PART I

RECOGNISING THE OBSTACLES TO IMPROVING SEISMIC SAFETY OF SCHOOLS

Introduction

The collapse of school buildings in earthquakes can be attributed to basic deficiencies in both the nature and implementation of laws and regulations concerning the planning, construction and maintenance of school buildings. Countries often lack building codes or poorly enforce existing codes.

The following papers tell the stories of why schools have collapsed in earthquakes in nine countries: Algeria, Former Yugoslav Republic of Macedonia (FYROM), Italy, Mexico, New Zealand, Portugal, Turkey, the United States and Venezuela. While these papers assess the relative importance of the specific factors contributing to the poor performance of school buildings, they also reveal the extent to which the lessons learned from past earthquakes have been used to change and improve building codes and construction practices. In addition, these stories highlight the crucial role of the many groups and individuals who have taken responsibility and action to improve the safety of school buildings and their occupants, often in the face of numerous obstacles. Other important contextual factors are considered, such as the economic development of the country or region, location of the building (urban vs. rural) and ownership of the building (public vs. private).

Based on the experiences recounted during the meeting, the *ad hoc* experts' group identified a number of obstacles to achieving seismic safety in schools.

Defining obstacles

The responsibility of all

- *A lack of awareness* on the part of the public and public officials of the threat of school collapse from earthquakes can be attributed to the seemingly infrequent occurrence of earthquakes in any one place and few fatalities involving schoolchildren in the past. Even when heavy damage is inflicted on lives and public buildings, it is often quickly forgotten. Unless stakeholders such as communities and government officials are informed of the risks and the economic and social costs associated with these rare events, they can lack the means to influence decisions and to find common values by which to reach solutions.

- *Poor communication* between stakeholders and the *lack of a system of accountability,* legal or moral, in the event of a disaster, have in many cases proven a grave impediment to improving earthquake safety standards in public buildings such as schools.

Government

- *Inadequate enforcement of seismic codes* and the *absence of statutory requirements for hazard safety programmes* are two related obstacles that represent the root of problems encountered in several countries. The presence of these powerful tools would improve accountability, communication and awareness between all stakeholders.

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- *Lack of supporting systems of governance*, *inadequate emphasis on human decision-making* and *decentralised control of school buildings* can also hinder the improvement of school building safety.

The private sector

- *Inadequate knowledge of current engineering principles* and *inadequate training, testing and certification of architects, engineers, inspectors and others in the construction industry* have significantly contributed towards damage to school buildings following an earthquake. In many cases, existing expertise and technologies have not been transmitted to stakeholders in a meaningful way. Such problems could be addressed by applying simple and inexpensive technical information, such as short columns, "capacity-based" design and base isolation.

- *Lack of quality controls* for construction of new buildings and for structural modification and change of use of existing buildings, in addition to *poor facility maintenance, use of poor construction materials and methodologies, and poor site conditions*, significantly contribute towards school building collapse.

- *Inadequate hazard determination and little pre-event evaluation* are further obstacles to ensuring earthquake-safe school buildings.

- *Absence of insurance incentives* is another impediment to ensuring that construction companies and others enforce code requirements.

CHAPTER

1

EARTHQUAKE VULNERABILITY OF SCHOOL BUILDINGS IN ALGERIA

Fouad Bendimerad

Risk Management Solutions, United States

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	Mag-nitude	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	Mag-nitude	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

		Number		Cost (DZD millions)*	
	Type of school	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.

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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

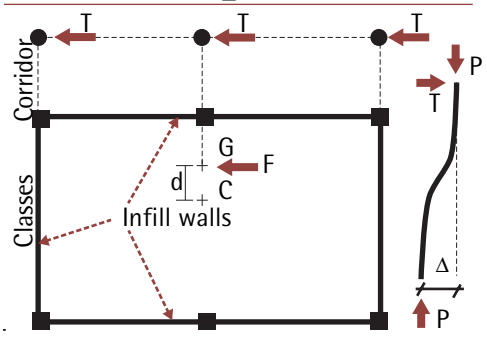
Typical architectural layout

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

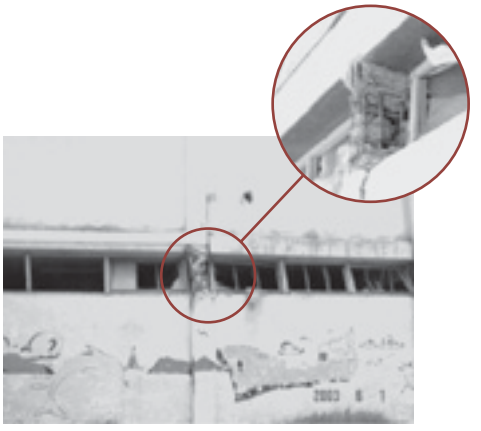


Figure 1.3. Failure of columns at joint

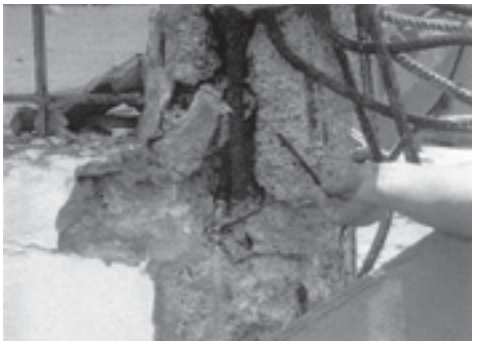


Figure 1.4. Collapse of first floor due to column failure

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.

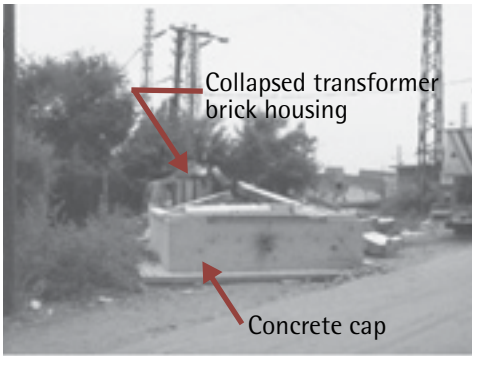
Building codes and construction control

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



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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

The author is grateful to Professor Djillali Benouar at the University of Science and Technology of Algiers for providing insight and additional data on school performance and cost of reconstruction from the Boumerdes earthquake.

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CHAPTER

2

LEARNING ABOUT SEISMIC SAFETY OF SCHOOLS FROM COMMUNITY EXPERIENCE IN BERKELEY, CALIFORNIA

Arrietta Chakos

City Manager's Office,
City of Berkeley,
California,
United States

Abstract: Following the 1989 Loma Prieta earthquake in California, the Berkeley community has worked diligently to reduce seismic hazards in its schools. This paper describes the efforts of the Berkeley community and local leaders to address the serious risk to students in its 16 public schools through persistent legislative efforts and development of multi-sectoral partnerships. The catalyst for action to improve school safety was not the discovery of improved technical standards or the financial means to correct building deficiencies; it was the fact that a small group of people decided to take action for a safer community for their children.

Introduction

Seismically safe schools must be recognised as a basic human right. Because we require young children to attend school, it is incumbent upon the responsible government agency to provide structurally sound facilities. This statement is easy to make but difficult to accomplish. Government officials and community stakeholders are accountable and morally responsible for acknowledging the necessity to improve seismic safety in schools and to act upon that knowledge. Forging alliances between the many groups involved in school administration and government can be an initial step towards significant safety improvements. These alliances can provide a multi-disciplinary approach to problem-solving, and bring added capacity and energy to accomplishing the daunting tasks of seismic assessment and reconstruction.

Communities rarely have a systematic approach to improving school seismic safety. Facility infrastructure is not often a primary consideration when other, more immediate, issues call for attention and scarce resources. Despite the fact that many countries have seismic engineering codes, it is not common practice for schools, or their governing bodies, to embark on a safety programme to reduce seismic hazards. Typically, newly constructed buildings in countries with effective regulatory oversight have improved levels of earthquake resistance, but experience demonstrates that school districts and school administrators do not undertake unbidden seismic evaluations of existing school facilities.

One critical issue is to link legislative mandates with everyday practice and implementation. Though a state, provincial or federal law may require implementing certain safety measures or precautions, often the local government agency responsible for implementation may not be able to fulfil its obligation. Educational and social service programmes are always at the forefront for administrators, and mandates that detract from those initiatives are not given equivalent attention. California has developed a series of safety requirements for local school facilities that include earthquake-resistant construction. These state mandates are adhered to in new construction projects, but many California school buildings were not recently built. A significant safety problem exists in school buildings constructed before contemporary standards were enacted. Some school districts, including those in California and Seattle, Washington, have developed systems for incorporating seismic analysis into routine checks of all building systems in order to determine baseline facility health.

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A case study

Local authorities are reluctant to thoroughly review the structural integrity of schools for fear they will find unsolvable safety problems. Such was the case in Berkeley, California, after the 1989 Loma Prieta earthquake. Since 1989, the Berkeley community of 103 000 residents has worked diligently to reduce seismic hazards in its schools. The effort took time to develop as local leaders realised that there were no simple solutions to address the serious risk to students in its 16 public schools. The schools were threatened by the significant seismic and wildland fire risk in the region, especially in the densely populated hills in the eastern part of Berkeley where the Hayward fault lies. The Hayward/Rogers Creek fault system has a 32% likelihood that a M6.7 or greater event will occur in the next 30 years. In addition, the region is at risk of conflagration. The October 1991 East Bay hills fire is the latest example of such an incident; 25 lives were lost and over 3 000 residential units in the area were destroyed.

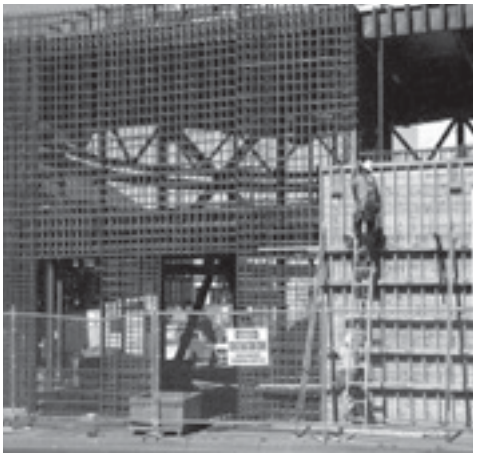
The 1989 disaster prompted a group of parents to approach officials with their concerns about the safety of the local schools constructed in the 1950s and 1960s using concrete. The buildings appeared to be suspiciously like the collapsed Cypress freeway overpass structure in nearby Oakland, where many fatalities occurred. Local officials appointed parent advocates to serve as an advisory body to the school district, and they worked together to evaluate the facilities and to develop a plan for reducing seismic risk. Group members discovered engineering reports issued ten years earlier that confirmed that at least one of the schools, still in use, was unsafe and was to have been closed. The materials had been misplaced by school officials and had never been acted upon. The parent advisory group informed the district, and supported by another parent who was a structural engineer, convinced authorities to review all the schools again. The district architect and engineers conferred with the parent group over the next year as the schools were evaluated using current technical information. Eventually, the community learned that seven of the 16 district schools posed serious life threats to students.

The parents also turned to regional and state officials for guidance on how best to advise the local officials. The Bay Area Earthquake Preparedness Project, the California Seismic Safety Commission (CSSC) and the Office of the State Architect gave crucial technical assistance to parents. Seismic and policy experts from the agencies also attended school board meetings to advise policy-makers about seismic risk and best practices to evaluate structural systems. Berkeley community members became conversant in state laws governing seismic safety in school buildings – the Field Act, the Riley Act and the Katz Act – all aimed to enhance earthquake safety in school buildings.

Once the school district determined the extent of the risk in so many of its buildings, the city's state legislators also joined the safety improvement efforts. Berkeley's state assemblyman and state senator worked with district officials to change the distribution of state funds to partially fund upgrades for Berkeley schools. Further, they sponsored state legislation that enabled local districts to tap into state emergency funds for school facilities deemed life safety hazards. Engineers at the Office of the State Architect co-ordinated with the

Figure 2.1. Cragmont School, Berkeley

Figure 2.2. Berkeley High School, California



involved officials and community leaders to ensure that state regulatory and funding agency staff understood the severity of the safety problems and would act responsibly to assist Berkeley. Federal agencies were also contacted for funding assistance. The state and federal programmes only funded a small portion of the costs to rebuild the unsafe schools, but this seed funding provided a vital catalyst for action; local leaders knew that they would have to raise a considerable part of the reconstruction costs.

In December 1991, a larger community advisory group proposed that school district officials embark on a comprehensive safety programme, totalling USD 158 million, to rebuild the Berkeley schools. Improvements would include seismic upgrades for all facilities and modernisation of all building systems. After many community meetings and public hearings, the school board voted to place a tax measure on the June 1992 ballot to request approval for a special tax to fund the programme. The tax measure was approved by over 70% of Berkeley voters in the 1992 election, and the measure was the first of six special hazard mitigation taxes that the Berkeley voters would approve over the next ten years. In the meantime, state and federal officials granted over USD 20 million in matching funds to the seismic safety projects. The State Allocation Board, the California Office of Emergency Services and the Federal Emergency Management Agency all contributed significant funds to several school projects, including the reconstruction of Cragmont Elementary School (Figure 2.1) and Berkeley High School (Figure 2.2). Since 1992, all of the Berkeley schools have been rebuilt. Some – Thousand Oaks and Rosa Parks schools – were replaced with new buildings, as upgrading the old facilities proved too costly. In the period from 1992 to 2004, all the local schools were vastly improved using the proceeds from the original 1992 bond measure, which was supplemented by funds from two other special tax measures approved in 2000. Few if any other school districts in California have accomplished so much in order to reduce seismic risk.

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Partnership leads to successful change

Through persistent legislative efforts and development of multi-sector partnerships, a grassroots parents' group convinced decision-makers that the risk in local schools was more than they were willing to accept for their children. The tipping point in this quest for safer schools was not the discovery of improved technical standards or the financial means to correct building deficiencies. It was the fact that a small group of people decided to take action for a safer community for their children. The group faced many obstacles as they attempted, over time, to first convince local officials that a genuine problem existed. Persistence in pursuing the issue and making sure that district officials would address the safety problems were twin challenges for the parents' group.

Prominent community members questioned the parents' right to ask certain questions about seismic safety and to challenge the decisions made by the school board. Not until the engineering reports from the previous decade were found and the findings of these reports substantiated by a practicing engineer did the broader community start to understand the extent of the problem. Scepticism encountered at the state level was even more pronounced. State legislators and agency officials responsible for allocation of school facility funds were reluctant to recognise the seriousness of the seismic safety issue. Many felt that opening public discussion about the safety of California schools, and especially performing a detailed examination of the large number of older buildings in the state inventory, was like opening Pandora's box. It was only after district officials attended numerous state hearings and provided repeated, unsolicited testimony that the state regulators finally took up the issue of pre-disaster hazard mitigation for schools. Ironically, in a subsequent state election, the very same state officials used safety information presented by Berkeley officials as ballot arguments to convince the state electorate to approve special funding for California school buildings.

In retrospect, the group learned that achieving improved seismic safety is not solely a technical problem, but rather a challenge to prompt community engagement, accountability and action. In Berkeley, a curious situation developed as the technical experts followed the lead established by community advocates. Even though public officials and engineering professionals monitored school safety, they did not sound the alarm when the 1989 Loma Prieta earthquake revealed the vulnerability of inadequately reinforced-concrete structures. It took the deep, heartfelt concern of involved parents to initiate the much-needed, thorough evaluation of the buildings. Even then, community leaders took two years to negotiate the labyrinth of state bureaucracy before the need for action was acknowledged and improved seismic safety laws were enacted for local district funding.

Another element that added to the mitigation success was the identification of "champions" at each level of the endeavour. The grassroots effort began with a few parents, who in turn found sympathetic allies in key settings such as City Hall, school site meetings, state agencies like the Seismic Safety Commission and the state legislature. At each juncture, every obstacle encountered was swiftly bypassed as the resourceful

advocates sought out other, more likely supporters. Over time, a network of interested people was established with the professional capacity and personal interest to sustain the long-term investment in a worthy cause: improved seismic safety for schools.

In Berkeley, however, the work did not end with the school safety programme. The seismic safety programme established in schools set the stage for a community-wide mitigation programme (Table 2.1).

After the school district successfully passed its USD 158 million bond measure, the municipal government followed suit and asked the voters in 1992, 1996 and 2000 for approval of special tax measures to further the hazard mitigation work. All Berkeley fire stations and many major city buildings have been seismically reconstructed. The community also built a new public safety building and emergency operations centre, and are making plans to provide a contingency water supply system.

The local investment in community safety is significant; Berkeley has one of the highest local tax rates in California, largely attributable to the hazard mitigation taxes. The community has approved over USD 362 million in taxes for these safety improvements over the last 12 years. The City Council has established fiscal incentive programmes for homeowners, which has prompted residents to make safety improvements in nearly 60% of single-family homes. Grants and loan programmes assist senior, low-income and disabled residents to retrofit their homes. These governmental efforts, totalling over USD 1 million annually, spurred private sector owners of large public assembly buildings to upgrade their facilities. The neighbouring campus at the University of California, Berkeley launched a USD 1 billion seismic retrofit programme for its instructional and administrative buildings. What began as a simple inquiry about school safety blossomed into a community renaissance.

Table 2.1. Timeline of Berkeley mitigation activities and key events

Date	Event	Results
1868	Hayward earthquake	Impact on Berkeley not known
1870	South Hall constructed at the University of California, Berkeley with steel straps to resist earthquakes	An early example of seismic-resistant design
1878	Founding of the City of Berkeley	
1898	Mare Island earthquake	Impact on Berkeley not known
1906	San Francisco razed by major earthquake	Damage in Berkeley is significantly smaller than damage in San Francisco
1911	Damaging earthquake near San José	Impact on Berkeley not known
1923	Major wild fire	Affects large area of current downtown Berkeley; hundreds of residences burn
1927	City of Berkeley adopts Uniform Building Code	Community conforms to building regulations and safety codes
1962	Flood in Berkeley environs	Damage builds awareness about need for damage prevention

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Date	Event	Results
1978	Enactment of floodplain ordinance	Flood Insurance Rate Maps are developed for the community
1980	Grass fire in hills consumes some Berkeley houses	City develops hazardous hills zones and regulates building materials in hills
July 1989	Establishment of Disaster Council	Establishment of monitoring and advocacy
Oct. 1989	Loma Prieta earthquake	Berkeley sustains minimal damage; event prompts local preparedness action
Dec. 1989	Establishment of unreinforced masonry (URM) building inventory, identification of risks and notification of owners	
Aug. 1990	Meeting of the Board of Education to review school engineering analysis	Life safety hazards found in seven out of 16 district schools
July 1991	Adoption of transfer tax rebate ordinance	Rebate is allowed for one-third of the real estate transfer tax up to USD 1 500 for seismic safety improvements to dwellings, retroactive to 17 October 1989
Mid-1991	Establishment of fee waiver programme	Permit fees are waived on residential seismic safety projects
Oct. 1991	East Bay Hills Fire	Over 3 200 residences destroyed in area; 67 in Berkeley. Community mobilises mitigation response
Oct. 1991	Creation of Special Assessment District for Berkeley Hills	Assessed USD 50/parcel/year for fire safety programmes
Oct. 1991	Adoption of strengthened requirements for hazards hill fire zones	Stricter standards for roofing and other building materials
Dec. 1991	Establishment of mandatory URM retrofit programme	To date nearly 600 out of 700 URMs have improved seismic resistance
June 1992	Approval of State bill for school funding	Berkeley and urban districts eligible for state money
June 1992	Approval of Measure A	USD 158 million made available for school safety programmes
Nov. 1992	Approval of Measure G	USD 55 million made available for municipal safety improvements
Mar. 1995	Meeting of the Seismic Technical Advisory Group	Expert panel of advisors provides technical guidance to city on seismic issues
July 1996	Development of soft-storey and tilt-up building inventories	A ballot measure was defeated in 2002 aiming to raise funds to reduce risk in soft-storey structures
Nov. 1996	Approval of Measure S	USD 45 million made available for seismic retrofit of city buildings
Aug. 1997	Establishment of the University of California's SAFER Programme	Ten-point action plan for the university's USD 1.2 billion reconstruction programme
Dec. 1999	Awarding of FEMA Community of the Year for mitigation work	Recognised nationally as model for mitigation efforts
Nov. 2000	Approval of Measures AA and Q	USD 116.5 million for school safety programme; tax measure for safety efforts
Feb. 2003	Completion of CGS hazard maps	New buildings are required to meet strict design and construction standards if they are located in potential liquefaction or landslide areas

CHAPTER

3

SEISMIC SAFETY OF SCHOOLS IN ITALY

Mauro Dolce

Laboratory for Material and Structural Testing, University of Basilicata, Italy

Abstract: This paper examines the possible causes of collapse of a primary school in San Giuliano, Italy, in the 2002 Molise earthquake, which killed 27 students and one teacher. It also considers the general sources of seismic vulnerability of school buildings in Italy prior to the introduction of new seismic zonation and new seismic codes in 2003. In addition to incomplete seismic zonation and inadequate seismic codes, the author cites irregular architectural and structural layout of schools, low standards of construction execution and maintenance, and dangerous structural changes implemented over the lifecycles of schools as the primary causes of vulnerability of the country's school buildings.

Introduction

The damage caused by the Molise earthquake in 2002 drew attention to an ongoing problem in Italy with regard to seismic vulnerability: many of the municipalities affected by the earthquake were not classified as seismic areas, and structures were built without seismic provisions. Therefore, the damage exceeded that which would be expected in an earthquake of moderate magnitude. The collapse of the primary school Iovene in San Giuliano, where 27 children and one teacher died, alerted the country to the vulnerability of critical structures.

However, the problem of the seismic vulnerability and risk of critical structures, especially of buildings where important public functions are carried out (such as schools and hospitals), had been addressed in an extensive investigation carried out in 1996: the *Lavori Socialmente Utili* (LSU) project, a government project aimed at improving the knowledge of seismic risk in southern Italy. A total of 20 420 school buildings were surveyed, from pre-primary to secondary schools. Several useful statistics were gathered and preliminary analyses conducted in the first evaluation of their seismic vulnerability.

In the first half of 2002, before the Molise earthquake, a national research project – GNDT-SAVE – was also initiated. The aim of the project was to use all available data to improve the knowledge of the vulnerability of public buildings, especially schools. This project is still in progress, and important findings are currently available (Dolce and Zuccaro, 2003).

After the Molise earthquake, national attention focused on the problem of high seismic vulnerability of schools. The National Civil Protection Department immediately tried to understand the general causes of this problem and proposed the development of a new seismic zonation of the Italian territory and a new seismic code. Five months after the earthquake, an Ordinance of the Prime Minister (Ordinance 3274, 2003) stated that the seismic vulnerability of all public strategic buildings, including schools and hospitals, as well as the infrastructure in medium and high hazard areas, had to be evaluated within the next five years in order to start a seismic rehabilitation programme. An annex in the ordinance containing new seismic zonation and a new seismic code was also enforced. In the meantime, the evaluation of the seismic risk of schools was initiated independently by several local administrations, mayors and presidents of provinces, all of which oversee secondary schools.

Causes of the collapse of the San Giuliano Primary School

There are several reasons why most Italian schools are vulnerable, or highly vulnerable, to earthquakes: the inadequacy of seismic zonation and of seismic codes prior to 2003; the architectural layout of schools; the low level of maintenance of schools; the dangerous structural changes implemented over the lifecycles of schools; and the low standard of construction execution. It is not yet clear the extent to which each of these factors contributed to the collapse of the San Giuliano Iovene school, but the following points should be noted:

- The area of San Giuliano was not classified as a seismic zone, although recent studies indicate that earthquakes with 0.165 g maximum peak ground acceleration (PGA) (MMI = VIII-IX) are expected with a 475-year return period. Therefore, seismic criteria were not considered in the building design. In addition, recent works – such as the partial addition of one storey – completed in August 2003 did not require any seismic upgrading, only verification for vertical loads. According to the new 2003 seismic zonation, San Giuliano is now classified in Zone 2 (Ordinance 3274, 2003).
- The low standard of construction execution also contributed to the collapse. The school was constructed using poor quality masonry and with a heavy reinforced-concrete roof (Figure 3.1) (Augenti *et al.*, 2004).
- The increase of masses caused by the addition of a second storey may have contributed to the collapse.

Figure 3.1. Rubble stones, reinforced-concrete kerb in the ruins of the San Giuliano primary school

In addition, significant soil amplification occurred at the school site (Dolce *et al.*, 2004). An analysis of the damage distribution resulted in the allocation of the 8th grade of the European Macroseismic Scale (EMS), or equivalent intensity (MMI) of X, to the site of the school; and lower grades of the 6th EMS to adjacent areas. Average amplification factors as high as 1.6 to 1.8 were evaluated through careful and detailed analyses of experimental geological, geotechnical and geophysical data (Baranello *et al.*, 2004). These results were also compared with the amplification factor obtained during the aftershock events of magnitudes greater than M4.0. In the final microzonation map for the reconstruction, the school site was assigned an amplification factor of 1.6.

It can be concluded that all of the usual vulnerability factors contributed to the collapse of the San Giuliano school, and that the event was unexpectedly strong due to soil amplification.

