CHAPTER

1

EARTHQUAKE VULNERABILITY OF SCHOOL BUILDINGS IN ALGERIA

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Abstract: This paper describes the nature and cost of damage to school facilities in the 21 May 2003 Boumerdes earthquake and other earthquakes in Algeria. It provides statistics on the extent of damage and estimated costs of reconstruction and rehabilitation. The author discusses the factors that increase the vulnerability of school construction in Algeria, such as urban development, structural flaws in existing school building stock, and inadequacy of building codes and construction control for school buildings. Approaches to reduce the vulnerability of both existing and new school buildings are also presented.

Algeria seismic setting

Northern Algeria, in which about 90% of the country's population reside, is located along the plate boundary between Eurasia and Africa. The convergence of the two major plates creates a complex system of active faults that has resulted in a number of moderate to strong earthquakes in the region. On 28 January 1716, an earthquake with an epicentral intensity of X (MMI) destroyed Algiers and caused more than 20 000 deaths; and on 7 October 1790, an earthquake in Oran destroyed the city and resulted in the capture of Oran by the Ottomans, after many unsuccessful attempts. The M7.3 El-Asnam earthquake of 10 October 1980 was the most destructive modern earthquake recorded in the country, causing about 5 000 deaths – out of a population of 120 000 – and destroying close to half of the building construction in the city of El Asnam. The same city was also severely damaged by a M6.7 earthquake on 9 September 1954, which killed 1 243 people. The Boumerdes earthquake (M6.8) of 21 May 2003 is the latest destructive earthquake in Algeria. It was preceded by several moderate to small earthquakes, which also caused significant human and material losses.

Table 1.1 summarises the major destructive earthquakes in Algeria since 1980, as well as provides data on human and material losses.

Table 1.1. Destructive earthquakes in Algeria since 1980

Earthquake	Date	Magnitude	Intensity (MMI)	Dead	Injured	Homeless	Structures destroyed*
El-Asnam	10 Oct. 1980	M7.3	X	5 000	20 000	120 000	7 000
Constantine	27 Oct. 1985	M6.0	VIII-IX	5	300	–	–
Chenoua	29 Oct. 1989	M6.0	VIII	35	700	50 000	4 095
Beni Chougrane	18 Aug. 1994	M5.6	VIII	172	292	10 000	751
Temouchent	22 Dec. 1999	M5.5	VII	25	174	25 000	600
Boumerdes	21 May 2003	M6.8	IX	2 287	11 000	100 000	19 000

* A housing unit, which is a multi-storey building, is typically counted as one structure.
Source: Algerian Ministry of Housing.

The Boumerdes earthquake

The Boumerdes earthquake struck on 21 May 2003 at 19:44 local time. The shallow earthquake of magnitude M6.8 was located offshore, 7 km north of the locality of Zemmouri in the province of Boumerdes and about 50 km east of the capital city of

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Algiers. The earthquake caused damage in an area about 100 km long and 35 km wide. The epicentre was located in the city of Boumerdes but extended to five provinces in the north-central part of the country. The hardest-hit regions included the cities of Boumerdes, Zemmouri and Thenia, in addition to the eastern districts in the province of Algiers. Most of the buildings in the damaged areas had been constructed in the last 30 years; however, several large buildings dating from the colonial era (early 20th century) were heavily damaged in the popular districts of Belcourt, Bab-El-Oued and El-Casbah in Algiers. The earthquake generated a tsunami that was observed as far away as the southern coast of Spain, but there was little or no local damage. Geological investigations also revealed offshore effects such as uplift of the seafloor of at least 50 cm, and minor landslides and liquefaction along the coastline.

The affected area is heavily developed and urban. About 2.3 million people were affected by the earthquake. As of 14 June 2003, there were 2 287 people dead, and about 11 000 injured. Damage was estimated at USD 5 billion. Approximately 182 000 apartments and private houses were damaged, and 19 000 dwellings were rendered uninhabitable. The earthquake left more than 100 000 people homeless.

