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PRELIMINARY RESULTS REGARDING THE ROCK FALLS OF DECEMBER 17, 2009 AT TEMPI, GREECE

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Abstract

On December 17, 2009, a large size rock fall generated at the area of Tempi, Central Greece causing one casualty. In particular, a large block was detached from a high of 70 meters and started to roll downslope and gradually became a rock slide. About 120 tones of rock material moved downward to the road resulting to the close of the national road. Few days after the slope failure, a field survey organized by the Department of Geology, AUTH took place in order to evaluate the rock fall hazard in the area and to define the triggering causal factors. As an outcome, we concluded that the heavily broken rock mass and the heavy rain-falls, of the previous days, contribute significantly to the generation of the slope failure. The rocky slope was limited stable and the high joint water pressure caused the failure of the slope.

Key words: *rock fall, Tempi, engineering geology, hazard, Greece*

1. Introduction

A rock fall is a fragment of rock detached by sliding, toppling or falling that falls along a vertical or sub-vertical cliff, proceeds down slope by bouncing and flying along ballistic trajectories or by rolling on talus or debris slopes (Varnes, 1978). Very occasionally, rock fall initiates catastrophic debris streams, which are even more dangerous (Hsu, 1975). Rock falls range from small cobles to large boulders hundreds of cubic meters in size and travel at speeds ranging from few to tens of meters per second (Guzzetti et al., 2002). Minor rock falls affect most of the rock slopes, whereas large size ones such as cliff falls and rock avalanches, affect only great rock slopes with geological conditions favourable to instability (Rouiller et al., 1998).

After the rock has been detached it descends the slope in different modes of motion mainly depending the mean slope gradient. The three most important modes of motion (Fig.1) are freefall through the air, bouncing on the slope surface and rolling over the slope surface (Dorren, 2003).

The detachment of rock from bedrock slope is triggered by several factors such as weathering, earthquake and human activities while the fall of a rock is determined by factors like the slope morphology and the direct surrounding of the potential falling rock (Dorren, 2003). The generation of rock fall is a rapid phenomenon and represents a continuous hazard in mountain areas worldwide. There are numerous examples of infrastructure destroyed or people killed by rock fall. To protect endangered residential areas and infrastructure, it is necessary to assess the risk posed by rock fall (Dorren, 2003).

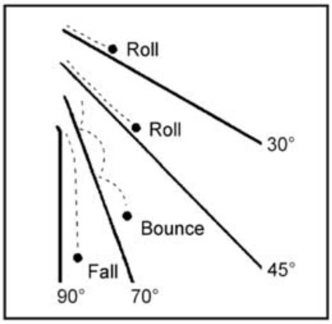


Fig. 1: The three most important modes of motion (from Dorren 2003).

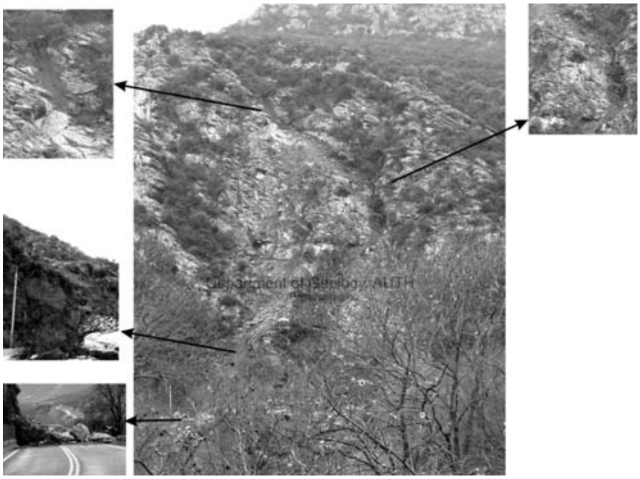


Fig. 2: Source area and path of the of rock falls.

On December 17, 2009 large size slope instability took place at the area of Tempi, central Greece resulting to one casualty and the permanent close of the national road Athens-Thessaloniki. In particular a large block was detached from a high up to 70 meters and moved downward (figure 2). During its fall the initial boulder triggered the detachment of smaller rocks, creating a combination of rock falls and rock slides. As it is shown in figure 3, the fall track of this failure is separated into two paths.

The basic aim of this study is the evaluation of rock fall hazard in the area of Tempi and the definition of the main triggering causal factor of the large size rock fall of December 17, 2009.