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Causes of inherent seismic vulnerability and risk of school buildings in Italy

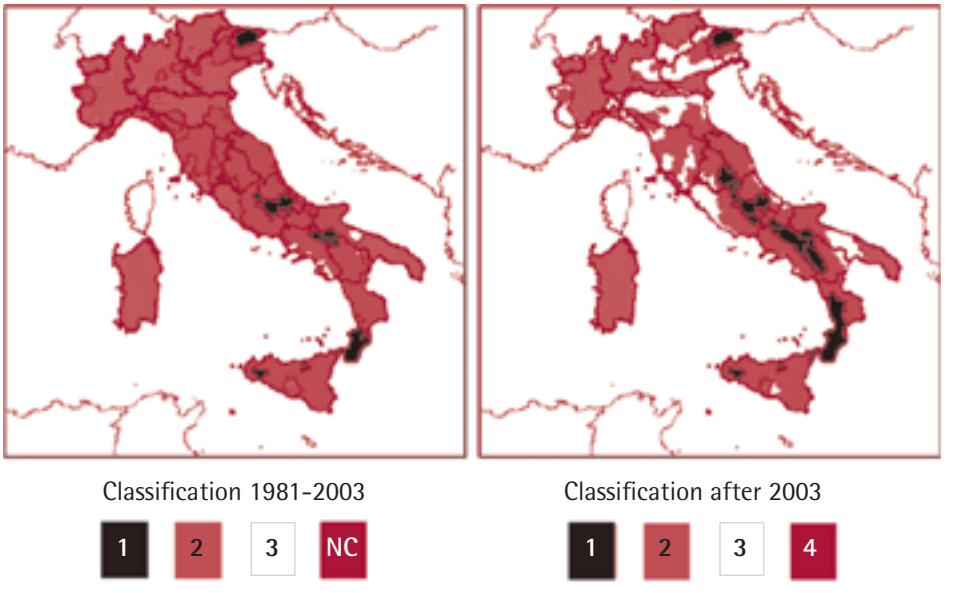
Several general sources of seismic vulnerability in Italy must be considered when examining the seismic risk of existing school buildings.

Seismic zonation

Seismic classification in Italy has evolved considerably over the last century. The first zonation – in which only the most damaged areas were classified – was made after the 1908 Messina earthquake, resulting in the first Italian Seismic Code in 1909. Until 1980, similar regulations were enforced after each damaging earthquake. This meant that for much of the 20th century, only the areas that suffered significant seismic damage – *i.e.* only 25% of the Italian territory – were classified into seismic zones, and that the constructions built in these classified zones were designed according to the Italian seismic code in force at the time.

In 1981, after the 1980 Irpinia earthquake, a more comprehensive and rational seismic zonation was undertaken, taking into account the Italian seismic history of the past several centuries. At this time, about 45% of the territory was classified as seismic zones 1, 2 and 3, although no seismic provision was made for constructions in the remaining 55% of the country. Over the next 20 years, understanding of Italian seismic hazard advanced rapidly, resulting in a new seismic classification proposal in 1998, whereby about 70% of the territory was classified into these three seismic zones. In 2003, based on this proposal, the new national classification was officially implemented (Figure 3.2). The classification recognised that all Italian territory is subject to seismic hazard and introduced a new, low seismicity zone to cover the remaining unclassified 30% of the territory.

Figure 3.2. Seismic classification of the Italian territory



Seismic codes

In 1974, the Law N. 64 established rules for updating seismic codes. In 1986, for the first time, the problem of existing constructions, and not only the design of new buildings, was addressed in a seismic code. Unfortunately, code updates did not follow the actual developments in research on seismic design, and the Italian seismic codes did not change significantly until 2003. The earlier codes were mainly concerned with the strength of structures, while neglecting the attainment of an adequate ductility, which allows structures to survive strong earthquakes. In addition, until 1996, no provision existed in the code to prevent excessive flexibility, which can cause damage to non-structural elements of the construction in low to medium intensity earthquakes. In practice, Italian buildings designed according to pre-1996 seismic codes usually have deficiencies that result in a high risk of collapse in strong earthquakes and high risk of heavy non-structural damage in low to moderate intensity earthquakes.

According to LSU project data, in southern Italy, about 70% of reinforced-concrete buildings and more than 95% of masonry buildings were constructed before 1980. This means that few of the reinforced-concrete buildings and practically no masonry buildings were designed according to seismic design criteria, making the risk of collapse very high. For reinforced-concrete buildings, the design for vertical loads often leads to a structure with resistant frames in one direction only. In this direction, the structure can be sufficiently rigid, with extra-strength to withstand low and moderate intensity earthquakes; but in the weak direction there are no frames or merely external frames, resulting in high flexibility with little extra strength available to withstand seismic actions. As stated above, excessive flexibility causes great damage to non-structural elements (*e.g.* internal and external infill panels), even in low intensity earthquakes.

Architectural layout

A major cause of vulnerability of school buildings is the architectural and structural layout. Most schools are composed of a number of different teaching areas, such as traditional teaching rooms, laboratories, gymnasiums and theatres. If these different areas are located in the same building, then the building will be irregular and/or articulated in shape, both in plan and in elevation. Shape irregularity, which often results in structural irregularity, is an unfavourable feature of buildings in seismic areas, as the shape determines the concentration of damage in specific parts or storeys of a building, and may even cause collapse. In addition, school buildings need wide windows to light up teaching rooms and gymnasiums, and wide doors to facilitate the passage of students. Most rooms are also large and do not have structural obstacles (*i.e.* columns). However, the effect of these large spans and wide openings on the structural layout of masonry buildings is that the masonry-resisting panels are often too slender with inadequate resistant area, in relation to the heavy loads that they must carry, to withstand strong earthquakes.

Sometimes, long corridors are placed along the building, thus completely separating the façade from the remainder of the masonry structure. For reinforced-concrete buildings, the wide openings in the infill panels can cause irregularity in the plan (torsional effects)

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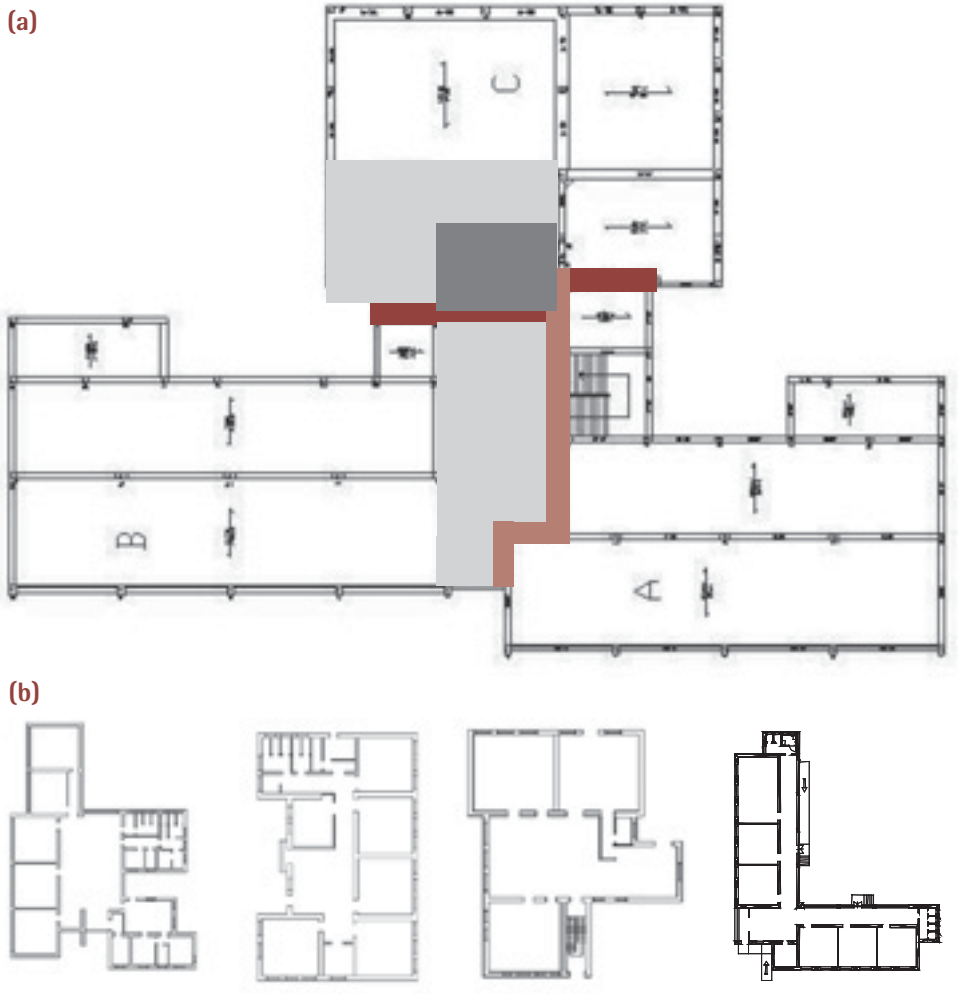
Figure 3.3. Typical irregular layout of single and multi-storey schools

(a) Structural layout of a reinforced-concrete multi-storey school at Campobasso
(b) Layout of three single-storey schools with masonry structures



and in elevation (soft storey), creating local weaknesses and unaffordable ductility demand. The excessive inter-storey height, commonly seen in gymnasium and theatre structures, increases the flexibility of the structure and the danger of collapse of infill panels in reinforced-concrete structures in low intensity earthquakes. Figure 3.3 presents the planimetric layout of a reinforced-concrete multi-storey school and masonry single-storey school, showing the plan irregularity, the wide windows and the large span that is characteristic of school buildings. Figure 3.4 provides an example of schools with wide openings and large inter-storey height.

Figure 3.4. Wide windows, large inter-storey drift, irregular shapes of single- and multi-storey schools

Standards of construction execution and maintenance

Other causes of vulnerability are the low standards of construction execution and maintenance. Concrete used in pre-1980 buildings is often of bad quality and of less than the design strength. Steel corrosion and collapse of concrete cover are some of the structural consequences of low maintenance standards in reinforced-concrete structures. Inadequate bar anchorage and lap splicing are quite common defects in old reinforced-concrete structures, in addition to poor execution of concrete casting. Floor slabs are often inadequate – *i.e.* not sufficiently stiff and resistant – for distribution action in reinforced-concrete and masonry constructions. In masonry buildings, structural masonry often comprises natural irregular blocks and low quality mortar, resulting in low strength. In addition, inadequate connections between masonry walls and the floor slabs or roof do not guarantee good overall behaviour of the building. Adjacent buildings often have poor separation joints. Figure 3.5 provides examples of these construction and maintenance defects.

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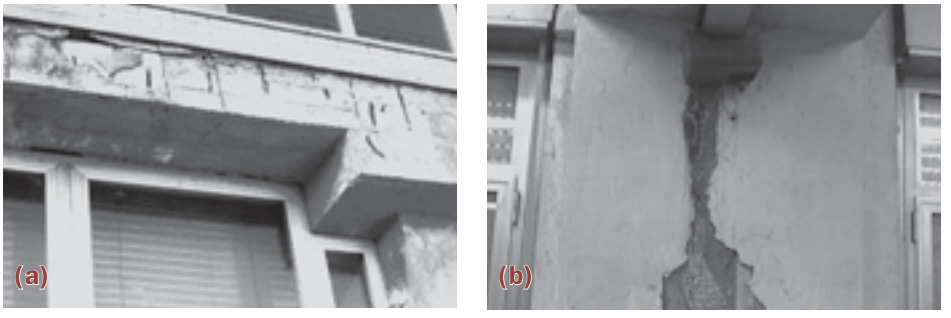
Figure 3.5. (a) Deterioration due to no maintenance (b) Inadequateness of separation joints



Structural changes to buildings

Changes that have been made to a building during its lifetime – such as the addition of new storeys, openings or a heavy roof – are an additional cause of vulnerability, particularly in masonry buildings. Such changes introduce irregularities and often result in an increase in mass and a decrease in resistant area, thus increasing the seismic vulnerability of the building.

Sometimes, schools are located in private buildings that are designed to serve as apartments. In addition to the difficulties involved with fulfilling the functional requirements of a school and the inadequateness of such buildings for vertical service loads – in Italy private buildings are designed for 2 kN/m^2 service loads while school buildings are required to carry 3.5 kN/m^2 – vulnerability is also increased by the number of storeys and the less conservative design (*i.e.* higher compressive stresses in columns). Research carried out for the Provincial Administration of Potenza showed that about 15% of the 78 school buildings examined were private; three of these buildings were among the five buildings with the highest seismic risk.

On the other hand, a specific common feature of school buildings is that they have a limited number of storeys; "low schools" typically have no more than two storeys. It is not unusual for a designer to be over-conservative with regard to service loads (*e.g.* columns are larger than necessary), even when the structure is not designed to withstand seismic actions. This allows an extra safety margin with respect to seismic action. In general, considerable variability in seismic resistance can exist between different schools, and in the same school on different storeys and in two orthogonal directions (Figures 3.6, 3.7, 3.8 and 3.9).

These causes of vulnerability can also be considered according to the type of school, by level of education:

- *Upper secondary schools* are tall, large, reinforced-concrete buildings of relatively recent construction. Teaching rooms, laboratories, gymnasiums, etc. are often located in separate buildings, and each has different structural characteristics.

- *Lower secondary schools* are of intermediate size and number of storeys. The type of structure depends on the age of the building.
- *Primary schools* normally have one or two storeys and rarely more than three storeys. The type of structure depends on the age. Pre-1940 buildings often have a masonry structure.
- *Pre-primary schools* are small with a single-storey masonry structure.

Figure 3.6. Reinforced-concrete buildings: Minimum PGA resistance at the various storeys and in X and Y directions

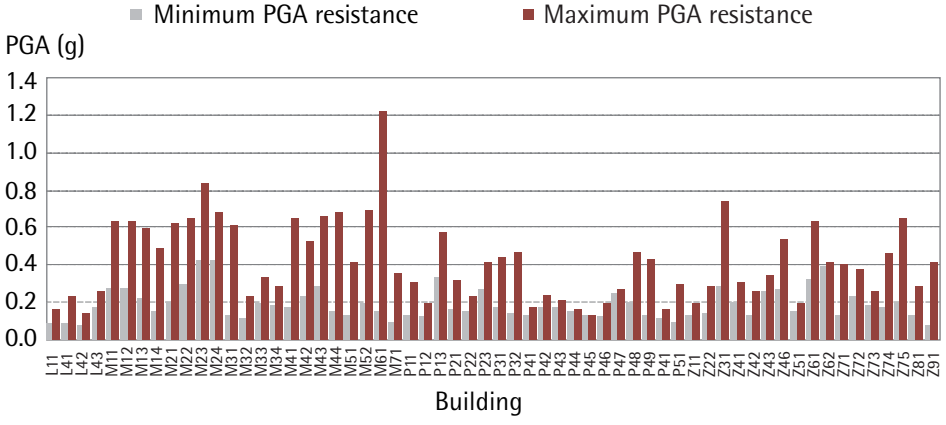
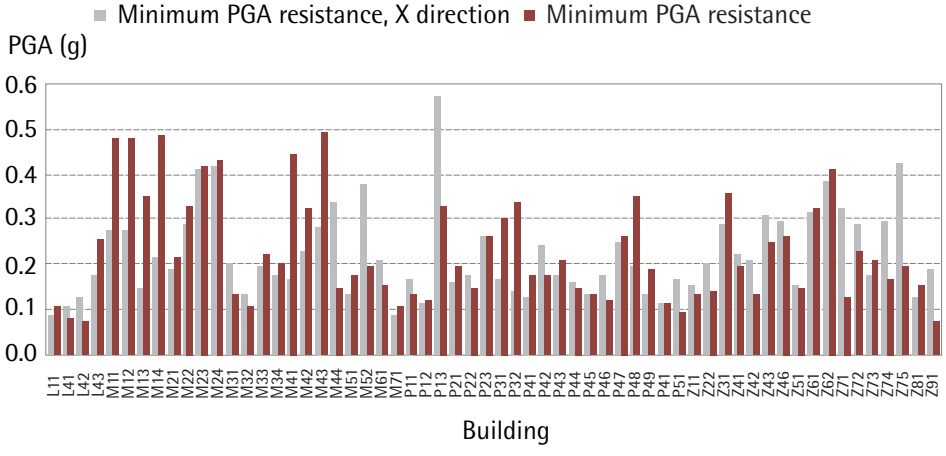


Figure 3.7. Reinforced-concrete buildings: Minimum PGA resistance in the X and Y directions



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Typical condition of school buildings

To better understand the typical condition of upper secondary schools in Italy that are not designed according to seismic criteria, the conclusions of the final report of the investigation on 78 school buildings in the Potenza Province are presented below (see also Figures 3.6 to 3.10).

- 26 buildings have a *seismic vulnerability* that will result in collapse in intensities (MMI) of VIII (PGA = 0.137 g). Ten of these buildings also have poor overall structural quality, which increases the vulnerability of these structures; 13 buildings are of average structural quality; and one has a good structure.

- Concerning the *vulnerability of non-structural elements*, 12 buildings are classified as high-vulnerability and four schools as low-vulnerability in terms of non-structural elements.

- Of the buildings with *better theoretical performance*, 21 schools could collapse in earthquakes that have an intensity greater than IX (PGA = 0.2 g). However, four of these buildings have poor overall structural quality, 12 schools have average structural quality, and three buildings have a good structure. Finally, nine of the 21 best-performing buildings are highly vulnerable with regard to non-structural elements, eight buildings are of average vulnerability, and nine buildings are of low vulnerability.

- Concerning *seismic risk*, nine buildings have a return period of less than 100 years, which means a 10% probability of occurrence in ten years; 26 schools have a return period of less than 200 years; and for 28 buildings, the return period of collapse in an earthquake is more than 500 years.

Figure 3.8. Masonry buildings: Minimum and maximum PGA resistance at the various storeys in X and Y

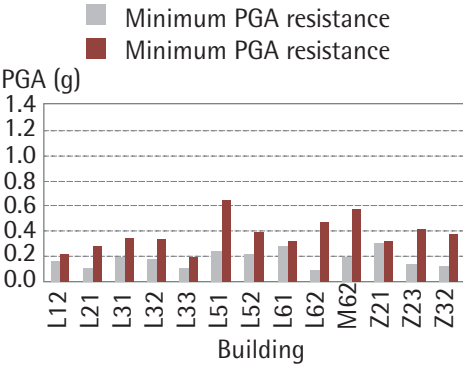


Figure 3.9. Reinforced-concrete buildings: Minimum PGA resistance in the X and Y directions

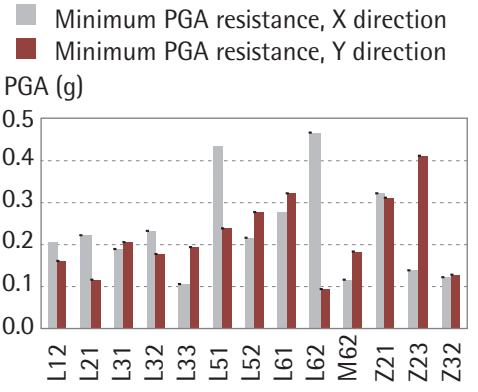
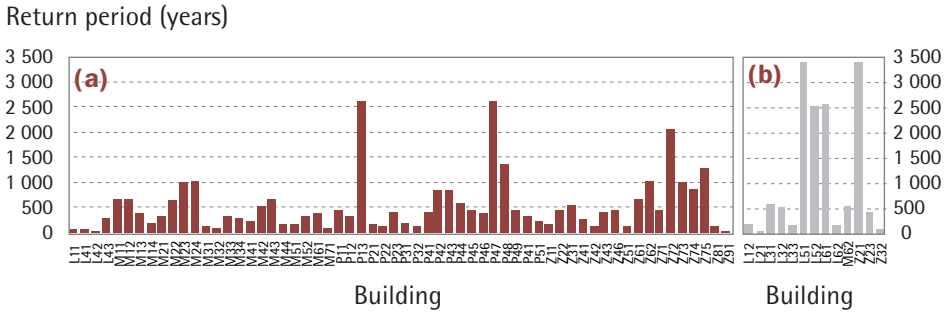


Figure 3.10. Return period of the collapse earthquake of (a) reinforced-concrete and (b) masonry buildings



Measures to reduce seismic vulnerability and risk of school buildings

Two different problems must be considered:

- How to guarantee adequate safety in *new* school buildings.
- How to improve the safety in *existing* buildings.

Guaranteeing adequate safety in new school buildings involves choosing an acceptable level of risk, compared to other risks inside and outside the school. Currently, the Italian code prescribes a 20% increase in the design action with respect to normal buildings, such as apartment buildings. The additional cost is small compared to the cost of a normal seismic design. However, new protection strategies and technology, such as seismic isolation, allow for much higher safety levels with respect to collapse and avoid damage to non-structural elements. The extra cost is minimal, depending on the number of storeys, but the benefits outweigh the costs. In the opinion of the author, the use of seismic isolation should be a priority when constructing new schools, at least in high seismic risk areas. The level of technological sophistication of the isolation system allows for adjustment to specific conditions. Evidently, other issues relating to construction standards must also be carefully considered; good execution is as crucial as good design, irrespective of seismic protection.

Existing schools present a more complicated problem. As seen above, most schools are inadequate from the perspective of safety; but the level of risk varies between schools. The first step is to improve the knowledge of risk levels in school buildings. This is not an easy task and cannot be addressed using current vulnerability methodologies for ordinary buildings, due to the diversity of school building types and the variability in safety levels within the same building. On the other hand, a good evaluation requires much time and money, which is probably incompatible with the urgency and the dimension of the problem. Intermediate assessment procedures are required in order to select the most at-risk school buildings.

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Conclusion

It is difficult to measure the relative importance of each of these seismic vulnerability factors; each factor can affect seismic risk differently in different schools and the occurrence of two or more factors can dramatically increase the seismic risk of a school building. Importantly, existing and new schools present different problems and may require different approaches to reducing seismic risk.

In new school buildings, correct application of modern seismic codes, updated zonation and microzonation maps, and good standards of execution should guarantee the desired level of safety. However, seismic performance can be significantly improved through the use of modern protection techniques, such as seismic isolation, which has negligible or little extra cost.

Existing buildings are more complicated. First, rapid and reliable vulnerability assessment must be carried out to identify the most vulnerable buildings. Second, a target safety level must be identified based on the remaining lifetime of the building and the necessity of retrofitting or rebuilding the school. Finally, quality design and execution are critical to good new construction. In any case, modern technologies can, even in the case of retrofit, help to raise safety levels.

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CHAPTER

4

OBSTACLES TO IMPROVING SEISMIC SAFETY OF SCHOOL BUILDINGS IN TURKEY

Polat Gülkan

Disaster Management Research Centre, Middle East Technical University, Turkey

Abstract: This paper examines the process of school design in Turkey. It describes the responsibilities and authority of the government bodies involved in the construction, maintenance and repair of school buildings, as well as past and current legislation and code enforcement concerning construction practices. These elements are described within the context of the factors impeding quality construction in both public and private buildings. An appendix provides additional information on damage to school buildings during the 2003 Bingöl earthquake.

Introduction

There are currently 18.6 million students, 680 000 teachers and 60 000 school buildings in primary and secondary education in Turkey. The country is earthquake-prone, and the seismic safety of school buildings is a constant concern for public authorities and parents. That such fears are not unfounded was recently confirmed when many school buildings were seriously damaged in the 1 May 2003 earthquake in Bingöl, a city of 70 000 inhabitants in the east of the country (Figure 4.1). Three relatively new schools collapsed when the ground storeys were sheared off. A dormitory building next to a school also collapsed, killing many children as they slept (see Appendix for a discussion of the seismic performance of school buildings in the Bingöl earthquake).

Figure 4.1. The Republic of Turkey

The ensuing public outrage vigorously questioned the seismic safety of the country's school buildings. Public buildings, including school facilities, are under constant scrutiny in the wake of earthquakes because there is a widespread conviction that these buildings experience heavier damage than privately-owned property. Although randomly sampled statistics on the number of affected structures may not support this perception, it is worth

noting that many buildings are not quickly reoccupied after the event, despite the fact that a national public body exists to conceive, design, supervise, operate and maintain these buildings and that the budgetary appropriations for replacing or retrofitting government-owned property are considerable.

This paper addresses this issue by examining the government process by which a new school is created, from the completion of feasibility studies to the delivery of the finished product to the school district concerned. It also analyses the deficiencies of the current system and suggests improvements in the interest of enhanced safety. A description of the technical causes of building failure following the severe earthquake in Bingöl is provided in the Appendix.

Construction of public facilities

Turkish Ministry of Public Works and Settlement

The Constitution of the Republic of Turkey requires that areas of responsibility and authority be clearly defined for every major sphere of activity. For example, the Ministry of Health is the only public body with the authority to serve the public's needs in the health domain. This also applies to the construction of new public facilities, which is the designated authority of the Ministry of Public Works and Settlement (MPWS).

With the exception of public construction organised by the Ministry of National Defence – which oversees the construction of all facilities and infrastructure required by the Armed Forces – and the Ministry of Transportation – which builds rail and telecommunications facilities – the MPWS is responsible for constructing, maintaining and repairing all public buildings in the country. A Decree concerning the "Organisation and Responsibilities of MPWS" No. 180 (dated 14.12.1983; revised by Decree 209) defines the competencies of MPWS. With reference to disasters, the role of MPWS is to:

- Provide standards for urban plans, infrastructural systems, public services, etc.
- Determine mitigation methods and rehabilitation aid in both pre- and post-disaster situations.
- Keep records of contracting firms that serve the public sector.
- Determine urban plan upgrading methods as necessitated by disasters.

The MPWS is composed of three bodies:

- *The General Directorate*[1] *of (Public Building) Construction Affairs* is responsible for the planning, tendering and management of construction programmes for all types of public buildings in the country. State hospitals, schools and other public buildings are built according to the standards and procedures developed by this body.
- *The General Directorate of Disaster Affairs* co-ordinates emergency aid, organises

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temporary housing, determines hazard areas and proposes mitigation measures to minimise life and property losses. This body is charged with preparing and approving hazard maps to be employed by urban development plans "with ministerial consent".

- *The General Directorate of Technical Research and Implementation* determines building materials and methods, design principles and height of buildings in high-risk areas. Municipal and regional plans involving two or more municipalities are approved by this body.

The MPWS also has a number of designated "affiliated" bodies:

- Under-Secretariat for Government Housing.
- Land Office.
- General Directorate of State Highways.
- General Directorate for Property Registry and Cadastral Plans.
- General Directorate of Bank of Provinces.[2]

The General Directorate of (Public Building) Construction Affairs

To understand the interplay of administrative forces that combine to create school buildings, a closer examination of the General Directorate of (Public Building) Construction Affairs (GDCA) is required. The GDCA ensures that all public buildings – school buildings are among the primary responsibilities of the GDCA – are adequately maintained, and that new facilities and buildings are planned according to the requirements specified by other government agencies. The GDCA is also responsible for supervising construction financed by the Provincial Special Authorities, which are agencies with annexed budgets, and municipalities. Public housing and post-disaster reconstruction are planned and contracts for their realisation are tendered by the GDCA. A large budget is allocated each year to the GDCA.

