REVERSE FAULT RUPTURE MITIGATION MEASURES FOR CONTINUOUS SHALLOW TUNNELS

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In recent years, long tunnels for highway, railway, water and hydroelectric purposes are developed in many parts of the world (Alp & Apaydin, 2019). In earthquake-prone areas faulting is one of the hazard risks for these structures. Surface faulting is the propagation of displacement along a fault in soil deposits that reaches the ground surface (Ghalandarzadeh et al., 2016). If the hanging wall moves upwards in relation to the footwall, the fault is called reverse (Twiss & Moores, 1992). 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).

The best approach for this situation is avoiding the fault, but for many reasons, we may have to build a structure in the fault zone. In these cases, efforts are made to minimize damage to the injured, and to this end, measures and techniques are used to reduce the damage (Oettle & Bray, 2013).

Lifelines such as pipelines and tunnels are stretched over a long length and are more vulnerable to the fault rupture than other structures (Kiani et al., 2016; Moradi & Ghalandarzadeh, 2010; Moradi et al., 2013; Rojhani et al., 2012).

The extensive use of tunnels in urban and rural areas for transportation, water transfer and utility is increased the need for paying attention to the phenomenon of fault rupture as a potential risk. The measures of faulting damage mitigation are categorized in two categories of geotechnical and structural measures. Methods such as soil improvement and construction of a trench that act to changes in soil conditions are named geotechnical methods, and methods such as retrofitting where by changing structural conditions, reduce earthquake damages, are structural measures (Ashtiani et al., 2017).

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. Although the tunnels are vulnerable to activity of faults, research in this area is very limited (Burridge et al., 2016).

Russo et al. (2002) claim that there are basically two practical ways to reduce the tunnel damage in the fault activity, one is over excavated and other one is articulated design (Figure 1).

Koohrang water conveyance tunnel passes through many active faults in its path. A flexible lining approach consisting of 1500 cm long reinforced concrete segments with an 85 cm distance, which is filled with plastic concrete and a continuous steel lining that prevents water leakage (Figure 2), (Shahidi & Vafaeian, 2005).

Here, by running a series of centrifuge tests, several ways to reduce the damage to the tunnels are presented, and the strengths and weaknesses of each one are discussed.

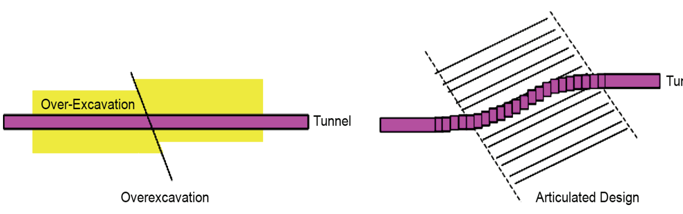

Figure 1. Strategies for active fault crossing (Russo et al., 2002).

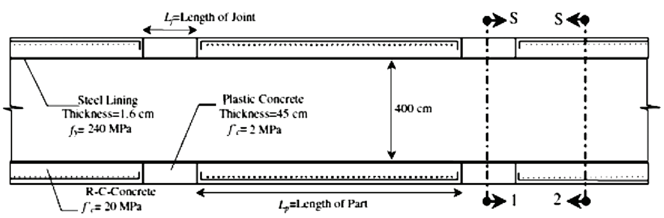

Figure 2. Schematic shape of concrete joints used in koohrang tunnel.

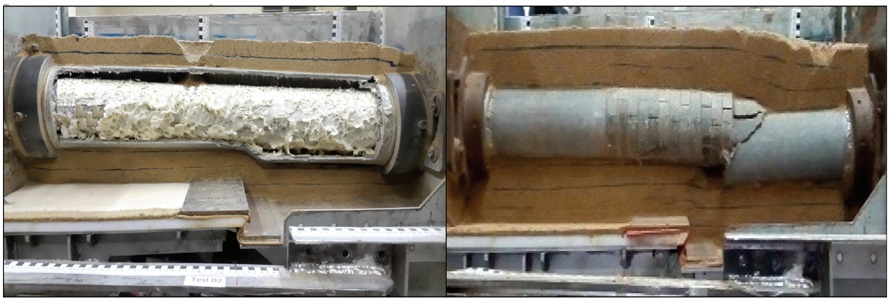

Figure 3. Response of tunnel damage mitigation measures to reverse fault rupture.

REFERENCES

Alp, M., and Apaydin, A. (2019). Assessment of the factors affecting the advance rate of the Tunnel Gerede, the longest and one of the most problematic water transmission tunnels of Turkey. *Tunnelling and Underground Space Technology, 89*, 157-169.

Ashtiani, M., Ghalandarzadeh, A., Mahdavi, M., and Hedayati, M. (2017). Centrifuge modeling of geotechnical mitigation measures for shallow foundations subjected to reverse faulting. *Canadian Geotechnical Journal* (JA).

Burridge, P.B., Scott, R.F., and Hall, J.F. (1989). Centrifuge study of faulting effects on tunnel. *Journal of Geotechnical Engineering, 115*(7), 949-967.

Ghalandarzadeh, A., Moradi, M., Ashtiani, M., Kiani, M., and Rojhani, M. (2016). Centrifuge model tests of fault rupture effect on some geotechnical structures. *Japanese Geotechnical Society Special Publication, 2*(3), 212-216.

Kiani, M., Akhlaghi, T., and Ghalandarzadeh, A. (2016). Experimental modeling of segmental shallow tunnels in alluvial affected by normal faults. *Tunnelling and Underground Space Technology, 51*, 108-119.

Konagai, K., Hori, M., Meguro, K., Koseki, J., Matsushima, T., Johansson, J., and Murata, O. (2006). Key Points for Rational Design for Civil Infrastructures near Seismic Faults Reflecting Soil-Structure Interaction Features. *Japan Geotechnical Society, Tokyo, JP, Report of JSPS research project, grant-in-aid for scientific research (A) Project* (16208048), 146.

Moradi, M. and Ghalandarzadeh, A. (2010). A new geotechnical centrifuge at the University of Tehran, IR Iran. *Paper presented at the Proceedings of the Conference on Physical Modeling in Geotechnics*.

Moradi, M., Rojhani, M., Galandarzadeh, A., and Takada, S. (2013). Centrifuge modeling of buried continuous pipelines subjected to normal faulting. *Earthquake Engineering and Engineering Vibration, 12*(1), 155-164.

MRl, H. (2003). Multi-hazard loss estimation methodology: Earthquake model. *Department of Homeland Security, FEMA, Washington, DC*.

Oettle, N.K. and Bray, J.D. (2013). Fault rupture propagation through previously ruptured soil. *Journal of Geotechnical and Geoenvironmental Engineering, 139*(10), 1637-1647.

Rojhani, M., Moradi, M., Galandarzadeh, A., and Takada, S. (2012). Centrifuge modeling of buried continuous pipelines subjected to reverse faulting. *Canadian Geotechnical Journal, 49*(6), 659-670.

Russo, M., Germani, G., and Amberg, W. (2002). Design and construction of large tunnel through active faults: a recent application. *Paper presented at the Proceedings of the International Conference of Tunnelling and Underground Space Use*, Istanbul, Turkey.

Shahidi, A. and Vafaeian, M. (2005). Analysis of longitudinal profile of the tunnels in the active faulted zone and designing the flexible lining (for Koohrang-III tunnel). *Tunnelling and Underground Space Technology, 20*(3), 213-221.

Twiss, R. and Moores, E. (1992). WH Freeman and Co. New York. 532 pp. *Structural Geology*.