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The mine collapse at Lo Tacón (Murcia, Spain), possible cause of the Torre Pacheco earthquake (2nd May 1998, SE Spain)

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ABSTRACT

On 2nd May 1998, a sudden and rapid collapse occurred in an area of abandoned metal ore mines in La Unión (SE Spain). Due to this event, surface subsidence occurred at "Lo Tacón" industrial park resulting in extensive damage to buildings in the affected area.

This mine collapse coincided with an earthquake of magnitude 2.4 M_w recorded by seismic stations near the National Geographic Institute of Spain (Spanish acronym, IGN) that situate the epicentre in the town of Torre Pacheco, about 20 km northeast of the city of La Union, at a depth of 2.6 km. The lack of coverage of seismic stations east of Torre Pacheco created uncertainty regarding the precise location of the epicentre which we believe to be reasonable.

In this paper, we consider the hypothesis that it was the failure in the mine that triggered the collapse and induced a seismic energy of M_w magnitude equal to the earthquake at Torre Pacheco. The seismic energy of the earthquake came from a percentage of the strain energy stored within the rock (massive grey dolomite) that was released by rupture of a rock volume due to the increase in the roof span when a pillar failed, thus triggering cascading pillar failure (CPF).

The results of the study prove that the energy recorded at the Spanish National Geographic Institute (IGN) seismic stations is consistent with the calculated released seismic energy for the mining collapse at Lo Tacón.

1. Background

Historically, earthquakes have caused damage to underground structures such as natural caves, tunnels and underground mines. The data available indicate that these effects are significant only when earthquakes have a magnitude greater than 5.5 M_w and certain levels of acceleration of ground vibration are also exceeded Ref. [1]. However, underground civil engineering structures (tunnels, hydroelectric stations, etc.) are generally resistant to earthquakes, although they can be damaged if the ground motion becomes permanent (Refs. [2,3]).

1.1. Seismic moment magnitude

Aydan and Kawamoto [1] provided information of their own and that of other authors in which it is proven that the earthquakes which cause damage to underground structures are those with a magnitude greater than 6 M_w. One such example is

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that of the Miyagi-Hokubu earthquake, of magnitude 6.1 M_w, which occurred on 26th July 2003 near the city of Yamamoto (Japan) causing damage to abandoned lignite mines just above the hypocentre. The authors from Ref. [1] compiled a historical list of earthquakes that have caused damage to underground structures. Based on this list, a database was developed for three different damage categories: failure-induced damage (18 cases), shock-induced damage (98 cases) and induced slope failure (47 cases).The diagram in Fig. 1 shows an empirical relationship between the M_w magnitude of the earthquake and the limiting distance of damage in a number of cases. The diagram shows that for distances under 50 km from the hypocentre, only earthquakes of a moment of magnitude between 6 and 7.5 M_w cause structural damage.

Lenhardt [4] also provided his own information and that of other authors indicating that earthquakes of magnitude greater than 5.5 M_w are those that cause damage to shallow underground structures. Tamura et al. [5] demonstrated that the ground motion observed at depths of 67 m is about half that measured on the surface during earthquakes in the range of magnitude between 5.5 and 7.5 M_w, with focal depths of between 10 and 80 km and distances from the hypocentre to the underground structure of between 50 and 250 km. Berardi et al. [6] confirmed this observation following the 1976 earthquake in Friuli, Italy.

1.2. Peak velocity and acceleration of ground vibration

Dowding and Rozen [2] showed that the damage caused by earthquakes only becomes significant once certain levels of acceleration are exceeded. Kanai and Tanaka [7] likewise measured the acceleration of ground motion in underground caverns and on the surface during earthquakes. The data recorded by these authors indicate that surface acceleration is at least twice that measured deep underground. In this regard, Smit [8] proposed the following Eqs. (1) and (2), which allow the peak ground velocity (PGV) in m/s and peak ground acceleration (PGA) in m/s^2 on the surface above the underground structure to be calculated:

$$\mathrm{Log}_{10}(\mathrm{PGV}) = M - 1.66\ \mathrm{Log}_{10}(R) - 5.3 \tag{1}$$

$$\mathrm{Log}_{10}(\mathrm{PGA}) = 0.868M - \mathrm{Log}_{10}(R) - 0.00159\ R - 3.77 \tag{2}$$

where "M" is the seismic magnitude and R the hypocentral distance in km. These formulas take into account the damping of ground motion with increasing distance due to dispersion and attenuation, as observed in the Alps (see Fig. 2). It is confirmed that peak acceleration on the surface lower than 1.77 m/s^2 does not produce damage in underground structures. In the case of the Torre Pacheco earthquake, the peak velocity and acceleration values (PGV, PGA) in the ground of the underground mines at Lo Tacón are found to be minimal using the formulas proposed by Ref. [8] (M_w = 2.4, R = 20 km).

2. Justification of the research study

On 2nd May 1998, seismic stations belonging to the National Geographic Institute of Spain (Spanish acronym, IGN) registered a 2.4 M_w earthquake on the scale of Ref. [9]. The epicentre was situated in the town of Torre Pacheco in the province of Murcia, SE Spain, at a depth of 2.6 km (Fig 3). The IGN associated the origin of the earthquake with a fault slippage. Coinciding in the time with this earthquake, a sudden and rapid collapse occurred in the area of abandoned zinc and lead ore mines worked by the room-and-pillar method located in the vicinity of the town of La Union (Fig. 3), causing surface subsidence with substantial damage to buildings in the affected area. This area of mines is nowadays an industrial estate named Lo Tacón, situated about 20 km northeast of the town of Torre Pacheco.

The IGN stated in Ref. [10] that the mining collapse at Lo Tacón was induced by the Torre Pacheco earthquake, having its origin in a fault slippage. They said that it was impossible to think that the seismic records registered could be from mine collapse, because the wave shape due to mine collapses or blasting are completely different from those of seismic events.

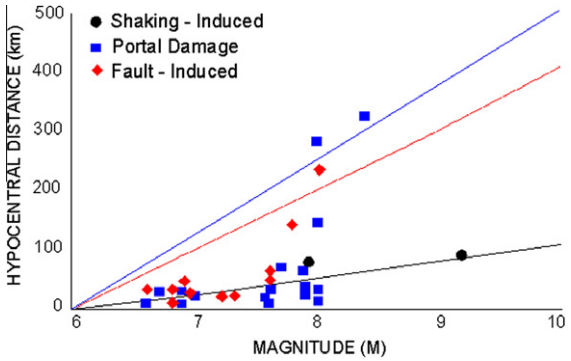

Fig. 1. Plot of hypocentral distance (km) versus M_w magnitude.Compilation of earthquakes according to Ref. [1].