Earthquakes- induced landslides in Algeria: The Laalam, March 20th (M_w=5.2), 2006 earthquake

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SUMMARY:

Northern Algeria is a prone area for moderate-sized and strong destructive earthquakes because of its tectonic setting in the Africa-Eurasia plate boundary. The country suffered, historically, from induced landslides. Indeed, in addition to ground motion the effects of earthquakes has made heavier by the induced landslide effects. On March 20th, 2006 a moderate-sized earthquake (M_w=5.2) struck the Laalam (NE- Algeria) region. During this seismic event damage was centered in the Laalam village where four deaths, 68 injured and more than 40 housing units have been destroyed making dozens of peoples homeless. Damage and casualties are directly related to an earthquake-induced landslide occurred at10 km far from the epicenter favored by local geological and geomorphologic conditions.

Keywords: Landslide, hazard, earthquake, Algeria, damage.

1-INTRODUCTION

Earthquake hazards include numerous phenomenons such us direct vibratory effect (shaking) and the secondary induced effects among with landslides, liquefactions and tsunamis (figure 1). The induced effects, throughout the world, may be the main cause of damage and casualties as observed during the recent extreme disasters caused by the 2004 Sumatra and 2011Tohoku giant earthquakes. Effects of landslides during earthquakes may be the cause of destructions of houses and lifelines; it may also obtrude rivers and cause flooding (Wang et al., 2007). On the other hand, it may obtrude ways of rescue delaying, hence, relief operations during earthquakes disasters. Literature related to the study of landslides triggered by earthquakes is very abundant; Many studies have been dedicated to landslides associated with moderate-sized and strong earthquakes (Keefer, 1984; Sassa et al., 1995; Rodriguez et al., 1999; Havenith et al., 2003; Keefer et al., 2006; Owen et al., 2008). Any strategy of development and land planning in mountainous zones of seismically actives regions should consider this geological hazard. In Algeria, moderate to strong earthquakes are often associated with secondary hazards, particularly landslides (Gabert, 1984;CRAAG, 1994; Benouar, 1994; Bouhadad et al., 2003; Bouhadad et al. 2004; Machane et al., 2008). During the last three decades, several seismic events triggered landslides such as the El-Asnam, 1980 (Ms =7.3), the Constantine 1985 (Ms=5.7), the Chenoua 1989 (Ms=6.0), the Mascara 1994 (Ms= 5.6), the Ain Témouchent, 1999 (Ms =5.4), the Beni-Ourtilane 2000 (Ms= 5.4), the Zemmouri 2003 (Mw = 6.8) and the Laalam 2006 (Mw=5.2) earthquakes. During the strong seismic events of El-Asnam (1980), and Zemmouri (2003) many communication cables, that link North Africa to Europe, were broken by a sub-marine landslides and turbidity (Bounif & al., 1987; Meghraoui & al.,1991;Benouar & al., 1994; Bouhadad & al.2004; Machane & al, 2008). The Laalam, March 20th, 2006 earthquake (Mw= 5.2) triggered a landslide that was the main cause of casualties (Bouhadad & al., 2009; Guemache & al., 2010). The landslide crossed through the village and destroyed many houses. We aim in this work to present the geological and, geomorphological conditions that leaded to the occurrence of this landslide.

2- SEISMOTECTONIC SETTING

Northern Algeria belongs to the Tell Atlas Mountains ranges of Algeria which constitute with the Rif Mountains in Morocco and the Betic cordillera in Spain, a peri- mediterranean segment of the plate boundary which results from convergent movement between the African and Eurasian tectonic plates. The rate of motion is about 4 - 6 mm yr^{-1} (Mc Kenzie, 1972; Anderson & Jackson, 1988; De Mets & al.,1989, Nocquet & Calais, 2004). The shortening direction determined by microtectonic and seismological analysis is NNW-SSE (Philip & Thomas

1977). The Tell Atlas mountains has been the subject of several seismotectonics and seismological studies over the last two decades, particularly following the El Asnam earthquake of October 10, 1980 (M_s=7.3). Therefore, the neotectonic framework of the region and it's relation with the seismicity is better understood. The Tell Atlas is a band of about 150 km to 250 km wide where Neogene post-nappes basins, elongated E-W are characterised by intense compressional deformations, particularly in the Cheliff basin (Thomas, 1985, Meghraoui & al., 2004). Active geological structures in North of Algeria are mainly represented by faulted-folds, in an echelon system, oriented NE-SW and having a length ranging from 20 km to 70 km (Meghraoui & al, 2004).

