School Safety and Security

Keeping Schools Safe in Earthquakes

OECD

Sécurité scolaire
School Safety and Security

P E B

KEEPING SCHOOLS SAFE IN EARTHQUAKES

Proceedings of the *ad hoc* Experts' Group Meeting on Earthquake Safety in Schools, Paris, 9 to 11 February 2004

FOREWORD

The OECD Programme on Educational Building (PEB) is working to keep schools around the world safe in earthquakes. A safe and secure environment is a prerequisite for effective teaching and learning. Threats to the safety and security of people and property can arise from natural hazards – such as earthquakes, floods and storms – or from human actions – such as vandalism, arson and violent crime. While catastrophic events and human tragedies cannot be eliminated entirely, their negative impact can be mitigated. As part of the Organisation's activities on school safety and security, PEB seeks to improve understanding of such issues, to identify appropriate responses and to initiate action.

This report is one product of the *ad hoc* Experts' Meeting on Earthquake Safety in Schools, organised by PEB and GeoHazards International (GHI) in February 2004 in Paris. Another significant outcome is the recommendations of the experts' group, which have been submitted to OECD Council for approval by all OECD countries. These recommendations are included in the final chapter of this publication and represent an important step forward in the recognition by governments that greater effort is required to address the urgent problem of improving the safety of schools in earthquakes.

OECD work on school safety and security began in February 2002 with an experts' meeting in Washington, D.C. on "Helping Schools Prepare for and Respond to Terrorist Attacks", which was organised by PEB and the United States Department of Education (USDOE). PEB and USDOE also held a general conference on school safety and security in Paris in November 2003. This meeting focused on safety and security risk assessment in schools; crisis planning and management; infrastructural approaches to school safety; collaborative approaches to school safety; and education, training and support approaches to school safety (*www.oecd.org/edu/schoolsafety*).

This publication is the result of a collaborative effort between Brian Tucker from GHI, the authors, other meeting experts and the PEB Secretariat. PEB and GHI would like to acknowledge the valuable contribution of Wilfred Iwan from the California Institute of Technology to this meeting. The manuscript was prepared by Hannah von Ahlefeld, and editorial assistance was provided by Jill Gaston, both from the PEB Secretariat.

TABLE OF CONTENTS

Preface 6
Richard Yelland and Brian Tucker

Executive summary 8

Reader's guide 15

Introduction: Acknowledging the importance of improving earthquake safety in schools .. 19
Hannah von Ahlefeld

Part I. Recognising the obstacles to improving seismic safety of schools 31

1. Earthquake vulnerability of school buildings in Algeria 35
   Fouad Bendimerad
2. Learning about seismic safety of schools from community experience in Berkeley, California 45
   Arrietta Chakos
3. Seismic safety of schools in Italy 52
   Mauro Dolce
4. Obstacles to improving seismic safety of school buildings in Turkey 64
   Polat Gülkan
5. Seismic risk in schools: The Venezuelan project 88
   Oscar A. López, Julio J. Hernández, Gianina Del Re, José Puig and Magnolia Santamaría
6. Towards effective mitigation and emergency response in the Former Yugoslav Republic of Macedonia 101
   Zoran Milutinovic and Jean-Pierre Massué
7. Making schools safer: The New Zealand experience 119
   Brian Mitchell
8. Damage in schools in the 1998 Faial earthquake in the Azores Islands, Portugal 131
   Jorge Miguel Proença
9. Earthquakes and educational infrastructure policy in Mexico 140
   Jaime de la Garza Reyna

Part II. Defining seismic safety principles for schools 147

10. Fundamental concepts and principles for assuring acceptable performance of schools and the education system 149
    Dennis Bellet

 © OECD 2004

Part III. Assessing vulnerability and risks to schools and other public buildings 155

11. Building Code Effectiveness Grading Schedule: Measuring the community's commitment to adopting and enforcing building codes 157
Dennis Gage

12. Translating earthquake hazard mitigation measures from one country to another: A case study 164
Christopher Rojahn

13. Seismic risk mitigation practices in school buildings in Istanbul, Turkey 176
Özal Yüzügüllü, Gülay Barbarosoglu and Mustafa Erdik

Part IV. Identifying strategies and programmes for improving school seismic safety .. 185

14. A brief review of school typologies in Italy: Specific vulnerability and possible strategies for seismic retrofitting 187
Nicola Cosentino, Giovanni Manieri and Andrea Benedetti

15. Implementing school seismic safety programmes in developing countries 197
Sudhir K. Jain

16. Supporting local seismic experts: Experiences in Nepal and India 204
Richard Sharpe

17. Evaluating earthquake retrofitting measures for schools: A cost-benefit analysis .. 208
A.W. Smyth, G. Deodatis, G. Franco , Y. He and T. Gurvich

18. Strengthening school buildings to resist earthquakes: Progress in European countries 217
Robin Spence

Part V. Taking an initial step towards improving earthquake safety in schools: *ad hoc* Experts' Group Report on Earthquake Safety in Schools 229

Contributors to this publication 239

PREFACE

Schools play a vital role in every community. They are not only the places where students learn and teachers teach; they are also used for social gatherings, theatre and sports. In addition, school buildings play an important role in responding to and recovering from natural disasters. In the event of an earthquake, hurricane or flood, schools can serve as emergency shelters and, as such, can be used to house, feed and care for the local population.

Earthquake-threatened communities need earthquake-resistant schools. When schools are closed because of earthquake damage, education is hampered, community life disrupted, and emergency shelters unavailable. Where school attendance is compulsory, communities have a moral obligation to provide a safe study and work environment. But the most important reason earthquake-threatened communities need earthquake-resistant schools is to protect their children and teachers.

Recent earthquakes in Algeria, Italy, Iran, Morocco and Turkey demonstrate that many threatened communities do not yet have earthquake-resistant schools. In some of these earthquakes, schools that collapsed and killed students were modern and located near older buildings that did not collapse. In one case, a poorly constructed new addition appears to be the cause of collapse; in other cases, unexpectedly strong ground shaking contributed to the problem; and in most cases, the building code was not sufficiently enforced. Most of these earthquakes did not occur when school was in session; otherwise, the death toll could have been far heavier.

Unless something changes, this situation will worsen. Many countries experiencing the greatest increase in population – and, hence, having the greatest need for additional schools – are also the poorest. Under these circumstances, there is the temptation to build new schools and enlarge existing ones using inferior designs, materials and construction techniques. All countries – rich and poor – face the problem of how to make the large number of their existing schools earthquake-resistant. The infrequency of great earthquakes in any one location makes it easy for the public and for public officials to forget about the important need to design, construct and maintain earthquake-resistant schools – until it is too late.

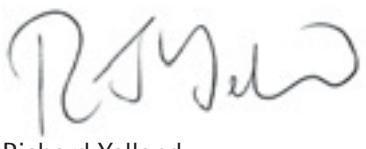
In response to this need, the OECD Programme on Educational Building and GeoHazards International convened a meeting of internationally renowned experts from 14 countries and five continents on school earthquake safety – representing international organisations, government, academia, business and non-governmental organisations – to review this problem and identify possible solutions. The meeting was held at the OECD in Paris from 9 to 11 February 2004. The participants were asked to prepare a report that would provide the following:

© OECD 2004

- A statement of the obstacles to achieving seismic safety of schools and education systems.
- A discussion of methodologies and criteria for assessing the seismic safety of schools and education systems, and for monitoring progress toward achieving seismic safety.
- Suggestions for strategies to promote greater seismic safety internationally.
- Recommendations for OECD actions to assure seismic safety of schools in its member countries.