2. Geology and geomorphology of the area

The area of study is located in the inner part of Pinios straits (Tempi valley) between the Mounts of Olympos and Ossa. It is located within the Pelagonian zone (Aubuin 1959, Mountrakis 1984) between the geological masses of the Olympos and Ossa Mounts. The structural sequence in the Mt. Olympos region of the Pelagonian zone, from top to bottom, comprises (Schmitt 1983, Schermer 1993): (A) the *ophiolite unit,* consisting of ophiolitic igneous rocks, in coherent thrust sheets and serpentinite-matrix melange, overlain by limestone; (B) the *Infrapierien unit,* gneiss and schist overlain by metasedimentary and metavolcanic rocks and Triassic-Jurassic neritic carbonate rocks; (C) the *Pierien unit,* Paleozoic granitic gneiss overlain by a thin metaclastic sequence and Triassic- Jurassic neritic carbonate rocks; (D) the *Ambelakia unit,* continental margin carbonate and quartzofeldspathic sedimentary rocks, and basic to intermediate volcanic rocks of uncertain age; and (E) the *Olympos unit,* Triassic and Lower Cretaceous to Eocene neritic carbonate rocks overlain by Eocene flysch (Godfriaux 1968, Schmitt 1983). The rock falls area is placed in Ambelakia Unit (Fig. 4).

The study area is located on the steep slopes of the foothills of Ossa Mt. shaped by the erosional processes of the Pinios River. These erosional processes formed the steep-walled inner gorge of the Tempi valley. The gradual changes of the base level in combination with the tectonic uplift of the area (Gonnoi Horst) are the main causes for the lowering of the river's profile and the creation of several pairs of degradational terraces (Psilovikos, 1991). Between these terraces

Fig. 3: Fall track of the boulders (red circles indicate the source area and green lines show the path).

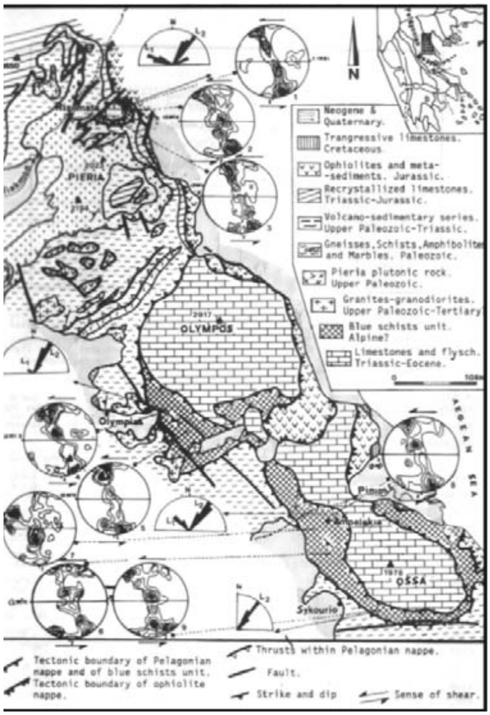


Fig. 4: Geological map of the Olympos Ossa window (from Kilias et al., 1991). The rock falls area is located in Ambelakia – Ossa unit.

steep walls were formed by the action of running water. Finally, the landscape of the valley is shaped by the intense karstification of the carbonated rocks of the slopes due to the elevated water table and the dissolution – erosion caused by the surfacial and underground water runoff.

3. Seismotectonic settings of the area

During the second half of the 20th century, Thessaly and the broader area of northern Greece experienced a series of strong earthquakes (Ms 6.3 to 6.9), which caused damage to a large number of localities and to all its major towns. It is therefore characterized an area of moderate-to-high seismicity. In fact, low-to-moderate seismic activity was also observed in the 19th century and there are a few sources reporting earthquakes in the area even in the previous centuries (Ambraseys & Jackson, 1990).

The last moderate size earthquake occurred on June 9, 2003 (MS=5.5; NOA). when Northern Thessaly (central Greece) was shaken and dozens of buildings in the area of southern (or lower) Mt Olympus and western Tempi were shocked. The macro-seismic intensity was assessed at 6/7EMS-98. The magnitude of the earthquake using the Quick RCMT solution was computed at MW=5.2 (NOA). Spectral analysis of the mainshock records provided a moment magnitude of MW=5.3. The epicentre was originally located SW of Mt Olympus and NE of the city Larisa, between the villages Gonnoi and Karya, both of which suffered considerable damage. The focal mechanism solution of the main shock was obtained from P-waves first motion polarities (Pavlides et al., 2004). The two nodal planes gave strike, dip and rake values of 299o/44o/-67o for NP1 and 90o/50o/-110o for NP2, respectively. The spatial distribution of the aftershocks showed a WNW-ESE orientation of the fault plane, in agreement with the focal mechanism of the main-shock. The first survey aimed at the identification of the seismogenic zone and correlation of geological evidence with damage distribution. Geological and tectonic information of the region point out the occurrence of a major active fault (Omolio Fault, eastern Tempi), as well as the Kallipefki segment and the Gonnoi smaller structures, all directed WNW-ESE. These dip-slip normal faults show evidence of Late Quaternary activity. The WNW-ESE trending structures dominate the area. Accordingly, from the two nodal planes of the focal mechanism, NP1 is likely the seismogenic plane, therefore confirming the N-S regional direction of crustal extension.