Performance of schools in past earthquakes

The vulnerability of schools and other educational facilities has been observed in every recent destructive earthquake in Algeria. Earthquake reports issued by the Algerian Ministry of Housing on these events pointed to the higher vulnerability of schools and identified several structural causes that contribute to the vulnerabilities. These observations are demonstrated by the statistics on school damage shown in Table 1.2.[1] During the 1980 El-Asnam earthquake (M7.3), more than 75% of schools sustained serious damage and about 70% were extensively damaged or destroyed by the earthquake. The experts who collected and analysed the damage data from the earthquake reported the disproportionate level of damage to schools (EERI, 1983). The same observations were made by Algerian engineers who surveyed the damage from the moderate earthquakes of Chenoua in 1989, Beni Chougrane in 1994 and Temouchent in 1999. In the Beni Chougrane earthquake, one school completely collapsed; and in the Temouchent earthquake, one of the two secondary schools in the region needed to be demolished and rebuilt.

During the Boumerdes earthquake, 564 schools – out of 1 800 inspected – were considered to be seriously damaged. Of these, 373 were primary schools, 119 lower secondary schools and 72 upper secondary schools. In addition to schools in the provinces of Algiers and Boumerdes, those in the peripheral provinces of Blida, Bouira, Tizi Ouzou, Tipaza and Medéa were also damaged. The University of Boumerdes sustained heavy damage and several buildings collapsed. The University of Science and Technology, the largest university campus in the country, which is located in the district of Bab-Ezzouar in the eastern part of Algiers, also sustained damaged and was temporarily closed to allow for damage assessment and repairs.

Table 1.2. Statistics of school damage from recent destructive earthquakes

Earthquake	Magnitude	No or light damage	Moderate damage	Extensive to complete damage	Total*	Damage ratio
1980 El-Asnam	M7.3	5	25	70	100	95%
1989 Chenoua	M6.0	167	36	7	210	21%
1994 Beni Chougrane	M5.6	30	16	4	50	40%
1996 Temouchent	M5.8	36	17	6	59	39%
2003 Boumerdes (total)	M6.7	810	860	130	1 800	55%
2003 Boumerdes (Algiers province only)	M6.7	554	330	11	895	38%

* Total includes only schools located in the area where damage was observed.
Source: Algerian Ministry of Housing.

Due to the timing of the earthquakes, which occurred after school hours or on weekends or holidays, the lives lost from damage to schools was fortunately very low. This fact may have obscured the vulnerability of schools to the general public and government authorities. Cost of repairs to schools from previous earthquakes is very sketchy. An estimated DZD 600 million (Algerian Dinars) (about USD 7 million) was provided by the Ministry of Housing for the 1999 Temouchent earthquake. However, the actual cost for the repair and reconstruction of schools in previous earthquakes is not known. Data obtained from the Ministry of Education on school reconstruction and rehabilitation from the 2003 Boumerdes earthquake is presented in Table 1.3. It shows a cost of DZD 5 565 million or about USD 70 million. However, it is not easy to correlate these costs with the damage statistics shown in Table 1.2, and to evaluate the percentage of these costs compared to the total rebuilding cost of schools facilities from the Boumerdes earthquake. This may become clearer at a later date when more data on repair and reconstruction are made available by government authorities.

Table 1.3. Reconstruction and rehabilitation costs for schools in the Boumerdes earthquake

	Type of school	Number		Cost (DZD millions)*	
		Rebuilt	Rehabilitated	Rebuilt	Rehabilitated
Algiers	Primary	3	122	75	585
	Lower secondary	3	76	180	760
	Upper secondary	3	40	450	570
Boumerdes	Primary	97	131	225	160
	Lower secondary	9	35	540	700
	Upper secondary	7	18	1 050	270
Total		122	422	2 520	3 045

* USD 1 = DZD 80.
Source: Algerian Ministry of Education.

An analysis of the social losses related to school damage and closure cannot be provided because no information or study exists. Undoubtedly, the sudden damage and/or demolition of a school by an earthquake certainly translates into a negative social impact, as schools constitute important focal points for communities. This is most important in the countryside, where schools have extended social functions and are perceived as a safe place in the community. Finally, schools are relied upon as shelters during and after disasters; the loss of a school reduces options for sheltering victims during a disaster, thus increasing the social losses.