This publication contains the report of this *ad hoc* experts' group. It provides a clear and urgent message to OECD governments and others that the problem of schools collapsing during earthquakes and killing students and teachers can and must be addressed before more, greater disasters occur.

We urge you to read this report and help us implement its recommendations.



Richard Yelland
Head
OECD Programme on Educational Building

Brian Tucker
President
GeoHazards International

EXECUTIVE SUMMARY

The issue

> ...schools built world-wide routinely collapse in earthquakes due to avoidable errors in design and construction...because existing technology is not applied and existing laws and regulations are not sufficiently enforced...Unless action is taken immediately to address this problem, much greater loss of life and property will occur. (extract from "*ad hoc* Experts' Group Report on Earthquake Safety in Schools", in this publication)

This report is the product of an *ad hoc* experts' meeting held at the OECD in Paris from 9 to 11 February 2004 on earthquake safety in schools. The meeting was organised by the OECD Programme on Educational Building (PEB) and GeoHazards International (GHI), a non-governmental organisation comprised of specialists in earthquakes and earthquake risk in academic, business and government sectors in the United States and Japan. The aim of the organisers was to initiate an activity that would improve earthquake safety in schools and education systems. The motivation was simple: schools frequently collapse during earthquakes and will continue to do so unless individuals, communities, scientists, governments and other bodies discuss and devise solutions to address the problem. The expert knowledge, opinions and experiences presented in this report provide valuable insight into the nature and scope of the problems involved in protecting school buildings and their occupants. Importantly, these accounts also give us hope that the seismic risk of schools can be lowered to prevent further injury and death during earthquakes.

The process

In order to explore the issue of *how* to initiate change, the experts were asked to follow an evolution of themes – to acknowledge the problem, to recognise obstacles, to define key safety principles, to assess vulnerability and risk, and to identify strategies and programmes for improving school seismic safety – that would lead to a concrete proposal towards action. Key elements of the themes and the papers contained within them are presented below.

Acknowledging the importance of improving seismic safety in schools

Few individuals will contest the importance of protecting society's most valuable and vulnerable members, children; and few will contest the importance of providing compulsory education for all children. Even fewer people will argue with the fact that earthquakes kill people and damage property. But these three essential principles do not hold up in modern society. In many earthquake-prone countries, a surprisingly high number of school buildings are not constructed to withstand the most moderate of earthquakes. The fundamental question that we must ask ourselves is "Why is it so simple to acknowledge the importance of the education and safety of our children, yet so difficult to ensure?"

© OECD 2004

From the great Lisbon earthquake of 1755 to present-day disasters, the task of engaging governments, communities and others to reduce the risk and vulnerability of the world's populations has made variable progress. Over the last decade or more, there has been a strong movement towards establishing a culture of disaster prevention and mitigation, which has been reflected in the responses of these stakeholders to the issue of improving the safety of schools in earthquakes. But despite the success of community advocacy groups, the commitment of engineers and other scientists, efforts by some governments to address the problem and the considerable international attention generated by such global initiatives as the International Decade for Natural Disaster Reduction, the human and material costs of disasters are increasing, especially in developing countries. In the face of advancing technologies, growing urbanisation and increasing populations, a new approach to addressing such problems is required.

Recognising the obstacles to improving seismic safety of schools

To first identify the scope of the problem, experts were asked to describe and assess the relative importance of the specific factors contributing to the poor performance of school buildings, and also to measure the extent to which the lessons learned from past earthquakes have been used to improve building codes and construction practices. Common, inter-related and in most cases avoidable obstacles were encountered by experts from Algeria, Former Yugoslav Republic of Macedonia (FYROM), Italy, Mexico, New Zealand, Portugal, Turkey, Venezuela and the United States: from lack of awareness of the threat of school collapse and poor communication between the scientific, public and government communities; to basic deficiencies in the nature, implementation and enforcement of laws and regulations concerning planning, maintenance and construction of schools buildings.

- *On the evening of 21 May 2003, an earthquake in Boumerdes, Algeria, left 2 287 people dead and 11 000 injured.* Schools were badly affected by the earthquake: 122 schools had to be rebuilt and 560 – out of 1 800 schools inspected – were seriously damaged. The cost of the earthquake in terms of school reconstruction and rehabilitation was estimated to be USD 70 million. The failure of school buildings during the disaster can be attributed to a growing urban population and subsequent demand for inexpensive and rapid school construction, poor quality construction, failure to adhere to construction regulations, lack of quality control in construction, absence of licensing for professionals and underestimated code hazard parameters. The earthquake occurred outside of school hours.
- *Following the 1989 Loma Prieta earthquake in California, which demonstrated the weakness of many reinforced-concrete structures, a group of parent advocates in Berkeley found that seven of its 16 district schools posed serious life threats to students.* In 1991, a community group proposed that school district officials embark on a USD 158 million comprehensive safety programme to rebuild Berkeley schools. Since that time, all Berkeley schools have been rebuilt, and the community has approved over USD 362 million in taxes for safety improvements. Improving seismic safety was not only a technical problem but a challenge to prompt community engagement, accountability and action.

- *In 2002, a primary school in San Giuliano, Italy, collapsed, killing 29 children and one teacher.* Further investigation revealed that the area of San Giuliano was not classified as a seismic zone and thus the building was not constructed using seismic criteria. Use of poor quality masonry and a heavy reinforced-concrete roof also contributed to the collapse. The event alerted authorities to the vulnerability of critical structures. In 2003, five months after the earthquake, an ordinance of the prime minister stated that seismic vulnerability of all public strategic buildings, including hospitals and schools, had to be evaluated in the next five years. Soon after, new seismic zonation and seismic codes were introduced.
- *On 1 May 2003, a medium-sized earthquake in Bingöl, Turkey, caused the collapse of three new schools and a dormitory building located next to a school, killing many children as they slept.* These tragic events prompted many to question the seismic safety of school buildings. A subsequent survey of 29 school buildings concluded that none of the structures were built according to the 1998 Turkish Seismic Code. In this case, a shortage of resources and expertise to conduct reliable project and construction supervision, and lack of formal qualifications of contractors, engineers and architects were two factors that led to non-compliance with existing building codes. Of the 29 buildings surveyed, three collapsed, ten suffered severe damage and 12 buildings sustained moderate damage.
- *On 9 July 1997, an earthquake struck north-eastern Venezuela, destroying two school buildings in the town of Cariaco and killing 46 students.* In addition to grave design flaws, the schools were not constructed according to the seismic requirements for that region specified in the 1968 building code. More than 1 000 school buildings of the same structural type exist in areas of high seismic hazard in the country. In response to this tragedy, a three-stage project on reducing seismic risks in schools in Venezuela has been implemented to identify and classify existing schools in terms of vulnerability and to determine and reduce the level of risk to which schools are exposed.
- *New Zealand is one of the most seismically active countries in the world. However, most earthquakes have occurred in sparsely populated areas.* The most damaging earthquake in New Zealand took place in February 1931 in Hawke's Bay and resulted in more than 250 deaths. The city of Wellington was destroyed in the largest earthquake ever recorded in 1855. If such an event should occur again, a number of mechanisms have been established to ensure that school buildings will not collapse. In 1991, the Building Act was created to regulate building design and construction in New Zealand. 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.
- *On 9 July 1998, an earthquake struck the islands of Faial and Pico in the Azores Islands, Portugal, killing eight people and leaving 1 000 homeless.* Following the earthquake, 21 educational buildings were inspected in an attempt to discern the correlation between general building classification factors – building structure, building quality, conservation condition and number of storeys – and damage state and post-event use of the building. Half of the schools were considered suitable for immediate occupation, two schools were marked for demolition and the remainder of schools could be used after minor to moderate repairs.

