13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 1830

THE BOUMERDES-ZEMMOURI, (ALGERIA) EARTHQUAKE (MAY 21, 2003, Mw=6.8): RESULTS OF FIELD RECONNAISSANCE ON DAMAGE EVALUATION, SURFICIAL DEFORMATION AND GEOLOGICAL SITE EFFECTS

Efthimios L. LEKKAS[1] and Haralambos D. KRANIS[2]

SUMMARY

The earthquake 21May 2003 in NE Algeria (Mw=6.8) was the second most destructive event in northern Algeria in the last 50 years, after the El-Asnam earthquake of 1980 (Ms=7.3). The epicentral location was at 3.58E, 36.91N, a few km NW from the town of Zemmouri. The area mostly affected by the shock is a ENE-WSW-trending zone along the Algerian coast, which roughly corresponds with the frontal portion of the collision boundary between the Eurasian and African tectonic plates. The causative fault is presumed to be an offshore structure, trending approximately NE-SW. The shock also caused a tsunami, which affected the Iberian coast and the Balearic Islands. Our field reconnaissance, which was effected soon after the earthquake, revealed the occurrence of geological site effects, including ground fissures, liquefaction and landslides. Abundant surface breaks, forming a NE-SW zone, were observed close to Zemmouri; what is of interest is that the destroyed town lies at the prolongation of this zone. The strike of this deformation zone is slightly oblique to the causative fault of the earthquake, as it was constrained by the CMT solution. The town of Zemmouri, 70 km east of Algiers, was practically reduced to debris; very few buildings did not collapse, having however suffered heavy structural damage. In Boumerdes, the affected buildings were four- to six-story residential blocks. Most collapses or heavy damage were due to the fact that the constructions behaved as soft first- (and/or second-) story. The collapses were mostly sandwich-type and in a few cases pancake. The foundation soil consisted of dry, compact sandy material. No damage in Boumerdes caused by liquefaction was observed, while the effect was particularly serious close to Dellys.

The effects of the Algerian earthquake were aggravated various factors, such as (i) the shallow focal depth (10 km); (ii) the nature of the geological formations that outcrop in the affected area, which favored the (ii) the local ground deformation, which reflects the regional compressive, N-S stress field (iii) the inadequacy of the applied building practices and (iv) the time of the earthquake, which combined with the high residential density (eight or more tenants per apartment) meant that most families were at dinner. The

[1] Associate Professor, Department of Dynamic, Tectonic & Applied Geology, University of Athens, Athens, Greece. E-mail: elekkas@geol.uoa.gr

[2] Research Associate, Department of Dynamic, Tectonic & Applied Geology, University of Athens, Athens, Greece. E-mail: hkranis@geol.uoa.gr

realization that the shock occurred on a previously unknown thrust, coupled with the regional tectonic setting, suggests that this part of Algeria corresponds to a large-scale pop-up structure.

INTRODUCTION

The earthquake 21May 2003 in NE Algeria (Mw=6.8) was a very destructive event which killed 2,273 people, injured more than 8,000 and left over 200,000 homeless, while total estimated economic impact is estimated to US$65 billion, or roughly 10% of Algeria's total GDP (EERI, [1]). It was second most destructive event in northern Algeria in the last 50 years, after the El-Asnam earthquake of 1980 (Ms=7.3). The epicentral location was at 3.58E, 36.91N, according to the Algerian Seismological network and the depth of the shock was 10 km, which means that the epicenter was located just off the Algerian coast in the Mediterranean, a few km NW from the town of Zemmouri. The meizoseismal area corresponds to a broad ENE-WSW zone, running almost parallel to the Mediterranean coast. Algiers, the capital of the country, was severely hit, but the damage was far more serious in the coastal city of Boumerdes, 50 km east of Algiers and the towns of Zemmouri, Ain Taya, Thenia, Djinet and Dellys (Fig. 1). The shock also caused a tsunami, which affected the Iberian coast and the Balearic Islands.