The country is subdivided into 81 administrative units or "provinces". The governor, an appointed civil servant, is the chief administrator of each province, and each province has Ministry of Public Works and Settlement (MPWS) offices, which are also managed by the governor. Thus, the governor is responsible for the administration of the GDCA, with the assistance of the local office.

A change in the established roles and responsibilities for planning, designing and contracting public schools occurred in 1997 when the length of compulsory primary education in Turkey was extended from five to eight years. To fulfil the requirement of the new law, where possible, all five-year primary and three-year lower secondary schools were combined. However, even before the law was introduced, many school buildings were used in two shifts; children were divided into those who attended school only in the morning, and those who attended in the afternoon. When the new law was introduced, combining primary and lower secondary levels resulted in an acute shortage of physical space.

In 1998, the Ministry of National Education made an ambitious decision to eliminate all multi-shift education, and to reduce class size to 30 students. This resulted in a huge increase in workload for the GDCA, creating funding problems[3] as thousands of new buildings needed to be built quickly and new designs created for the combined facilities. The Government of Turkey responded to the new situation by charging one of its own agencies – the Division of Investments and Facilities (DIF) of the Ministry of National Education – with conducting feasibility analyses, planning, designing and contracting services for the new generation of school buildings. The DIF appointed private consultants to oversee the design and construction of the new facilities.

In many rural or remote locations, it was not feasible to build a single school building for only a small number of children. In addition, transportation and climatic conditions often adversely affect school attendance. Thus, boarding schools – known as Regional Boarding Primary Schools or YIBO in Turkish – were established to serve rural settlements. When such schools are close to or on the periphery of urban settlements, only those students who live in remote rural areas are permitted to attend as full boarders and other students must use public transport to travel to and from school. These schools are known as Pension-Type Primary Schools or PIO in Turkish.

The DIF also developed standard designs for sports facilities, multi-purpose assembly halls for cultural activities, computer and science laboratories, language laboratories, music halls, workshops and libraries. During the initial phase of this project, some 360 new school complexes, translating into several million square metres of built space, were tendered nationwide.[4]

Legislation and code enforcement

Law of Contract Tenders No. 2886

In 2002, the Law of Contract Tenders No. 2886 was superseded by Law No. 4734, which established a new agency called the State Contracts Establishment or KIK in Turkish. From its implementation in 1983, Law No. 2886 has provided an accurate representation of how goods and services were procured in Turkey.

Contract law applies to all government bodies, administrations with annexed budgets, municipalities and provincial special administrations concerning procurements of goods and services, involving contracting surveys, planning, design, construction, supervision and consultant services for public buildings. Contract law regulates the construction, fabrication, repair, installation and refurbishment of physical facilities.

According to Law No. 2886, after preparing estimated costs based on unit prices, agencies were required to submit proposals from contractors to the Contract Bid Evaluation Commission, appending any supplementary specifications to the contract document package. The proposals would include the discount proposed by the contractor. Offers could be made in the form of closed envelope, open bids, negotiated bids or competition bids. For building construction, the most common form is the closed envelope bid.

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While Article 28 of Law No. 2886 required the commission to select the "most suitable" offer, in practice this was interpreted as accepting the lowest bid. For public construction contracts, there were frequent complaints of fraudulent practices, fixed evaluations or offers, low bids subsequently padded to cost over-runs, and negligence of supervisory personnel at the expense of quality.

Following the destructive Kocaeli and Düzce earthquakes in 1999, the Government of Turkey obtained a loan from the International Bank for Reconstruction and Development, which is the primary lending component of the World Bank. One of the terms of the agreement was the replacement of Law No. 2886 with a new legal framework for the management of institutional contracts. In theory, the articles of the new law, No. 4734, would lead to improved construction practices.

Development Law No. 3194

In 1958, a ministry was established to study and administer the natural hazards problem in Turkey, with the aim of reducing future losses. This ministry was charged with enforcing both the Development Law and the Disasters Law. Development Law No. 3194 is the principal legal instrument governing building design. Several articles in Part IV of this law relate to supervising building construction. The law holds municipalities – or governorates for buildings located outside urban areas – responsible for project supervision. Construction supervision is entrusted to "engineers of record".[5] For certain classes of buildings located outside municipalities, non-holders of engineering degrees have been allowed to serve in this capacity. There are other exceptions granted in the case of rural settlements.

Holders of deeds or parcel assignment certificates submit petitions to the relevant municipality or governorate to acquire building permits. In addition to the certificate of land ownership, the applicant must submit architectural, structural and mechanical designs, and a schematic drawing of the building's location. The law states that local governments are responsible for design verification, although some municipalities have transferred this duty to the local branches of the Chambers of Civil Engineers or Architects through informal agreements. In the opinion of the author, this is a dangerous and ultimately illegal practice because the law clearly holds the local government liable for ensuring the life and property safety of the people it serves. While technical offices of municipalities function as "rubber stamps" for approval work, the qualifications of those controlling designs is not made clear. In addition, the Development Law does not specify the measures to be applied in the case of approval of an erroneous design. According to legal precedent, design engineers have been held responsible, despite the fact that others may have approved the design.

Development Law No. 3194 requires the engineer of record to report any design violations made by the contractor to the municipality or governorate. When such a violation occurs, it is incumbent upon the local government to verify that it has occurred, to seal the construction site, to halt construction activity and to order the owner to take corrective action. If corrective action is taken within one month, then the order to halt work is lifted. If the owner does not comply with the order, then the building permit is revoked and the building is torn down at the owner's expense. There are a number of penalties for the contractor or the engineer if certain provisions of the law are not fulfilled. In general, the penalty clauses of the law are not sufficiently enforced, and violations are tolerated. An important omission in the law is the absence of guidelines for engineers on supervision of construction. In addition, the engineer is only required to report violations and has little influence over the construction process. Importantly, although the engineer of record is charged with the protection of the rights of the property owner, in the case of private build-sell agreements between parcel owner and contractor, the engineer of record usually receives salary from the latter. In addition, municipalities and governorates are known to be understaffed, and cannot fulfil the task of keeping registers for contractors active within their jurisdictions.

In theory, construction of public buildings should be immune to many of the deficiencies that are widespread in private property construction. The MPWS employs many engineers and architects who are responsible for ensuring that construction is done properly. Figure 4.2 shows the evolution of private and public building construction in Turkey. The rapid turnover of personnel in provincial offices and the general lack of awareness that small errors can seal the fate of buildings in earthquakes have generated a generally sub-standard building stock.

Summary of factors impeding quality in public construction

The factors that have negatively influenced the quality of public and private construction in Turkey are summarised below[6] and in Figure 4.3.

General problems

- No formal qualifications are required for building contractors.[7]
- No formal proficiency requirements are needed for engineers or architects.
- Preference for accepting the lowest offer for public tenders results in low-price, low-quality products.[8]

Supervision of projects

- Technical expertise, resources and knowledge of routine methods and practical standards of supervision in local authorities are insufficient to carry out reliable project supervision.
- No higher authority exists with the authority to inspect and exact penalties on local authorities that do not fulfil their supervisory function.

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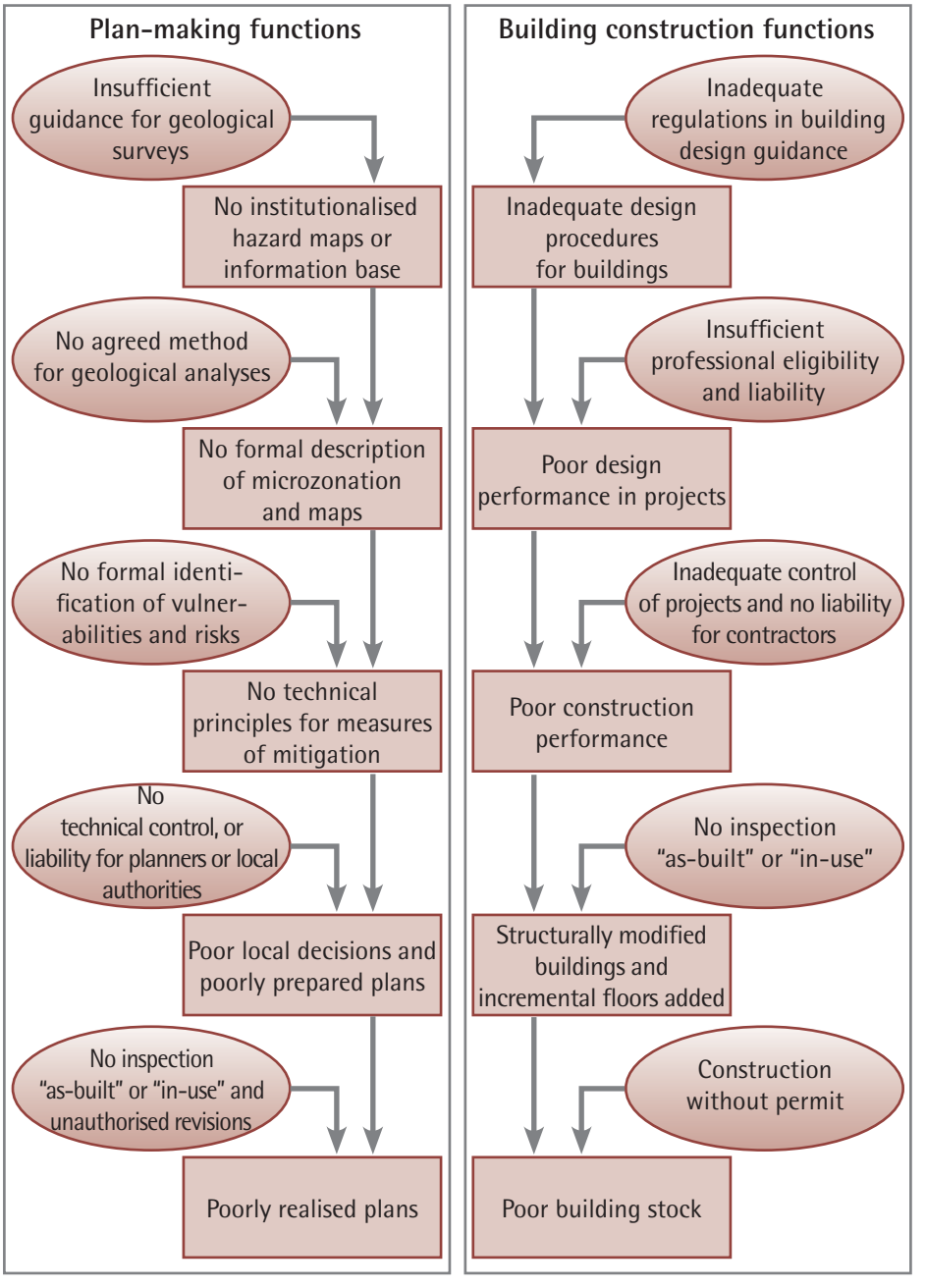
Figure 4.2. General management structure for building construction in Turkey

Process	Building type: Single, detached building (business or rental facility)	Building type: Collective housing through co-operatives	Building type: Land in exchange for share of property (build-sell)	Approval mechanism
	Body responsible for overseeing process			
1. Establish land ownership	The Deeds Bureau or Assignment/Lease Bureau Acquisition of the deed or assignment paper			Deed and/or expropriation through eminent domain
2. Make financial arrangements	Individual	Collection of money from members	Private agreement between parcel owner and contractor	Budget and funds
3. Conform with development plan	Municipality or Provincial Office of Ministry of Public Works and Settlements			End user applies with deed and petition
	Deed holder applies	Deed holder or co-op board applies	Deed holder applies	
	For land with no plans, new plans must be attached			
4. Design: architectural, structural, installations	Design offices (engineers and architects)			Sub-contracted, with in-house verification or design
5. Obtain building permit	Municipality or Provincial Office of Ministry of Public Works and Settlements An "engineer of record"[5] must be designated			
6. Prepare for construction and contracting	Private award to contractor, call for tender or turnkey arrangement		Private arrangement	Contracts and legal procedures
7. Construct	Contractor, sub-contractor and engineer of record. The municipality checks only the foundation, sub-basement and storey elevations			Contractor, sub-contractor and site engineer
8. Supervise, progress payment and carry out quantity surveys, work plan and conformance check	Private supervisors As agreed between parties			Agency units, supervisory units, engineer of record
9. Establish engineering responsibility	The engineer of record is designated when the permit is awarded on paper only. The law holds the contractor responsible, even for design errors. The contractor is often able to pass responsibility on to the site engineer			True responsibility does not exist: civil employees cannot be held liable
10. Obtain occupation permit: delivery of works to owner	The Social Security Agency must be consulted regarding workers' compensation; and municipality, public health, fire bureau, architectural and engineers chambers and utility connections must be consulted upon completion of project			Supervisory unit within agency grants certificate of completion

Figure 4.3. Obstacles to good quality construction in Turkey



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- No liabilities are imposed on the designer or on the approving authority in case of errors or damages inflicted on any party.
- The practice of "Chamber visa" has no legitimate basis and does not secure the necessary standards.

Construction supervision

- An "engineer of record" – who is required by law to be on the site – is often paid by the developer, only needs a basic diploma and cannot intervene in the construction process. Professionals such as engineers, architects and city planners could act in this capacity, although their qualifications are not appropriate for the job.
- Assignment of a construction site inspector is not practiced, even for larger projects.
- According to Article 42 of the Development Law, developers can incur pecuniary penalties for deviating from projects. However, this law is not effective.
- Contrary to all provisions envisaged in the law, unauthorised buildings or those constructed without permission can be connected to water, power and communications without any party incurring liabilities.
- Local authorities have no means by which to follow unauthorised development, other than through the efforts of private informers.
- The legal process by which unauthorised or contravening buildings can be demolished is very long: at least one year.
- Local authorities lack the expertise, means and tools by which to remove buildings.
- No legal liability can be obtained for prospective damages and losses inflicted by production failures in buildings, other than the provisions in the Law of Obligations.

Conclusions

This article has examined the causes of inadequate building quality in Turkey, including school buildings. It would appear that many of the tens of thousands of school buildings and other educational facilities in the country are hazardous to their occupants. Even if an imported version of a "Field Act" were established, replacing or retrofitting buildings would be expensive and intrusive. The author believes that an incremental approach to improving the general quality of construction, involving the use of far stricter requirements for school buildings, would provide a better long-term solution.[9]

Notes

1. A General Directorate is similar, for example, to an "agency" in the United States administration system.

2. The General Directorate of Bank of Provinces is a public agency that provides financing to the country's municipalities for their essential infrastructure construction. Turkey has some 3 500 municipalities.

3. Nation-wide pledge campaigns from private citizens raised much of the money required to finance the new schools. Turkey has an established tradition for this type of charity.

4. The three school buildings that collapsed in Bingöl were of this generation.

5. This is the author's translation only. The phrase can also be rendered as "the technically responsible party", but the author has chosen to use this more familiar expression.

6. The author is indebted to Murat Balamir for this pithy list.

7. The MPWS has instituted a system of classifying contractors according to the size and number of tenders successfully completed. The so-called "carnet" categories have been the subject of much dispute.

8. The former Law for Contracts No. 2886 was replaced two years ago by another law that regulates all public construction. It is still too early to comment on the benefits of this change.

9. Gülkan, P. and D. Utkutu (2003), "Minimum Seismic Design Requirements for School Buildings", *Türkiye Mühendislik Haberleri*, Vol. 425, No. 3, pp. 13-22 (in Turkish).

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APPENDIX

The Appendix contains observations from a survey of school buildings in Bingöl (Figure A4.1), which was carried out after the city was struck by an earthquake on 1 May 2003.

Background

The earthquake

The epicentre of the earthquake was located north of Bingöl, a city that is situated among a series of complex and heterogeneous fault patterns. On the macroseismic scale, the earthquake occurred inside the Bingöl-Karlıova-Erzincan triangle, which is defined by the Karlıova triple junction to the east, the right lateral strike-slip North Anatolian Fault (NAF) to the north, and the left lateral strike-slip East Anatolian fault (EAF) to the south. The Bingöl-Karlıova-Erzincan triangle is bordered and traversed by conjugate faults of

Figure A4.1. Location of the school and dormitory buildings surveyed

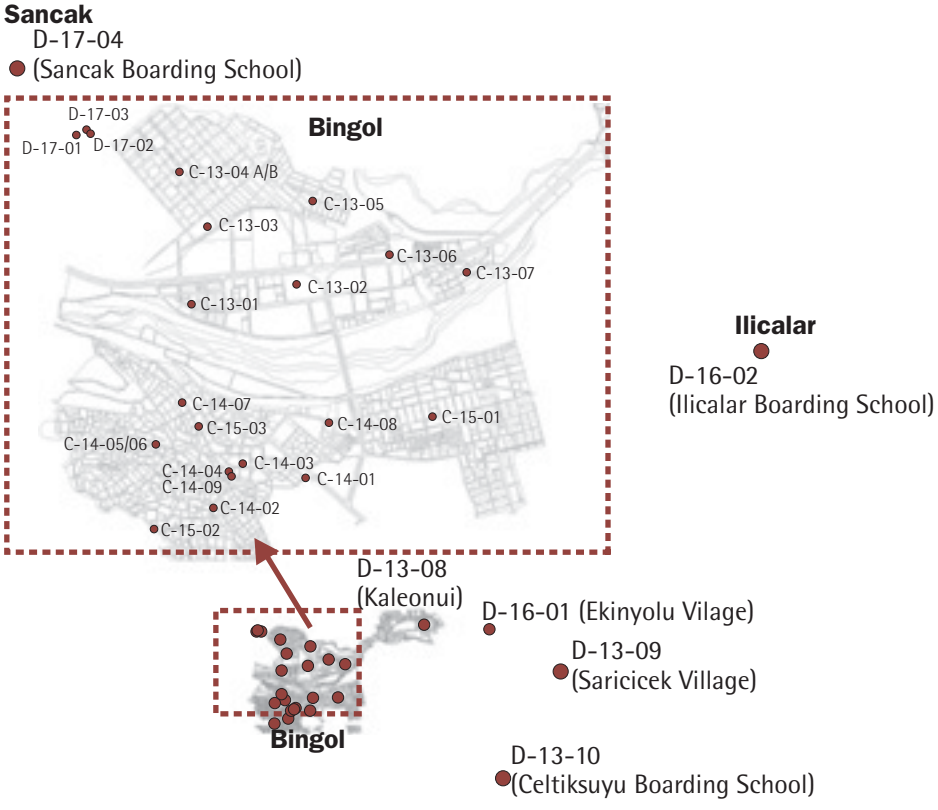

Table A4.1. Damage to school buildings in the Bingöl area

School ID	Name	Location	Damage to reinforced concrete	Damage to masonry	Struct-ural type	Position
C-13-01	75. Yil Ilkogretim Okulu	Bingöl	Severe	Severe	Frame	Independent building
C-13-02	Anadolu Ogretmen Lisesi	Bingöl	Moderate	Moderate	Frame	Dependent building
C-13-03	Rekabet Kurumu Lisesi (Building B)	Bingöl	Moderate	Moderate	Dual	Dependent building
C-13-04A	Mustafa Kemal Pasa Ilkogretim Okulu Building A1	Bingöl	None	Moderate	Dual	Dependent building
C-13-04B	Mustafa Kemal Pasa Ilkogretim Okulu Building A2	Bingöl	None	Moderate	Dual	Dependent building
C-13-05	Sehit Mustafa Gundogdu Ilkogretim Okulu	Bingöl	Moderate	Light	Frame	Independent building
C-13-06	Kazim Karabekir Ilkogretim Okulu	Bingöl	Moderate	Light	Frame	Independent building
C-13-07	Vali Kurtulus Sismanturk Ilkogretim Okulu	Bingöl	Light	Moderate	Frame	Independent building
C-13-08	Kaleonu Ilkogretim Okulu	Bingöl	Collapsed	Collapsed	Frame	Independent building
C-13-09	Saricicek Koyu Ilkogretim Okulu	Saricicek	Collapsed	Collapsed	Frame	Independent building
C-13-10	Celtiksuyu Ilkogretim Okulu	Celtiksuyu	Collapsed	Collapsed	Frame	Independent building
C-14-01	Karaelmas Ilkogretim Okulu	Bingöl	Severe	Severe	Frame	Independent building
C-14-02	Fatih Ilkogretim Okulu	Bingöl	-	-	Masonry	Independent building
C-14-03	Mehmet Akif Ersoy Ilkogretim Okulu	Bingöl	Severe	Severe	Frame	Independent building
C-14-04	Ataturk Lisesi	Bingöl	Moderate	Moderate	Frame	Independent building
C-14-05	Vali Guner Orbay Ilkogretim Okulu (Main Building)	Bingöl	Moderate	Moderate	Frame	Independent building
C-14-06	Vali Guner Orbay Ilkogretim Okulu (2nd Building)	Bingöl	Moderate	Moderate	Frame	Independent building
C-14-07	Ataturk Ilkogretim Okulu	Bingöl	Severe	Moderate	Frame	Independent building
C-14-08	Bingöl Lisesi (Building B)	Bingöl	Moderate	Severe	Dual	Dependent building
C-14-09	Bingöl Imam Hatip Lisesi (Building B)	Bingöl	Severe	Moderate	Dual	Dependent building
C-15-01	Sarayici Ilkogretim Okulu	Bingöl	Severe	Severe	Frame	Independent building
C-15-02	Murat Ilkogretim Okulu	Bingöl	Severe	Severe	Frame	Independent building
C-15-03	Bingöl 100.Yil Ilkogretim Okulu (Building B)	Bingöl	Moderate	Moderate	Dual	Dependent building
D-16-01	Ekinyolu Koyu Ilkogretim Okulu	Bingöl	Severe	Severe	Frame	Independent building
D-16-02	Ilicalar Yatili Ilkogretim Bolge Okulu Dormitory Building	Ilicalar	Moderate	Moderate	Dual	Independent building
D-17-01	Merkez Cumhuriyet Kiz Yatili Ilkogretim Bolge Okulu Boys' Dormitory Building	Bingöl	Severe	Moderate	Dual	Independent building
D-17-02	Merkez Cumhuriyet Kiz Yatili Ilkogretim Bolge Okulu Girls' Dormitory Building	Bingöl	Severe	Moderate	Dual	Independent building
D-17-03	Merkez Cumhuriyet Kiz Yatili Ilkogretim Bolge Okulu School Building	Bingöl	Moderate	Moderate	Dual	Independent building
D-17-04	Sancak Yatili Ilkogretim Bolge Okulu Dormitory Building	Sancak	Moderate	Moderate	Dual	Independent building

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the NAF and EAF that run in north-east by south-west and north-west by south-east directions. The right lateral strike-slip conjugate faults extend from the NAF and follow a parallel pattern to the EAF (*i.e.* north-east by south-west direction). The left lateral strike-slip conjugate faults extend from the EAF and follow a pattern parallel to the NAF (*i.e.* the north-west by south-east direction). These faults do not follow a straight path but rather form an echelon pattern.

The 1784 Yedisu and 1866 Göynük-Karlıova earthquakes were historically the most devastating ground motions experienced in the province. The last damaging earthquake before this event was the 22 May 1971 Bingöl earthquake (M6.8), which was located on the EAF, approximately 10 km to the south of the city. Considering the seismicity of the Bingöl-Karlıova-Erzincan triangle, the 1 May 2003 event was a medium-sized earthquake that could be expected to occur relatively frequently given the faulting system in the region. Most geological survey teams that visited the earthquake area did not report the existence of visible surface rupture.

Building damage

The number and distribution of buildings surveyed was representative of the general building population. Only one masonry-type structure was represented. The year of construction could not be determined for many structures, and none of the structures were built according to the latest 1998 version of the Turkish Seismic Code. An overall summary of observed damage, structural systems, number of floors and apparent material quality of the school buildings surveyed is presented in Table A4.1. Among the buildings investigated, ten experienced "severe" damage and three had totally collapsed, 12 suffered "moderate" damage, and three sustained "light" or no damage.

Seismic performance of typical school building designs in Bingöl[1]

The structural systems of schools shown in Table A4.1 can be grouped as:

- Reinforced-concrete moment-resisting frame systems (17 buildings).
- Reinforced-concrete dual systems (11 buildings).
- Masonry (one building).

School buildings with reinforced-concrete moment-resisting frame systems

Of the 17 buildings in this category, 16 had the same column layout (Figures A4.2 and A4.3). As the floor plan indicates, the lateral load-resisting system in these buildings was categorised as regular in plan. The majority of the columns were aligned in regular bays, and most of the beams were framed into columns. The dimensions of the columns in the buildings were typically 0.3 m x 0.5 m. The orientation of the columns was the same in all buildings, with the exception of a corner column in building C-13-01. The location of the masonry infill walls varied depending on the use of space in these schools. The exterior masonry walls were typically thicker than the interior walls.

Figure A4.2. Typical school plan without shear walls

All walls shown in the drawing occupied a full span. Walls with openings are excluded. All columns have dimensions of 0.3 m x 0.5 m. The arrow indicates the entrance to the building (dimensions are in cm).