 © OECD 2004

Defining seismic safety principles for schools

In order to begin to improve earthquake safety in schools, the fundamental concepts and principles that lead to the construction of earthquake-resilient schools must be identified. This section defines these concepts and principles, taking into account cost/benefit and resource implications; and also uses them as a starting point from which to develop a programme of recommendations for school seismic safety in countries.

A number of safety principles for schools were identified by the group.

- Need for *"champions" of seismic safety*, who can promote a risk-averse society and effectively communicate the risks involved in earthquakes to all stakeholders.
- Acknowledgement of the *important role of school buildings within the community as post-disaster shelters*.
- Establishment of a *system for assigning risk ownership and a legal or regulatory basis for action*, which contains clear lines of accountability and achievable performance goals with an incremental implementation strategy.
- Clear understanding of *financial responsibility and cost*.
- Availability of *detailed and up-to-date hazard maps and building codes*, which are implemented by strong and stable institutions.
- Establishment of a *well-monitored process for quality control,* with certified design professionals, independent plan review, checking and approval, independent inspection and testing and final reporting.

California's 1993 Field Act illustrates how effective legislation can lead to developing and implementing a successful programme.

Assessing vulnerability and risk to schools and education systems

Is it feasible to develop norms for assessing risk and for quantifying structural and non-structural hazard, vulnerability and exposure in schools and other public buildings? Importantly, if establishing and monitoring norms is realistic, to what extent are these norms transferable across cultures and countries?

A number of risk scoring and assessment systems have been developed that could be adapted to schools in different countries, as seen in the case study of the collaborative United States-Italy programme to improve seismic safety in Italy's hospitals. Common performance objectives, standard criteria for specifying expected ground-shaking severity, and standards, regulations, licensing, education and training could be realistically implemented across countries. Similarly, United States' processes of code administration, plan review and field inspection used in grading systems could be adopted as standard procedures across countries.

© OECD 2004

The *ad hoc* Experts' Group on Earthquake Safety in Schools concluded that adequate risk assessment methodologies and metrics currently exist to evaluate the state of school seismic safety, and to monitor the progress and success or failure of school seismic safety programmes throughout the world.

- In 1994, the Northridge earthquake in California caused USD 7 billion of insured losses to properties. The Insurance Services Office (ISO) – an independent statistical, rating and advisory organisation that serves the property/casualty insurance industry in the United States – helps distinguish between communities with effective building-code enforcement and those with weak enforcement through a comprehensive programme called the *Building Code Effectiveness Grading Schedule (BCEGS)*. The concept behind BCEGS is simple. The prospect of minimising catastrophe-related damage and ultimately lowering insurance costs gives communities an incentive to rigorously enforce their building codes. ISO collects information on a community's building-code adoption and enforcement services; analyses the data by looking at the administration of codes and reviewing building plans and field inspections; and then assigns a Building Code Effectiveness Classification from one to ten. Class 1 represents exemplary commitment to building code.
- In the 1990s, the *Applied Technology Council (ATC) in the United States* and the *Servizio Sismico Nazionale (Italian National Seismic Service, NSS) in Italy* embarked on a collaborative programme to improve seismic safety in Italian hospitals. In the first phase of the programme, recommendations were made, addressing issues of regulation, design of new hospitals and implementation of earthquake mitigation measures such as planning for earthquake response and recovery. In the second phase, completed in 2002, ATC and NSS prepared emergency response procedures. In the third phase, completed in 2003, collaborative guidelines were developed for bracing and anchoring non-structural components. In all three phases, the recommended procedures and guidelines were developed from existing guidelines and regulations in both countries, with innovations added.

Identifying strategies and programmes for improving school seismic safety

In this section, the experts were invited to describe the application of known seismic safety concepts and principles to existing strategies and programmes for school safety, and to consider the most effective ways to encourage, facilitate and assess progress made towards seismic safety goals. Importantly, the experts were also asked how best to motivate countries and political leaders to consider that it is in their interest to establish programmes that build seismically-resistant schools. Awareness-raising through the dissemination of knowledge and data regarding school seismic safety using both formal and informal channels plays an important role in empowering and motivating individuals for change. Examples of formal channels include a National Programme on Earthquake Engineering Education in India and establishing criteria and procedures to compare the vulnerability national building typologies in Italy. Informal channels include delivering lectures to school communities on seismic resistance improvements to school buildings and simply distributing leaflets on better construction practices to workers at construction sites.

 © OECD 2004

In developing countries, implementing a strategic programme is further complicated by such factors as lack of local knowledge, shortage of finances, disagreement between external experts and scarcity of materials. In a European context, while the material, financial and human resources exist to establish a number of programmes for screening, evaluating and strengthening existing buildings in earthquake-prone countries, much greater regulatory effort is required in all countries to significantly reduce the highest risk to public buildings.

- *During the Bhuj 2001 earthquake in India, 971 students and 31 teachers died, and 1 051 students and 95 teachers were injured.* After the earthquake, the Ministry of Human Resource Development of the Government of India launched a comprehensive National Programme on Earthquake Engineering Education (NPEEE). In the project, eight institutes of technology serve as resource institutes to train teachers from colleges of engineering, architecture and polytechnics. Components of the project include one to four-week and one-semester training programmes for faculty members in the country; international exposure for faculty members; development of resource materials and teaching aids; development of library and laboratory resources; and organisation of conferences and workshops. The programme is open to all recognised engineering colleges/polytechnics and schools of architecture – both public and private – with related academic degrees or diploma programmes.
- *The following example from Nepal illustrates the importance of considering simple solutions to solve seemingly complex problems.* As in many countries, it is common practice to bend hoop steel for reinforced-concrete columns, without using the hooks necessary to make the hoops effective in large earthquakes. This is similar to having the belt in one's trousers constantly undone. After failing to persuade the authorities to undertake a simple campaign of distributing leaflets on best practice to local construction sites, one of the national project team members decided to produce the leaflets privately, which he distributed from his motorcycle bag.
- *A cost estimate for strengthening all school building stock in the six European Union countries with a significant seismic risk* (Table 1) shows that Italy is the country with the highest relative cost, followed by Greece, Portugal and Austria. The costs do not seem completely unmanageable given that the estimated length of such a programme is 20 years and also considering that these costs should be offset by the ensuing reductions in damage, disruption and human casualties. In practice, a 20-year programme could be designed in such a way that retrofitting work would be carried out alongside other necessary maintenance or refurbishing work; and the natural process of replacement of older school buildings already planned and budgeted for would avoid the need for upgrading some of the oldest and most vulnerable school buildings. Thus, the real additional costs would be significantly less.

