protect a structure, fault rupture deviation is an effective technique. Rupture deviation can be obtained by introducing a weak vertical element in the soil. Soil bentonite wall (SBW) is used as the weak vertical element which is installed near the foundation, at sufficient depth to intercept the propagating fault rupture. Extensive numerical analysis, can reveal that such a wall, due to its high deformability and low shear resistance, absorbs the compressive thrust of the fault and forces the rupture to deviate upwards along its length. As a consequence, the foundation is left essentially intact. Finite element analysis, evaluates the efficiency of the method and provides validation by analyses.***

Keywords: soil bentonite wall, fault rupture, fault deviation, fault offset, rupture deviation

1. Introduction

Ground differential movements due to faulting have caused damage to engineered structures and facilities in strong earthquakes. Surface rupture has caused devastation of numerous structures like buildings, bridges, pipelines. There are only a few potential mitigation schemes for reducing the risks. Fault setbacks or avoidance of construction in the proximity of seismically active faults, are of first priority but due to difficulty in determination of fault setback and also due to the increasing demands on land use, avoidance is becoming more difficult and so it would be prudent to have a reliable strategy available for protecting building over fault zone.

Faults emerge at the ground surface from bedrock. When infrastructure is present the fault emergence may destroy or cause significant damage to infrastructure close to the fault. The amount of damage will depend on the proximity of the fault and the magnitude of displacement, the type of infrastructure and the soil conditions. To protect a structure, a thick diaphragm-type soil bentonite wall (SBW) is installed in front and near the foundation, at sufficient depth to intercept the propagating fault rupture. Soil-bentonite wall is constructed by backfilling a trench with a mixture of soil, bentonite, and water.

Retrofitting of existing structures is not that simple, especially for historic buildings and monuments. To protect a structure, a thick diaphragm-type soil bentonite wall (SBW) is installed in front and near the foundation, at sufficient depth to intercept the propagating fault rupture. Soil-bentonite wall is constructed by backfilling a trench with a mixture of soil, bentonite, and water. Trench is stabilized while being filled with slurry. The other end of the trench is backfilled with soil-bentonite while the excavation proceeds along one end of the trench. Slurry walls are used extensively to control the seepage flow under embankment dams as well as landfill leakages. By constructing a soil bentonite wall the future fault rupture deviate into the wall and downstream of the wall is protected from future hazard.

1.1. Literature Review

A. Shafiee et al. [1]investigated a potential mitigation scheme for protection of structures from rupture. The main idea of his paper is to make a specific weakness in soil media, the propagation pathway of rupture zone can be diverted toward this area and other areas can be protected from this hazard. The weakness zone can be soil bentonite wall with low shear strength, comparing to alluvium. To investigate the applicability of this method for fault deviation, physical modeling tests were carried out considering reverse fault rupture. Then, small-scale numerical model was built and it's results were compared to 1g tests. It was shown that, the wall can absorb the fault offset due to lower shear strength and higher compressibility regarding to surrounding soil. Secondary rupture forms at higher fault offsets & when slurry walls are placed above fault break. Thicker wall is required to suppress secondary rupture. Further analyses are needed for determining suitable depth of wall. Fraser Bransby et al[11] (2010),his paper reports a series of centrifuge model tests designed to study the effect of foundation position on the interaction of reverse, dip-slip faults with shallow foundations. All tests are conducted with a 15 m deep, dry sand layer and a reverse fault with dip angle 60degree. Results of a „free -field" test are first presented which allows the fault rupture propagation through the soil to be investigated when no foundation is present. Additional tests are then reported in which shallow foundations are placed at different positions relative to the fault. It is seen thatinteraction between the foundation and the fault often causes deviation of the fault from the free-field condition, and this may protect the foundation from damage. A series of centrifuge model tests has been conducted to investigate how the position of a shallow foundation affects the amount of foundation damage in close proximity to reverse faulting. The main findings were as follows: A free-field test revealed a progressive failure and an overall dip angle in the soil layer lower than in the bedrock as seen by previous researchers. The position of a foundation was critical to its performance. The foundations were able to deviate the fault from the free-field position due to fault-footing interaction. Fadaee et al[5] (2013), compared the experimental and analytical results in terms of vertical displacement profiles of the ground surface, for a range of fault offsets at bedrock. To focus on the

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effectiveness of the SBW on structures on the ground, uniform surcharge loads were applied for width of foundation. The location of the foundation relative to the free-field fault outcrop were considered. The SBW absorbs a fault offset of up to 5% of soil layer thickness and further increasing the fault offset to 10% of soil layer thickness, reduced the benefit from the SBW significantly. To maintain satisfactory performance of the SBW protected foundation, a thicker wall would be needed to accommodate the larger lateral compressional deformation.