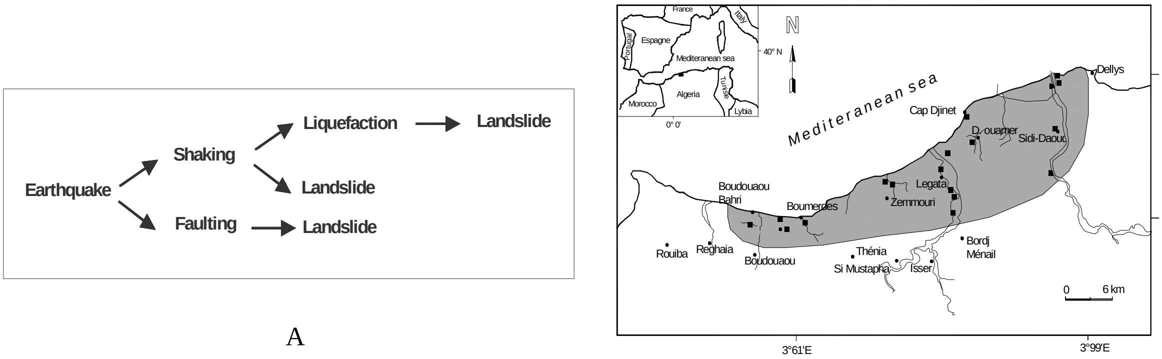


Figure 1. A- Flow chart showing the causes of landslide during earthquakes, B- Geographical distribution of landslides related to liquefaction during the May 21st 2003, Zemmouri earthquake.

2-THE LAALAM LANDSLIDE

The Lallam 2006 (Mw=5.2) earthquake is the best example where casualties dues to induced effects are greater than the shaking effects. Indeed, despite its small size, the earthquake triggered several landslides. The largest one is the damaging landslide which affected the village of Lallam. The landslide strikes a dweller of about 1000 inhabitants where more than 40 houses units were destroyed causing four deaths (Bouhadad et al., 2010). The landslide started 02 hours after the main shock (Mw=5.2) with an instantaneous 0.45 m of displacement, however, the cracks continued to be listened during the aftershock activity without noticeable displacement. Field investigations allowed us also to measure 1.2 m of total displacement including 0.75 m of pre-2006 earthquake (Figure 2). Indeed, the last time where the landslide moved extends back to 1974 following a same size earthquake.

2.1- Geology

Lithologically, the studied area, which belongs to the sheet thrust area of external zones, was made of Jurassic limestone and Cretaceous marls, covering more than 90% of the site. The Neogene and Quaternary deposits are very sparse corresponding to down slope accumulated colluviums deposits, on which the Laalam village was build. Indeed, the weathered marls and clays form a good agricultural fertile land. The materials involved in the slide mass are constituted by colluviums and weathered cretaceous marls at the bottom of the slide. Jurassic rocks are much fractured constituting reservoirs for water that feeding many sources by continuous water even during summer season. Therefore, water contributes to the alteration of the marls and to maintain the landslide in a state of quiescence.

2.2- Geomorphology and climate

The studied area is characterized by a Mediterranean climate with dry seasons (June – September) and rainy, sometimes snowy, winters (October-April). The annual average precipitations range between 600 mm to 900 mm; eighty percent (80%) of these precipitations fall between December and February as flash flood. From geomorphological point of view, the earthquake occurred in area which consists of elevated crests exceeding 1000 m in altitude and steep sides (about 70°) as well as deep waterways alimented by several spring flowing through rock fractures. The drainage is characterized by a densely constituted network of waterways flowing mainly from the SE to NW (Figure 2). The Laalam village is built on relatively steep slope at a mean altitude of 400m.