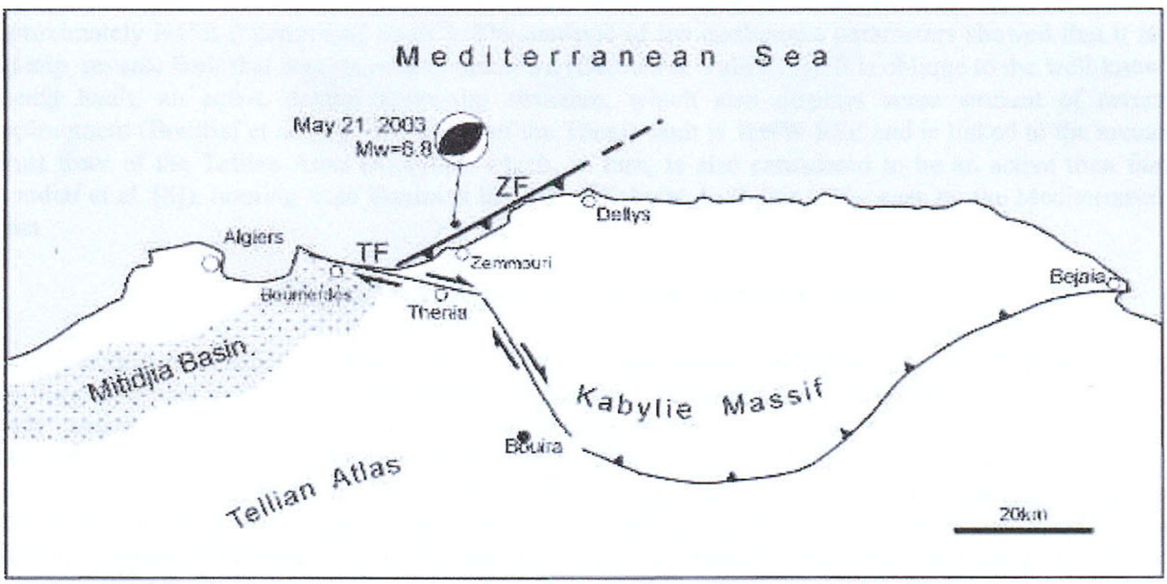

Fig.1 Location and generalized tectonic map of NE Algeria. Heavy lines are faults. Triangles on hanging-wall of thrust faults; arrows denote sense of movement on strike-slip faults ZF: Zemmouri Fault; TF: Thenia Fault.

SEISMOTECTONIC SETTING

Northern Algeria is located on the western part of the Eurasia – Africa tectonic plate boundary. The area mostly affected by the shock is a 35 km-wide, ENE-WSW-trending zone along the Algerian coast. This zone roughly corresponds with the frontal portion of the collision boundary between the Eurasian and African tectonic plates. The causative fault is presumed to be an offshore structure, trending approximately NE-SW. Seismological data suggest that the length of the fault is around 40 km (Delouis & Vallée [2]), while focal mechanism solutions showed reverse faulting, coherent with the compression regime which is present along this collision zone (Meghraoui [3]). The current tectonic configuration includes extended SE-verging thrust nappes and folds, WNW-ESE wrench faults and NE-SW thrusts (Fig. 1). The calculated rate of convergence between the African and Eurasian plates is 0.6 $cm*yr^{-1}$ (Argus et al. [4]).

GEOLOGY AND TECTONICS

The area hit by the earthquake corresponds to the easternmost part of the Mitidja basin, a ENE-WSW elongated structure, bounded from the south by the Mts Dahra and Blida, members of the Tellian Atlas mountain range (Fig. 1). The basin was formed in the Miocene, as a result of the N-S extensional stress field that was present then (Philip [5]); however, in the last 5 million years (since the Pliocene), the Africa – Eurasia convergence has led to the establishment of a compressional stress regime, oriented approximately N-S to NNW-SSE (Philip [6]; Meghraoui [3]).