1.3 Methodology

Literature survey on fault and its propagation through soil from bedrock to the surface were done. Model geometry for soil and boundary conditions were arrived from the literature survey. Finite element modeling of soil structure with the arrived geometry was done in PLAXIS. Parameters for the analysis were determined from the literature survey. They include different soil types, fault offset, normal fault, reverse fault, position of SBW from fault break position. Soil model considering these parameters were modeled and analysed. The methodology of the study is given in the Fig 1.3.

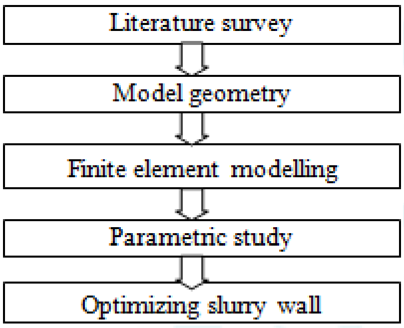

Figure 1.3: Methodology flow chart

2. Quasi-Static Analysis

A fault is a discontinuity in a volume of rock, across which there has been significant displacement as a result of rock mass movement. Large faults within the Earth's crust result from the action of plate tectonic forces. Two types of ground displacement occurs. Permanent quasistic offsets and transient dynamic oscillations. Energy release associated with rapid movement on active faults is the cause of most earthquakes. The two sides of a fault are known as the hangingwalland footwall. The hanging wall occurs above the fault plane and the footwall occurs below the fault. Normal faults form when the hanging wall drops down.

2.1 Parametric Study

Ground displacements which produces permanent quasistatic offsets are considered in this study. Dip-slip faults which includes reverse fault and normal faults occurring at the bedrock are studied with three different properties of soil such as loose sand, medium dense sand, dense sand were studied. Initially the analysis is done without SBW for different soil types and with normal & reverse fault. The analysis were then conducted with SBW. The properties of soil used for the analysis is given in the Table 1

Table 1: Properties of soil

Soil type	*Dry density kN/m^3*	*Friction angle*	*Dilation angle*	*Young's modulus (MPa)*
Loose sand	18	30	0	10
Medium sand	19	38	8	20
Dense sand	20	46	16	40

2.2 Numerical Analysis

Fault rupture propagation through different soil types were analysed in PLAXIS considering dip-slip faults. Free field condition in loose sand were analysed with first. Then analysis were done by introducing SBW. From the analysis it was found that fault rupture propagtion deviates towards soil bentonite wall.

The analysis conducted on loose sand in free field condition and with SBW wall for 1m fault offset is shown in Fig.1, Fig.2, Fig.3,and Fig.4.The SBW deviates the fault rupture towards it.