Table 1. Likely cost of school strengthening programmes in high-risk countries in the European Union

	Austria	France	Greece	Italy	Portugal	Spain
Total strengthening costs (millions euro)	84	250	350	1670	80	130
Education capital expenditure (ECE) (millions euro)	614	6 297	751	3 513	376	3 725
Strengthening costs as % ECE	14%	4%	47%	48%	21%	4%
...or annual cost as a 20-year programme	0.7%	0.2%	2.3%	2.4%	1.1%	0.2%

The outcome

The final recommendations of the *ad hoc* Experts' Meeting on Earthquake Safety in Schools represent the culmination of three days of discussion on the fundamental principles and elements of a national school seismic safety programme. These recommendations present a call to action for all governments in OECD and non-OECD countries to facilitate the implementation of these recommendations.

Further resources

The Web site *www.oecd.org/edu/schoolsafety* provides up-to-date information on earthquake safety in schools, in addition to material on related OECD activities on school safety and security.

The Web site *www.oecd.org/edu/facilities* contains information on other activities of the OECD Programme on Educational Building (PEB), such as the Programme's journal *PEB Exchange*, which is published three times per year; international conferences; related publications on school facilities; and other resource material.

© OECD 2004

READER'S GUIDE

This guide provides the reader with information on three terms that are used throughout this publication to describe the size of an earthquake: magnitude, intensity and peak ground acceleration.

Earthquake magnitude

Magnitude is the most common measure of the relative size of earthquakes, and is based on the maximum movement of the ground caused by the earthquake and recorded by seismographs. Unlike measures of earthquake intensity, which vary with distance from the earthquake source, magnitude is an inherent characteristic of the earthquake.

While a number of magnitude scales exist – each measuring the amplitude of ground motion at different frequencies – all magnitude scales yield approximately the same value for any given earthquake. In this publication, all earthquake magnitudes are reported as an "M" followed by a value (*e.g.* M6.8, M4.5). Although the magnitudes of some of the earthquakes mentioned here were originally reported using different magnitude scales, the differences are not important for the purposes of this text.

The most commonly-used magnitude scales are:

- Local magnitude (ML), commonly referred to as the "Richter scale" (Table 1). The Richter scale is logarithmic, meaning that an increase of one magnitude unit represents a factor of ten times in amplitude.
- Surface-wave magnitude (Ms).
- Body-wave magnitude (mb).
- Moment magnitude (Mw).

While the first three scales have limited range and applicability and do not satisfactorily measure the size of the largest earthquakes, the moment magnitude scale, based on the concept of seismic moment, is uniformly applicable to all sizes of earthquakes but is more difficult to compute than the other types.

Table 1. Richter magnitudes and measurable earthquake effects

Richter magnitudes	Effects near earthquake source
< M3.5	Generally not felt, but recorded.
M3.5 – M5.4	Often felt, but rarely cause damage.
> M6.0	At most slight damage to well-designed buildings. Can cause major damage to poorly constructed buildings over small regions.
M6.1 – M6.9	Can be destructive in areas up to about 100 km.
M7.0 – M7.9	Major earthquake. Can cause serious damage over 100 km.
> M8	Great earthquake. Can cause serious damage in areas over 1 000 km.

Earthquake intensity

Intensity is a measure of the shaking and damage caused by the earthquake. Unlike values of magnitude, rating the intensity of an earthquake's effects does not require any instrumental measurement, and the earthquake intensity value changes from location to location, in general decreasing with distance from the earthquake source.

The Modified Mercalli Intensity (MMI) scale is the most commonly-used earthquake intensity measurement. It describes the severity of an earthquake in terms of its effects on the earth's surface and on man and built structures (Table 2). Intensity ratings are expressed as Roman numerals between I and XII.

Table 2. Modified Mercalli Intensity (MMI) scale and description of effects and corresponding peak ground accelerations (PGA)

MMI	PGA (g)	Earthquake effects
I	<0.002	Not felt except by a very few under especially favourable circumstances.
II	0.002-0.003	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	0.004-0.007	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognise it as an earthquake. Standing automobiles may rock slightly. Vibrations felt like passing of truck.
IV	0.015-0.020	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking a building. Standing automobiles rocked noticeably.
V	0.030-0.040	Felt by nearly everyone, many awakened. Some dishes, windows, and so on broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	0.060-0.070	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight.

© OECD 2004

MMI	PGA (g)	Earthquake effects
VII	0.100-0.150	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars.
VIII	0.250-0.300	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed.
IX	0.500-0.550	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; damage great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X	>0.600	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks.
XI		Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in the ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII		Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.

Source: Federal Emergency Management Agency (FEMA).

Peak ground acceleration

Peak ground acceleration (PGA) is a measure of the ground motion severity experienced during an earthquake. It is expressed as a fraction of gravity, so a vertical acceleration of 1 g means that an individual or object has been pushed hard enough to leave the ground. Peak ground acceleration usually refers to the maximum horizontal acceleration measured at the site, although PGA can also refer to the peak in vertical accelerations. A PGA of 0.2 g means that the maximum horizontal acceleration is 20% of the earth's gravity. Since force is proportional to acceleration, that would mean that the earthquake generated horizontal forces equivalent to 20% of the structures weight at its base (Table 2).

Peak ground acceleration is measured using an accelerogram. Accelerographs refer to the paper/electronic trace of the acceleration time histories recorded at a station during an earthquake. To obtain a complete definition of ground motions, most stations record in two horizontal directions (one perpendicular to the other) and one vertical direction.

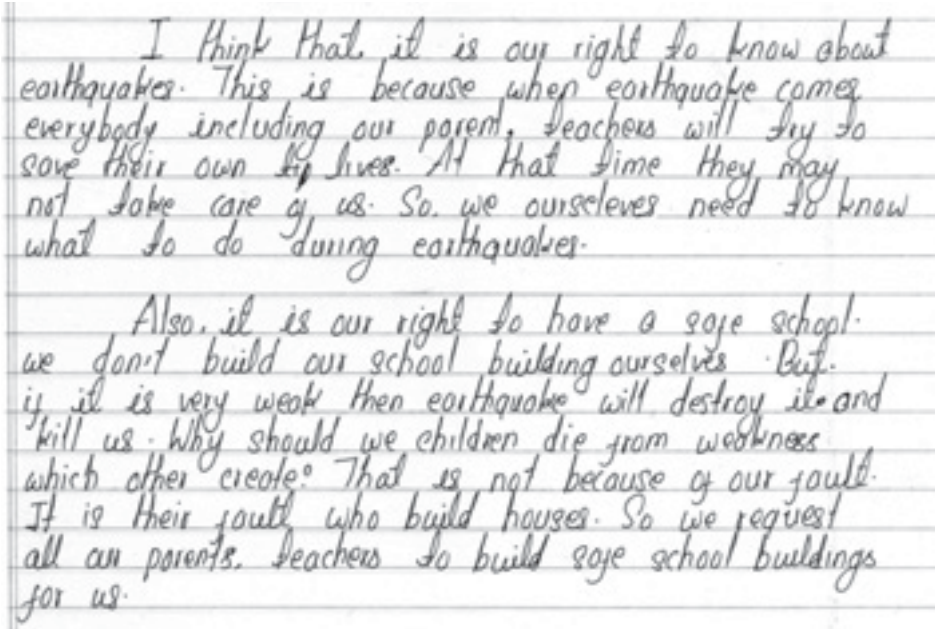
© OECD 2004

INTRODUCTION

ACKNOWLEDGING THE IMPORTANCE OF IMPROVING EARTHQUAKE SAFETY IN SCHOOLS

Hannah von Ahlefeld

OECD Programme on Educational Building



I think that it is our right to know about earthquakes. This is because when earthquake comes everybody including our parent, teachers will try to save their own ~~lip~~ lives. At that time they may not take care of us. So. we ourselves need to know what to do during earthquakes.