The deposits in the alluvial plain consist mostly of sand and silt, which cover the Pliocene – Miocene sediments of the basin (mostly sandstones and marls of considerable thickness). The geological basement of the basin comprises rocks deformed in the Tertiary and Precambrian metamorphics.

The fault that was activated in the May 21 earthquake was found to be an offshore structure, trending approximately N45E ("Zemmouri Fault"). The analysis of the earthquake parameters showed that it is a dip-slip, reverse fault that was previously unknown (Delouis & Vallée [2]). It is oblique to the well-known Thenia Fault, an active dextral strike-slip structure, which also displays some amount of reverse displacement (Boudiaf et al. [7]). The strike of the Thenia fault is WNW-ESE and is linked to the arcuate thrust front of the Tellian Atlas (Kabylie), which, in turn, is also considered to be an active trust fault (Boudiaf et al. [8]), running from Bouira at the SW of Kabylie, to Bejaia in the east, on the Mediterranean coast.

GEOTECHNICAL CONDITIONS – SITE EFFECTS

The geotechnical conditions in Boumerdes are more or less uniform, which means that they did not play any important part in the spatial distribution of damage. The foundation soil consisted of dry, compact sandy material, a fact that prevented the occurrence of liquefaction in Boumerdes. However, it is noteworthy that the morphological conditions seemed to control the distribution and severity of damage, at least to some extent. Specifically, the collapses of buildings located along, or close to natural or artificial escarpments (such as river banks) were indicative of localized increase in peak ground acceleration. This resulted in toppled buildings (Fig. 2) and massive collapses. Such case was also observed in the Athens, Greece earthquake of September 7, 1999 (Mw=6.0), where localized, linear development of damage was observed along the banks of Kifissos river and its tributaries (Lekkas [9]).

Contrary to the situation in Boumerdes, in Zemmouri, Djinet and Dellys, liquefaction phenomena were quite widespread. The effect was quite serious close to the Zemmouri and Djinet, but occurred mainly in rural, uninhabited areas. Sand was liquefied and ejected through linear ground fissures of considerable length (between a few m. and some tens of m.), trending approximately N20-40E (Fig. 3). There were also manifestations of lateral spreading on the banks of Isser River (Fig. 4). Rockfalls and other slope failure occurrences were limited in number and magnitude. Most of them took place on the coastal national road and a few along the Mediterranean coast. The former affected well consolidated but densely fractured sandstones exposed on steep road cuts; the latter were noticed on loose sand dunes. Coastline retreat and uplift of the sea floor was also observed: the magnitude of uplift ranged between 0.4-0.8 m, between Boumerdes and Zemmouri (Yelles et al. [10]).