The area is dominated by normal faults, which began forming during the Middle Pleistocene, as a consequence of the N-S extension, which affected the whole Aegean region (Caputo & Pavlides 1993). Geological and tectonic information of the broader study area (Caputo & Pavlides 1993), point out the occurrence of many small to moderate length faults and a major active fault (or series of faults) affecting this region of Thessaly, the so-called "Omolio Fault" (Caputo, 1990) and the ESE-WNW (~100-110^o) Tempi valley normal faults. The Omolio tectonic structure is a WNW-ESE trending northward-dipping dip-slip normal fault showing evidences of Late Quaternary activity.

Regarding the relation between seismotectonic parameters within an area and the occurrence of slope instabilities, Keefer (1984) stated that the most susceptible to initiation under seismic conditions landslides are rock falls and rock slides. The characteristics of the rock falls, described by Keefer (1984), are movement of bounding, rolling or free fall of high velocity with shallow depth (less than 3m). In particular, he concluded that earthquakes with M<6.5 triggered proportionally more these type of failures and proportionally fewer landslides of all other types. Furthermore, the lower magnitude that could be defined as a threshold of earthquake-induced rock falls is equal to M=4.

Therefore, historical seismicity information of the area was collected regarding the instrumental period in order to examine the occurrence of earthquakes capable to generate rockfalls within the area of Tempi. As it can be seen on Table 1, many events of magnitude M>4 occurred in the vicinity of study area (fig. 5), thus the parameter of active tectonic should be taken into account during the construction of remedial measures.

4. Engineering geological investigation

Three main tectonic systems are found in the area, given in Table 2. In the area where the failure was generated most unstable conditions of rock slopes are related to planar weaknesses. Wedge failures most likely where line of intersection of two fracture planes dips<φ and daylights in slope. The studied failure started by the sliding of a big block along the joint 350/47 (Fig. 6) which activated and drifted smaller geomaterials, down slope, toward the road (Fig. 7). The bedding of the crystalline limestone is 110/10 (Fig. 8). The related stability analysis of the slope is given in Fig. 9.

According to Fig. 9, joint 350/47, corresponded to the field observed sliding surface, is limited included in the sliding area of stability analysis diagram, confirming the limited stability of the slope. This block was retaining in situ, for long time, as joint surfaces are not, usually, totally open, but some small retaining "bridges", remain inside the rock-mass and keep the stone parts together. Another joint, with data: 15/48, also gives limited safety conditions, even for dry con-

Table 1. Parameters of the earthquakes that occurred in the area after 1941

Year	Mm/dd	Lat	long	Depth (km)	Magnitude (M)
1941	0301	39.670	22.540	00.0	6.3
1941	0301	39.600	22.500	00.0	5.1
1941	0301	39.600	22.500	00.0	4.9
1964	0921	39.650	22.680	33.0	4.8
1981	1229	40.050	22.660	04.0	4.0
1990	0313	40.000	22.490	08.0	4.5
1990	1115	39.880	22.510	05.0	4.3
1993	1003	39.920	22.440	07.0	4.0
1997	0725	39.960	22.540	09.0	4.1
2003	0609	39.940	22.420	16.0	5.1

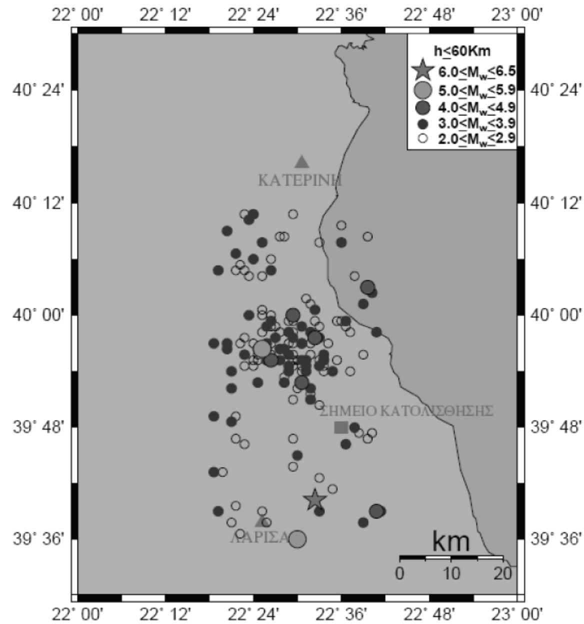


Fig. 5: Map showing the distribution of earthquake epicenters.

dition, found on the boundary line of the sliding area. Furthermore, another joint, with data: 202/83, is found, on the boundary line of the toppling area of the diagram of Fig. 9. The above data give the impression of a slope with limited general stability, which could decrease in heavy rain conditions, as happened in the studied case.