Also, it is our right to have a safe school. we don't build our school building ourselves. But. if it is very weak then earthquake will destroy it and kill us. Why should we children die from weakness which other create? That is not because of our fault. It is their fault who build houses. So we request all our parents, teachers to build safe school buildings for us.

Letter written by Sony, a student in Nepal

Introduction

Few individuals will contest the importance of protecting society's most valuable and vulnerable members, children; and few will contest the importance of providing compulsory education for all children. Even fewer people will argue with the fact that earthquakes kill people and damage property. But these three essential principles are not valid in modern society. In many earthquake-prone countries, a surprisingly high number of school buildings are not constructed to withstand even moderate-sized earthquakes. The fundamental question that we must ask ourselves is "Why is it so simple to acknowledge the importance of the education and safety of our children, yet so difficult to ensure them?" This paper explores the development of man's consciousness concerning natural disasters, particularly those involving schools, and the nature and effectiveness of his response to natural disasters, especially to earthquakes.

From the great 1755 Lisbon earthquake to the recent tragedies in Algeria, Italy, Japan and Turkey, governments, communities, scientists and decision-makers have all witnessed the collapse of school buildings and other essential structures. In the Kobe earthquake, for example, approximately 40% of the city government employees were victims of the disaster and 300 000 people lost their homes (Tierney and Goltz, 1997). The extent to which such disasters act as a catalyst for change is a reflection of the willingness of these groups to acknowledge that a problem exists and thereafter empower themselves and

 © OECD 2004

others to mitigate future disasters. In an effort to comprehend this process of realisation and action, the responses of communities, governments, inter-governmental organisations and the scientific community to the problem of earthquake safety in schools must be closely examined.

The lessons of Lisbon

> When they had recovered a little, they [Candide, Pangloss and the "brutal sailor"] walked towards Lisbon. They still had some money, and hoped, having escaped from the storm, also to save themselves from starvation...At this moment the earth shook, the sea rose up foaming in the harbour and dashed to pieces the ships lying at anchor. The streets and squares were filled with whirling masses of flaming and cinders. The houses collapsed, the roofs crashing down on the shattered foundations. Thirty thousand inhabitants were crushed beneath the ruins. (extract from *Candide*)

Next year marks the 250th anniversary of the great Lisbon earthquake, in which up to 70 000 people were killed. Only 3 000 of 20 000 dwellings were inhabitable after the event (Dynes, 2000). This event is significant for two principal reasons.

First, while formerly earthquakes had been perceived as catastrophic events unleashed on a deserving populace, this event served as a catalyst for great philosophical, religious and scientific debate, signifying the union of fatalistic ("Act of God"), scientific ("Act of Nature") and sociological ("Acts of Men and Women or Society") paradigms on disasters (Quarantelli, 2000). Voltaire used the earthquake as a vehicle to attack the prevailing Enlightenment views on optimism, while his antagonist in correspondence, Rousseau, suggested that urbanisation and inappropriate construction in a seismic zone contributed to the damage in Lisbon (Dynes, 2000).

> Without departing from your subject of Lisbon, admit, for example, that nature did not construct 20 000 houses of six to seven stories there, and that if the inhabitants of this great city had been more equally spread out and more lightly lodged, the damage would have been much less and perhaps of no account. (Masters and Kelly, 1992 in Dynes, 2000)

The Lisbon earthquake also prompted Kant to write three essays on earthquakes. Kant's theory that earthquakes occurred as a result of explosions of combustible gases in subterranean caves in mountain ranges proved incorrect – it was not until 1855 that faults were recognised as the source of earthquakes – but his search for a proto-scientific explanation for the disaster was a considerable departure from prevailing religious interpretations (Oeser, 2001).

Second, the Lisbon earthquake can be considered as "the first modern disaster in which the state accepted the responsibility for mobilising the emergency response and for developing and implementing a collective effort for reconstruction" (Dynes, 1997). One of the most significant figures in Lisbon at the time of the earthquake was the Marques de Pombal, who organised the emergency response and reconstruction of the city of Lisbon. For emergency response, he appointed 12 district leaders and gave

them emergency powers, disposed of bodies immediately to avoid plague, ensured a continued food supply, controlled the price of food and increased security to prevent looting; even the weekly newspaper was published on time. For reconstruction, Pombal appointed engineers and surveyors to draw up plans for the new city and to ensure that sanitary and levelling operations were carried out correctly, controlled land rents, passed laws prohibiting landlords to evict tenants, and prohibited unauthorised construction that did not conform to planned reconstruction. A wooden frame or *gaiola*, which was known to provide flexibility in the case of earthquakes, was required for all construction (Dynes, 1997).

Earthquakes in the world today: Towards a culture of disaster prevention and mitigation

As societies have developed and knowledge about seismic events has improved over the centuries, the task of engaging governments, communities and others to reduce risk and vulnerability of the world's populations has made variable progress. Over the last decade or more, there has been a movement towards a "culture of risk prevention", meaning that the focus of many programmes has moved from response and recovery towards prevention and mitigation. The responses of the principle stakeholders described in this paper attest to this evolution. Yet the fact that structures continue to collapse as a result of earthquakes would indicate that insufficient priority is being given to this issue by decision-makers. Some of the most recent tragedies are described in Part I of this publication.

Building strong communities

Disasters can often provide a strong impetus for social change, and an increasing amount of anecdotal evidence illustrates the fundamental role of concerned citizens and communities in advocating not only social, but also political and economic change (Nigg and Tierney, 1993). The disturbing post-disaster reality is that the "window of opportunity" for action is only open for a short period of time following a disaster, and without concerted and continued intervention and pressure by individuals and groups, there is a real danger that systems will return to their pre-disaster states. Several case studies from Canada, the United States and elsewhere attest to the effectiveness of this "bottom-up" approach to disaster mitigation with regard to school buildings – where mitigation activities are initiated at the community level and communities leverage moral and financial support from public and private sector partners.

> When Jules Quesnel [elementary school] parent Tracy Monk went looking for information about her daughter's school's ability to withstand an earthquake, she thought what she found out must be a mistake. "I discovered that the co-efficient of risk for my child's school building was a hundred times greater than that of the typical wood-frame houses of the neighbourhood…At first I thought, this can't be right…" Not only was her school – Jules Quesnel – found to be seismically at-risk according to the school district's most recent assessments, so were 46 other Vancouver schools. (Ince, 2004)

 © OECD 2004

This realisation marked the starting point of one parent's quest to improve the basic safety of the structure in which her child is schooled. After geologists informed Monk that an earthquake "strong enough to cause serious damage" could occur in the next 20 to 40 years, she and a group of equally committed colleagues – who came to be known as Families for School Seismic Safety (FSSS) – lobbied seismic experts, national and local government officials, and school board members. After establishing support from experts and public officials, FSSS worked to obtain numerous endorsements for a programme of seismic upgrades for at-risk schools in Vancouver.