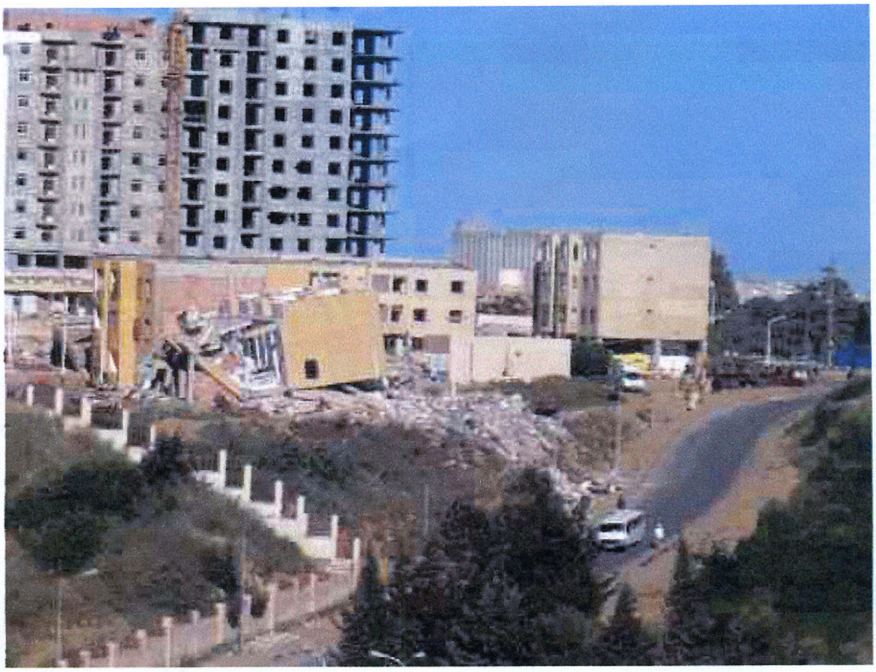

Figure 2. Toppled building, located on the crest of a natural escarpment in Boumerdes.

Figure 3. Ground fissures and liquefaction close to Djinet. The trend of the fractures is approximately N35 E.

Figure 4. Lateral spreading on the banks of Isser River.

Of all the geological site effects that were observed in the meizoseismal area, the most noteworthy ones are the ground fractures which were observed close to Zemmouri, because the vast majority of them were consistently oriented NE-SW. Some of them displayed a measurable displacement (a few mm to a few cm), associated with shortening (Dr. H. Djellit, pers. comm.), often accompanied by a tiny amount of right-lateral shearing. The suite of ground fractures formed a broad (approximately 300 m.) deformation zone, with a visible length of a few km; the strike of this deformation zone is slightly oblique to the causative fault of the earthquake, as it was constrained by the CMT solution. It is also noteworthy that some of the fissures displayed NNW-SSE compression, which in accordance with the regional seismotectonic setting (Philip [6]).

DAMAGE EVALUATION AND CONTROLLING FACTORS

In Boumerdes, the affected buildings were four- to six-story residential blocks that housed working-class families. These constructions consisted of reinforced concrete frame with brick infill walls. Most collapses or heavy damage were due to the fact that the constructions behaved as soft first- (and/or second-) story. This is attributable to the following factors: (i) the first stories (ground floors) were had commonly very large openings, as they were used for commercial purposes and the gravity load-carrying elements of the second floor were insufficient; (ii) the exterior cavity walls consisted of an outer leaf that enveloped the R/C frame and the inner shell had usually very low cohesion with the frame. This meant that the stretcher-bond cavity walls did not play any active part in the shear strength of the buildings and the constructions were subjected to column-shearing at the tops of the first stories. The collapses were mostly sandwich-type and in a few cases pancake. (Figs. 5, 6). Also, in a few cases, as described in the previous part, localized sharp increase in PGA led to the toppling of buildings.

Figure 5. Pancake-collapse of four-story residential building in Boumerdes.

Figure 6. Soft ground floor (first story) at several residential blocks in Corso, at the eastern outskirts of Boumerdes.

Figure 7.Column-beam failure due to insufficient seismic detailing at a private home in Zemmouri.

Figure 8. Loss of exterior shell (foreground) and total collapse (background) in newly-built apartment blocks in Zemmouri.

The town of Zemmouri, 70 km east of Algiers, was practically reduced to debris; very few buildings did not collapse, having however suffered heavy structural damage. In this town, again the construction quality privately-owned houses was poor (including low-quality materials and wrong construction -- insufficient seismic detailing in columns, strong beam/weak column, etc) (Fig. 7). However, not only private homes, but also modern, multi-story apartment blocks (most of them still under construction) suffered severe damage (Fig. 8). In Algiers, mainly the western part of the city was hit. In this case, the damage was mainly to private homes that were constructed without adhering to the Algerian seismic design code.

The heavy toll of the earthquake was also partly due to high residential density (eight or more tenants per apartment) and the time of the earthquake (20:44 local time), which meant that most families were at dinner.

DISCUSSION AND CONCLUSIONS

The shock of 21 May was second most destructive event in northern Algeria in the last 50 years , after the El-Asnam earthquake of 1980 (Ms=7.3) and occurred on a fault that was not previously known (Zemmouri Fault), as it is located offshore. The trend of Zemmouri fault (NE-SW) and its kinematics (thrust fault) are compatible with the overall tectonic setting of Northern Algeria.

