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CENTRIFUGAL MODELING OF CONTINUOUS SHALLOW TUNNELS CROSSING ACTIVE REVERSE FAULTS

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Tunnels are long lifelines which are at damage risk due to faulting in earthquake-prone areas. Interaction of soil and tunnel at an intersection with an active fault will be a useful guide for tunnel design engineers. In the present study, a series of centrifuge tests were designed and tested on modeled tunnels at a 60-degree reverse faulting. Mechanism and location of damage to the tunnels is assessed. Four damage state are defined and damage progress are monitored with increase in permanent ground displacement (PGD). The ground surface deformations and strains, the surface trace of the fault, the fault scarp and the sinkhole caused by the fault movement are explained. The tunnel is vulnerable to reverse fault rupture and its operation may be stopped by few displacements.

Most of the earthquakes are associated with plate tectonic and a sudden movement on the fault plane which releases large amounts of energy is an earthquake (Kusky & Kusky, 2008). The ground breaks are accompanied by horizontal, vertical or combined displacement and may cause considerable damages (Hung et al., 2009). If the hanging wall moves upwards in relation to the footwall, the fault is called reverse (Twiss & Moores). Surface faulting is the propagation of displacement along a fault in soil deposits that reaches the ground surface. (Ghalandarzadeh et al., 2016). Faulting can cause severe damage to tunnels and can stop its operation. Faulting can cause ground settlement, crack in tunnel lining, soil falling and complete collapse (MRl, 2003).

(Konagai et al., 2006) outlined key points for designing civil-infrastructures near seismic faults. The damage to eight tunnels caused by faulting in Japan, the United States and Turkey has been highlighted. Despite the tunnels are vulnerable to activity of faults, research in this area is very limited (Burridge et al., 1989; Kiani et al., 2016).

For most laboratory researches at the University of Tehran, Firouzkuh #161 sand is used (Bayat & Ghalandarzadeh, 2017; Haeri et al., 2012; Kiani et al., 2016). For each continuous tunnel model, a 6 mm thickness PVA fiber-cement cylinder was used. The compressive strength was obtained by a uniaxial compression test and flexural strength using a two-edge bearing test (Aashto, 2001; Fahimi et al., 2016; Peyvandi et al., 2014; Young & Trott, 2014). According to the tests, compressive strength 27 MPa, tensile strength 20 MPa and elasticity modulus 18 GPa were obtained.

The premise of centrifuge modeling is the testing of a $^{1}/_{N}$ scale model of a prototype in the centrifuge enhanced gravity field (Madabhushi, 2014).

In order to investigate the propagation of reverse fault rupture in alluvial deposits, the free field model was placed under a 60-degree angle fault displacement. To fault displacement development, the hydraulic jack force was applied by wedges and linear guideways to the hanging wall, Figure 1. The maximum Faulting displacement at bed-rock is 48 mm, which is applied at an angle of 60 degrees to the horizon, so the vertical component of the displacement is 42 mm. According to the scale rules of centrifuge modeling, maximum vertical displacement in the prototype is 2.5 m.

At the final stage of surface faulting, the tunnel part on the side of the hanging wall remained horizontal and other part slope was 8.6%. Due to soil falling in the tunnel, a large sinkhole created on the ground surface, Figure 2.

Figure 1. The tunnel model and its surrounding soil that are compacting.

Figure 2. Longitudinal view of damaged tunnel subjected to reverse faulting.

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