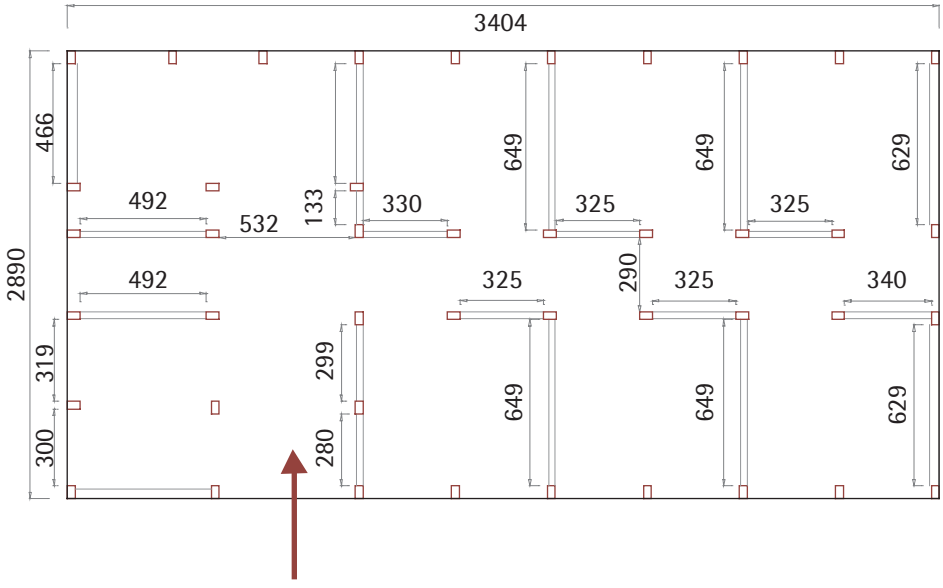

Figure A4.3. School buildings with a typical floor plan

Column dimensions are the same irrespective of the number of floors.

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C-13-02 was the only school building with a different column layout. The school complex was a combination of two separate buildings. The separation afforded by the expansion joint between the two buildings was not sufficient to avoid pounding between the two structures. The floor plan of the northern building is shown in Figure A4.4. All columns shown in the figure have dimensions of 0.2 m x 0.5 m.

The total column area of buildings with moment-resisting frames was approximately 1% of the floor area, regardless of the number of floors. Consequently, the performance of the structures during the earthquake was significantly influenced by the number of floors. The level of damage of the lateral load-resisting system with respect to the number of floors can be categorised as follows:

- Five two-storey schools: four moderately damaged and one lightly damaged.
- Eleven three-storey schools: three collapsed, six severely damaged and two moderately damaged.
- One four-storey school: severely damaged.

Damage to the masonry walls was classified separately. The three- and four-storey buildings typically sustained severe masonry wall damage (Table A4.1). This indicates that earthquake motions placed a significant displacement demand on these structures.

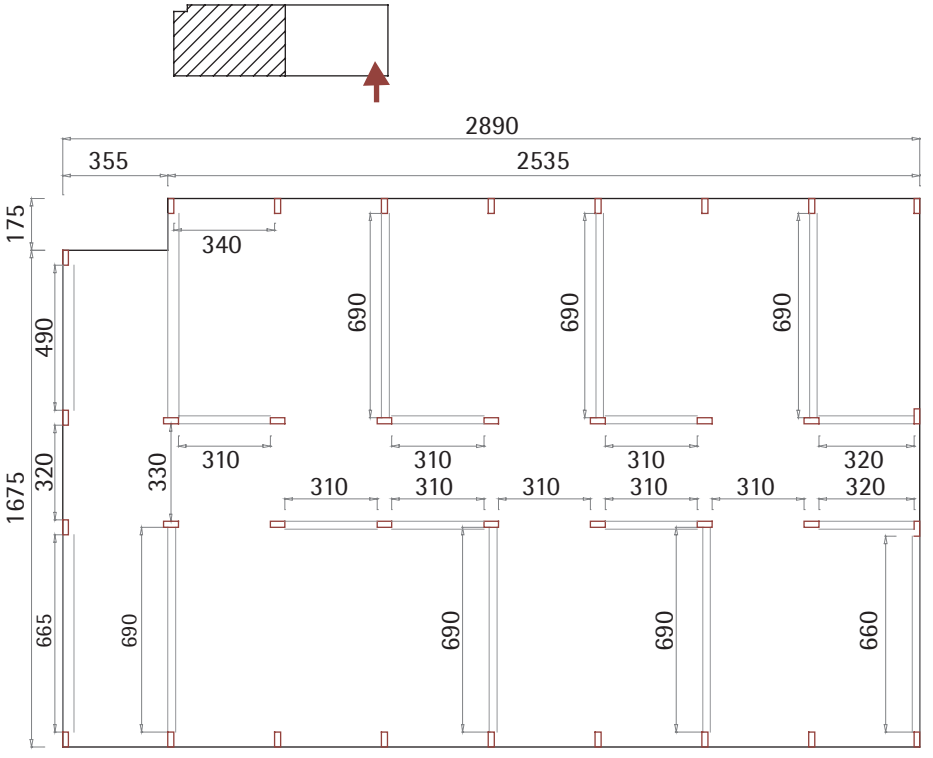
There were several construction and structural design deficiencies commonly observed in school buildings. In most of the structures surveyed, the quality of construction practices was uniform. Specific problems noted were:

- Use of unwashed aggregate.
- Use of aggregates with large maximum size (up to 10 cm).
- Use of undeformed bars.
- Inadequate preparation of cold joints.

One of the most common structural problems observed in these buildings was the presence of captive columns, which made the structures vulnerable to shear failures. In almost all schools, openings for small windows in the furnace room and restrooms were placed adjacently to columns. The exterior rectangular columns were oriented with the strong axis resisting moments in the short direction of the building layout, as in Figure A4.2. Therefore, windows on the exterior walls in the long direction of the building exposed columns to shear forces acting perpendicular to their weak axis for bending (Figure A4.4). It was observed also that crushing of the masonry walls in the upper corners created captive columns (Figure A4.5).

Figure A4.4. The floor plan for building C-13-02

The structural system is a moment-resisting frame. The columns are 0.2 m x 0.5 m. The school building comprises two independent structures separated by an insufficient expansion joint. Only the shaded area of the upper figure was surveyed. The arrow indicates the entrance to the building (dimensions are in cm).



In all school buildings surveyed, the detailing of structural members was inadequate with respect to requirements of modern seismic codes. Lack of confinement in plastic hinge regions of the columns was observed to be one of the most significant causes of damage. Although the spacing of the stirrups was reduced in the end regions of some columns, the amount of transverse reinforcement provided was not sufficient to prevent shear failures, particularly in the case of captive columns (Figure A4.6). Another commonly observed detailing deficiency was the inadequate anchorage of the free ends of the stirrup reinforcement (Figure A4.7).

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Figure A4.5. Shear failure of captive columns created by the small windows of the furnace room in building C-14-03

Figure A4.6. Shear failure of captive columns as a result of upper corner of masonry walls' crushing in building C-14-01

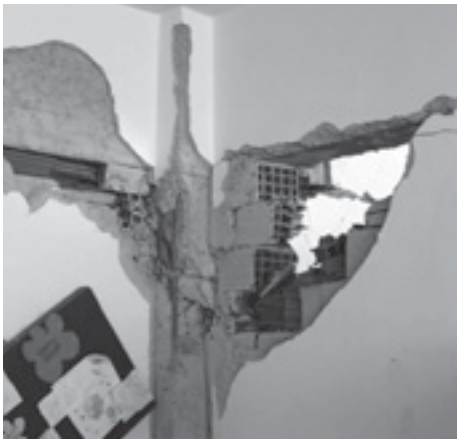


Figure A4.7. Typical confinement detail of a column in building C-13-09

The shear failure in the columns initiated the collapse of the first floor. The spacing of the transverse reinforcement was 10 cm at the top 30 cm portion of the columns. The ends of the stirrups were not anchored properly.

School and dormitory buildings with dual systems

Surveyed schools with dual systems can be categorised in four groups.

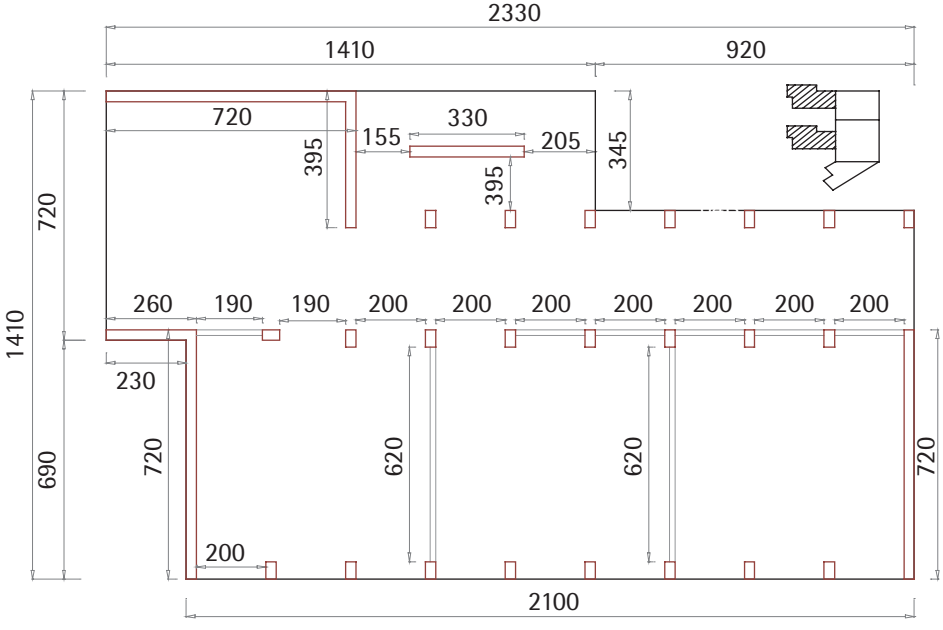
Buildings C-13-04A and C-13-04B

These buildings were part of the same school complex, which comprised five different structures that were separated by expansion joints. Buildings C-13-04A and C-13-04B had a similar lateral load resisting system, as shown in Figure A4.8. The only difference between the buildings was the location of masonry walls. The total shear wall area of the structure in the longitudinal and transverse directions was 1.4% and 2.0% of the floor area, respectively.

There were no indications of structural damage to these buildings, and the masonry walls were only lightly damaged.

Figure A4.8. Structural floor plan for building C-13-04A

All columns have dimensions of 0.3 m x 0.5 m. The thickness of the reinforced concrete and masonry walls was 0.30 m and 0.16 m, respectively (dimensions are in cm).



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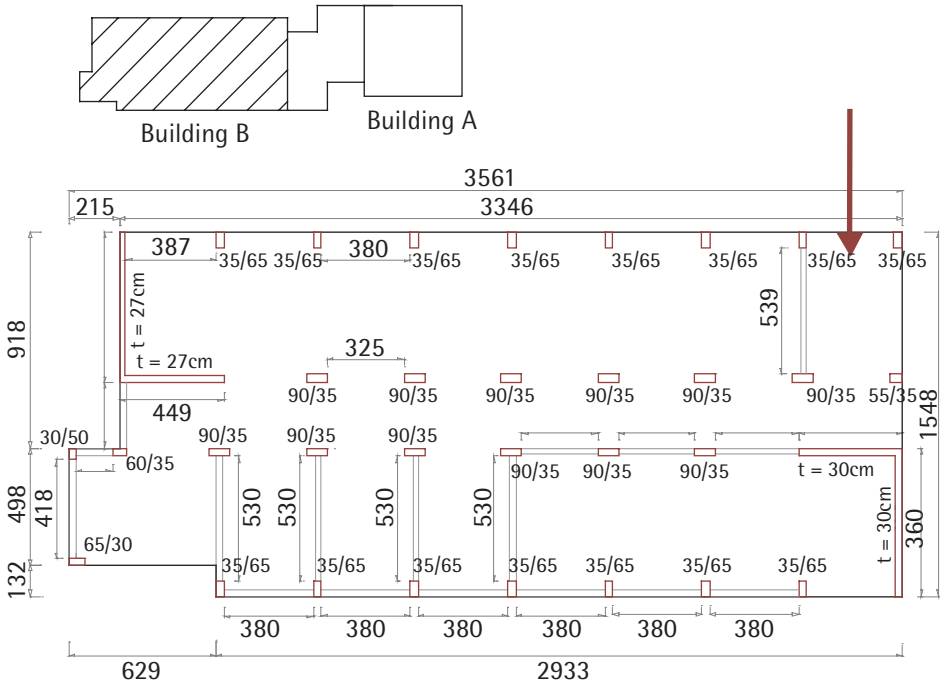
Buildings C-13-03, C-14-08, C-14-09 and C-15-03

Each of these buildings represented one structure of a three-structure complex that conformed to the plan of a typical secondary school building used by the Ministry of National Education in Turkey. Each of the buildings had four storeys. Although buildings C-14-09 and C-15-03 were smaller than the other two, the structural plans were similar in all four buildings. The main difference was that the smaller buildings had two less bays in the longer direction. The total column area was 1.5% of the floor area for all buildings. The ratio of shear wall to floor area was not uniform. Building C-14-08, which has the smallest ratio of shear wall to floor area, had wall areas of 0.7% and 0.4% of the total floor area in the two principal directions (Figure A4.9). The highest ratio of wall to floor area was found in building C-13-03 (Figure A4.10).

The most severe damage in this group was observed in C-14-09. A cold joint in one of the shear walls in the structure initiated a horizontal crack along the joint during the earthquake. Although other structural members showed no signs of damage, the building was classified as severely damaged because of the damaged shear wall. The masonry walls of the building did not suffer any severe damage.

Figure A4.9. Structural floor plan for building C-14-08

The thickness of interior and exterior masonry walls was 0.25 m and 0.30 m, respectively. The arrow indicates the entrance to the building (dimensions are in cm).

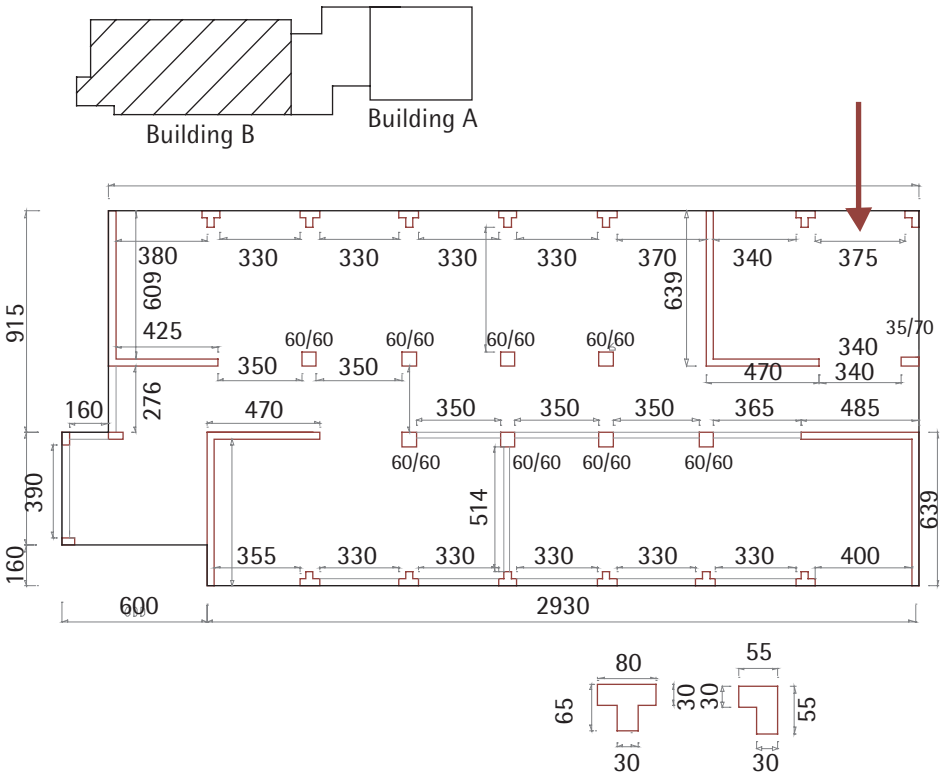


In building C-14-08, damage to the structural system was confined to significant crushing of concrete in the shear walls. No damage was observed in the columns, and a few beams had severe flexural cracks. The structural system of this building was rated as severely damaged. The masonry walls were separated from the structural frame because of crushing of the bricks at the edge of the walls. There was no partial or full collapse of the masonry walls.

Buildings C-13-03 and C-15-03 – which had higher shear wall ratios than the other two buildings (ratio of wall to floor area) – sustained only moderate damage to the structural system and masonry walls. Damage to the structural system and masonry walls were both classified as moderate. There were no inclined cracks observed in the columns or shear walls, but some local damage to members was observed in the form of spalling of concrete cover as a result of construction defects.

Figure A4.10. Structural floor plan for building C-13-03

The thickness of the shear walls was 0.3 m. The masonry wall thickness was 0.25 m for the interior walls and 0.3 m for the exterior walls. The arrow indicates the entrance to the building (dimensions are in cm).



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Building C-17-03

Building C-17-03 contained four stories. The total column area was 1.1% of the floor area, and the area of shear walls was 0.8% and 1.0% of the floor area in the longitudinal and transverse directions, respectively. Another structure was located adjacent to the west end of the building. Although the buildings were separated by an expansion joint, the gap between the two structures was small.

Moderate damage to the structural system and the masonry walls was reported. No inclined cracks were observed in the columns or shear walls, although some local damage to members in the form of spalling of concrete cover from construction defects was noted.

Dormitory buildings (D-16-02, D-17-01, D-17-02 and D-17-04)

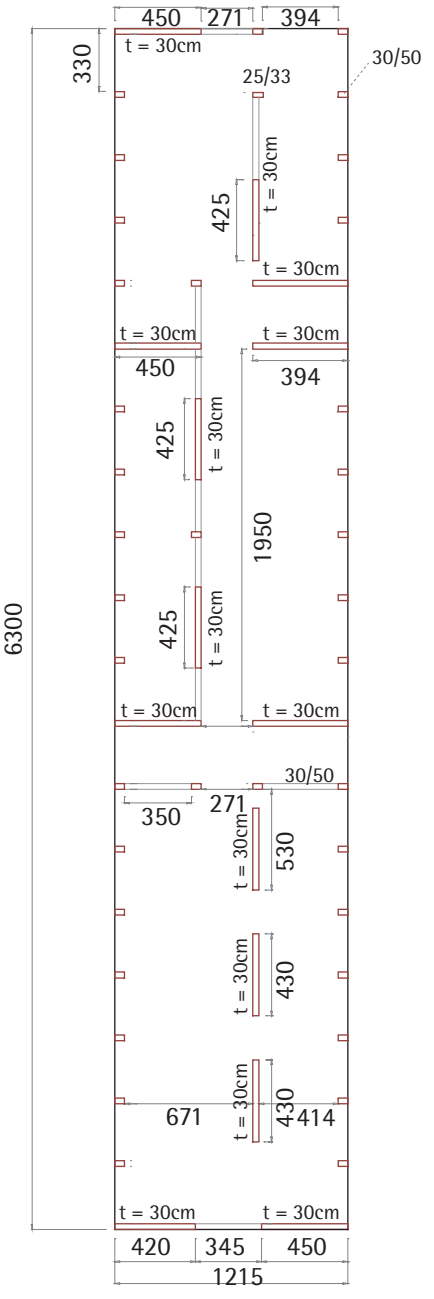
These buildings were not adjacent to other structures, had identical floor plans – as shown in Figure A4.11 – and all comprised four-storeys. Regarding the structural system, the schools had a column area of 0.7% of the floor area, and wall areas of 1.0% and 1.5% of the total floor area in the two principal directions.

The structural systems of two of the four dormitory buildings surveyed – D-17-01 and D-17-02 – were classified as severely damaged because of the inclined cracks on the captive columns. There were also inclined hairline cracks on the shear walls. Some of the beams had flexural and shear cracks, and damage was observed in beams that framed into other beams, as opposed to columns.

Building damage to D-16-02 and D-17-04 was rated as moderate due to the inclined hairline cracks on shear walls, and the shear and flexure cracks on the beams. The most striking building damage was the collapse of the free-standing

Figure A4.11. Structural floor plan for dormitory buildings

The masonry wall thickness was 0.3 m (dimensions are in cm)



masonry walls separating the sleeping units in the upper levels. These walls were not included in the damage rating because they were not attached to the structural system. However, these walls presented a serious hazard to the students living in the dormitories because in some cases the walls collapsed on the beds (Figure A4.12).

Figure A4.12. Collapse of free-standing masonry walls onto beds in dormitory buildings

Comparison of the performance of frame and dual systems

Damage assessments were categorised in order to compare the performance of both groups of school buildings. The wall and column indices in this procedure were defined and calculated as the ratio of the area to the total floor area. The wall index was calculated for both main horizontal axes of the buildings, and the smaller of the two was taken as the wall index for the given building. The correlation between the damage category of the building and the wall and column indices are presented in Figure A4.13. As the figure shows, the damage level tended to decrease as the wall and column indices increased.

Observations of damage in the buildings indicate that the performance of buildings with dual systems was satisfactory. Although some of the dual system buildings were rated as severely damaged because of the damage caused by structural defects such as captive columns and cold joints, observed damage to the masonry walls indicated that the reinforced-concrete walls were effective in maintaining the lateral drift below a reasonable limit. Buildings with moment-resisting frame systems did not perform as well in the earthquake. Although the quality of construction was quite uniform for all the buildings, frame systems were more vulnerable to damage associated with deficiencies in construction practice. The flexibility of moment-frame buildings resulted in larger drift demands than those in buildings with dual systems, which caused severe damage and in many cases the total collapse of the structure. The damage level of infill masonry walls in moment-frame buildings that were severely damaged supported the conclusion that the drift demand was excessive. The shear damage to columns was very severe in buildings with moment-resisting frames. A boundary for the minimum column and wall indices for satisfactory performance is shown in Figure A4.13.

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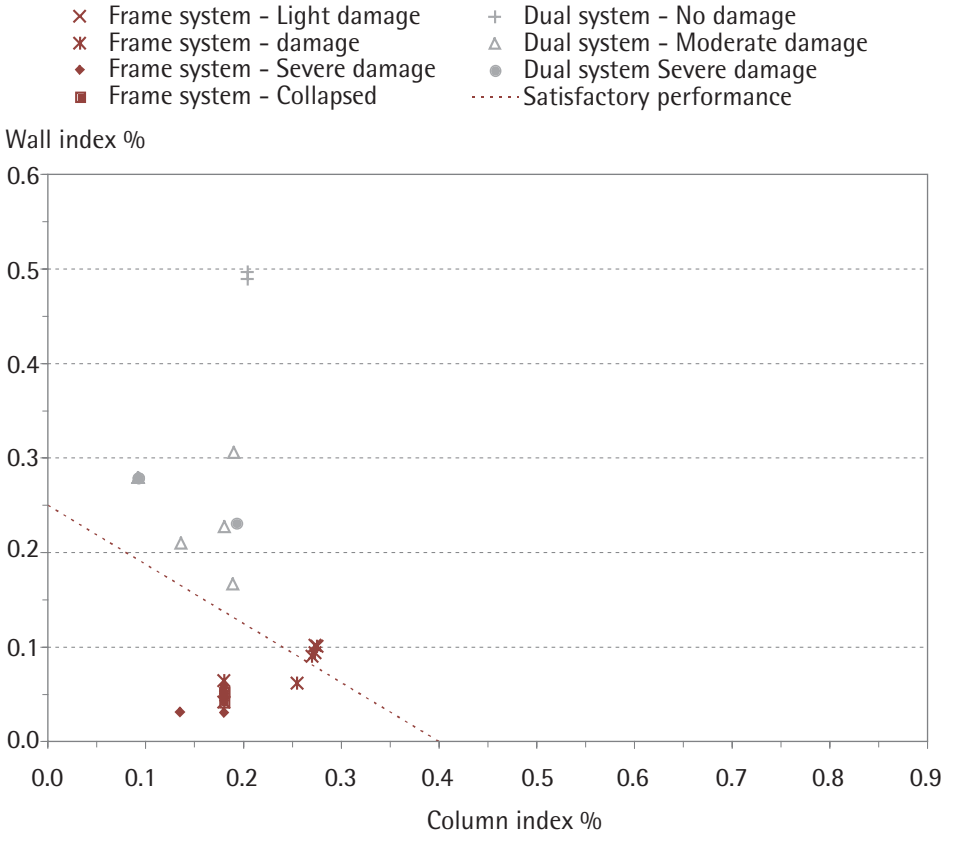
Figure A4.13. Correlation between structural performance and wall and column indices in schools and dormitories



Note

1. This account is drawn from the observations of a team sponsored by the United States National Science Foundation (NSF), who worked jointly with a team of researchers from the Middle East Technical University (METU). The joint report of these two teams is G. Özcebe, J.A. Ramirez, S.T. Wasti and A. Yakut (eds.) (2004), "1 May 2003 Bingöl Earthquake Engineering Report", Report No. 2004/1, TÜBITAK SERU/YMAÜ, Department of Civil Engineering, Middle East Technical University, Ankara.

CHAPTER

5

SEISMIC RISK IN SCHOOLS: THE VENEZUELAN PROJECT

Oscar A. López, Julio J. Hernández, Gianina Del Re and José Puig

Institute of Materials and Structural Models, Central University of Venezuela, Faculty of Engineering, Venezuela

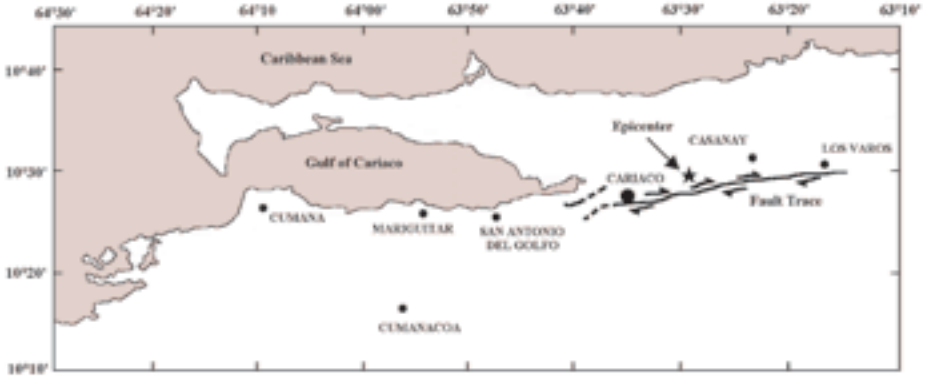
Magnolia Santamaría

Ministry of Education, Venezuela

Abstract: This paper describes the performance of school buildings in the 1997 earthquake in north-east Venezuela, in which two schools collapsed and 46 students were killed. It provides seismic data on the region and country, and analyses two typical school structural types in Venezuela: "box-type" and "old-type" buildings. The causes of school collapse are provided for each structural type. The analysis was conducted as part of a project to reduce seismic risks in schools in Venezuela, which identifies and classifies existing schools in terms of vulnerability.