School vulnerability and urban development factors

Since gaining independence from France in 1962, Algeria has experienced one of the highest birth rates in the world. The population has grown from less than 10 million inhabitants to more than 30 million in three decades. The increase in population, coupled with rural-urban migration, has resulted in the rapid growth of cities. For example, the region of Algiers and Boumerdes has seen phenomenal urban sprawl; more than 67% of construction has taken place in the last 30 years. Following its independence, Algeria adopted a political system that offered free and mandatory education to all Algerians. These factors have contributed to a large demand for new school construction both in the cities and the countryside. Educational investments accounted for the largest proportion of the government's capital expenditures for many years.

The need to build quickly and cheaply required some standardisation in the school construction process, which was encouraged by the Soviet-style system that characterised the Algerian economy from independence to about 1990. Typical school architectural layouts that could easily be duplicated were developed. Construction needed to take place quickly, often at the expense of quality control, particularly in rural areas, where local contractors have fewer capabilities and poor training, and where institutional oversight is more lenient. The data from Table 1.2, while limited, reflect some of these factors; the relatively small rural earthquakes of Beni Chougrane and Temouchent resulted in very high damage ratios – about 40% – to schools.

From 1990, political reforms in Algeria disrupted the building construction process and further increased the vulnerability of school construction. In a few short years, Algeria went from a rigid state-controlled system to a free-market economy. The apparatus responsible for planning and construction in the country was dismantled. Construction was liberalised and quickly taken over by an emerging but largely unqualified private sector. Construction control, which was formerly the responsibility of one governmental institution – CTC (*Control technique de Construction*) – was broken down into five competing organisations. Responsibility for construction control was further diluted by outdated and unenforceable regulations. For example, the laws did not clearly delineate responsibilities of the different parties (*i.e.* architect, engineer, contractor and owner) involved in building construction. During the period 1991 to 1997, non-adherence to construction regulation and requirements became the rule rather than the exception. Statistics from the Ministry of Housing indicate that during the period 1990 to 2002, about 50% of houses were constructed without a building permit. This environment had a negative impact on the process of planning and delivery of school construction in Algeria and further aggravated its vulnerability. This point is well-illustrated by the fact that a large proportion of the buildings that collapsed in the 2003 Boumerdes earthquake were completed within the last ten years.

Physical factors of school vulnerability

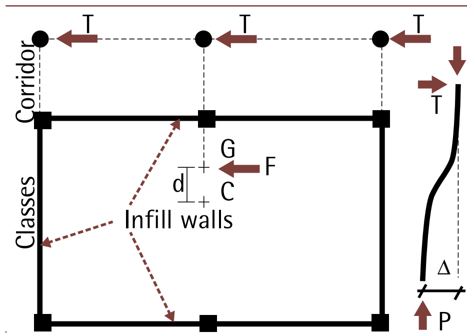
Typical architectural layout

School buildings in Algeria are typically one or two-storey long narrow buildings with an open corridor on the school courtyard side and classrooms on the longitudinal side. The structural system is typically reinforced-concrete frame (*i.e.* beams and columns that connect together to form a frame) with a concrete slab, and walls made of hollow clay tiles (brick). The courtyard side of a classroom typically has large windows; and the back wall is solid up to about 70 cm from the upper floors, where long and narrow longitudinal windows ("vasistas") are located to allow for ventilation and extra lighting. School class blocks are often aligned in an L-shape or U-shape around the school courtyard.

Inherent structural flaws in school layout

The typical architectural layout for school construction contains several well-known inherent flaws for seismic resistance:

Figure 1.1. Illustration of torsional forces and P-Δ effects



- The reinforced-concrete frame system relies on its beam-column connections and column-foundation connections to transfer the lateral loads from earthquakes. These connections require special detailing of the steel and concrete in order to accomplish the transfer. Additional detailing is also required in the columns and beams to ensure that the system is "ductile" (*i.e.* it can deform without cracking) and, if failure develops, it will take place in the beams and not the columns to avoid collapse (weak beams/strong columns concept). In addition, deflection of the columns needs to be controlled to avoid instability of the frame due to large deformations (so-called P-Δ effects) (Figure 1.1). Stringent quality control is required during construction to ensure that the design details are well-implemented in the field. Hence, the reinforced-concrete frame system requires a level of sophistication in design and construction that is typically beyond the standard practice in Algeria, and in many other developing countries.