In Table 3, daily rainfall data, from Meteorological Stations found at both sides of Tempi area (Volos, Larissa, Makrinitsa, Zagora, and Dion), are given for the former period of that event. According to these data, on Dec 10, 09 and Dec 12, 09, heavy rainfalls occurred at both sides

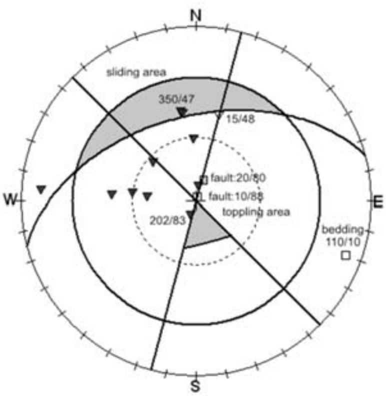
Fig. 6: The initiation of the slope failure originated as sliding along the joint 350/47.

Fig. 7: Boulders on the road.

Fig. 8: Bedding 110/10 and fault 20/80.

Table 2. Bedding and tectonic systems of the limestone, at the southeastern slope of Tempi ravine, at the site of the failure.

Bedding	110°/10°
Joint system 1	350°/47°
Joint system 2	277°/60°
Joint system 3	20°/80°
Road direction	70°-80° (mean: 75°)
South eastern slope (mean)	345°/50°



Tempi discontinuities at the slope of failure

Discontinuity	Structure	Dip direction	Dip
1	large joint	350	47
2	large joint	277	60
3	fault	20	80
4	large joint	351	48
5	fault	10	88
6	bedding	110	10
7	large joint	357	61
8	large joint	8	83
9	large joint	15	48
10	large joint	311	63
11	large joint	274	12
12	large joint	275	67
13	large joint	202	83
14	large joint	274	50

Fig. 9: Stereographic projection of the planes mapped on the rock slope in order to estimate the sliding potential.

Table 3. Daily rainfalls in the studied area.

	Larissa	Volos	Makrinitsa	Zagora	Dion (Pieria)
Date	**EMY**	**Nat.Observatory**	**Amateurish**	**Amateurish**	**Nat.Observatory**
1/12/2009	0,0	0,2	0,0	0,0	0,0
2/12/2009	5,0	4,4	6,6	14,5	24,8
3/12/2009	10,0	8,2	16,6	25,3	16,2
4/12/2009	0,0	0,0	0,0	0,0	0,0
5/12/2009	3,0	17,2	47,2	66,3	8,6
6/12/2009	0,1	2,2	8,4	15,6	0,0
7/12/2009	0,0	0,0	0,0	0,0	0,0
8/12/2009	0,0	0,0	0,0	0,0	0,0
9/12/2009	2,0	3,8	5,4	6,5	24,8
10/12/2009	27,0	126,4	417,2	208,3	70,2
11/12/2009	1,0	8,6	45,4	52,7	0,4
12/12/2009	11,0	8,0	23,6	100,8	22,0
13/12/2009	2,0	0,2	2,0	4,4	0,4
14/12/2009	0,0	0,0	0,0	0,3	3,0
15/12/2009	7,0	10,0	10,0	12,6	10,2
16/12/2009	0,0	0,4	0,0	0,0	0,2
17/12/2009	0,0	0,2	0,2	0,5	0,2
18/12/2009	7,0	5,2	4,4	20,1	3,2
19/12/2009	1,0	0,2	0,0	0,9	1,0
Total	76,1	195,2	587,0	528,7	185,2
Mean	**50,8**	**47,1**	**29,35**	**26,44**	**9,26**

of the studied slope failure. Groundwater is the most important single factor in triggering landslide events. High rainfalls cause numerous shallow slides where high water pressure can rapidly reach slip surfaces. The increase of joint water pressure reduces significantly rock mass strength, by increasing the driving forces along the joints. Joint water becomes more active in cases where the rock mass is highly broken, as result of the combination of the tectonic systems which firstly contribute to the loosening of the rock mass but also contributes to higher joint water pressure which increases the driving forces and decreases the slope stability.

5. Conclusions-Results

Based on the above analysis, the following conclusions are derived:

— Three joint sets were determined, which are presented in Table 2. These joint sets limit the created rock blocs and involve in their sliding.

— The heavily broken rock mass and the heavy rain-falls, of the previous days, contribute significantly to the generation of the slope failure. The rocky slope was limited stable and the high joint water pressure caused the failure of the slope.

— According to our stability analysis, the failure activated by the sliding of the rock block along the joint: 350/47. Also other joints with relative data could also be activated, under favorable conditions.

— According to the above results, we propose the engineering site investigation of the area for better knowledge of sliding conditions.

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