Engineering
UPDATE©
MARINO ENGINEERING ASSOCIATES, INC. • Issue 45

EARTHQUAKE EFFECTS AND SUBSIDENCE ASSOCIATED WITH MINING OPERATIONS

There has been a number of earthquake events that affected mining operations and other similar structures. This article discusses the observations and experience in the aftermath of such events.

Surface Versus Underground Damage. There are a number of published reports which have concluded that there is a distinct difference between the damage experienced on the surface compared to underground from Earthquakes. EQ damage to surface structures is consistently reported to be significantly greater than that to underground openings (see Figure 1). In fact, there are numerous severe events where underground opening or workings (UGO) damage was non-existent. This phenomenon occurs because solid rock is a good energy transmitter and, as such, waves pass through it without losing velocity. If speed is lost, such as through the unconsolidated overburden, the kinetic energy is maintained by an increase in amplitude which in turn causes increased shaking which depends on the shaking frequency of the EQ.

One salient example of this was the Alaskan Earthquake of 1964. The event was an 8.5 magnitude quake which caused region-wide devastation, yet no significant damage was reported to any underground facilities, such as mines and tunnels. Also, it has been reported by various mining personnel, that seismic shaking is not even felt underground, even when it was distinctly perceptible on the ground surface at the mine site. One senior MSHA official stated "in general mines and tunnels are actually pretty safe places to be in an earthquake compared to a structure on the surface"…

Susceptibility to Damage. Based on the earthquake and damage observations made, the main factors which determined the susceptibility of the UGO to EQ damage are depth of the opening or mine complex, the distance from the epicentral area, and the magnitude of the earthquake.

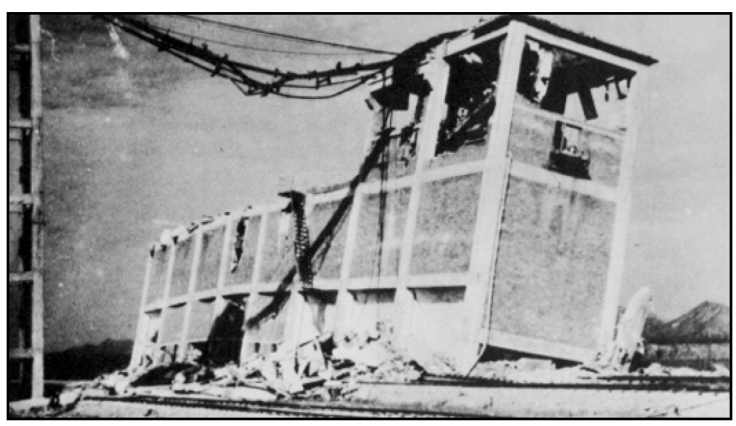

FIGURE 1 COLLAPSED COAL STORAGE STRUCTURE FROM THE GREAT TANGSHAN EARTHQUAKE (CALIFORNIA INSTITUTE OF TECHNOLOGY, 2002)

The reported damage levels in UGO generally decrease with increasing depth. In a "world-wide" study, Sharma and Judd (1991) found that for a depth of 1,000 to less than 1,600 ft., there were 4 cases of slight damage and 3 moderate damage, but state that there must be literally hundreds of other instances where no damage occurred, but these observations were not documented. However, Miyabayashi, et al., 2008, in a study of the response of shallow pass-through tunnels in Japan to 5 significant EQ events included serious damage to the tunnel portals.

Where damage was noted, the underground structure was within the immediate epicentral area (Raney, 1987, Carpenter and Chung, 1986, and Dowding and Rozen, 1978 South African Mine). In this area of typically a strong quake, underground workings may experience damage due to shaking. The shaking damage may include dislodging of timber supports, collapse of roof and walls, and groundwater inflows, however, outside the immediate epicentral area there can be up to moderate damage from shaking including some rock spalling, and falling of loose rock.

Types of EQ Damage. When quake damage is present, it can be summarized into several categories. These categories which are more typically observed in underground openings and workings are given immediately below (Dowding and Rozen, 1978, Sharma and Judd, 1991, Xiaoqing et al., 2008 and Miyahayshi et al., 2008)

- **Shaking damage.** In competent bedrock, damage would include rock falls and cracking in concrete liners at high EQ magnitudes. However, with severe shaking in poor or soft ground, or fractured rock conditions, the UGO is prone to roof/wall collapse and severe liner damage.

FIGURE 2 TILTED VENTILATION TOWER AT THE TANGSHAN COAL MINE FROM THE GREAT TANGSHAN EARTHQUAKE (CALIFORNIA INSTITUTE OF TECHNOLOGY, 2002)

- **Fault displacement.** Underground openings which are subject to displacement of an intersecting fault can result in severe, but more localized damage and may include collapse of the opening under certain conditions.