- The open corridor in the front of the building creates an offset between the centre of mass and the centre of rigidity of the building, as shown in Figure 1.1. This results in torsional effects that increase the loading on the building's exterior columns. Often, these loads

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are not accounted for in design and can lead to additional damage and eventually failure of the columns.

- The narrow windows ("vasistas") on the back wall create so-called "short column" conditions for the portion of the column that extends above the wall and below the floor. These short columns are subject to high shear stresses because of the restrictions imposed by the walls below the windows. During the design process, the walls are ignored because they are considered to be "non-structural", and consequently the shear stresses are underestimated, leading to failure as illustrated in Figure 1.2.
- The L- and U-shaped configurations also create some additional weaknesses in the seismic ability, where stress is concentrated in the corners of the building (re-entrant corners) and can lead to failure if not properly designed.

Damage patterns from past earthquakes have consistently demonstrated the consequences of the flaws in design and construction. Extensive damage was observed in the non-ductile concrete frames, including crushing and cracking of concrete and buckling of steel bars in the columns due to lack of transverse confinement and improper longitudinal reinforcement of joint connections (Figure 1.3). Other types of failure include shearing in columns with a clear indication of a strong beam/weak column approach, and minimal ductility. Failure in the columns sometimes causes partial or total failure of the first floor (Figure 1.4). Failure of short columns is also widespread and has been reported in each major earthquake (Figure 1.2). Cracking of masonry infill walls was also reported. The extremely poor quality of concrete is another factor in the failures.

Figure 1.2. Concrete cracking on short column along back wall

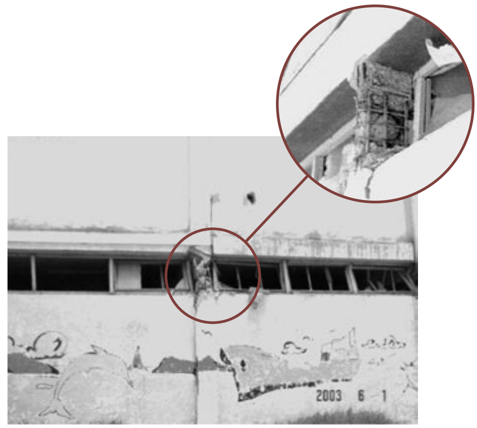

Figure 1.3. Failure of columns at joint

Figure 1.4. Collapse of first floor due to column failure

These damage observations are described in every earthquake report issued by Algerian governmental institutions and have been regularly discussed by Algerian earthquake engineering experts in conferences and workshops. However, these observations and discussions remain between experts and have made little impact on public policy or school construction practices. As a result, schools remain vulnerable in Algeria.

Building codes and construction control

Building code regulation

School construction in Algeria lies within the jurisdiction of the Ministry of Education, which is institutionally represented in each province or "wilaya" of the country. The ministry draws national plans, which are then implemented by the provincial governmental institutions. Hence, design and construction procurement is completed at the local level. School construction is subject to national building codes and construction control regulation. In 1981, after the 1980 El-Asnam earthquake, Algeria adopted its first seismic design code, referred to as RPA-81. In 1988, the code was revised (RPA-88), and the most recent version was published in 1999 (RPA-99). The earthquake code requirements are related to four geographical regions of the country, which are organised according to the seismic hazard exposure of the area. Zone 0 is considered aseismic and has no requirements, while Zone III has the highest seismic hazard and is subject to the most stringent requirements. Algiers and Boumerdes were located in Zone II until after the 21 May 2003 earthquake, when the cities were upgraded to Zone III. According to the code, school buildings are considered of "great importance" but "not critical". For Zone II, the code specifies a lateral design acceleration of 20% of gravity for earthquake design; versus 15% of gravity for general occupancy buildings.

The Boumerdes earthquake showed that code hazard parameters significantly underestimate the severity of earthquake ground motion in the northern part of Algeria. For example, seismic instruments located 20 km to 30 km from the epicentre recorded peak ground accelerations (PGA) greater than 50% of gravity. The author provided evidence that the PGA in the epicentral region exceeded 100% of gravity. As shown in Figure 1.5, the concrete cap of this transformer housing was overturned and thrown about 2 m from its location, indicating that both the vertical and horizontal motion exceeded 100% of gravity. Hence, the underestimation of the ground motion input in the code consistently results in school structures with lower earthquake capacities than the potential demands from earthquakes. Even under the best circumstances – *i.e.* good concept, good design and good construction – this underestimation translates into high vulnerability.