A similar story of community advocacy started in the 1990s in California. Following the 1989 Loma Prieta earthquake, which demonstrated the weakness of many reinforced-concrete structures, a group of parent advocates in Berkeley found that seven of its 16 district schools posed serious life threats to students. In 1991, a community group proposed that school district officials embark on a USD 158 million comprehensive safety programme to rebuild Berkeley schools. Since that time, all Berkeley schools have been rebuilt, and the community has approved over USD 362 million in taxes for safety improvements. Achieving improved seismic safety was not only a technical problem, but also a challenge to prompt community engagement, accountability and action. (see Chakos in this publication)

In a national effort to reduce the escalating social and economic costs of natural disasters, a pilot community-based national disaster mitigation programme was initiated in 1997 by the Federal Emergency Management Agency (FEMA) in the United States (Wachtendorf, 2000). The objectives of Project Impact were to build community partnerships, involving federal and local government, schools, local businesses and federal agencies; to identify hazards and community vulnerability; to prioritise and complete risk reduction actions; and to develop communication strategies to increase public awareness of the importance of reducing disaster losses. In 2000, more than 250 communities and 2 500 businesses partners were involved in Project Impact (FEMA, 2000). An independent assessment of the project (Wachtendorf, 2000) found that valuable local partnerships, particularly between schools and local government agencies, had been developed and strengthened; although Project Impact communities need to work to include all members of the community, particularly its most vulnerable members, and to better capitalise on regional partnerships and those involving other Project Impact communities. Other countries such as Canada, New Zealand and Turkey are considering implementing similar studies (Wachtendorf, 2000).

Scientific expertise

> The knowledge presently exists to significantly lower the seismic risk of schools and to help prevent further injury and death of school occupants during earthquakes...at reasonable cost and in a reasonable time frame. (extract from "*ad hoc* Experts' Group Report on Earthquake Safety in Schools", in this publication)

Scientists and communities have often worked together to gain the attention and support of the wider community and government. In the case study of Vancouver

schools, engineers from the Association of Professional Engineers and the Director of the Earthquake Engineering Research Facility at the University of British Colombia worked with the parent advocacy group to identify and explain the seismic risk in Vancouver's schools. A number of university research centres such as the European Association for Earthquake Engineering (EAEE), the Earthquake Engineering Research Institute (EERI), the Disaster Management Research Centre in the Middle East Technical University in Turkey, the Italian National Association for Earthquake Engineering at the University of Basilicata and the Disaster Research Centre at the University of Delaware are heavily involved in national research projects on earthquake safety in schools. A number of non-governmental organisations such as GeoHazards International (GHI) and Volunteers for India Development and Empowerment (VIDE) are also working with communities to reduce seismic risk, particularly in developing countries, where there is an even greater need for expert knowledge and experience and for collaboration on the part of all stakeholders.

But while experts possess the knowledge and experience required to advance the cause of important issues such as seismic safety, they may encounter any number of obstacles applying this expertise. Sharpe (in this publication) recounts the reluctance of authorities to implement a simple and cost-effective measure to improve the seismic resistance of school buildings. In other cases, public bodies may be unwilling to allocate resources to improve existing seismically hazardous structures. Spence (in this publication) states that the annual cost of a 20-year school strengthening programme in the six European Union countries with the highest seismic risk is between and 0.2% and 2.4% of total capital expenditure on education.

The response of governments

> The Commission deeply regrets the loss of human lives and the damages caused to the population of San Giuliano di Puglia. At this stage, the Commission does not envisage any specific proposal for legislation in the field of earthquake mitigation. (EU Environment Commissioner Margot Wallström, cited by Spence in this publication)

This is the disappointing response by the European Commission to the request by a member of the European Parliament to establish a directive requiring member states to set up programmes for assessing all buildings in high seismic zones. The statement was made in the wake of an earthquake in Molise, Italy, in which a school building collapsed, killing 25 children. The reluctance of this body to establish a regulatory framework at a European level, as Spence notes, is related to preference for other methods of "achieving desirable social and environmental goals", which probably cost less and do not require the enforcement of regulations. The effectiveness of the non-regulatory approach was tested less than three months later, when more than 100 schoolchildren were killed as a result of a school collapsing in an earthquake in Turkey.

In some cases, individual governments have been more willing to take regulatory action, particularly following devastating earthquakes. Within months of the Molise earthquake, the Italian government drafted an earthquake code, which introduced new seismic zonation for the whole of the Italian territory and set out a detailed process for evaluating and

 © OECD 2004

strengthening existing structures (see Dolce in this publication). Further legal instruments and supporting funding mechanisms are also being established. In Portugal, a National Plan for Reducing the Seismic Vulnerability of Constructions, which is modelled on the National Earthquake Hazards Reduction Programme in the United States, envisages the creation of legislation that will require certification of designers, improvement of building control and creation of tax incentives (see Spence in this publication).

In other countries, a number of different mechanisms have been established by governments to oversee the general safety of school buildings, including updating building acts to include seismic provisions. In Mexico, federal, state and municipal governments are providing updated and regional building codes and supporting public infrastructure in case of disaster through the Natural Disaster Fund, the Natural Preventive Disaster Fund and a seismic alarm system (see de la Garza Reyna, in this publication). In 1995, the French Government set up a National Observatory for Safety in Schools and Higher Education Institutions, comprising representatives of public authorities holding title to school buildings, school staff, parents of students in public and private schools, and public officials to deal with all issues affecting the safety of persons, buildings and equipment (Schléret, 2004). In New Zealand, new seismic safety standards were incorporated into the 1991 Building Act, and a structural survey of 2 361 schools was conducted between 1998 and 2001 to (see Mitchell in this publication).

Undoubtedly, the fact that public bodies are supporting a wide range of safety-related initiatives is encouraging, but experiences from previous earthquakes have shown that the existence of a building code does not mean that the code is rigorously enforced. This is the task of a formal regulatory body, which rarely exists at a national level and at present does not exist at an international or European level. Future events will continue to test the effectiveness of non-regulatory approaches to improving earthquake safety in schools.

The response of inter-governmental agencies

A number of international organisations have embarked on ambitious programmes to address issues of disaster reduction. These global initiatives have proven successful in that they have increased the general level of awareness of the importance of disaster mitigation in many areas of society.

In 1990, the United Nations proclaimed an International Decade for Natural Disaster Reduction (IDNDR). The Decade brought issues of disaster-risk reduction to the attention of the world and led to some improvement in disaster planning, particularly in developing countries. It also represented a major conceptual shift from disaster response to disaster reduction and to the promotion of a general "culture of prevention", the principles of which are outlined in the "Yokohama Strategy and Plan of Action for a Safer World" adopted at the first World Conference on Natural Disaster Reduction in 1994. In January 2005, a second World Conference on Disaster Reduction will take place in Kobe. One of the goals of this meeting is to further motivate and guide governments and policy-makers to incorporate disaster risk reduction to poverty reduction. There is also a focus on the needs of the most vulnerable members of the community and on assessing the achievements and identifying good practices since the

Yokohama Strategy in 1994. The conference will be organised around three main processes: intergovernmental process, public participation and knowledge exchange within the thematic area of "Building a culture of resilient communities". The latter will include a topic related to disaster risk reduction in schools (United Nations, 2004).