Figure 5.1. Epicentre, fault trace and the town of Cariaco

Structural plan at first storey of one unit of RMC school (in metres)



The Cariaco earthquake

Figure 5.2. Right-lateral strike-slip fault

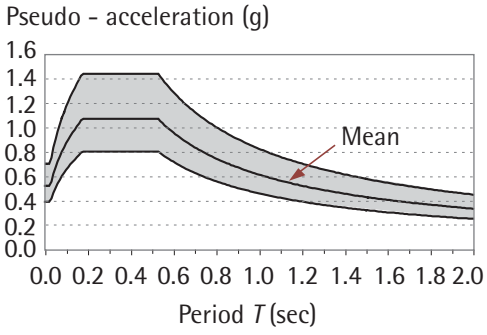
At 15:24 on 9 July 1997, an earthquake struck the north-eastern region of Venezuela, located some 300 km from Caracas. The ground motion caused five reinforced-concrete buildings – two of which were school buildings – to collapse, killing 74 people and leaving 522 wounded. The earthquake also caused liquefaction and soil failure in several towns on the coast. In the town of Cariaco, two school buildings, a two-storey bank and a hotel that was under construction – all reinforced-concrete structures – collapsed. Three hundred single-family dwellings made of *bahareque* or masonry walls were also destroyed. Other single-storey buildings located near the schools were not damaged.

Earthquake data and estimated ground motion in Cariaco

The epicentre of the earthquake of magnitude M6.8 was located at 10.43° W and 63.49° N, with a focal depth of 10 km. The town of Cariaco was situated approximately 10 km from the epicentre, but only 600 m from the fault trace (Figure 5.1). The right-lateral strike-slip fault had

a mean displacement of 30 cm along 30 km in the east-west direction (Figure 5.2). This fault trace corresponds to the El Pilar fault, which is the boundary between the Caribbean and the South American tectonic plates. The ground motion was recorded in the city of Cumaná, located approximately 70 km from the epicentre. Peak ground accelerations (PGA) of 0.09 g, 0.05 g and 0.03 g in two horizontal and vertical directions were recorded, respectively, with a total duration of about 20 seconds.

Figure 5.3. Pseudo-acceleration response spectrum



The soil at the sites of the two school buildings in Cariaco consists of pre-dominantly fine materials with similar characteristics throughout the soil column: very soft for the first 10 m, moderately dense between the depths of 10 m and 20 m, and dense or very dense at a depth of more than 20 m. Using attenuation laws for near-fault motions recorded on soil (Abrahamson and Silva, 1997; Boore, Joyner and Fumal, 1997; Campbell, 1997; Sadigh *et al.*, 1997), the median of the PGA was associated with a probability of exceedence of 50% (Table 5.1). Averaging for all the laws, the median PGA was 0.52 g, with a 50% probability of being between 0.39 g and 0.70 g. The pseudo-acceleration response spectrum was determined using the smooth spectrum built from the mean spectrum of a collection of 38 near-fault motions recorded on soil, for 5% damping (López *et al.*, 2004). Figure 5.3 shows the resulting mean, upper and lower smoothed spectra, which define a range of pseudo-acceleration values with a probability of occurrence of about 50%.

Table 5.1. Range of peak ground acceleration (PGA) "a" with 50% probability of occurrence in Cariaco

Reference	Standard deviation	Lower quartile	PGA a (g) Median	PGA a (g) Upper quartile
Abrahamson and Silva (1997)	0.44	0.39	0.53	0.71
Boore, Joyner and Fumal (1997)	0.52	0.38	0.53	0.75
Campbell (1997)	0.39	0.38	0.49	0.64
Sadigh *et al.* (1997)	0.42	0.41	0.54	0.72
Mean		0.39	0.52	0.70

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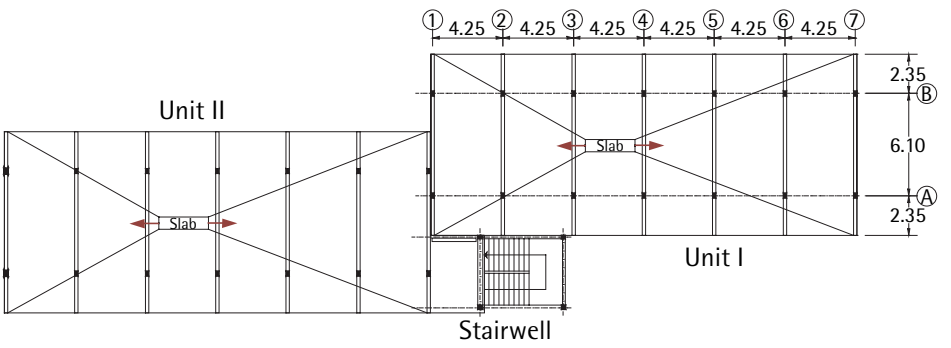
Performance of the Valentín Valiente School

Description and behaviour during the earthquake

The Valentín Valiente School (VV), built in 1958, consisted of two independent modules (Figure 5.4). Each module had two storeys and was rectangular in shape, with a reinforced-concrete structure and masonry infill made of 15 cm-thick hollow concrete blocks connected to the frames (Fernández, 1998; IMME, 1998). The concrete joist floor system had a 5 cm slab with joists spaced 50 cm apart in the longitudinal direction, and all columns had a 20 cm x 30 cm section. Frames with deep beams (20 cm x 65 cm) were located along the transversal direction of the building, but there were no beams along the longitudinal direction. Materials tests performed after the earthquake showed a concrete strength in compression of 140 kgf/cm^2; the minimum yield stress for the bars is 2 400 kgf/cm^2. No transversal reinforcement was placed in the joints. The transversal reinforcement in beams and columns consisted of plain bars Ø 1/4" hoops set 25 cm and 15 cm apart, respectively (Bonilla *et al.*, 2000; Fernández, 1998). Two types of masonry infill were used (Figure 5.5(a)): some were 2.25 m high and completely filled the transversal frames along axes 1, 3, 5 and 7; others were 1.70 m high and generated short columns with 55 cm clear length on longitudinal frame A. Longitudinal frame B had a very rigid reinforced-concrete bench stiffly connecting the columns at a height of 50 cm from the floor.

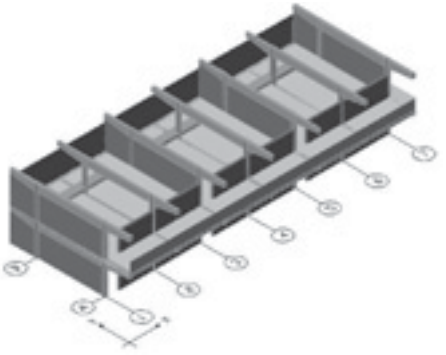
Figure 5.4. Structural plan at first storey of Valentín Valiente School (dimensions in metres)



The building had very low energy-dissipation capacity due to the small amount of transversal reinforcement and the short columns. Furthermore, the building was weak in the longitudinal direction due to the lack of beams and the small size of the columns. The collapse of both modules during the earthquake was similar – five people were killed – with great displacement along the longitudinal direction (Figure 5.5(b)). When the columns on both floors failed, the slabs were left resting on the walls. Brittle failures were observed in the short columns, and ductile failures were seen in the long columns.

Figure 5.5. Three-dimensional view of Valentín Valiente School and structural collapse

(a) Three-dimensional view of Valentín Valiente School showing frames and infill walls



(b) Structural collapse in longitudinal direction of Valentín Valiente School (Bonilla et al., 2000)

Analysis of the structure

The building's capacity was determined by means of a non-linear static (pushover) analysis; lateral triangular loads were applied in the longitudinal direction until the structure became unstable. The masonry infill was modelled by diagonal compression struts. The slab concrete joists were modelled by equivalent beams. Figure 5.6(a) shows the base shear against the roof displacement. The results indicated a first shear failure in the short columns A2, A4 and A6 of the first storey (Figure 5.4), for a base shear of 23 t; followed by a second shear failure in the same three columns on the second storey, for a base shear value of 26 t; and subsequent bending failures of the joists and of the other columns, up to 36 t, for a roof displacement of 7 cm. In order to estimate the risk index, a value of 30 t was given as the ultimate capacity of the structure.

Demand was estimated based on the dynamic elastic response to the pseudo-acceleration spectrum (Figure 5.3) applied in the direction of the collapse. With a total weight of 42 t, the fundamental period for the structure is 0.65 s. A base shear demand between 254 t and 456 t with a 50% probability of occurrence was obtained. Displacement demand corresponds to drifts between 15% and 27% in both storeys (Figure 5.6(b)). This demand is between eight and 15 times greater than the capacity of the structure, which creates an intolerable ductility demand, especially for a structure with very low energy-dissipation capacity.

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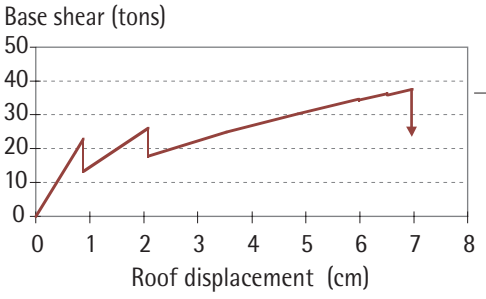
Figure 5.6. Capacity and demand in longitudinal direction of Valentín Valiente School

(a) Capacity from a pushover analysis



(b) Probable range of elastic dynamic demand during the earthquake

Base shear (tons)	Displacement (cm)	
	Storey 1	Storey 2
254 - 456	5 - 8	9 - 16

Causes of the collapse of the V V School

The collapse of the V V School was caused by conceptual design deficiencies, which can be summarised as:

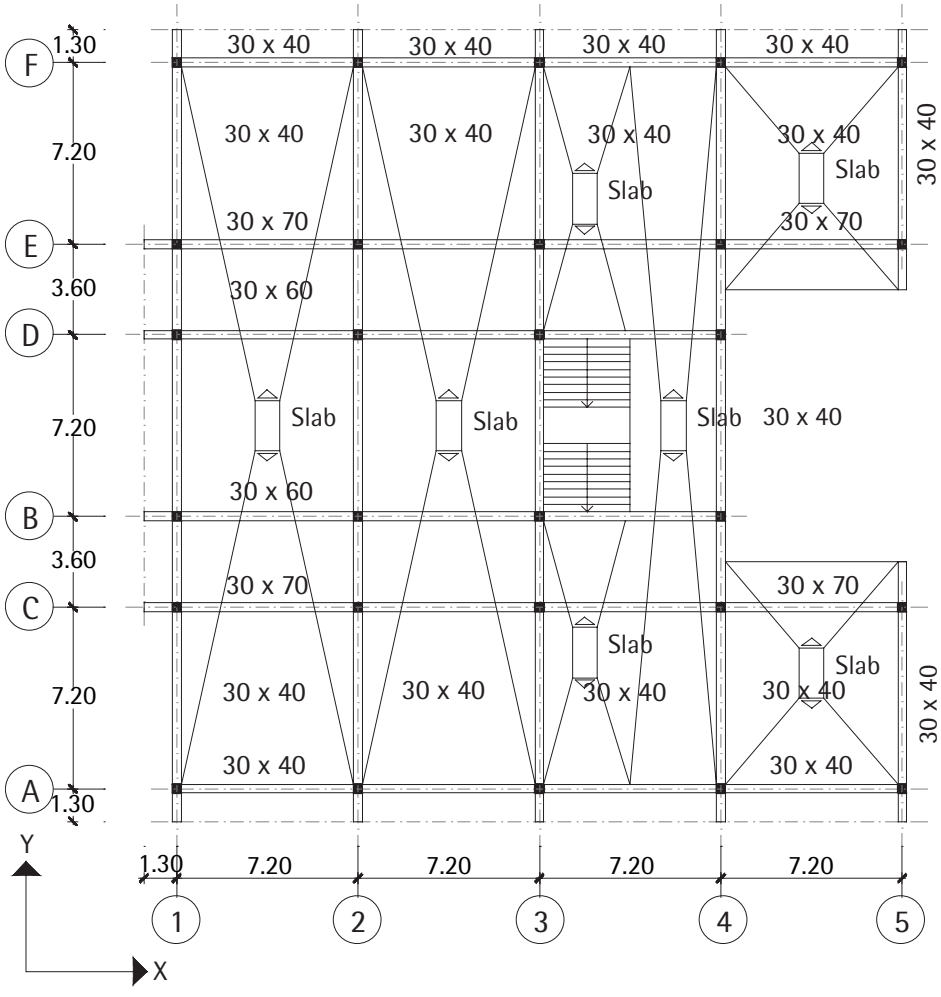
- The very low resistance and stiffness of the structure in the longitudinal direction as a result of the small size of the columns and the lack of beams.
- The presence of masonry infill connected to the columns, creating short columns and leading to brittle failures.
- The building's limited energy-dissipation capacity caused by inappropriate detailing. Although the ground motion at the site was very strong due to its proximity to the fault, it is likely that even weaker motions would have caused the building to collapse given that, intrinsically, it was extremely vulnerable. No construction flaws were observed, with the exception of the low concrete strength.

Behaviour of Raimundo Martínez Centeno High School

Description and behaviour during the earthquake

Raimundo Martínez Centeno High School (RMC) in Cariaco was built in 1985, although the structural drawings are dated 6 April 1978. The blueprints indicated that the structure had been designed for Seismic Zone 2, following the 1967 standards in force at the time. According to those standards, Cariaco was located in Seismic Zone 3, where seismic requirements were two times greater than those for Zone 2. The school consisted of two similar, independent modules, with a C-shaped floor plan. One module had three storeys, and an additional floor had been added in a small area of the other module. Only the three-storey module, the floor plan for which is shown in Figure 5.7, was analysed. Each unit had a reinforced-concrete structure with frames in both horizontal directions and 15 cm thick masonry infill (Figure 5.8(a)). The total thickness of the concrete joist floor system was 30 cm, with ribs in the Y direction (Figure 5.7). The columns measured 35 cm x 35 cm.

Figure 5.7. Structural plan at first storey of one unit of RMC school (in metres)



The beams in the Y direction had a 30 cm x 40 cm section. In the X direction, the beams were 30 cm wide and between 40 cm and 70 cm high. The masonry infill in frames 1 to 5 completely filled the frames. In frames B and E, the masonry infill created short columns with a length of 70 cm. In frames A and F, the length of the short column was 170 cm. The first storey only had one-third the number of walls filling the frames as on the second storey, and half the number of those on the top storey. Tests performed after the earthquake showed a concrete strength of about 250 kgf/cm^2, and 4 200 kgf/cm^2 for the yield stress of the reinforcing bars (IMME, 1998), which was consistent with the values specified in the design. Columns hoops of Ø 3/8" were installed 10 cm apart near the

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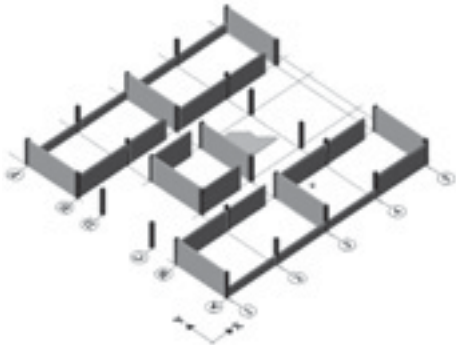
joints and 20 cm apart further away from the joints, with no transversal reinforcement at the joints. The number of hoops was 66% of the total amount required in the actual code for high seismic zones.

The school had very low energy-dissipation capacity; the columns were weaker than the beams and had little shear strength. The masonry infill was connected to the columns, creating short columns with a potential brittle failure mode. In addition, there was a significantly higher number of masonry infill on the upper storeys compared to the ground floor, creating a weak and soft first storey. Both modules exhibited similar behaviour during the earthquake, consisting of failure of the columns on the lower level and collapse of the building – causing 18 deaths – with displacement predominantly in direction X, leaving the second storey resting directly on the ground (Figure 5.8(b)). There were no signs of collision between the two modules. On the second and third storeys that were left standing, shear failures were noted in several of the short columns, and compression and buckling of the longitudinal steel was seen in others (Castilla and Marinilli, 2000; IMME, 1998).

Figure 5.8. Three-dimensional view of RMC school and structural collapse

(a) Three-dimensional view of RMC school showing infill walls in first storey



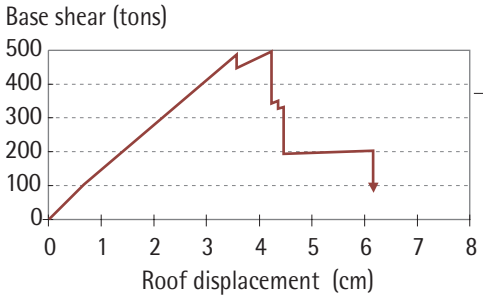
(b) Collapse of first storey of RMC school (Photo courtesy of E. Castilla)

Analysis of the structure

The lateral capacity of the building in the direction of the collapse X was determined using a pushover analysis. The masonry infill was modelled using diagonal struts. The building had a fundamental mode period equal to 0.58 s in direction X and a weight of 1 900 t. The shear force at the base vs. displacement at the roof is shown in Figure 5.9(a). The results indicated a shear failure in short columns B3 and E3 on the first storey, for a load of 477 t; followed by a shear failure of the other short columns B1, E1 and A4 to 487 t; and, subsequently, shear failure of several long columns. A value of 450 t was taken as the ultimate capacity of the building. The demand brought about by seismic motion (Figure 5.3) was determined by means of a dynamic elastic analysis (Figure 5.9(b)). This demand was between 2.8 and 5.1 times greater than capacity, which is considered excessive given the low energy-dissipation capacity of the structure.

Figure 5.9. Capacity and demand of RMC school in the X direction in Cariaco

a) Capacity from a pushover analysis



b) Probable range of elastic dynamic demand during the earthquake

Base shear (tons)	Displacement (cm) Roof
1 280 - 2 300	8 - 14

Causes of the collapse of RMC High School

The collapse of RMC High School was due to:

- The low energy-dissipation capacity of the structure, caused mainly by the lack of proper confinement of the columns and joints and the low shear resistance of the columns.
- The presence of masonry infill creating short columns and leading to brittle failures.
- The large difference in strength and stiffness between the first and upper storeys, which was created by the termination of the masonry infill of the upper storeys. No construction flaws were observed.

Schools and the earthquake scenario in Venezuela

Seismic hazard in schools

The seismic hazard map contained in the Venezuelan earthquake-resistant building code sets values of PGA in rock for schools associated with a 5% probability of exceedence in 50 years (COVENIN, 2001). The country is divided into seven zones, with a PGA of up to 0.52 g, which can be classified as of very high, high, moderate and low seismic hazard (Table 5.2). There are 28 119 educational units, from pre-school to secondary school, in the country; approximately 70% of schools, or 19 516 units, are located in high to very high seismic hazard zones (Table 5.2). In general, school units consist of several independent buildings, and many educational units have been built using only a small selection of structural designs. An estimated several hundred "box-type" buildings – similar to RMC High School – and "old-type" buildings – similar to V V School – exist. Figure 5.10 shows that some of these buildings are similar to those that collapsed in Cariaco. The high risk of these buildings was confirmed in the 1991 Curarigua earthquake (west of Venezuela), when an old-type school similar to V V School was severely damaged. This moderate earthquake (M5.3), with an epicentre located 20 km from the town of Arenales (Lara State), caused a brittle shear failure in the short columns on the first storey, similar to the

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failure that occurred in Cariaco. Recorded accelerograms from nearby areas suggested a PGA of less than 0.10 g, which provided clear proof of the vulnerability and high risk of these schools, even in the case of low to moderate intensity seismic motion.

Table 5.2. Distributions of schools according to the seismic hazard zones in Venezuela

Zone	Seismic hazard	PGA (g)*	Number of schools	% of schools
6,7	Very high	0.46 - 0.52	1 671	5.9
4,5	High	0.33 - 0.39	17 844	63.5
1,2,3	Moderate	0.13 - 0.26	8 205	29.2
0	Low	-	399	1.4
		Total	28 119	100

*With 5% probability of exceedence in 50 years.

Figure 5.10. Schools in Venezuela that are identical to the schools that collapsed in Cariaco

a) Identical to RMC (Figure 5.8(b)) (Photo courtesy of E. Castilla)

b) Identical to V V (Figure 5.5(b))

Reduction of seismic risks in schools

The risk of these types of schools – the old-type and the box-type structures – is determined for different seismic zones in Venezuela in the "Reduction of Seismic Risks in Schools" project. The goal of this project is to identify and classify existing schools in terms of their vulnerability, to determine the level of risk to which these schools are exposed, and to propose measures aimed at reducing risk to the levels stipulated in the current earthquake-resistance standards. The project is divided into three stages: preliminary evaluation, detailed evaluation and structural retrofitting.

Preliminary evaluation (Stage I)

This initial stage covers:

- Identification and classification of schools in the country; preferential selection of repetitive-design and high-occupancy units; and correlation with seismic hazard maps.
- Evaluation of schools using rapid visual screening methods.
- Classification of schools based on risk level; and selection of schools to be included in Stage II.

Detailed evaluation (Stage II)

A detailed evaluation is carried out according to the current design and construction standards in Venezuela. This stage covers:

- Determination of elastic demand imposed by seismic action by dynamic analysis.
- Determination of local strength of the structural elements and overall strength of the structure by non-linear static analysis.
- Determination of risk indices defined by the demand/capacity quotient; and selection of schools to continue to Stage III.

Structural retrofitting (Stage III)

This stage consists of:

- Consideration of three performance levels in the retrofit project: immediate occupancy, for moderate ground motions; life safety, for strong ground motions; and structural stability, for maximum ground motions. Levels 2 and 3 include non-linear dynamic analysis of the retrofitted buildings.
- Study of different structural retrofit alternatives to increase the reliability of buildings to the level required under current standards of life safety performance, while minimising cost and disruption of school activities.

Risk indices in standard school types

The old-type and box-type schools were selected for detailed evaluation early in the project because these schools are identical to those that collapsed in Cariaco and are found throughout the country. The purpose of the evaluation was to determine the risk index for each school in each of the seven seismic zones in the country (Table 5.2). Maximum dynamic response was calculated by means of a linear elastic model subject to the ground motions specified in each seismic zone. Two qualities of concrete and five different models were considered in order to evaluate the influence of the walls and stairs and the cracking of the structural elements. The joint action of gravitational loads, two horizontal components of the earthquake, the vertical seismic component and accidental

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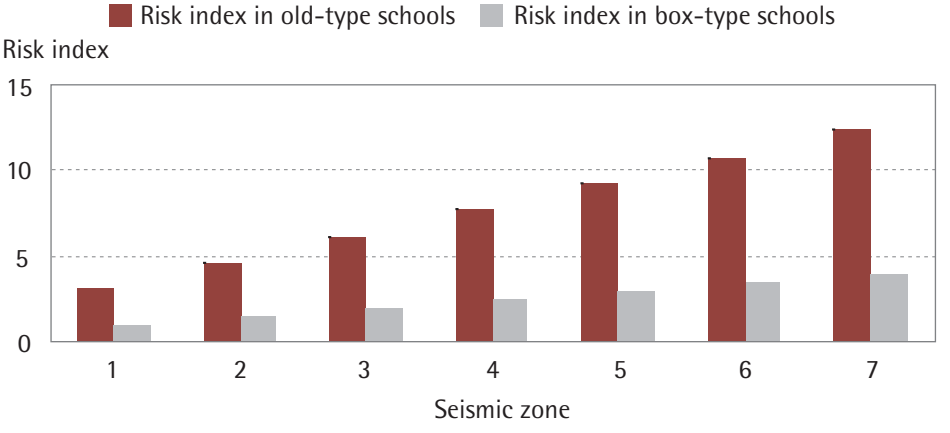
torsional moments were also considered. These load cases were combined following the guidelines provided in the standards (COVENIN, 2001).

The risk indices, RI, were determined at the local and global levels. At the local level, the RI is the quotient of force-demand and capacity in a given structural element. In elements with ductile failure modes, this index is an approximation of local ductile demand. At the global level, the RI is the quotient of the base shear demand and capacity as determined by a non-linear static analysis, and the other index is the quotient of drift demand and admissible drift according to the code. Selected results for the RI of the base shear for the model with walls and stairs and concrete strength of 200 kgf/cm² are presented in Figure 5.11. The characteristics and detailing of elements and joints do not allow for indices of more than 2.

The results presented in Figure 5.11 show unacceptable risk levels for the old-type school, even in low seismic zones, indicating an urgent need for retrofitting. Results also suggest that only those box-type schools located in high seismic risk zones need to be retrofitted.

Figure 5.11. Risk index of standard school types in seismic zones in Venezuela



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Acknowledgements

This research is supported by FONACIT (Ministry of Science and Technology of Venezuela).

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CHAPTER

6

TOWARDS EFFECTIVE MITIGATION AND EMERGENCY RESPONSE IN THE FORMER YUGOSLAV REPUBLIC OF MACEDONIA

Zoran Milutinovic

Institute of Earthquake Engineering and Engineering Seismology, EUR-OPA Major Hazards Agreement European Centre on Vulnerability of Industrial and Lifeline Systems, FYROM

Jean-Pierre Massué

EUR-OPA Major Hazards Agreement

Disclaimer

Any reference to Macedonia or to a Macedonian institution in this paper refers to the Former Yugoslav Republic of Macedonia (FYROM).

Abstract: This paper describes the performance of educational buildings in FYROM in recent earthquakes, such as the Skopje earthquake in 1963, where 57% of the total urban school building stock was destroyed. It also discusses regional, national and international initiatives – the United Nations Development Programme and the EUR-OPA Major Hazards Agreement – to improve the disaster preparedness of schools, students and teachers in FYROM. The School ID Card, School Emergency Preparedness Plans and other educational programmes provide essential data on potential damage to school buildings from earthquakes of different magnitudes, as well as elements for effective first-response and emergency management operations.