- **Groundwater Inflows.** Underground structure subjected to more severe EQ movement have, in some cases, been reported to be prone to increased groundwater flows into the opening, but occasionally have resulted in reduced flows. Increased flow appears to be mainly related to faulted zones where dilation (and thus an increase of the transmissivity) occurs concurrently with the slip displacement.

Shaft Damage. Based on review of the available publications from this investigation, there has been little focus of the response of vertical shafts to earthquakes. Pratt et al., 1978 noted that the case data indicated vertical structures (e.g. walls and shafts) are not as susceptible to damage as surface structure. Yucheng, 2002, provided the comprehensive investigation of the response of vertical mine shafts, albeit for one event. This study was related to 8 coal mines in the Kailuaun mine area during the 7.8M Tangshan quake in 1976. Yucheng summarized the damage reported for 9 vertical shafts which were 336 to 2,206 ft. in depth, and 15 to 25 ft. in diameter. Depending upon the shaft, there was no significant damage reaching a depth of 843 ft. (with the no damage case noted as 2 km from the epicenter). The damage was typically described in terms of cracking and spalling. In some cases, an increase in ground water inflow was reported. Also, damage can be significant in the sump pit below the shaft.

It would be expected that superstructures installed on the top of the shaft (e.g. hoists) or other surface facilities would be much more susceptible to EQ damage. See Figure 2.

Subsidence Potential. Given the nature and frequency of damage reported in UGO, sag subsidence is not expected, or has been reported from an EQ event. Where the workings are shallow and prone to roof collapse EQ shaking may exacerbate the roof caving process and result in surface subsidence settlement. Also, it has been our observation that EQ shaking can result in additional subsidence settlement from consolidation of loosened soil from an existing subsidence.

REFERENCES

Carpenter, D.W., & Chung, D.H. (1986). Effects of earthquakes on underground facilities Literature review and discussion (NUREG/CR--4609). United States

Dowding, C.H. and Rozen, A., 1978. Damage to rock tunnels from earthquake shaking. J. Geotech. Eng. Div. Am. Soc. Siv. Eng., 104(2): 175-192.

Miyabashi, H. and Tosaka, T., Isogai, A. 2008. Basic studies on earthquake damage to shallow mountain tunnels. World Tunnel Congress 2008 – Underground Facilities for Better Environment and Safety – India. 406-416 pp.

Power, et. al. 1998. Observations of Hybrid Seismic Events at Soufriere Hills Volcano, Montserrat: July 1995 to September 1996. Geophysical Research Letters, Vol. 25, Issue 19. 3657-3660 pp.

Raney, R.G., 1987. Reported Effects of Selected Earthquakes in the western North American Intermontane Region, 1852-1983, on Underground Workings and Local and Regional Hydrology: A Summary. Prepared for the Division of Waste Management, Washington, D.C. October 1987.

Sharma, S. and Judd, W.R., 1991. Underground opening damage from earthquakes. Eng. Geol., 30: 263-276.

Xiaoqing, F., 2008. Damage Evaluation of Tunnels in Earthquakes. The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China.

Yucheng, Z., 2002. The Great Tangshan Earthquake of 1976. Industrial Structures and Equipment, Earthquake Damage to Shafts and Roadways in Kailuan. Chapter 4. P. 626-640. Huixian, Liu and Housner, George W. and Lili, Xie and Duxin, He (2002). The Great Tangshan Earthquake of 1976. California Institute of Technology, (unpublished) http://resolver.caltech.edu/CaletechEERL:EERL.2002.001.

Other MEA Publications that may be of Interest:

UPDATE #14: Establishing Mine Subsidence Risk

UPDATE #5: Response of House Foundations During the Loma Prieta Earthquake

ABOUT MEA: Marino Engineering Associates, Inc. focuses on engineering research, practice and expert evaluations and is licensed in 25 states in the U.S. Our projects primarily have an emphasis on Geotechnical Engineering, however, we also have significant experience in projects involving transportation, subsidence engineering, laboratory testing, training, and geophysical exploration. Gennaro G. Marino, Ph.D., P.E., D.GE is president and principal engineer of Marino Engineering Associates, Inc., and has been a licensed professional engineer since 1984. To obtain additional information on MEA, one can also visit our website at www.meacorporation.com.

FOR MORE INFORMATION: There is a significant amount of additional information that is available on the above subject. For more information, please contact MEA at the address listed below.

MARINO ENGINEERING ASSOCIATES, INC.

1370 MCCAUSLAND AVENUE, ST. LOUIS, MISSOURI 63117
PH: 314.833.3189 FAX: 314.833.3448
http://www.meacorporation.com