Other international organisations such as the Council of Europe have also established significant mechanisms by which to address issues of disaster reduction within the framework of advocating a "culture of risk prevention". The Council of Europe's EUR-OPA Major Hazards Agreement was adopted by the Council's Committee of Ministers in March 1987. The agreement – which was signed by 25 member states – was designed "to ensure better prevention, protection and organisation of relief in the event of major natural or technological disasters" and to ensure effective contact, exchange and co-operation between the "States of Eastern Europe, the Southern Mediterranean and Western Europe". One section of the Agreement is dedicated to risk prevention in schools and in universities. Pilot programmes to raise student awareness of risk prevention have been established in Algeria, France, Morocco and other countries; a "Street Net" programme has been implemented to target socially excluded children; and a number of post-graduate degrees in risk management-related areas have been initiated in several universities in Europe (Council of Europe, 2004).

The success of these global initiatives and intergovernmental conferences is difficult to quantify; in fact a review of the achievements and challenges of the Yokohama Strategy is currently underway. Importantly, none of these global initiatives have addressed the specific problem of school building collapse. So although the importance of awareness-raising for global issues such as disaster reduction cannot be underestimated, in order to accurately assess the specific problem of *why* school buildings are collapsing, a more systematic problem-solving approach may be required.

The way forward

Several million earthquakes occur every year, and about 20 000 of them are recorded. According to the National Earthquake Information Centre, based on observations made since 1990, an average of 18 major earthquakes (>M7), 134 strong earthquakes (M6) and over 1 300 moderate (M5) earthquakes occur every year (NEIC, 2004). In the 1990s, natural disasters affected some 2 billion people world-wide, killed 400 000 to 500 000 people and cost more than USD 600 million, more than in the previous four decades combined. Floods and earthquakes were the two largest causes of death (Rischard, 2002). In the last two years alone, economic losses from disasters rose from USD 55 billion in 2002 to USD 60 billion in 2003, and the number of victims killed in 2003 has increased fivefold compared to the previous year. Indeed, the gap between the more and less affluent countries is widening in terms of their capacity to cope with disasters. The integration of disaster-reduction strategies into effective national policies is also difficult (United Nations, 2004). Does this mean that the current concerted efforts of communities, intergovernmental agencies, governments, experts and others to address

 © OECD 2004

issues such as disaster mitigation and school building collapse during earthquakes are *insufficient*, or rather that in the face of advancing technologies, growing urbanisation and increasing populations, a new approach is required?

> ...what's needed is imagination, and a different type of thinking. New thinking about how government, business and civil society ought to work together and about how to coax nation states into passing legislation in the interest of the planet, not just their own local constituencies. New thinking about network-like setups that create, global issue by global issue, a sort of horizontal cross-border source of legitimacy that complements the traditional vertical representation processes and legitimacy of nation states. (Rischard, 2002)

In *High Noon: 20 Global Issues, 20 Years to Solve Them*, Jean-François Rischard identifies natural disaster prevention and mitigation as one global issue that is "so urgent and pervasive that nothing less that a global commitment or coalition will solve [it]". He envisages a "global issues network" that can address this issue. This network would embark on a three-phase approach involving a *constitutional phase*, in which a network of committed problem-solvers is convened by a global multilateral, for example, who could act as a facilitator; a *norm-producing phase*, involving the production of norms, standards and policy recommendations; and an *implementation phase*, during which the network takes on a rating role. This final phase may involve enacting conforming legislation or "naming and shaming" those who violate or ignore norms.

Certainly, implementation and enforcement mechanisms do exist at an international level. The OECD Convention on Combating Bribery of Foreign Public Officials in International Business Transactions is a recent example of the effectiveness of an international monitoring programme. Countries that accede to the convention agree to make bribing foreign public officials in international business transactions a criminal offence. They also accept the OECD Revised Recommendation on Combating Bribery in International Business Transactions, which contains broader measures to prevent and combat transnational bribery. If the convention is to have any real effect, companies must become fully implicated in ensuring compliance with the convention and with national anti-bribery laws. To date, more than 34 countries have ratified and transposed the convention into domestic legislation (OECD, 2003). In the field of education, "league tables" in such publications as *Knowledge and Skills for Life: First Results from PISA 2000* (OECD, 2001) and *Education at a Glance* (OECD, 2003) rank countries according to certain criteria such as student performance, graduation rates and expenditure on education. Such international country comparisons, which could be interpreted as a type of "naming and shaming" can often have a significant impact on education policy. The most striking example is the performance of Germany in the Programme for International Student Assessment (PISA) (Bulmahn, 2002), which has resulted in significant public debate and re-evaluation of the German education system.

Similarly, the recommendations of this *ad hoc* Experts' Group on Earthquake Safety in Schools could be adopted, implemented and enforced by national governments and international agencies. The only requirements are a shared commitment on the part of governments to address this problem and a consensus-based monitoring mechanism to support them.

References

Bulmahn, E. (2002), "PISA: The Consequences for Germany", *OECD Observer*, OECD, Paris.

Council of Europe (2004), "International Organisations and Major Hazard Management. Open Partial Agreement on the Prevention of, Protection against and Organisation of Relief in Major Natural and Technological Disasters", *http://www.coe.int/T/E/Cultural_Co-operation/Disasters/Resources/APCAT_2003_12e.pdf*.

Dynes, R.R. (2000), "The Dialogue Between Voltaire and Rousseau on the Lisbon Earthquake: The Emergence of a Social Science View", *International Journal of Mass Emergencies and Disaster*s, Vol. 18, No. 1, pp. 97-115, *http://www.udel.edu/DRC/preliminary/pp294.pdf*.

Dynes, R.R. (1997), "The Lisbon Earthquake in 1755: Contested Meanings in the First Modern Disaster", *Disaster Research Centre Preliminary Papers*, Vol. 255, *http://www.udel.edu/DRC/preliminary/255.pdf*.

Federal Emergency Management Agency (FEMA) (2000), "Project Impact: Building Disaster Resistant Communities", *http://www.app1.fema.gov/impact/impact00.htm*.

Ince, J. (2004), "Students' Earthquake Play Shakes Politicians", *The TYEE*, 26 May 2004, *http://www.thetyee.ca/News/current/Student+Earthquake.htm*.

National Earthquake Information Center (NEIC) (2004), Earthquake Hazards Program Web site, *http://neic.usgs.gov*.

Nigg, J.M. and K.J. Tierney, (1993), "Disasters and Social Change: Consequences for Community Construct and Affect". *Annual Meeting of the American Sociological Association*, Miami, Florida, 13-17 August 1993.

OECD (2003), *Education at a Glance: OECD Indicators*, OECD, Paris.

OECD (2003), "OECD Policy Brief. Fighting Bribery in International Business Deals", OECD, Paris, *http://www.oecd.org/dataoecd/2/58/20610942.pdf*.