The effects of the Algerian earthquake were aggravated various factors. The most important of these seems to be the inadequacy of the applied building practices, as a large percentage of the buildings in the area did not conform to the Algerian seismic design code and were constructed with materials of low quality. Another point, which is related to the urbanization of the area is the high residential density, with large families living under the same roof (and in this case, in the same apartment); this in combination with the time of the earthquake meant that all family members were gathered for dinner the time the earthquake occurred.

From the geological – tectonic point of view, what is noteworthy is the fact that the deformation zone observed at the outskirts of Zemmouri had an average NE-SW trend, approximately parallel to the Zemmouri fault that was activated in the earthquake. The geometrical and kinematic characteristics of the fractures that constituted the deformation zone suggested similar dynamic characteristics with those of the causative fault and the regional stress field.

Finally, the realization that an offshore thrust fault, with NE-SW trend is located just off the coast of Boumerdes – Zemmouri can help elucidate the active tectonics of Northern Algeria. And this, because the SE-dipping Zemmouri fault can be functioning as a (secondary) blind back-thrust fault, in relation to the Kabylie thrust front. These two structures are linked by NW-SE to WNW-ESE strike slip faults (such as the Thenia fault), which can actually play the part of compartmental faults. In this sense, the Kabylie (and probably an offshore area to the NE) may by a large pop-up structure on the collision front between Africa and Eurasia.

ACKNOWLEDGMENTS

We would like to thank Dr. K. Yelles, (CRAAG) for the seismological information he provided; Dr H. Djellit (CRAAG) for field assistance; and the Ambassador and the staff of the Greek Embassy in Algiers for their support in accommodation, transportation and all protocol matters.

REFERENCES

1. EERI, "The Boumerdes, Algeria Earthquake, May 21, 2003. Earthquake." Engineering. Res. Institute 2003, Oakland, California, 57 p.
2. Delouis, B., Vallée, M., "The 2003 Boumerdes (Algeria) earthquake: source process from teleseismic data." Newsletter of the EMSC September 2003; 20: 8-10.
3. Meghraoui, M., "Géologie sismique du Nord de l'Algérie: paléosismologie, tectoniques active et synthèse sismotectonique." Thèse de doctorat des sciences, 1988, Université de Paris 11, France.
4. Argus, D.F., Gordon, R.G., Demets, C., Stein, S. "Closure of the Africa – Eurasia – North America plate motion circuit and tectonics of the Gloria Fault.". J. Geophys. Res. 1989; 94: 5585-5602.
5. Philip, H., "La tectonique actuelle et récente dans le domaine Méditerranéen et ses bordures, ses relations avec la sismicité." Thèse de Doctorat, Université des Sciences et Techniques du Languedoc 1983
6. Philip, H., "Plio-Quaternary evolution of the stress field in Mediterranean zones of subduction and collision." Ann. Geophysicae 1987; 5(B): 301-320.
7. Boudiaf, A., J.F. Ritz, Philip, H. "Drainage diversion as evidence of propagating active faults: example of the El Asnam and Thenia faults, Algeria." Terra Nova 1998: 10: 236-244.
8. Boudiaf, A., Philip, H., Coutelle, A., Ritz J.F. "Découverte d'un chevauchement d'age quaternaire au sud de la Grande Kabylie (Algérie)". Geodinamica Acta 1999: 12(2): 71-80.
9. Lekkas, E., "The Athens earthquake (7 September 1999): Intensity distribution and controlling factors." Engineering Geology 2001; 59: 297-311.
10. Yelles-Chaouche, A.K., H. Djelit and M. Hamdache (2003). The Boumerdes-Algiers (Algeria) earthquake of May 21st, 2003 (Mw=6.3). Newsletter of the EMSC, 20, September 2003, 3-5.