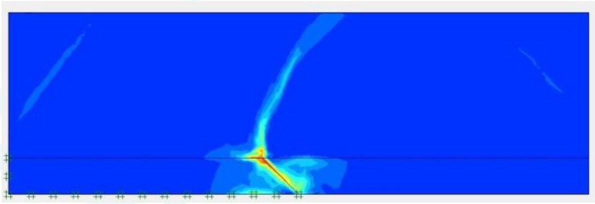

Figure 1: Loose sand with shear strain contour

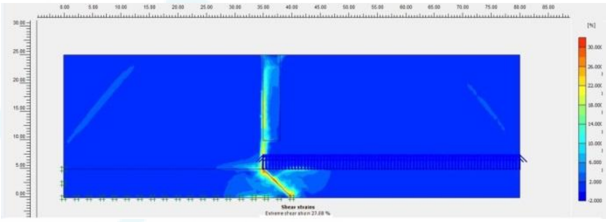

Figure 2: Loose sand with SBW above fault break

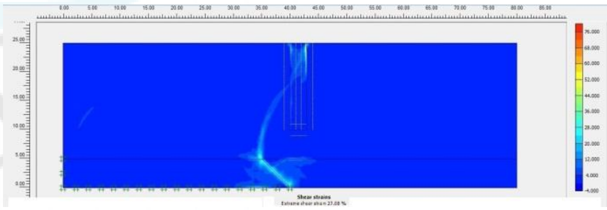

Figure 3: Loose sand with SBW 5m away from fault break

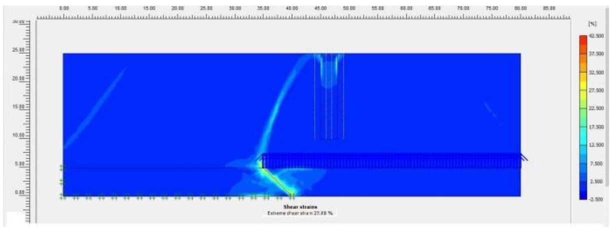

Figure 4: Loose sand with SBW10m away from fault break

From the analysis it was found that effective stress and strain is greater at free field condition. When SBW was used, the effective stress and strain reaching the surface was reduced. The analysis were then carried out with foundation load in loose sand of 20kPa, 40kPa, 80kPa without SBW and with SBW. The shear strain contour shown in the Fig.5. and Fig.6.

gives the propagation of fault rupture from the bedrock to the surface for 20kPa foundation load.

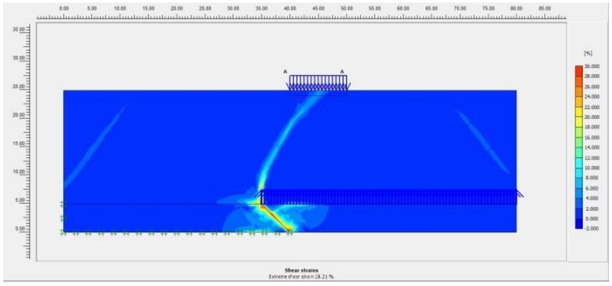

Figure 5: Loose sand with shear strain contour with foundation load of 20kPa in unprotected state

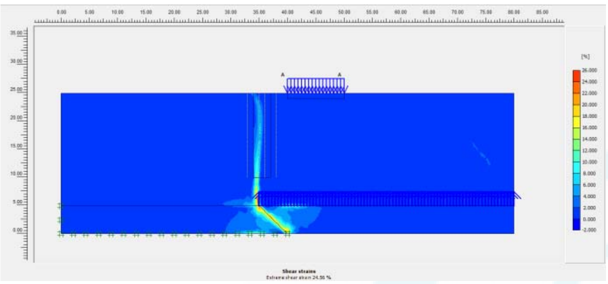

Figure 6: Loose sand with shear strain contour with foundation load of 20kPa in protected state with SBW

From the analysis with foundation, the effective stress and strain reaching the surface was reduced with the presence of SBW. the same analysis was conducted with 40kPa and 80kPa load. The effective stress and strain in those analysis was also found to be less at the surface, with the presence of SBW. As the effective stress and strain reaching the surface due to fault rupture is less, SBW can be placed near the foundation of structures without damageing the foundation during fault rupture.

3. Conclusion

Earthquakes are generated on faults in the earth‟s crust and are categorized according to the relative movement between displaced blocks. Soil bentonite wall facilitates rupture deviation by acting as a weak vertical element in soil to localize fault displacement in a pre-determined narrow zone. It has lower shear strength zone compared to the surrounding soil, this tends the rupture to be localized to this weak zone. The downstream of the wall is protected from future hazard.The analysis for fault rupture deviation by slurry wall was done in PLAXIS. The results from the analysis shows that fault rupture can be deviated towards slurry wall . the effective stress and strain of the rupture reaching the surface with SBW was found to be less compared to the free field condition. The stress value of rupture reaching the surface with and without SBW can be analysed as future research for medium dense and dense sand. From the future analysis, optimized slurry wall dimension can be fixed.

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