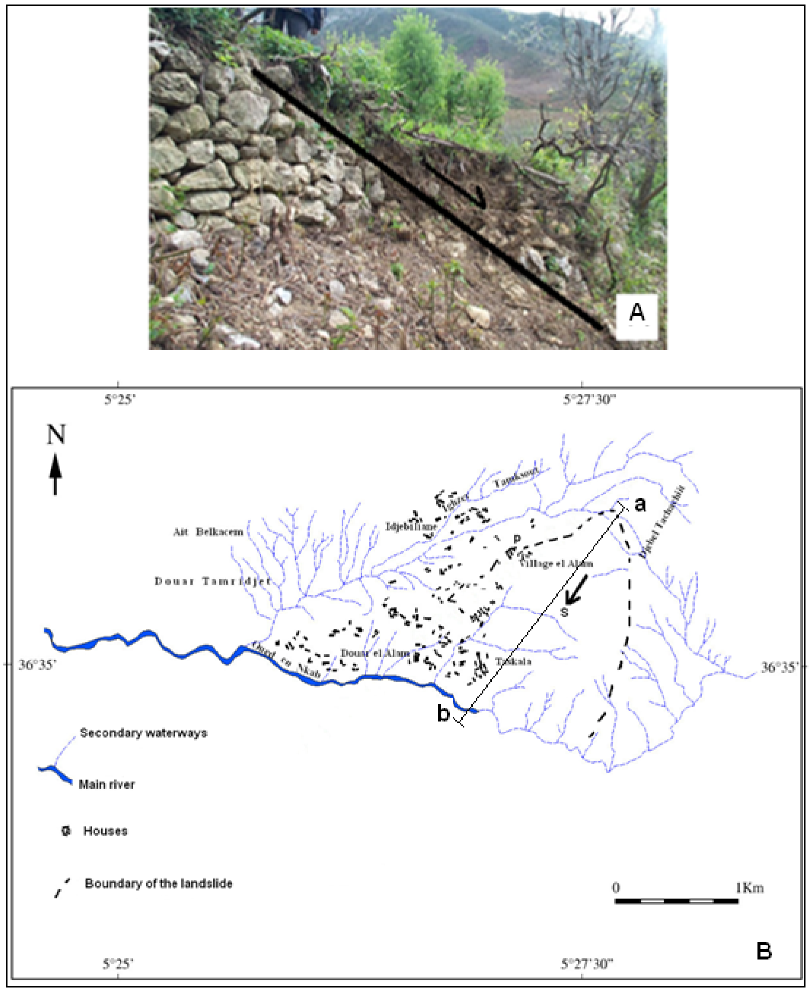
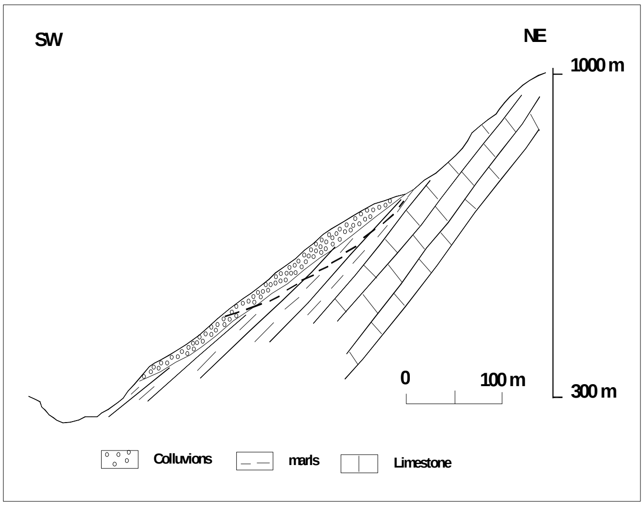
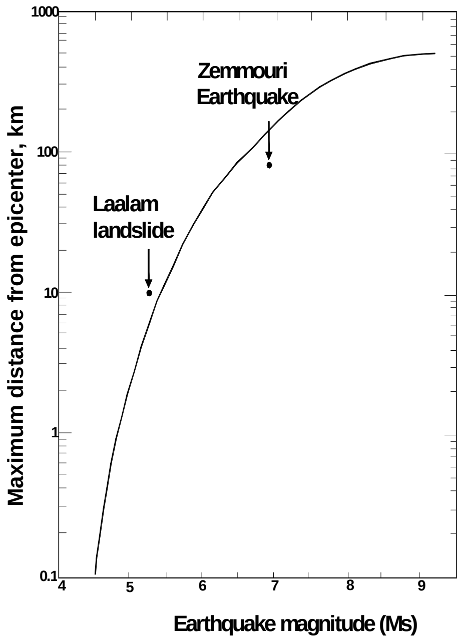


Figure 2. A- Photograph showing a 1.2 m displacement of stone cloture wall. B- Geographical setting of the Laalam landslide showing the drainage network and Laalam dweller. S= Landslide, p= point of view of the photography shown on A. (a-b line indicates the geological cross section shown on figure 3-A.)

3- DISCUSSION

As a mountainous and seismic area northern Algeria suffers from the effects of earthquakes induced landslides. During the 2003 Zemmouri earthquake roads were obtruded by earthquake induced liquefaction and landslides. The 2006 Laalam moderate earthquake (Mw=5.2) triggered a huge landslide in the epicentral mountainous area. This landslide is the direct cause of the numbered casualties and damage. In the case of Laalam landslide a pre-2006 trace of displacement has been observed. It is therefore, possible to use these repeatedly moving landslides as a paleoseismic marker to infer the long term behaviour of the causative fault. In terms of the distance from the epicentre we show in figure 3 two cases of earthquakes. The moderate Laalam and the strong Zemmouri earthquakes that fit in both cases the Keffer (1984) curve. In the same area, the Kherrata (1949) (M_s=4.7) earthquake was associated with a 0.3 m of vertical displacement due to rupture of foothill at 6 km far from the fault on the footwall (Rothe, 1950; Gabert, 1984, Bouhadad et al., 2010). The El-Asnam 1954 and 1980 earthquakes (Ms=6.5, Ms=7.3) were also associated to landslides caused by secondary normal faulting on the top of the faulted fold. (Rothe et al., 1977; Philip et Meghraoui, 1983). Finally, based on the above described cases, we can consider that, in northern Algeria, landslides are often triggered during earthquakes of intensity (MSK) $I_0 \geq$ VII.





A **B**

Figure 3. **A-** Geological cross section of the Laalam landslide (the dashed line indicates the rupture plan of the landslide), **B-** Maximum distance of landslide from epicentre of Laalam 2006 and Zemmouri 2003 earthquakes as a function of earthquake magnitude, in comparison with the upper bound curve by Keefer, 1984.

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