Rock Avalanche Investigation in Tempi Valley, Greece

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Abstract

On December 17th 2009, a rock avalanche with a total volume of about 500 m^3 occurred after heavy rainfall near the western entrance of Tempi Valley, Greece. The road was hit by rocks and boulders with a single maximum size of about 20 m^3 causing one fatality. A close up inspection showed that dissected and toppled rock fragments had collapsed 100 m above the road. Apart from the tectonic predisposition, possible triggers were the absorption of infiltrating water in open joints, the possible hydraulic head in closed cracks during rain fall and the lowering of the friction angle of the material (earthfill) in the slide plane during rain storm. First response measures were carried out to secure the critical section of the rockfall incident. An instable rock mass was monitored and stabilized directly with high tensile steel netting and an adequate amount of rock bolts. Step by step, measures were then deployed from top to bottom of the site: Scaling of the uppermost transition zone, installation of a low energy barrier followed by scaling of the steep transit zone and finally scaling of the lowermost slope zone. As a permanent and long term protection measure, a rockfall barrier was built above the road. Now regular inspections are carried out on the slopes.

Keywords

Rock avalanche • Tempi valley • Geological model • Hazard mitigation • First response

365.1 Introduction

The present study area is located in the ENE–WSW trending Tempi Valley gorge between Olympus and Ossa mountains, Greece (Fig. 365.1). The gorge has a total length of about 7.5 km. An important national road runs through it, connecting Thessaloniki to Athens. On December 17th 2009, a rockfall event with a total volume of about 500 m^3 occurred after heavy rainfall near the western entrance causing one fatality (GEOTEST 2010). A close up inspection showed that dissected and toppled rock fragments had collapsed 100 m above the road. First response measures were carried out to secure the critical section of the rockfall incident followed by stabilization measures deployed from top to bottom. An instable rock mass was monitored and stabilized directly with high tensile steel netting and an adequate amount of rock bolts. Further measures included scaling of the uppermost transition zone, installation of a low energy barrier, scaling of the steep transit zone and finally scaling of the lowermost slope zone. As a permanent and long term protection measure, a rockfall barrier was built above the road. Now regular inspections are carried out on the slopes.

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Fig. 365.1 Investigation zone at the western entrance of Tempi Valley, Greece

365.2 Morphological and Geological Setting

The northern escarpment of the gorge has a maximum height of slightly over 300 m. The south-side of the gorge shows a very complex morphology with oblique ridges and deeply eroded gullies. The outcrops consist almost exclusively of low-grade metamorphic limestones belonging to the Olympus — Ossa tectonic window that is overlain by high-grade metamorphic Pelagonian units (Ambelakia unit). The greyish-white limestones include fine-grained flysch-like sediments, the so-called "phyllites" (Godfriaux 1962; Faupl et al. 1999).

365.3 Event of December 17th 2009

The road was hit by rocks and boulders with a maximum size of about 20 m^3 (GEOTEST 2010). Two smaller precursory events were recorded. The road was severely damaged and remained closed after the event. An investigation of the event included field work and modelling and led to a hazard analysis for the entire gorge.

365.4 Establishment of the Geological Model

A close up inspection of the actual detachment zone and the adjacent rock formations as well as transition and depositional zones was carried out by rappelling in order to establish rock mechanics and triggering mechanisms of the event.

Furthermore, analysis of the joint pattern, block formation, disintegration and typical size ranges of blocks was carried out prior to the analysis of fall trajectories along the slope and modelling of rockfalls to assess energy and saltation height.

A complex tectonic situation results from several generations of faults and joints namely:

- So = main schistosity (sub)parallel/comparable with the bedding azimuth between 230° and 270° with an inclination between 25° and 48°.
- K1 = main jointing with an azimuth between 350° and 015° and an inclination between 60° and 90°.
- K2 = secondary jointing with azimuths of 260 with an inclination between 50°–90° and 100°–122° with an inclination between 40° and 80°.
- K3 = rarely observed jointing with azimuths of 150°–180° with an inclination of around 30°.

In the detachment zone of the rockfall of December 17th 2009, all three main tectonic elements play a role for the formation of cliffs and pillars.

A photograph of the situation before the event shows a pile of huge and completely detached blocks in the detachment zone which was only stabilized by friction along the bedding plane. The actual detachment of in situ rock material took place along a dissected "slide-plane" and both K1 and K2 joints. The K1 joint had opened considerably due to the heavy backfill with earth material and roots from vegetation that grew inside the earth material (GEOTEST 2010).

Fig. 365.2 View of the transit zone of the event of December 17 2009 from the source zone (GEOTEST 2010)

The transit zone was covered by a thin soil cover, in many areas the limestone crops out. Fragmentation upon impact on the rock surfaces was intense as shown by the abundant small rock splinters that were strewn across the zone of impact. Bushes were completely uprooted and crushed (see Fig. 365.2).

Chemical and physical weatherings are both present in limestone rock faces. The karstification and intense dissection of the limestone massive along joints leads to defined high permeability along discontinuities like open joints, cracks and irregular karst conduits. Water that enters into open joints can build up local hydraulic pressure (IUGS 2013). Freezing water can enlarge fine cracks in the rock. Larger cracks will gradually fill with earth that can itself exert force on the slope, especially when the earth material is being saturated by inflowing rainwater. The whole Tempi Valley is vegetated by bushes that grow from earth-filled rock joints even in very exposed areas (see Fig. 365.2). Roots with a tendency to enter into cracks in the rock are abundant and can be identified as one factor that destabilizes rock formations along the slope.