Introduction

EUR-OPA Major Hazards Agreement (MHA) member states[1] are all situated in disaster-prone regions. These countries are thus exposed to the adverse effects of natural hazards, such as earthquakes, floods, wildfires, landslides and avalanches. Some hazards are localised and seasonal (*i.e.* wildfires, floods, landslides, avalanches), while others are incidental and widespread (*i.e.* earthquakes). A range of geological, ecological, meteorological, demographic, socio-economic and political factors contribute to disaster-proneness of EUR-OPA MHA countries. However, empirical data from past disasters indicate that, although rare, the effects of *earthquakes* – expressed in terms of physical and functional damage and human casualty – in many cases substantially exceed the adverse effects of all other hazards individually, and in some cases even the aggregate effects.

Table 6.1. Behaviour of education and health care facilities in recent earthquakes

	Damage state					
Building use	1	2	3	4	5	Total
Kindergartens						
Tbilisi earthquake*	77 (48.1%)	46 (29%)	37 (23%)	-	-	160
Schools						
Boumerdes earthquake**	420 (20%)	814 (39%)	467 (22%)	286 (14%)	103 (5%)	2 090
Tbilisi earthquake*	98 (49%)	68 (34%)	35 (17%)	1 (1%)	-	202
Hospitals						
Boumerdes earthquake**	94 (33%)	114 (40%)	44 (15%)	23 (8%)	10 (4%)	285
Tbilisi earthquake*	50 (42%)	32 (27%)	30 (25%)	8 (7%)	-	120

* Earthquake in Tbilisi, Georgia, 25 April 2002 (M4.5, h=3-4 km, MMI=VII MSK-64) (Gabrichidze, Mukhadze and Timchenko, 2003)
** Earthquake in Boumerdes, Algiers, 21 May 2003 (M6.8) (Belazougui, Farsi and Remas, 2003)

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Most reports of major disasters from the EUR-OPA MHA region refer to some damage to essential public facilities, such as schools and hospitals. In the last decade, earthquake data indicate that only a small proportion of existing buildings suffered severe earthquake damage. Unfortunately, these were mostly government buildings, especially schools, and in some cases health care facilities (Table 6.1).

Background

The territory of FYROM, which is located in the Mediterranean and Balkan seismic region, is exposed to intensive neo-tectonic movements, causing relatively high and frequent seismic activity. Over the last 100 years, more than 1 000 earthquakes have occurred within the national territory, a considerable number of which have been of damaging (MMI = VI-VIII) or destructive (MMI = IX-X) intensity. Of the 194 earthquakes with an intensity (MMI) greater than VI, 44 had an MMI of VII, 15 had an MMI of VIII, nine had an MMI of IX and two had an MMI of X.

Compared to the number of buildings that comprise the national residential building stock, school buildings have a high occupancy rate and can operate in up to three shifts. Pre-primary, primary and secondary education in FYROM is organised in 1 292 school facilities, which accommodate about 344 393 students and 17 849 staff. The total student population represents 18% of the total population of FYROM, which is estimated at 2 033 964 inhabitants (Republic Bureau of Statistics, 1992).

Preliminary architectural screenings of school facilities revealed that 874 (59%) school buildings almost satisfy standards for intended use, while 615 (41%) should be repaired, reconstructed or adapted. Out of 1 489 school buildings, 367 (25%) were built before 1945, 666 (45%) in the period 1945 to 1965, and 460 (31%) after 1965. The first seismic design code for the territory of FYROM was enforced in 1964. Thus, 1 033 (69%) educational buildings currently in use were built with no regard for seismic safety considerations.

An analysis of seismic exposure of school buildings and students (Table 6.2) indicated that there is a high probability that 100% of school buildings might be exposed to an MMI of greater than or equal to VI, and 98% of school buildings and 99% of students to an MMI of greater than or equal to VII.

Table 6.2. Seismic exposure of school buildings and students in FYROM

	Buildings		Students	
Intensity MMI (≥)	Number	%	Number	%
VI	1 489	100	344 393	100
VII	1 467	99	342 568	99
VIII	1 002	67	257 640	75
IX	264	18	57 720	17
X	37	3	4 959	1

In the Skopje earthquake of 1963 (Table 6.3), 44 urban school buildings – or 57% of the total urban school building stock, providing education for about 50 000 children – were destroyed. Fortunately, the Skopje earthquake occurred during the summer holidays, at 5:17 a.m. local time, when school buildings were not being used. Thus, there were no human casualties associated with the heavy school building loss. Nevertheless, schooling was heavily interrupted both in Skopje and throughout the entire country. Most children were evacuated until school buildings were repaired and strengthened and/or new temporary or permanent school facilities were erected. Unfortunately, neither the government nor schools had prepared emergency plans for such a situation. As in many other cases, if the earthquake had occurred while students were in the school building, the Skopje casualty figures would have been enormous (Figure 6.1).

Table 6.3. Behaviour of educational buildings in the Skopje earthquake

School type	Damage state 1	2	3/4	5	Total	Pre-earthquake occupancy
Primary	3 (9%)	7 (20%)	11 (31%)	14 (40%)	35	36 585
Secondary	8 (19%)	15 (36%)	1 (2%)	18 (43%)	42	13 772
Total	11 (14%)	22 (29%)	12 (16%)	32 (42%)	77	50 357

Earthquake in Skopje, FYROM, 26 July 1963 (M6.1, 8 km, MMI=IX MSK-64)
Source: Milutinovic and Tasevski, 2003.

Figure 6.1. Partial collapse of secondary schools in the 26 July 1963 Skopje earthquake

(a) Gymnasium "Cvetan Dimov"

(b) Gymnasium "Zefljus Marko"

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Emergency building damage inventory and needs assessment

Following the earthquakes in Skopje in 1963, Bucharest in 1977, Thessaloniki in 1978 and Montenegro in 1979, a number of Balkan countries became involved in the UNDP/UNIDO-RER/79/015 project "Building construction under seismic conditions in the Balkan region". Participating countries Bulgaria, Greece, Hungary, Romania, Turkey and Yugoslavia agreed upon the format of the first version of the Emergency Earthquake Damage Inspection Form. The primary objectives of the emergency damage inspection were:

- To protect human life and prevent injury by identifying buildings that had been weakened by earthquakes and which are therefore threatened by subsequent aftershock activity.
- To salvage property by identifying emergency strengthening needs and measures (shoring, bracing, partial or total demolition, etc.).
- To record damage and assess usability, thus permitting the use of a maximum number of buildings quickly and at an acceptable level of risk.
- To provide information on required sheltering, and to indicate shelter sites as well as to identify transportation routes that may be dangerous due to the collapse of hazardous buildings.
- To collect data necessary for obtaining reliable estimates of the disaster, such that authorities can take effective and efficient relief measures, formulate disaster mitigation policies and allocate available resources.
- To provide data that will identify frequent causes of damage. These data can then be used in the formulation of rehabilitation plans.
- To provide information for practical research studies that map the spatial distribution of earthquake effects (which may lead to reconsidering urban plans), re-evaluate existing codes and construction practices, update seismic hazard maps and elaborates seismic vulnerability models for pre-earthquake assessments. (UNDP/UNIDO-RER/79/015, 1985; Anagnostopoulos, Petrovski and Bouwkamp, 1989).

The form, which contains data entries coded for easy computer transfer and processing, requests the following general data:

- Building identification.
- Technical characteristics of the building, including its use.
- Data on the building's structural system, including the quality of workmanship and repairs.
- Building damage assessment parameters, for both structural and non-structural elements, building installations and the damage state of the entire building.
- Post-earthquake usability classification of the building and posting.

- Recommendations for emergency measures.
- Estimates of the building value, cost of damage and human casualty. (UNDP/UNIDO-RER/79/015, 1985; Anagnostopoulos, Petrovski and Bouwkamp, 1989)

The essential objective of the UNDP/UNIDO-RER/79/015 form is to establish a direct relationship between physical building damage and its usability (Table 6.4). Thus, one screening is sufficient to classify the building in terms of both damage and usability. The Applied Technology Council has recommended the use of similar criteria and methodologies in the United States (ATC, 1978).

A closed risk-ranking procedure based on pre-earthquake Rapid Visual Screening – which is described in the Federal Emergency Management Agency 154 Report (FEMA 154, 2002) and also in the paper by Christopher Rojahn in this publication – is used in the United States and in some other countries. In 1996, the Ministry of Construction in Japan issued standards for seismic damage assessment and performance of existing and damaged buildings (Fukuta, 1996).

While Balkan countries such as Bulgaria and FYROM have slightly modified the original UNDP/UNIDO-RER/79/015 format to allow for national specifications, Greece drastically revised it by adopting two levels of inspections; the second level uses a form that is quite similar to the 1984 UNDP/UNIDO-RER/79/015 format. Following the 1996 earthquake in Konitsa in northern Greece, EPPO (Earthquake Planning and Protection Organisation) introduced a first-degree inspection procedure for rapid post-earthquake usability evaluation (Dandoulaki, Panoutsopoulou and Ioannides, 1998). European efforts (*e.g.* Belazougui, Farsi and Remas, 2003; Benedetti and Petrini, 1984) to establish a procedure that relates pre-earthquake building characteristics, both technical and structural, to their vulnerability/risk rank never reached a consensus.

School ID Card: A prerequisite for effective mitigation and emergency response

The following five steps are essential in conducting any risk management programme:

- Understanding the current level of risk exposure.
- Assessing the acceptability of this risk.
- Evaluating alternative risk mitigation approaches.
- Selecting an appropriate approach.
- Implementing the approach.

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Table 6.4. Criteria for damage and usability classification of buildings

Damage and usability category	Usability category	Damage state	Damage degree	Damage description	Note
I	Usable	**None:** Slight non-structural damage, very isolated or negligible structural damage	1	- No visible damage to structural elements - Possible appearance of fine cracks in the wall and ceiling mortar - Non-structural and structural damage barely visible	Buildings classified as damage degrees 1 and 2 are without decreased seismic capacity and *do not pose* a danger to human life. These buildings are immediately usable, or usable after removal of local hazards, such as cracked chimneys, attics and gable walls.
			2	- Cracks in the wall and ceiling mortar - Displacement of large patches of mortar from wall and ceiling surfaces - Considerable cracks, or partial failure of chimneys, attics and gable walls - Disturbance, partial sliding, sliding or collapse of roof covering - Cracks in structural elements such as columns, beams and reinforced-concrete walls	
II	Temporarily unusable	**Severe:** Extensive non-structural damage, considerable structural damage yet repairable structural system	3	- Diagonal or other cracks in supporting walls, walls between windows and similar structural elements - Large cracks in reinforced structural elements such as columns, beams and reinforced-concrete walls - Partially failed or failed chimneys, attics or gable walls - Disturbance, sliding and collapse of roof covering	Buildings classified as damage degrees 3 and 4 are of significantly decreased seismic capacity. Limited entry to the building is permitted, and it is *unusable before repair and strengthening.* The needs for supporting and protection of the building and its surroundings should be considered.
			4	- Large cracks with or without detachment of walls, with crushed materials - Large cracks with crushed material from walls between windows and similar elements of structural walls - Large cracks with small dislocation of reinforced-concrete structural elements: columns, beams and walls - Slight dislocation of structural elements and the whole building	
III	Unusable	**Total:** Destroyed or partially or totally collapsed structural system	5	- Structural elements and their connections are extremely damaged and dislocated - Large number of crushed structural elements - Considerable dislocation of the entire building and roof structure. - Partially or completely failed buildings	Buildings classified as damage degree 5 are *unsafe and risk sudden collapse*. Entry is prohibited. Protection of streets and neighbouring buildings or urgent demolition is required. Decision on demolition should be based on an economic study that considers repair and strengthening as *one* of the possible alternatives.

The first step is important when establishing disaster preparedness strategies because understanding the current level of risk exposure provides essential qualitative and quantitative inputs for internal (school) and external (community/state emergency systems) response plans. The other four steps provide important inputs for mitigation strategies and their implementation, in particular for engineering mitigation measures, which require substantial resources.

The public and those employed in disaster management must be aware of risks in their educational facilities in order to be adequately prepared and to respond effectively in the event of a disaster. The School ID Card can be a useful tool to provide effective risk mitigation and emergency response. It provides essential data on potential damage to school buildings from earthquakes of different magnitudes and also includes elements for effective first-response and emergency management operation.

The adoption of a School ID Card system, which would be developed for every school building and school administration would ensure:

- Understanding of risk-ranking and thus the classification of school stock according to risk factors and vulnerability to earthquakes of different magnitudes.
- Development of community emergency response plans prioritised by risk factors.
- Planning of cost-effective community resources, both material and human, for efficient emergency response.
- Better estimation of support from regional and/or state emergency systems.
- Improved planning and organisation of relief needs.

In its simplest form, the School ID Card contains risk audit data. All these data can be gathered, computed, interpreted and synthesised prior to an earthquake by specialists. In summary, the School ID Card should include data on:

- Building identification.
- Technical characteristics of the building and its use.
- Building's structural system data, including the quality of workmanship and repairs.
- Site-specific data: seismological, earthquake hazard and geotechnical.
- Building vulnerability data as well as the risk rankings defined for several earthquake scenarios that are likely to affect the school. The low-probability high-impact event should also be included as the worst-case scenario. The FEMA-154 scoring scheme, or more accurate methods such as those incorporated in standards in Japan, may be used for estimating levels of expected damage. On this basis, for identified and/or predefined occupancies, the expected casualty should be estimated and included in emergency management plans.

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Schools and school gymnasiums are often used as emergency centres, as housing for the injured or as evacuation areas in post-earthquake situations. Thus, evaluation of the stability and safety of school buildings by rapid inspection becomes even more vital. Standard visual inspection techniques, which use either "side walk" or "building entry" methods, do not in many cases provide reliable diagnoses. However, rapid and cost-effective techniques do exist that can overcome these visual screening shortcomings. Ambient vibration measurements of the school building, performed prior to and after a damaging earthquake, can provide comparative data on the pre- and post-earthquake dynamic properties of the building. High-resolution analytical diagnostic techniques can also determine the post-damage earthquake usability of the building. If the instrumentation is telemetric, the diagnosis can be dispatched immediately to emergency centres. Establishing links with specialised organisations and/or institutions is necessary for such techniques to be most effective.

In addition to standard structural and other emergency parameters outlined in the UNDP/RER-79/015 or FEMA 154 forms, the School ID Card could include data on school building pre-earthquake dynamic properties, such as natural frequencies and mode shapes. The criteria for such inclusion are either the shift occupancy (more than for example 300 students) or the role of that particular school building in a city/regional/state emergency management plan.

As is the case in some countries, major schools can be instrumented. Depending on the adopted instrumentation technique – an individual strong-motion instrument or an array – a number of high-resolution analytical diagnostics techniques can determine the post-damage earthquake usability of the building. If the instrumentation is telemetric, the diagnosis can be dispatched directly to emergency centres. In order to establish such a system, it would be necessary to co-ordinate with specialised organisations and/or institutions.

Using a simple strong-motion instrument, an estimate on potential building damage can be made by comparing the school building input acceleration level and associated demands with the building capacity computed prior to the earthquake. Using an array, the processing of recorded array data would indicate the levels of developed non-linear deformation, which can be translated easily into damage states and dispatched to emergency centres.

The continuing work of EUR-OPA Major Hazards Agreement

Since its establishment in 1987, the EUR-OPA Major Hazards Agreement has made concerted efforts to promote a culture of risk prevention that can bring populations at risk, authorities, decision-makers and stakeholders to an enhanced awareness of risks and of safety measures to be implemented at individual and community levels.

Some of these efforts have already been realised, for example the Euro-Mediterranean Network of Schools (MEDSAFE Network), which is dedicated and mandated to promote a culture of risk prevention, was established in 1999.

The protocol for safety in schools agreed at the "Third Euro-Mediterranean Conference on Schools and Risks" (13-15 January 2000, Sofia, Bulgaria) and the conclusions of the "International Workshop on Safety in School Buildings" (11-12 December 2000, Sofia, Bulgaria) reaffirmed a strong need for:

- Identification of the risks to which schools are exposed; and a safety analysis that identifies the requirements that ensure an individual's safety.
- Training for school principals; and identification of measures to raise staff, student and parent awareness of the natural and industrial environment, and of the necessary precautions and procedures in the event of an accident.
- Placement of instructions and introduction of prevention and warning systems.
- Organisation of periodic drills to test these measures.
- Incorporation of information on the prevention of major risks in the school curriculum.

To further direct these EUR-OPA MHA efforts, two workshops were organised:

- Workshop on "Vulnerability of Buildings", 3-5 March 2003, Joint Research Centre, Ispra, Italy.
- International Workshop on "Safety and Emergency Management of Essential Facilities", 19-21 June 2003, Ohrid, FYROM (see "References").

These activities established that earthquake vulnerability and damage potential of essential facilities – such as kindergartens, schools and hospitals – lead to unacceptable levels of casualties and economic loss, particularly with regard to earthquakes. It was decided that adequate "facility-specific" ID cards should be prepared, which contain structural and other building-specific data (identification, quality of construction and maintenance, installations, emergency evacuation capacity, etc.), a site-specific hazard matrix and building-specific risk estimates. These cards should be used by local, regional and national governments for effective prevention, preparedness and emergency response planning.

Present EUR-OPA MHA efforts are focused on developing the School ID Card as an instrument for raising the awareness of the public, school administrators, authorities and emergency managers to school risk-ranking and to the potential scale of problems that these institutions may face during an earthquake emergency. However, to utilise these buildings following a disaster, their post-event safety must be known. While sufficient in some cases, visual screening methods based solely on expert judgment are not always reliable. Non-invasive and cost-effective methods, such as ambient vibration for pre- and post-event testing with results incorporated in a standard School ID Card, would significantly decrease the risk of misinterpreting a building's post-event safety. A

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consistent integrated approach to this problem will significantly improve the management capabilities of communities or state emergency services and allow the integration of schools in the system as a resource of significant capacity.

It is important and necessary at this time to propose and establish new approaches, in addition to suggest new co-operative mechanisms aimed at minimising risks in schools and assuring effective and efficient hazard response to protect their occupants. The School ID Card is seen as a cost-effective means of achieving this objective.

Earthquake preparedness in FYROM schools

During the last decade, earthquake preparedness of schools and students has been achieved through the national education system and activities of specialised NGOs (*e.g.* Macedonian Red Cross, First Children's Embassy) and agencies of the United Nations (*e.g.* UNICEF, UNESCO). Topics addressing natural and man-made hazards and disasters have also been integrated into the curricula and in students' extra-curricular activities.

In order to better educate students and teachers in disaster preparedness and management, UNICEF-Skopje Office launched a project on "Physical and Psychological Management of Earthquake-Related Emergencies in Schools in the Republic of Macedonia". This project had the following objectives:

- *Education programmes*. Topics addressing natural and man-made disasters will be further integrated into the curriculum, with particular emphasis on the main agents of disaster in FYROM. The basic elements of emergency management, in addition to stress management and counselling, will also be incorporated in educating and training existing and future teaching staff.

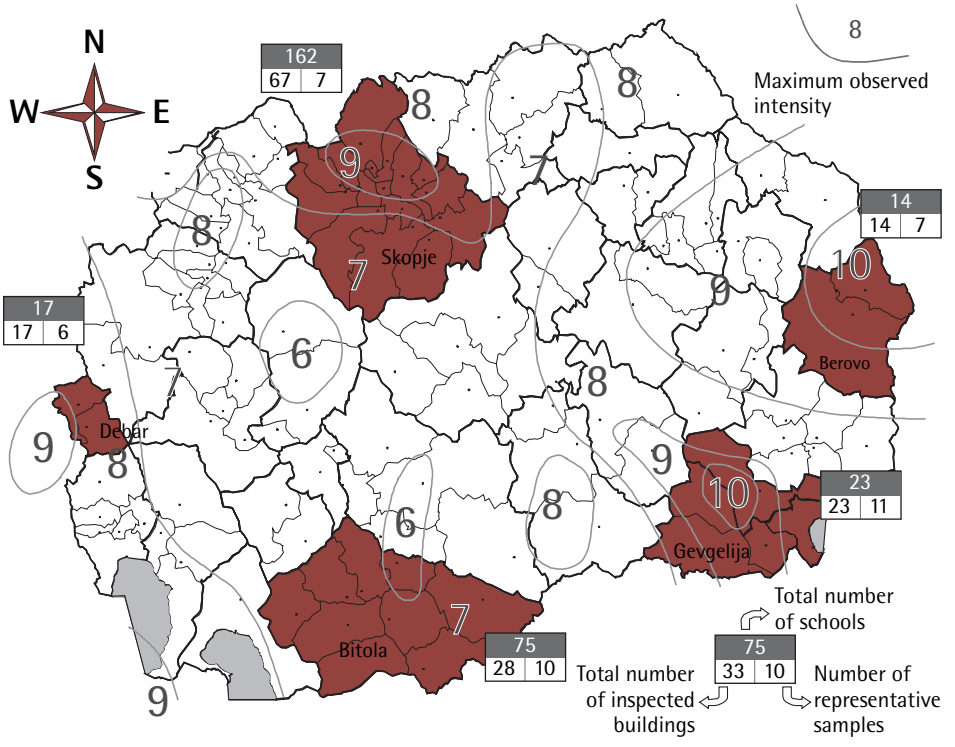
- *School Emergency Preparedness Plans (SEPP).* These plans are to be prepared at the school level. The roles and responsibilities of all stakeholders and instructions for emergency procedures will be clearly defined. Drills to test the effectiveness of SEPP will be organised regularly in co-ordination with the Pedagogical Institute of Macedonia and the Ministry of Education and Science.

A number of project activities have already been realised:

- *Definition of school survey sampling model.* To assess the present condition of school buildings and the prevalent structural typology, 15% (about 150 school buildings) of the overall school building stock was evaluated. The school building sample, sampling criteria and prioritisation were based on the local seismicity of FYROM, distribution of pedagogical regions, and the typology and present conditions of the exposure (Figure 6.2).

- *School building survey.* A school building survey focused on the characteristics of the building site, school building geometry and structural characteristics, materials used, characteristics of foundation media, age, quality of maintenance, existing conditions,

Figure 6.2. Regions of school survey sampling



provision of evacuation facilities and capacity. The UNDP/UNIDO-RER/79/015 form was slightly modified to include only pre-earthquake building data and data of interest to the Ministry of Education and Science for improvement of school maintenance, equipment, installations, etc. (Figures 6.3 and 6.4).

- *Determination of dominant school building structural typology.* The principal structural types of school buildings were defined based on data collected in a survey of school buildings.
- *Development of a GIS-oriented information database.* This database was developed from the school-building inventory and from data collected on structural, non-structural and other school building parameters.
- *Expected seismic behaviour of school buildings and probability of disaster.* The expected seismic behaviour of school buildings and the probability of disaster were estimated for prevalent structural types of school buildings in FYROM based on detailed analyses of buildings' behaviour in the post-elastic domain.
- *Definition of cost-effective measures and priorities for reduction of earthquake effects.* Cost-effective measures to reduce non-structural school building damage will

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be proposed, based on disaster potential caused by unacceptable behaviour of non-structural elements and school equipment.

- *Development of guidelines for the physical and psychological management of earthquake-related emergencies in schools.* These guidelines will provide information on present school building conditions, prevalent school building typology and expected structural behaviour of school buildings in the event of an earthquake. Measures and priorities to consider in the physical and psychological management of earthquake-related emergencies are defined in accordance with worldwide experiences and are adjusted to the existing seismic and school-building environment in FYROM.

- *Preparation of classroom materials.* In order to improve the skills and decision-making abilities of teachers and administrative staff, booklets and teachers' manuals will be prepared that contain measures and priorities for the physical and psychological management of earthquake-related emergencies. The booklets will contain approximate assessment of school building safety and instructions on how to organise building evacuation.

- *In-service teacher training.* Regional workshops for school co-ordinators will be organised to present relevant teaching models.

The project is being conducted in two phases:

- *Phase I.* This phase includes the sampling of school buildings and a survey, estimation of the building's seismic performance and probability of creating internal disaster conditions; definition of cost-effective measures for reducing non-structural risks and collateral effects; and measures for physical and psychological management of earthquake-related emergencies.

- *Phase II.* Development, preparation and printing of classroom materials, in addition to in-service teacher training, will take place.