Figure 1.5. Concrete cap thrown from its original location

Construction control

School design and construction are subject to construction control, which has been undertaken by the state organisation CTC. Even when CTC was a single governmental institution with a monopoly over construction control in the country, it lacked the resources, training and expertise to undertake effective inspections in the field, especially in light of the large number of schools that were being built all over the country. Most often, the field supervision was limited to occasional testing of concrete strength. The quality of the work in large part relied on the skills of the contractor. Architects and engineers typically did not go into the field, and did not consider field supervision as part of their professional duties. In standard practice, designers completed their drawings and specifications and handed them to the contractor, who then built the school. In view of the competitive nature of construction and the small fees associated with design, there was no incentive for field visits or other quality control mechanisms. Furthermore, Algeria had no licensing process for contractors, engineers or architects, and liability laws could not be enforced by the courts. As a result, workmanship was often poor and training inadequate. The Ministry of Education itself did not have technical specialists or an office within its organisation to ensure construction control, building code enforcement or pre-qualification of design offices or contractors. The poor quality of construction and the lack of respect for code requirements – key contributors to school vulnerability – have been reported repeatedly in post-earthquake damage investigations.

Recommendation for vulnerability reduction

Vulnerability reduction programmes in Algeria should seek to improve the procedures and standards for new construction and to reduce the vulnerability of the current inventory of schools by implementing a comprehensive seismic retrofit campaign. Essential guidelines are provided below.

New construction

The flaws of current construction practices could be corrected relatively easily by implementing the following provisions.

- Design ground motions specified in the code should be increased to reflect the actual hazard conditions of the country. Design hazard levels should include the seismic contribution of the active tectonic of northern Algeria, in addition to the uncertainty deriving from the lack of knowledge about the seismic potential of the country, which has been neglected in previous studies.

- A lateral system based on concrete shear walls – especially in the transverse direction of the building – would be preferable to the current frame system. Such a system would also be more reliable considering the lack of earthquake engineering expertise in Algeria.

- The current reinforced-concrete frame system could remain in use, but its design should follow strict requirements to ensure ductile behaviour and to take into consideration torsional effects and stability requirements.

- Design should eliminate short-column conditions.
- A system of construction control and building code enforcement should be put in place to ensure the quality of design and proper building practice. Designers and contractors should be adequately trained and qualified, preferably licensed, to design and build schools.
- The Ministry of Housing should establish an office for construction control and enforce stronger technical requirements in its procurement procedures.

Vulnerability reduction of the existing inventory

The vulnerability of the existing inventory has been demonstrated in past earthquakes. While the country has been fortunate not to have experienced large loss of life in schools due to the timing of past earthquakes, there is no guarantee that earthquakes will only occur outside of school hours in the future. Technically, reinforcing school buildings does not create exceptional challenges. Shear walls can easily be added to improve capacity and provide lateral stability, and new techniques such as fibre-reinforced material can be used to wrap columns and provide additional strength and ductility. However, seismically retrofitting all school buildings in Algeria is a costly and difficult endeavour that would compete for resources with the other educational priorities in the country, such as a chronic lack of classrooms and good teachers. The planning of such an operation would also require careful consideration of the country's seismic hazard, the physical conditions of the buildings and the occupancy of the schools. A priority system should be created, special inspectors need to be trained for quality control and a deployment strategy needs to be established. These difficulties can be overcome with external financial and technical help.

Without a comprehensive seismic retrofit and a new approach to design and construction of school buildings, continued loss of life and materials to schools in future earthquakes is to be expected.

Note

1. Statistics are based on damage surveys undertaken by Algerian engineers. These surveys classify the damage on a scale from 1 to 5, by increasing order of damage. Using this scale, degrees 1 and 2 indicate no or slight damage; degree 3 moderate damage; and degrees 4 and 5 extensive damage to collapse.

Reference

Earthquake Engineering Research Institute (EERI) (1983), *The Boumerdes, Algeria, Earthquake of May 21, 2003*, EERI, California.

Acknowledgments

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