365.5 Discussion of Causes and Triggering Effects of the Rockfall

From the observations made during the site inspection (Fig. 365.2) and the course of events before and during the rockfall, it is possible to deduce some important triggering factors including the overall tectonic predisposition, a long term destabilization along main tectonic lineaments (toppling etc.), the loading of K1 joints with earth material and the entering of roots in cracks. The event's initialization may have happened due to the absorption of infiltrating water by the earth backfill resulting in additional loading and lowering of the friction angle and a possible hydraulic overpressure in closed cracks during rain fall.

365.6 Rockfall Simulation and Mitigation

Rockfall simulation was carried out with a specialized model (Krummenacher et al. 2007). A high resolution digital terrain model was used. A predefined number of blocks were simulated to obtain results within a statistical range. The results showed that a rockfall barrier with energy absorption of 1000 kJ and a height of 3 m could protect the entire length of the affected section (GEOTEST 2010). First response measures were carried out to secure the critical section of the rockfall incident area. Measures were deployed from top to bottom according to Fig. 365.3. Design of measures was based on an existing design but adapted to new findings of the field investigation (GEOTEST 2010). A survey flight by helicopter of the rest of the southern side of the gorge revealed a number of Special Focus Areas (SFA). The inspection concentrated on natural outcrops above the road (GEOTEST 2010). Periodic inspections are carried out in order to monitor rockfall hazard (GEOTEST 2010).

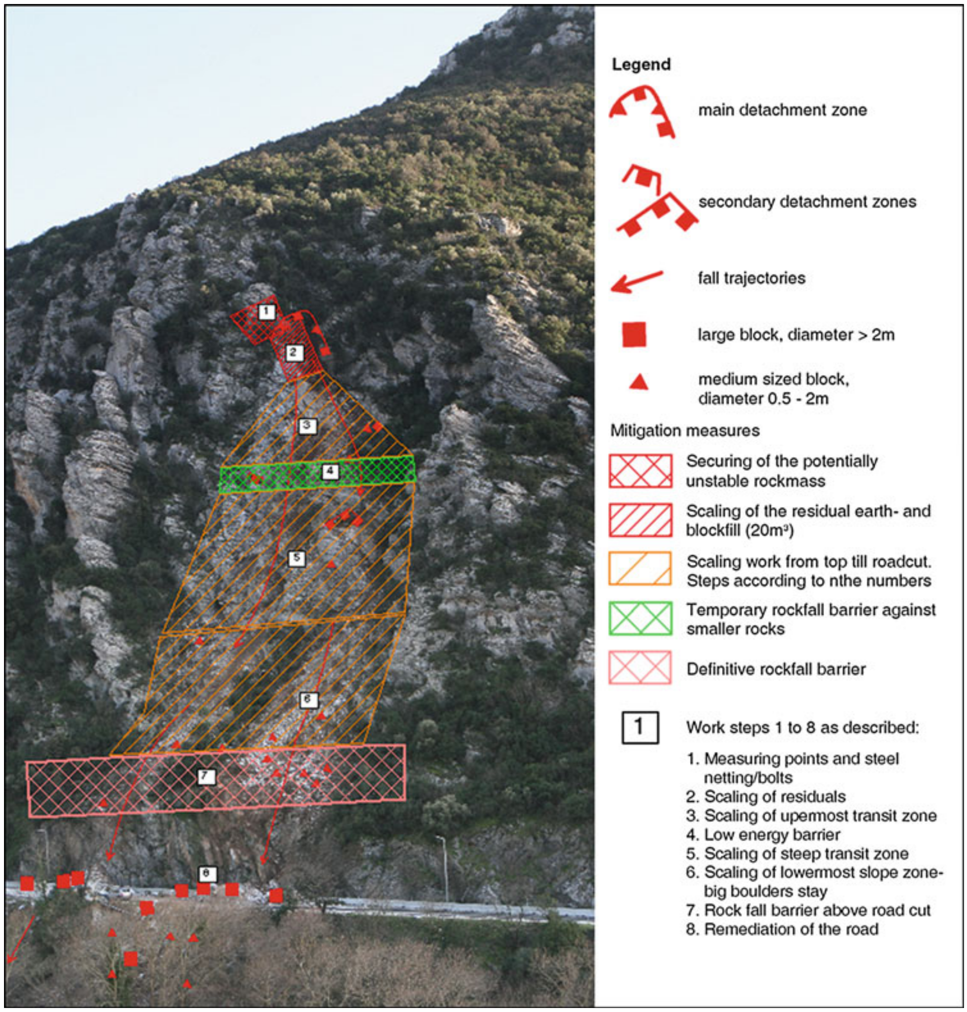

Fig. 365.3 Mitigation of the rock avalanche in Tempi valley (GEOTEST 2010)

365.7 Conclusions

Strong correlation exists between the Tempi Valley rock avalanche and a previous meteorological event (Christaras et al. 2010). Weathering and vegetation progressively widens earth-filled fractures. The close-up geological investigation of the site allowed establishing a geological model. Results showed that the pre-existing tectonic framework with intersecting brittle fault systems controls the stability of the rock. A detailed sequencing of the high-risk tasks to be performed by a specialized crew allowed a safe completion of the works. The geologic investigation of the rock faces in Tempi valley revealed several unstable rock formations that were scaled or stabilized in the course of completion of the rockfall protection design.

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