Figure 6.3. School survey form

1. **Municipality:**
2. **Town:**
3. **School ID:**
4. **Status of the school:**
   Principal school
   Branch school
5. **Name:**
6. **Address:**
7. **Contact person:**
8. **Number of buildings:**
9. **School gross area (m2):**
   Teaching facilities
   Sport facilities
   Kitchen
10. **Open areas (m2):**
    Yard
    Playground
11. **Number of pupils:**
    First shift
    Second shift
    Inter-shift
12. **Teaching and other staff:**
    First shift
    Second shift
13. **Emergency response and shelter plans:**
    Yes
    No
14. **Emergency supplies:**
    Yes
    No
15. **Earthquake drills:**
    Yes
    No
16. **Earthquake education and training programmes:** *(Yes/No)*
    Teaching staff
    Pupils

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Figure 6.4. Building survey form

1. School ID:

2. Building ID:

3. Building usability:
Teaching facilities
Sport facilities
Kitchen

4. Number of pupils:
First shift
Second shift
Inter-shift

5. Teaching and other staff:
First shift
Second shift

6. Building gross area (m^2):

7. Classrooms:
Number
Gross area (m^2)

8. Specialised cabinets:
Number
Gross area (m^2)

9. Other rooms:
Number
Gross area (m^2)

10. Hallways:
Gross area (m^2)

11. Width of stair flight (m):

12. Year of construction:

13. Plan shape:
Regular
Irregular
(T-shape, L-shape, U-shape, cruciform, other complex shape)

14. Number of storeys:
Basement (Yes/No)
Storeys
Mezzanine
Appendages

15. Average storey height (m):

16. First-floor stiffness relative to others:
Larger
About equal
Smaller

17. Type of structure:

18. Type of load carrying system:
Bearing walls
Frames
Frames with infill walls
Skeleton with infill walls
Mixed
Other

19. Partition walls:
Reinforced concrete
Wood
Masonry
Mixed
Other

20. Floors:
Reinforced concrete
Steel
Wood
Other

21. Floor covering:
Wood
Textile
Ceramic
Other

22. Roof:
Reinforced concrete
Steel
Wood
Other

23. Roof covering:
Tiles
Lightweight asbestos-cement
Metal sheets
Other

Installations: *(Yes/No/year)*
Electrical
Plumbing
Heating
Lightning conductor

25. Quality of workmanship:
(Good – 3; Average – 2; Poor – 1)

26. Maintenance:
(Good – 3; Average – 2; Poor – 1)

27. Quality of joinery:
(Good – 3; Average – 2; Poor – 1)
Windows
Doors

28. Existing damages (description):

29. Last repair and reconstruction works:
Repaired (year)
Strengthened (year)

30. Building internal hazards:
Potential of non-structural earthquake hazards in classrooms (Yes/No)
Potential of non-structural earthquake hazards throughout school building (Yes/No)
Marked evacuation routes (Yes/No)

---

31. Fire protection: *(Yes/No)*
Hydrants
Fire extinguishers
Alarms
Structural measures against fires

32. Technical documentation available:
(Yes/No)
Architecture
Structural design

33. Site-soil conditions:
Rock
Firm
Medium
Soft

34. Slope:
Flat
Slight slope
Moderate slope
Steep slope

35. Observed soil instabilities:
None
Slight settlement
Intensive settlement
Liquefaction
Landslide
Other

36. Seismic exposure:
Maximum observed intensity
Seismic zone

37. Flood danger:
Yes
No
Unknown

38. HazMat on site:
Yes (on what distance)
No
Unknown

39. Photographs:

40. Remarks and recommendations *(Yes/No):*
(if yes please attach a separate sheet)

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Acknowledgements

The project research team would like thank the UNICEF-Skopje Office for their support and co-operation and for making possible the present nation-wide initiative to improve skills of teaching staff in the physical and psychological management of earthquake emergency situations. The team would also like to acknowledge the collaboration of the European Centre on Vulnerability of Industrial and Lifeline Systems (ECILS, Skopje).

Basic data on quantifying the effects of natural hazards in FYROM were provided by the Institute of Earthquake Engineering and Engineering Seismology (IZIIS), University "St. Cyril and Methodius", Skopje. The research presented in this paper was conducted through the joint efforts of the author and many of his colleagues, particularly those from the Section on Risk, Disaster Management and Strategic Planning.

Note

1. The EUR-OPA Major Hazards Agreement (MHA) member states are Albania, Algeria, Armenia, Azerbaijan, Belgium, Bulgaria, Croatia, Cyprus, France, FYROM, Georgia, Greece, Lebanon, Luxembourg, Malta, Moldova, Monaco, Morocco, Portugal, Romania, the Russian Federation, San Marino, Spain, Turkey and Ukraine.

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CHAPTER

7

MAKING SCHOOLS SAFER: THE NEW ZEALAND EXPERIENCE

Brian Mitchell

Property Management Group, Ministry of Education, New Zealand

Abstract: This paper presents New Zealand's seismic risk profile, past seismic events in the country and strategies applied to reduce seismic risk. New Zealand experiences a large number of earthquakes, the most damaging of which took place in February 1931 in Hawke's Bay. Following the 1991 Building Act, which was created to regulate building design and construction, a number of strategies were implemented to ensure compliance of all school buildings constructed from 1976 onwards with the new seismic standards. Between 1998 and 2001, a structural survey of 2 361 public schools was commissioned by the Ministry of Education, and a significant investment programme was initiated to meet the recommendations of the report in terms of specific categories of buildings.

Introduction

This paper describes the seismic risk profile of New Zealand, actual seismic events in the country and strategies used to reduce seismic risk. Fortunately, these strategies have not been tested by a major, devastating earthquake. Despite the country's reputation as the "shaky isles",[1] it has only experienced one significant earthquake – in terms of human loss and property damage – since major settlement began in 1840. Most major earthquakes occurred when the country was sparsely populated, if at all.[2] But the risk remains, and seismic activity continues. This paper aims to demonstrate that New Zealand schools are prepared in the event of a major earthquake.

Seismic risk in New Zealand

New Zealand experiences a large number of earthquakes. It has a level of seismicity that is similar if not greater than some of the most seismically active regions in the world. It is located on the boundary of the Australian and Pacific tectonic plates, where relative plate motion is obliquely convergent across the plate boundary at about 40 mm/year. As a result of this plate motion, there are a number of active faults, a high rate of small-to-moderate (M<7) earthquakes, and many large (M7 to M7.9) earthquakes. In addition, the country is subject to volcanic eruptions; five volcanoes have been active in the last 100 years.

On average, each year 60 to 100 earthquakes in New Zealand are recorded between magnitude M4 and M5; 10 to 20 between M5 and M6; and at least one M6 or higher. Notable New Zealand earthquakes are shown in Figure 7.1. The most damaging earthquake occurred in February 1931 (M7.8) in Hawke's Bay, which caused widespread damage to buildings and infrastructure and 256 deaths in the cities of Napier and Hastings and the surrounding region.[3] Fortunately, the country's other large earthquakes occurred in non-urban areas.

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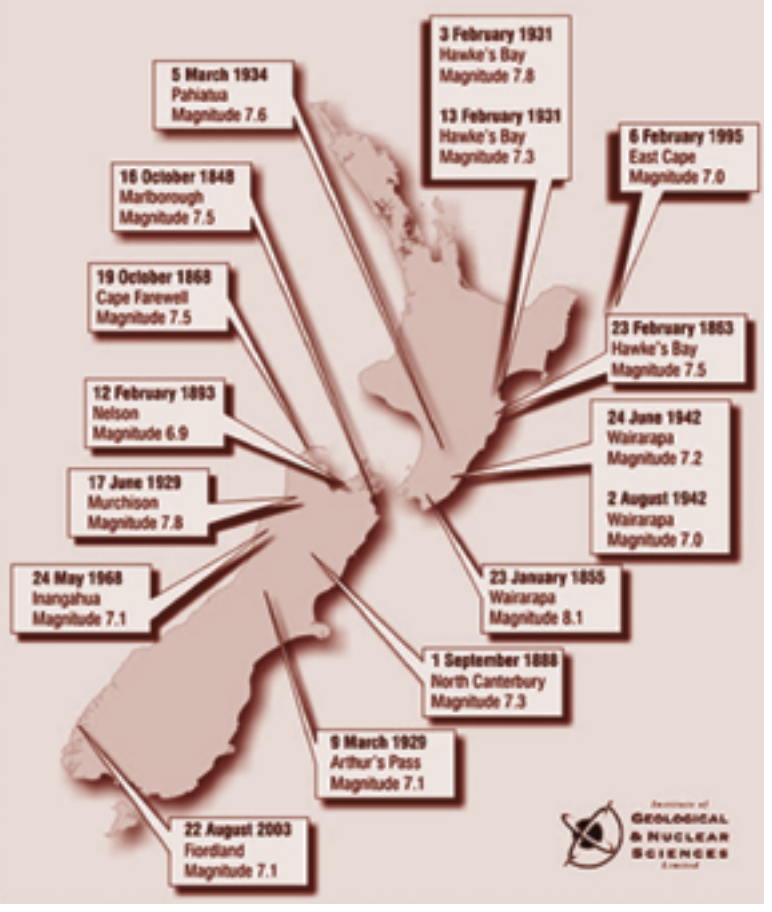
Figure 7.1. Large earthquakes in New Zealand since 1848



Current design provisions

A central piece of legislation, the 1991 Building Act, regulates building design and construction in New Zealand. These regulations specify performance standards and require that design and construction inspection be carried out by suitably qualified professionals.

Earthquake-resistant design of structures is included in undergraduate engineering courses, and professional bodies such as the Institution of Professional Engineers New Zealand and the New Zealand Society for Earthquake Engineering promote ongoing professional training through publications, seminars and conferences.

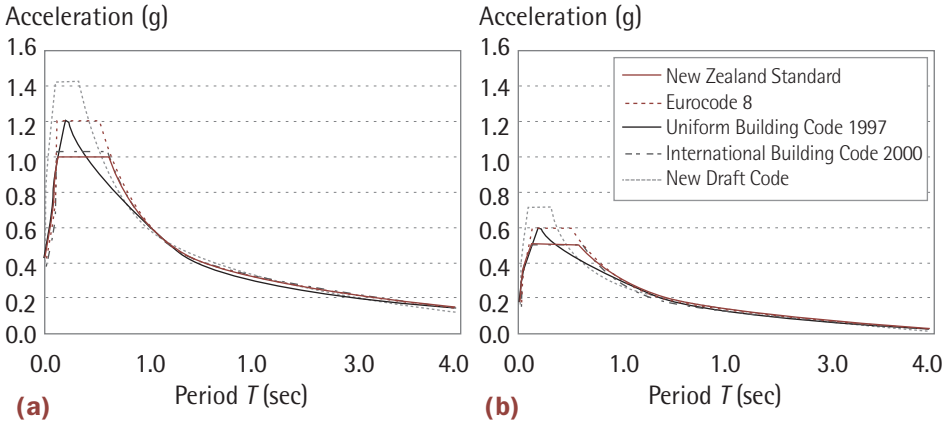
Seismic provision in design was first incorporated into legislation in 1935 following the 1931 Hawke's Bay earthquake. Subsequent improvement in design standards resulted from international experience of building performance in earthquakes and research into earthquake-resistant design. The following criteria, considered important to achieving "good" design, have been incorporated into the seismic design provisions of various design standards (*e.g.* New Zealand Loadings Code, Concrete Structures Standard, Steel Structures Standard).

- *Structural configuration.* The arrangements of structural members providing seismic resistance in buildings should be symmetrical and regular, both vertically and horizontally.
- *Appropriate mechanisms of "post-elastic" deformation.* The relative strengths of response modes and of members should ensure a desirable mode of post-elastic deformation of the structure during a major earthquake that exceeds the elastic design loads.
- *Adequate "ductility".* The structure should be detailed to ensure adequate ductility in the yielding regions during a major earthquake.
- *Displacement control.* The inter-storey drift of buildings during earthquakes should not lead to excessive damage to non-structural components or loss of integrity of the structure.

It is estimated that these seismic design requirements increase building construction costs by less than 5%.

The seismic design provisions in the New Zealand standards are generally comparable to international standards, such as the Uniform Building Code 97 (ICC, 1997), Eurocode 8 (BSI, 1998) and the International Building Code (BOCA and ICBO, 1998). A comparison of design spectra from these standards is shown in Figure 7.2.

Figure 7.2. Comparative design spectra for nominal 500-year return period for (a) high and (b) low seismic zones (elastic response)[4]



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The New Zealand design force spectra are generally similar to those found in other standards. However, it should be noted that the design and detailing standards and the on-site construction standards are at least as important as the design forces in determining effectiveness of a building's earthquake resistance.

History of construction

Early New Zealand non-residential buildings were constructed using timber, but by the early 1900s this material was replaced by brick and stone. Thus, non-residential buildings constructed before the early 1930s were commonly built using unreinforced brick or stone masonry, while timber was used mainly for houses. These masonry buildings, unless subsequently strengthened for earthquake loading, had low earthquake resistance. Many have been demolished and replaced over the years.

The 1935 legislative initiatives precluded the use of load-bearing unreinforced masonry construction. Non-residential multi-storey buildings constructed from 1935 to 1965 were usually built using reinforced concrete. Larger buildings were constructed using steel frames. Analyses of concrete buildings from this period have shown that structures containing full-height concrete walls often have a good standard of earthquake resistance, while frame buildings have relatively poor earthquake resistance. This is the result of inadequate shear strength or confinement in the beams and columns and the joint regions, which provides a low level of ductility.

A new loadings code published in 1965 introduced seismic design coefficients related to the natural period of the structure, the type of occupancy and the seismic zone. It also limited inter-storey deflections and introduced the concept of ductility. Important public buildings were required to be designed for earthquake forces approximately 33% higher than normal commercial buildings, and most government buildings – including schools – were designed for these higher forces.

From the mid-1960s to the mid-1970s, considerable advances were made in establishing ductile design procedures for reinforced-concrete structures. Up until the mid-1980s, reinforced concrete was the dominant construction material used for multi-storey commercial buildings. Since then, structural steel has gained a significant proportion of the market.

In 1976, a new loadings code defined seismic design forces as a function of ductility and potential seismic performance of different structural systems. This code and subsequently published concrete (1982), steel (1989), masonry (1984) and timber design codes advanced provisions for earthquake-resistant design of reinforced-concrete and reinforced-masonry structures, including provisions for the control of damage to non-structural elements. Buildings constructed to these standards are expected to have low vulnerability to earthquake damage.

Most houses and many low-rise (one- to two-storey) non-residential buildings, including school buildings, are built using timber-frame construction. These buildings exhibit very good earthquake resistance. Even if these buildings are damaged, they are less likely to kill or injure than buildings of heavier construction.

Quality control standards in the New Zealand building construction industry are generally high. The design engineer normally inspects the building construction work to check compliance with the design documents.

The common construction types used for school buildings and their relative vulnerabilities to earthquake damage are shown in Table 7.1. The majority of school buildings are one- or two-storey braced timber-frame construction and hence have low vulnerability.

Table 7.1 also shows the maximum damage – with approximately 10% probability of being exceeded – that the construction types would expect to sustain if subjected to severe earthquake shaking within 10 km from the epicentre of a large (>M7) earthquake. Descriptions of the extent of damage are provided in Table 7.2.

Strategies applied in a school building context

All school buildings constructed from 1976 onwards were made to comply with the new seismic standards. By the mid-1990s, unreinforced masonry buildings had been demolished and replaced, or structurally upgraded. The problem was that it was unclear if all at-risk buildings had been surveyed and identified, and also if remedial action had been taken. Although anecdotal evidence suggested that the programme was completed, there were no records to confirm that this was the case.

Table 7.1. New Zealand building vulnerability and expected earthquake damage

Date	Construction type	Vulnerability to damage	Maximum damage in severe earthquake
Pre-1935	Unreinforced masonry*	High (low to medium if strengthened)	Complete
	Timber	Low	Moderate
1935-1968	Timber	Low	Moderate
	Reinforced concrete, low ductility*	Medium to high (low to medium if strengthened)	Extensive
1968-1976	Timber	Low	Moderate
	Reinforced concrete, limited ductility	Low to medium	Moderate
	Reinforced masonry	Low to medium	Moderate
Post-1976	Timber	Low	Moderate
	Reinforced concrete, ductile	Low	Moderate
	Reinforced masonry	Low	Moderate
	Steelwork	Low	Moderate

*Most school buildings of these types of construction have been replaced or strengthened.

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Table 7.2. Damage state descriptions

Damage state	General description of damage
Light	Includes internal disruption caused by planters, furniture, bookshelves and other items that are free to move around during shaking, and some slight damage to permanent building elements such as ceilings, lighting fixtures and partitions. Damage may require clean-up and minor repairs to the extent that the building cannot be used immediately. Although essentially no injuries are expected in the building, there is always the possibility that shaking objects could shift or topple in such a way as to cause an "incidental" hazard.
Moderate	Includes more extensive damage to internal elements and minor structural damage such as cracks in masonry walls. The building is not in any danger of structural failure, but a slight risk of injury could result from falling light fixtures or equipment. The damage would be sufficient to require repair, and the building could be partially or completely closed, pending analysis and/or repairs. Partial closure is expected in any case while repairs and clean-up are completed.
Extensive	Includes damage to structural elements such as walls, columns and beams. The building may be leaning; certain floor levels or walls may be out of alignment; and internal elements may be damaged beyond repair. The building would be closed by Civil Defence until structural repairs were completed. Occupants or passers-by may have been injured by falling debris. For a building that has been severely damaged, the owner must often wait for completion of engineering and economic studies to determine if it is more economically justifiable to repair the building or to simply demolish it.
Complete	Includes a collapsed building or one that has been so severely damaged that repair is clearly uneconomical. Falling internal elements or collapsing floors would result in loss of lives. Because of the many structural requirements placed in modern codes specifically for the purposes of preventing collapse, this damage state should be rare in new buildings.

In addition, the "earthquake-prone" provisions of the Building Act related only to unreinforced-masonry buildings. While buildings designed after 1976 can generally be considered satisfactory – on the condition that subsequent alterations have not weakened them structurally – no national standard or requirement existed for assessing the seismic performance of other school buildings. Consequently, the Ministry of Education decided to set its own threshold and strengthening levels to adequately reflect the importance of preventing schools from collapsing in severe earthquakes. The standard adopted by the ministry for all school buildings can be summarised as follows:

- Buildings of heavy construction (*i.e.* concrete floors) must be reviewed against the full requirements prescribed by the Building Act. If these buildings are unable to meet those levels, they are to be strengthened to the specified performance levels.
- All buildings with major assembly areas must be reviewed against the full requirements and strengthened to those levels where necessary.

- Conventional timber-framed and floored school buildings with light roofing are to be reviewed against a two-third threshold of the full requirement levels. This lower level reflects the lower collapse potential compared to buildings of heavier construction. However, where practicable, these buildings should be strengthened to full requirement levels.
- For those school buildings with a heavy tile – rather than light tile – roof, the building must be strengthened to full requirement levels.
- A seismic risk factor of 1.20 must be used for the assessment of school buildings.

In order to address the information gap and the potential risk to non-masonry buildings, the Ministry of Education commissioned a structural survey by registered engineers over the period 1998 to 2001 of all 21 100 individual buildings at 2 361 state schools.

A walk-through survey was conducted. Given the nature and scale of the undertaking, practical constraints were imposed in certain areas. Priority was given to low-rise school buildings constructed using lightweight framing, as these structures comprised the majority of school building stock. Detailed structural assessments of each building were considered neither practical, given the number of schools, nor necessary, given the frequency of common designs used in earlier school construction.

The aim of the survey was to prevent loss of life or serious injury arising from a structurally defective building or site structure; not to prevent or minimise damage to property.

The buildings and site structures were evaluated on the basis of common-sense engineering principles that were broadly based on the Building Act requirements. Non-compliance was not in itself sufficient reason for a feature to be classified as a structural defect; the feature had to be a threat to life safety. Specific structural defects that could potentially cause death or serious injury during wind, earthquake or everyday loadings were identified and costed. Potential defects that required a more detailed investigation were also identified and made the subject of a follow-up investigation in 2000. In addition to buildings, site structures such as retaining walls and volley walls were also checked. Defective buildings and site structures are categorised as described in Table 7.3.

All other pre-1976 blocks containing at least two storeys were evaluated using a Rapid Evaluation (RE) method that was adapted for this project by the New Zealand Society for Earthquake Engineering. If the surveying engineer deemed that a more detailed assessment of the building was required, irrespective of the structural score obtained using the RE method, then the RE score was set to 100. Some of these buildings were evaluated in greater detail following this study.

All two-storey buildings, including post-1976 buildings, were also surveyed to identify specific defects for Category B and to determine if any general structural defects were present as a result of alteration.

The key finding of the survey was that school buildings and site structures are generally in sound structural condition, given the size and diverse nature of the school property

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Table 7.3. Categories of defective buildings and site structures

Category	Title	Description
A	Vulnerable buildings and site structures	These buildings or site structures were recommended for immediate evacuation or isolation. Action was taken immediately to rectify these defects. Thus, there are no longer any buildings or site structures that fall into this category.
B	Defective single-storey buildings and site structures	These buildings or site structures have structural defects – categorised as specific structural defects and general structural defects – identified as requiring rectification. The only difference between these two categories of defects is that "specific structural defects" are more common and were recorded on the survey forms, while "general structural defects" include any other structural defects. The specific structural defect categories were: • Heavy roofs. • Solid brick walls. • Heavy ceiling tiles. • Heavy light fittings or heaters.
C	Potentially defective single-storey buildings and site structures	Further investigation was recommended for these buildings to determine if the features noted during the survey were structural defects requiring rectification. Subsequently, a follow-up survey was carried out, and the potential defects recorded under this category were either moved into category B and costed, or eliminated altogether.
D	Buildings of two or more storeys	This category was further subdivided into "Nelson Blocks" and "non-Nelson Blocks". ("Nelson Blocks" are two-storey blocks of standard design generally built during the 1960s.) A total of 137 buildings were identified during the survey but no evaluations were carried out.

portfolio. Only four buildings were found to have an unacceptable level of structural risk. Corrective action was undertaken immediately. Approximately 11% of the buildings were found to have at least one structural defect that required remedial work. The most common structural faults are described in Table 7.4.

A significant investment programme was initiated to meet the recommendations of the report for specific categories of buildings. Over NZD 20 million has been spent since the survey was completed, and a further NZD 40 million will be spent in the course of other capital improvements over the next five to ten years. The 1987 Edgecumbe earthquake demonstrated the high risk of moving furniture and equipment during earthquakes, especially in areas such as mechanical and wood processing workshops.

Table 7.4. Common structural faults arising from national survey of school buildings

Defect	Survey outcome
Seismic	• Internal walls removed between classrooms, but compensating seismic bracing not provided. • Poor sub-floor bracing and pile/bearer connection, particularly for relocatable buildings. • Masonry swimming pool changing sheds often designed and built by voluntary and unsupervised labour, and many in poor condition. • Heavy roofs. • Heavy or poorly fixed light fittings. • Unbraced masonry chimneys. • Heavy or poorly fixed heaters. • Canopies and covered walkways with inadequate lateral bracing.
General structural	• Structural connections with bolts either missing or loose. • Decaying framing timber. • Weak handrails.
Nelson Blocks	The survey concluded that while these buildings are not as critical as buildings of heavy construction, strengthening should be undertaken in conjunction with future remodelling.
Other blocks*	Some of the 421 blocks evaluated using the Rapid Evaluation method were subsequently analysed to assess their resistance to earthquakes in relation to current requirements, thus determining what (if any) strengthening was required, and establishing a rough order of cost for the strengthening work. The highest priority category for strengthening are those buildings with a floor area exceeding 1 000 m^2 and with seismic strength of less than 33% of current requirements.
Site structures	Around 13% of schools were found to have defective site structures. The most common defects were inadequately restrained elevated water tanks and unreinforced volley walls. Some regional differences emerged. Significant numbers of poorly restrained elevated water tanks were recorded in rural districts.

* Containing two or more storeys.

Experiences of schools in seismic events

In theory, all New Zealand school buildings are structurally sound by modern-day standards. Fortunately, this assertion has not been put to the test. Although there have been large earthquakes since the Hawke's Bay event in 1931, none have caused the same damage in terms of loss of life and property. This is mainly due to the fact that most earthquakes have occurred in sparsely populated rural locations.

However, some reasonable assumptions can be made in terms of the seismic profile of the country.

The first assumption is that there is a risk of a major earthquake with high losses. New Zealand has a high level of seismicity and experiences large numbers of earthquakes. It has experienced large, damaging earthquakes in the past and will do so in the future. The capital city, Wellington, experienced the strongest earthquake ever recorded (M8.1) in 1855. The town was then only 15 years old as a European settlement and was

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practically destroyed. Another event of that force is predicted, if not overdue, and seismic engineers have estimated that the worst possible outcome for school buildings would be an earthquake of about the same magnitude in Wellington. Based on anticipated seismic performance, the maximum probable loss would be NZD 250 million in terms of property damage.

The second assumption related to New Zealand's seismic profile concerns the robustness of design standards. New Zealand has high earthquake design standards. Recently constructed buildings have relatively low vulnerability to damage. However, some of the older, non-school buildings have high vulnerability to damage and are likely to sustain extensive damage that would result in injuries and fatalities in a large earthquake.

The majority of school buildings are one- or two-storey braced timber-frame constructions with low vulnerability to earthquake damage. The risk of injuries or fatalities from earthquake damage to these buildings is very low compared to other construction types.

The final assumption concerns the opinion of experts. In the experience of Opus International Consultants Ltd, a leading New Zealand multi-disciplinary consultancy specialising in engineering, the key requirements for providing schools that are safe in earthquakes are:

- Effective building regulations that ensure that buildings are designed by suitably qualified professionals using appropriate design standards.
- Enforcement of good construction quality standards.
- Good quality training in earthquake-resistant design at undergraduate level, and continuing education of practising engineers.
- Accordance of priority to school buildings at risk and then the strengthening or replacing of them.

Notes

1. "New Zealand Yesterdays" (1984), text by Hamish Keith OBE – Readers Digest Pty Ltd, Sydney.

2. New Zealand was only populated within the last 1 000 years. The country was first populated by Maori from about 1000 AD (although official histories cite that a great migration from islands in the Pacific Ocean to the north took place in about 1350); by Europeans from 1814; and then from 1840 by the British.

3. To date, this earthquake is the most catastrophic event in terms of human and property loss in New Zealand. At the time, the population was around 1 million compared with an estimated 4 million in 2003.

4. The "New Draft Code" refers to a current draft revision of the New Zealand Loadings Code.

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Acknowledgements

I am indebted to Robert Davey, Principal Consultant, Structural and Earthquake Engineering, Opus International Consultants Ltd, Wellington, for his valuable contribution to this report.

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CHAPTER

8

DAMAGE IN SCHOOLS IN THE 1998 FAIAL EARTHQUAKE IN THE AZORES ISLANDS, PORTUGAL

Jorge Miguel Proença

Institute of Structures, Territory and Construction Engineering, Higher Technical Institute, Portugal

Abstract: On 9 July 1998, an earthquake struck the islands of Faial and Pico in Portugal, killing eight people and leaving 1 000 homeless. Following the earthquake, 21 educational buildings were inspected in an attempt to establish the correlation between general building classification factors – structure, quality, conservation condition and number of storeys – and the buildings' damage state and post-event use. This paper presents the inspection results.

Introduction

Portugal is located in a volatile seismic area, where both intraplate and interplate tectonic events have caused significant devastation over the centuries. An *interplate* earthquake, the epicentre of which is located between the Eurasian and the African tectonic plates, led to the 1755 Lisbon earthquake, which had an estimated magnitude of M8.5 to M9.0, and to other seismic occurrences. Interplate earthquakes are characterised by very large magnitudes and large focal distances; for those that affect Portugal, the epicentre is typically located in the Atlantic Ocean, southwest of the Algarve. An *intraplate* earthquake is generated in any of the fault complexes within the continental plate, such as the lower Tagus fault complex. Intraplate events led to the 1531 Lisbon (maximum MMI = IX) and the 1909 Benavente earthquakes (maximum MMI = IX). Intraplate events are characterised by large magnitudes (typically M6 to M7) and small focal distances to inhabited areas.

The Azores Islands have experienced a number of seismic events, as the archipelago is located near the confluence of the American, Eurasian and African plates. The 1998 Faial earthquake was the most recent significant earthquake in the Azores.

The 1998 Faial earthquake

On 9 July 1998, at 05:19 local time, an earthquake of magnitude M6.2 occurred in the strait between the islands of Faial and Pico in the Azorean archipelago at 38.33°N and 28.07°W. The epicentre was located at sea approximately 5 km from the island of Faial and 15 km from its capital, Horta. The earthquake was felt on most of the Azores Islands and led to significant destruction, mostly on Faial Island, where it reached an intensity of VIII (MMI). Eight people were killed and approximately 1 000 were left homeless. Figure 8.1 shows the location of the epicentre and the isoseismals for the most affected islands of Faial (to the west) and Pico (to the east).

These two islands have experienced a number of natural disasters in the past. The 1926 Horta earthquake destroyed part of Horta; volcanic eruptions occurred in 1957 in Capelinhos, which is located on the western tip of Faial; a series of minor-to-moderate earthquakes struck the islands of Pico and S. Jorge in 1973; and more recently, an earthquake shook the nearby island of Terceira in 1980, although it did not cause significant damage.

In the aftermath of the 1998 Faial earthquake, a team from the Institute of Structures, Territory and Construction Engineering at the Higher Technical Institute (ICIST/IST) in Lisbon completed damage assessments of religious and educational buildings on the

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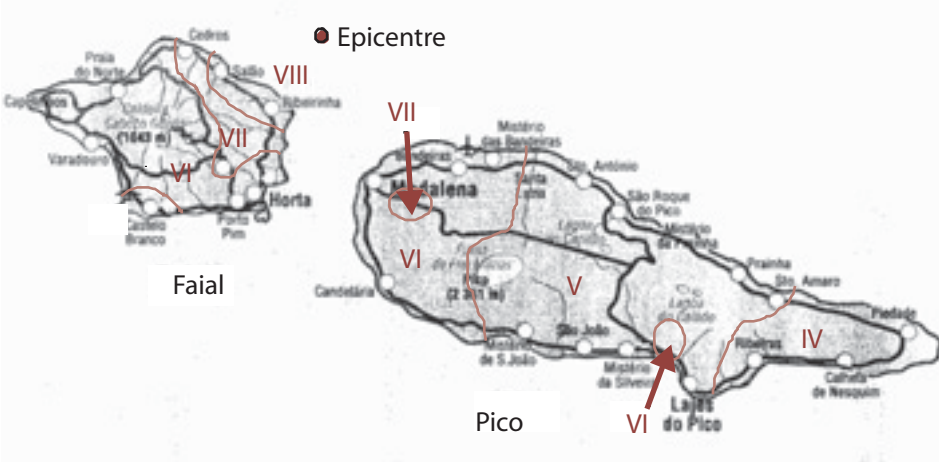
islands of Faial and Pico. A total of 21 educational buildings were inspected on the island of Faial (Azevedo *et al.*, 1998).

Figure 8.1. Epicentre location and isoseismals chart for 9 July 1998 Faial earthquake

(adapted from Nunes et al. (1998) and Oliveira (1999))



Classification of educational buildings

Educational buildings were classified in terms of the structural solution, building quality, conservation condition and number of storeys.

Building structures were classified as follows:

- The *masonry wall* structural type corresponded to a local, traditional construction method, which uses thick external block masonry walls, generally made from loose rock blocks with small mortar quantities, with light internal masonry walls and a timber roof structure.
- The *early reinforced-concrete* structures comprised thick external block masonry walls (with mortar) and discrete reinforced-concrete elements such as columns (particularly at corners) and lintels.
- The *frame reinforced-concrete* and *frame reinforced-concrete with reinforced-concrete wall* constructions are common structural solutions and comprise reinforced-concrete frames (continuous beam and column) with reinforced-concrete shear walls.

The *building quality* and workmanship varied from medium to high.

The *building conservation condition* ranged from average to good, depending on the frequency and thoroughness of maintenance operations.

The *number of storeys* varied from single storey to two storeys.

Table 8.1 summarises the classification of educational buildings that were inspected by ICIST/IST.

Figure 8.2 – a two classroom, one-storey, early reinforced-concrete school in Espalhafatos – shows one of the most common solutions for educational buildings. The school building design and construction is similar to that found in Salão, Capelo, Lombega and Feiteira (Rua da Portela).

Figure 8.2. Overview of school at Espalhafatos

Earthquake damage and use classification

In addition to the building classification fields, Table 8.1 also summarises the most important conclusions of the assessment in terms of the educational buildings' damage state and post-event use. Figures 8.3 to 8.8 show some typical damage situations. The effects of the earthquake were assessed using the following three *damage* categories:

- *Structural damage*. Damage to structural, vertical and horizontal load-carrying elements.
- *Non-structural damage*. Damage to non-structural or secondary structural components.
- *Other damage*. Damage to installations and adjacent earth-retaining structures.

The *post-event use* of the building was one of the most important elements of the ICIST/IST inspection. Immediate use was important as many school buildings provided shelter for those who had lost homes in the earthquake. Medium-term use was also relevant as school activities were scheduled to begin about two months after the earthquake. The use classification considered:

- *Immediate use*. Inexistent or negligible damage.
- *Use after minor repairs*. Generally slight to medium damage to non-structural components and installations.
- *Use after moderate repairs*. Slight damage to structural components and/or severe damage to non-structural components and installations.
- *No use*. Demolition.

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Table 8.1. Educational building classification, earthquake damage and use classification

Location	Intensity (MMI)	Structural solution	Building quality	Conservation condition	No. of storeys	Structural damage	Non-structural damage	Other damage	Use
Flamengos	V-VI	Masonry wall	High	Good	1	Corner cracks and slight cracking in partition walls	Dislocated roof tiles	Damage in entrance pediment and damage in external retaining walls	Use after minor repairs
Almoxarife	V-VI	Frame and wall (?) reinforced concrete	High	Good	2, partially	Cracks in columns and damage near expansion joint (pounding?)	Dislocated roof tiles and slight cracking in partition and external walls	Damage in external retaining walls	Use after minor repairs
Pedro Miguel	V-VI	Frame and wall (?) reinforced concrete	High	Good	2, partially	None	None	None	Immediate use
Ribeirinha	VII	Frame reinforced concrete	High	Good	1	Roof beams (pounding?)	Dislocated roof tiles and slight cracking in partition and external walls	Damage in external retaining walls	Use after moderate repairs
Espalhafatos	VII	Early reinforced concrete	High	Average	1	Damage at corners with separation between masonry and reinforced-concrete elements, damage at the column bases and cracks in external walls	Cracking in partition and external walls and floor settlement	Damage in external retaining walls	Use after extensive repairs
Salão	VII	Early reinforced concrete	High	Average	1	Damage at the columns	Cracking in partition and external walls and cracking in the connection between floors and walls	Damage in external retaining walls	Use after moderate repairs
Salão (kindergarten)	VII	Masonry wall	Medium	Average	1	External wall collapse	General damage	General damage	No use, demolition
Cedros	VI	Early reinforced concrete	High	Good	2	None	Cracking in partition and external walls	Cracking in external retaining walls	Immediate use
Cascalho	V-VI	Frame reinforced concrete	High	Good	1	Slight cracking in reinforced-concrete roof beams	Slight cracking in partition walls		Immediate use
Ribeira Funda	V	Masonry wall	High	Average	2	Extensive cracking in external walls	Cracking in partition walls	Damage in external retaining walls	No use, possible demolition
Praia do Norte	V	Frame reinforced concrete	High	Good	1	None	Slight cracking in partition walls		Immediate use
Capelo	V	Early reinforced concrete	High	Good	1	None	None	None	Immediate use
Lombega	V-VI	Early reinforced concrete	High	Good	1	None	None	None	Immediate use
Castelo Branco (Carreira)	VI	Early reinforced concrete	High	Average	1	None	Cracking in partition walls, dislocated roof tiles and stucco and plaster crumbling	None	Use after moderate repairs
Castelo Branco (Farrobim)	VI		High	Good	1	None	None	None	Immediate use
Feiteira (Travessa do Algar)	V	Frame and wall (?) reinforced concrete	High	Good	2, partially	None	None	Slight damage in external retaining walls	Immediate use
Feiteira (Rua da Portela)	V	Early reinforced concrete	High	Good	1	None	None	Damage in electrical installations and in external retaining walls	Use after minor repairs
Horta (Pasteleiro)	V		High	Good	2, partially	None	None	None	Immediate use
Horta (Rua Cônsul Dabney)	V		High	Good	2, partially	None	None	None	Immediate use
Horta (Coronel Silva Leal)	V	Masonry wall	High	Average	2	Cracks in external and partition walls	Cracking in plaster ceilings	Damage in electrical installations	Use after moderate repairs
Horta (Gaiatos)	V	Frame and wall (?) reinforced concrete	High	Good	2	None	Cracking in plaster ceilings	None	Use after minor repairs

Figure 8.3. Severe cracking in internal partition walls at school in Espalhafatos

Figure 8.4. Damage in reinforced-concrete roof beams and in retaining walls at school in Ribeirinha

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Figure 8.5. Cracking of stucco ceiling at Horta (Coronel Silva Leal) school

Figure 8.6. Dislocated roof tiles at Castelo Branco (Carreira) school

Figure 8.7. School in Espalhafatos: Separation between block masonry and reinforced-concrete elements

Figure 8.8. Collapse of external rubble masonry walls in kindergarten in Salão

Interpretation of damage and conclusions

The extent and nature of damage in these educational buildings was strongly influenced by the structural solution. In recent reinforced-concrete structures, cracks were observed in structural elements, such as columns. Other side-effects were also noted, such as pounding and the development of short-column phenomenon resulting from partial, initial or damage-influenced restraint by adjacent non-structural masonry walls. In masonry structures, cracks of varying widths and extensions were observed in external and internal walls. Damage in early reinforced-concrete structures was similar, although less pronounced, than damage detected in masonry structures, with some signs of separation between the block masonry and reinforced-concrete discrete elements.

The extent of damage naturally depended on the site intensity and structural solution, but it was also found to be influenced by building quality and to a lesser extent the conservation condition. Given otherwise equal conditions, frame reinforced-concrete buildings performed better than early reinforced-concrete buildings, and these buildings performed better than masonry wall structures. Good building quality and conservation conditions were found to have a positive effect on building performance.

One of the most prevalent forms of damage in the "other" category was the collapse, cracking or overturning of earth-retaining walls, generally made of rubble masonry. This was caused by the fact that the buildings were generally constructed on relatively steep slopes. Dislocated tiles were also found on a number of educational buildings.

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Acknowledgements

The inspection results presented in this paper were compiled with the assistance of the National Civil Protection Service (SNPC) and the Azores Regional Civil Protection Service (SRPCA). The author also recognises the help and guidance of the Azores Regional Secretariat for Housing and Equipment. The processing of data was undertaken in co-operation with the ICIST/IST and the *Secretaria-Geral do Ministério da Educação* (General Secretariat of the Portuguese Education Ministry). The support of José Freire da Silva is gratefully acknowledged.

CHAPTER

9

EARTHQUAKES AND EDUCATIONAL INFRASTRUCTURE POLICY IN MEXICO

Jaime de la Garza Reyna

Secretariat of Public Education, Undersecretary of Planning and Co-ordination, Mexico

Abstract: Mexico is located in a high seismic risk zone, and today's industrial and commercial development has elevated the existing threat. This paper describes the measures that are being taken to improve the response of Mexico's educational sector to earthquakes. Federal, state and municipal governments are acting to increase awareness in communities through civil protection; to support public infrastructure in case of disaster with the Natural Disaster Fund, Natural Preventive Disaster Fund and a seismic alarm system; and to provide updated and regional building codes.

Introduction

Approximately 105 million Mexicans live in an area of 1 958 201 km^2 on a 10 142 km coastline; 70% of the population reside in urban areas. Mexico is located in a high seismic risk zone, and other natural phenomena such as hurricanes, tropical depressions and unpredictable storms can also have a devastating effect. Today's industrial and commercial development has elevated the existing threat. It is clear that communities must be prepared for catastrophic events, or risk the momentary shutdown of social, economical and political systems.

In Mexico, the Civil Protection Agency and the National Disaster Prevention Centre – both bureaus are within the jurisprudence of the State Department – have implemented several disaster relief mechanisms for aiding the country's federal and state governments. These bodies have mapped risk zones, emphasising geological, hydro-meteorological and chemical environment vulnerability hazards.

Site effects

The site effect is the soil's reaction to the duration and frequency of the seismic wave. Although the geological characteristics of the site location are a significant factor, this unique element responds differently according to the released seismic energy. In the 1985 earthquakes, the assessed damage of buildings in Mexico City was related to the soil properties in the valley. The dynamic wave experienced on the surface was provoked by the site effects, whereby intensity increased for ground water deposits with widths ranging from 25 m to 45 m. Seismic intensities diminished for deposits of less thickness, becoming insignificant to surface effects.

As a result of these findings, several secretariats devised a number of preventative measures in the following four fields.

Investigation

- Greater knowledge about natural phenomena.
- Identification and evaluation of risk zones.
- Research and education.
- Special training, updating and development of programmes for relevant professionals.
- Increased coverage of the accelerogram network.

Civil protection

- Elaborate training and contingency plans for disaster events.
- Population training and awareness.
- Seismic alert system.

Construction techniques

- Damage assessment.
- Educational buildings security diagnostics.
- Structural reinforcement.

Guidelines and regulation codes

- Urban development plans.
- Periodic checking and updating.
- Distribution and application of guidelines and regulation codes in all risk zones.

Seismic classification

Mexico has been classified into four seismic zones – A, B, C and D – according to the level of risk – low to high.

- Zone A is located in the northern part of the country and the Yucatan peninsula.
- Zone B is located in the mid-region states.
- Zone C is situated in the Baja California peninsula in the south-east of the country.
- Zone D, significantly, is located in the Guerrero seismic gap.

Conurbations in under-developed regions, which are located in high seismic risk zones, increase the risk. Death tolls and material damage resulting from natural disasters are also much higher in these areas compared to more developed regions.

Seismic alert system

The Guerrero Gap is a well-known source of large earthquakes in the area surrounding Mexico City and Acapulco. The existence and dangers of the Guerrero Gap have been confirmed by accelerograms obtained in this region over a time period of six years. To prevent the disastrous effects of another major earthquake in Mexico City, funding was obtained from the city government to design, operate and build a seismic alert system. The Centre for Instrumentation and Seismic Registry is responsible for the system's

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operation. The seismic alert has 12 seismic sensor stations on the coast of Guerrero that can anticipate and track a major event. Mexico City is located approximately 300 km from the epicentres, and information can reach the city quickly.

The alert system is activated when two or more sensor stations located between Ixtapa and Acapulco sense a major earthquake above 6.0 on the Richter scale. Accelerograms linked to personal computers relay the signal to Mexico City Valley, where every broadcasting station – television and radio – alerts the population an estimated 60 seconds before the event occurs. However, the alarm is not activated by minor earthquakes or by events located outside the Guerrero Gap. Since 1993, the Ministry of Education has strongly encouraged all schools in the metropolitan area to listen to school emergency broadcasts on the radio. Seismic alerts, with evacuation drills for prevention and protection of the population, can save lives.

Guidelines and regulations

The evolving process of creating, implementing and monitoring social and construction guidelines and regulations has been driven by past destructive events. In many cases, structures did not adhere to existing structural codes and standards.

The regulations established by the Secretariat of Education through its technical advisor CAPFCE in the structural engineering and construction disciplines concerning seismic activity have been developing steadily. Further modifications have been made to the Mexico City Construction Code; more results have been obtained in the field; and building performance has been observed during seismic events. New codes extend beyond structural parameters and seismic-resistant factors to consider:

- Design policy criteria.
- Design methodology.
- Innovative structural systems.
- Material quality.
- Relation to structural behaviour.
- Professional responsibility.

President Fox delivered specific instructions to the Secretariats of Social Development, Education and Health on the last anniversary of the 1985 earthquakes. He prioritised the civil protection programmes within each sector, thus supporting a preventive culture for inhabitants in high and low risk areas. In addition, in 2003-04, the Secretariat of Education issued a strong statement endorsing the civil protection culture. As a result, 3 220 emergency drills were held in public buildings, schools – including pre-schools – and museums; 66 000 leaflets on prevention were distributed in the native language (Spanish), and in the Nahuatl, Tzotil, Mixteco and Purepecha dialects; and more than

70 seminars, courses and workshops in the area of civil protection were held in Mexico in 2003. Today, there are approximately 2 900 certified state and municipal officials in Mexico.

Stability design

The construction code bases its seismically resistant structural design on the following performance criteria:

- *Low intensity seismic activity*. The structure and its secondary elements remain unharmed.
- *Moderate seismic activity*. The structure remains undamaged.
- *High intensity seismic activity*. The structure does not collapse and the occupants of the building are unharmed.

Concerning educational spaces, it is important that the structure complies with additional criteria, such as:

- *Displacement limitation*. The design is structurally unyielding, avoiding excessive lateral deformation produced by cross momentums.
- *Damage confinement*. Limiting displacement reduces structural damage, thus helping to achieve:
  - Greater safety of occupants.
  - Less panic among occupants.
  - Better structure.
  - Fewer costs and reparation expenses.

Educational infrastructure

Education authorities initiated a major reconstruction programme in the capital following the 1985 earthquake in Mexico City, which included structural reinforcement and rebuilding of units located in high-risk zones, in compliance with construction codes and regulations imposed after the events of September 1985. Between 1986 and 1991, 2 400 facilities were rehabilitated. This programme is continuing in 2004.

In 1999, an earthquake shook 870 school buildings in the state of Puebla and another 486 buildings in the state of Oaxaca; 2 000 classrooms and 56 000 students were affected. 451 schools reported minor damage, and 17 schools reported major damage.

A summary of the damage to schools in Oaxaca is provided below:

- 7% of schools required structural refurbishing.
- 5% of schools were demolished.

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- 21% of schools were repaired.
- 67% of schools reported minor damage.

The majority of damage (93%) occurred in pre-school, primary and secondary education buildings. Oaxaca alone required EUR 13.9 million to repair schools. The estimated cost for both states was EUR 17.8 million.

In early 2003, the earthquake in Colima damaged an estimated 387 schools and 94 university buildings in the Autonomous University of Colima. 84 000 students were affected. Two major schools located in downtown Colima – three-storey buildings that offered basic education – were demolished. New single-storey buildings were constructed. The distribution of damaged buildings by type of facility is provided below:

- 27% state-owned basic education facilities.
- 5% higher education facilities.
- 68% federal-owned basic education facilities.

The cost of repairing federal and state basic education facilities was EUR 4.1 million; and the cost of repairs to the University of Colima was EUR 5.8 million.

Site selection

Destruction caused by natural phenomena can be significantly reduced given correct information. Scientific research has produced a vast amount of information and knowledge, and it is the responsibility of this specialised community to use and publicise these resources to generate awareness among the rest of the community. To this end, CAPFCE has recently created the Mexican Construction of Educational Buildings code.

However, there are events that are attributable to or aggravated by human factors, such as ignorance, negligence, lack of prevision, and allowing sites to be located in high-risk zones. Each year, there is a substantial loss of life and infrastructure damage due to urbanisation in high-risk zones, such as riverfronts, hills, faulty landfills, susceptible flood areas and unreliable terrain. In response to these problems, Mexican authorities are planning a mandatory regulation of urban sites, including school construction sites.

Natural Disaster Fund and the Natural Disaster Preventive Fund

The Natural Disaster Fund is a fund supported by the federal, state and municipal governments to provide public domain infrastructure in case of a disaster. The purpose of the fund is to aid non-protected sectors.

In the case of the educational sector, the fund provides a temporary resource until the insurance premium is collected. The objective is to restore the damaged property to pre-event conditions and to implement preventative measures. Since 2001, approximately 30%

of FONDEN disaster subsidies have been allocated to emergency earthquake situations.

The main task of the Natural Disaster Preventive Fund (FOPREDEN) is to devise preventative measures – including identifying possible risk situations and developing training and awareness material – for buildings that are located in high-risk zones or that have been damaged or repaired as a result of a natural disaster.

Future work

In 2004, the National Subcommittee for Damage Assessment will be formed, and every state will have its own local chapter. This will allow the establishment of permanent programmes and actions – with an emphasis on social participation – in such areas as improvement of local construction codes, national building diagnostics, and civil protection strategies and/or guidelines.

Summary

Mexico has reached a milestone, yet there is still much to be done. This paper has described some of the measures that have been implemented in Mexico to prepare its citizens for a seismic event:

- Better awareness in the communities through civil protection.
- Natural Disaster Fund.
- Natural Disaster Preventive Fund.
- Seismic alarm system.
- Updated and regionalised building codes.

While these measures are working effectively, civil protection must also become a way of life and not only a reminder of a life-threatening experience in an emergency situation.

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CONTRIBUTORS TO THIS PUBLICATION

ad hoc Experts' Group on Earthquake Safety in Schools

Alejandro AURRECOECHEA
Deputy Manager, Institutional Co-ordination and Communications
CAPFCE
Mexico

Emmanuel BALTAS
Managing Director, School Building Organisation S.A.
Greece

Dennis BELLET
Chief Structural Engineer, Department of General Services
Division of the State Architect, California
United States

Fouad BENDIMERAD
Technical Director, Risk Management Solutions
United States

Sálvano BRICEÑO
Director, UN Secretariat for the International Strategy for Disaster Reduction (UN/ISDR)

Arietta CHAKOS
Chief of Staff, City of Berkeley, California
United States

Nicola COSENTINO
Consultant, Emilia-Romagna Regional Administration
Italy

Mauro DOLCE
Director, Laboratory for Material and Structural Testing
Department of Structural, Geotechnical and Applied Geological Engineering
University of Basilicata
Italy

Polat GÜLKAN
Director, Disaster Management Research Centre
Middle East Technical University
Turkey

John HARDING
Associate Officer, UN Secretariat for the International Strategy for Disaster Reduction (UN/ISDR)

Wilfred IWAN
Director, Earthquake Engineering Research Laboratory
California Institute of Technology
United States

Sudhir JAIN
Head, Department of Civil Engineering
Indian Institute of Technology
India

Oscar A. LÓPEZ
Director, Institute of Materials and Structural Models
Faculty of Engineering
Central University of Venezuela
Venezuela

Jean-Pierre MASSUÉ
Executive Secretary of the EUR-OPA Major Hazards Partial Agreement
Council of Europe

Jorge MENESES
Assistant Scientist, Department of Structural Engineering
University of California
United States

Zoran MILUTINOVIC
Director, Institute of Earthquake Engineering and Engineering Seismology
University St. Cyril and Methodius
FYROM

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Marcos MIRANDA
Co-ordinator, School Infrastructure
Ministry of Education
Chile

Brian MITCHELL
Implementation Manager, Property
Management Group
Ministry of Education
New Zealand

Fausto PEDRAZZINI
Programme Director, NATO
Cooperative Programmes Section
Public Diplomacy Division

Jorge Miguel PROÊNÇA
Professor, Seismic Engineering and Structures
Institute of Structures, Territory and
Construction Engineering
Higher Technical Institute (ICIST/IST)
Portugal

Christopher ROJAHN
Executive Director, Applied Technology
Council
United States

Badaoui ROUHBAN
Chief, Section for Engineering and
Technology
UNESCO

Haresh C. SHAH
Director, Risk Management Solutions Inc.
United States

Richard SHARPE
Director, Earthquake Engineering
Beca Carter Hollings & Ferner, Ltd.
New Zealand

Anselm SMOLKA
Head, Geological Risk Research
Munich Reinsurance Co.
Germany

Andrew SMYTH
Assistant Professor, Columbia University
Civil Engineering and Engineering
Mechanics Department
United States

Robin SPENCE
Professor, Architectural Engineering
Cambridge University
President of the European Association for
Earthquake Engineering
United Kingdom

L. Thomas TOBIN
Manager, Tobin and Associates
United States

Brian E. TUCKER
President, GeoHazards International
United States

Carlos VENTURA
Professor and Director, Earthquake
Engineering Research Facility
Department of Civil Engineering
University of British Columbia
Canada

Friedemann WENZEL
Professor, Geophysical Institute
University of Karlsruhe
Germany

Özal YÜZÜGÜLLÜ
Professor, Department of Earthquake Engineering
Boğaziçi University
Kandilli Observatory and Earthquake
Research Institute
Turkey

Other contributors to this publication

Nicola BONUCCI (OECD)
BureauParis (layout)
Lucie BUXTORF (OECD)

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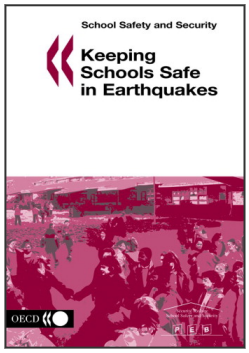

From:

Keeping Schools Safe in Earthquakes

Access the complete publication at:
https://doi.org/10.1787/9789264016705-en

Please cite this chapter as:

OECD (2004), "Recognising the Obstacles to Improving Seismic Safety of Schools", in *Keeping Schools Safe in Earthquakes*, OECD Publishing, Paris.

DOI: https://doi.org/10.1787/9789264016705-4-en

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