OECD (2001), *Knowledge and Skills for Life: First Results from PISA 2000*, OECD, Paris.

Oeser, E. (2001), HEAT. Historical Earthquake Theories, *http://www.univie.ac.at/Wissenschaftstheorie/heat/heat.htm*.

Quarantelli, E.L. (2000), "Disaster Planning, Emergency Management and Civil Protection: The Historical Development of Organised Efforts to Plan for and to Respond to Disasters", *Disaster Research Centre Preliminary Papers* Vol. 301, *http://www.udel.edu/DRC/preliminary/301.pdf*.

Rischard, J.-F. (2002), *High Noon: Twenty Global Issues, Twenty Years to Solve Them*, Perseus Press, Oxford.

Schléret, J-.M. (forthcoming),"Risk Assessment in Schools in France", *Keeping Schools Safe and Secure, Proceedings of an International Conference on School Safety and Security*, 12-14 November 2003, OECD, Paris, France.

 © OECD 2004

Tierney, K.J. and J.D. Goltz (1997), "Emergency Response: Lessons Learned from the Kobe Earthquake", *Disaster Research Centre Preliminary Papers*, Vol. 260, *http://www.udel.edu/DRC/preliminary/260.pdf*.

United Nations (2004), "First Announcement: World Conference on Disaster Reduction, 18-22 January 2005, Kobe, Hyogo, Japan: A Safer World for All", *http://www.unisdr.org/eng/wcdr/First-Announcement-WCDR-eng.pdf*.

Voltaire (1993), *Candide*. Wordsworth Editions, Ware.

Wachtendorf, T. (2000), "Building Community Partnerships Toward a National Mitigation Effort: Inter-Organisational Collaboration in the Project Impact Initiative", *Disaster Research Centre Preliminary Papers*, Vol. 306, *http://www.udel.edu/DRC/preliminary/pp306.pdf*.

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.

 © OECD 2004

- *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

 © OECD 2004

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.

© OECD 2004

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

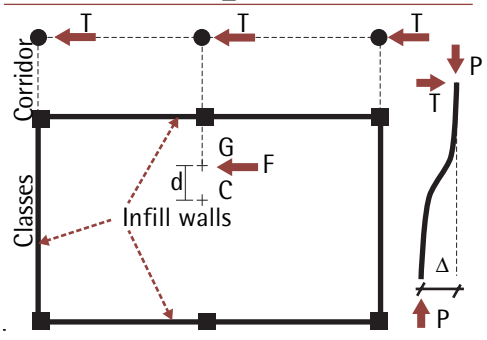
Typical architectural layout

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

© OECD 2004

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

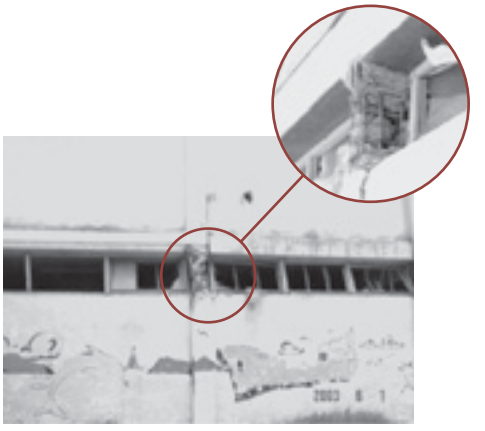


Figure 1.3. Failure of columns at joint

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.

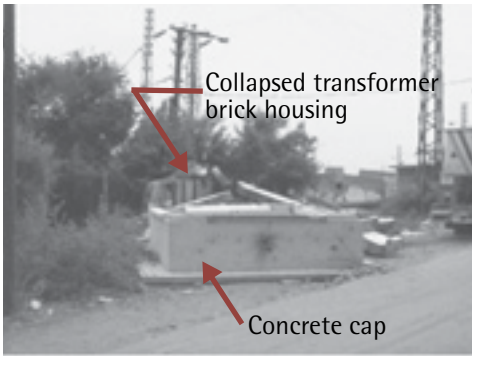
Building codes and construction control

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



© OECD 2004

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.

 © OECD 2004

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.

 © OECD 2004

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.

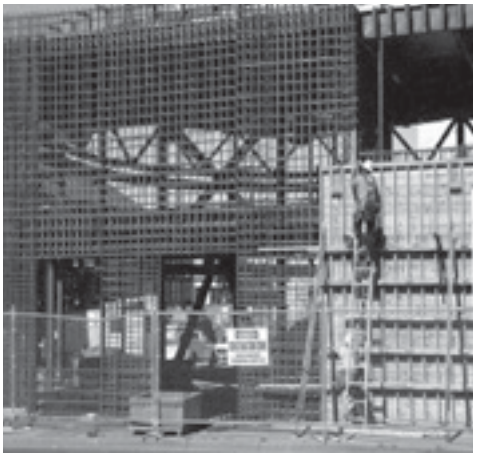
The 1989 disaster prompted a group of parents to approach officials with their concerns about the safety of the local schools constructed in the 1950s and 1960s using concrete. The buildings appeared to be suspiciously like the collapsed Cypress freeway overpass structure in nearby Oakland, where many 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.

 © OECD 2004

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

 © OECD 2004

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.

© OECD 2004

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

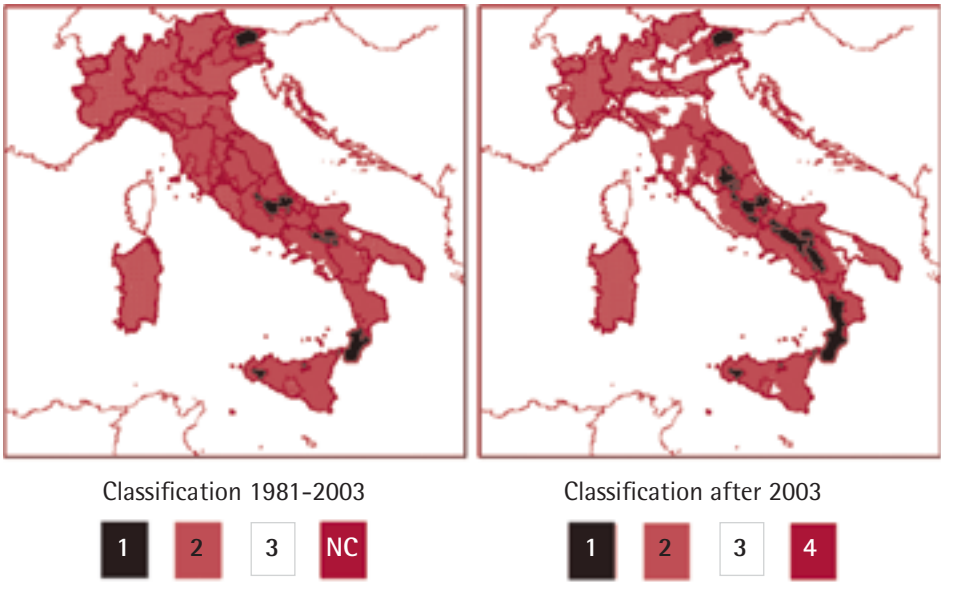
Several general sources of seismic vulnerability in Italy must be considered when examining the seismic risk of existing school buildings.

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

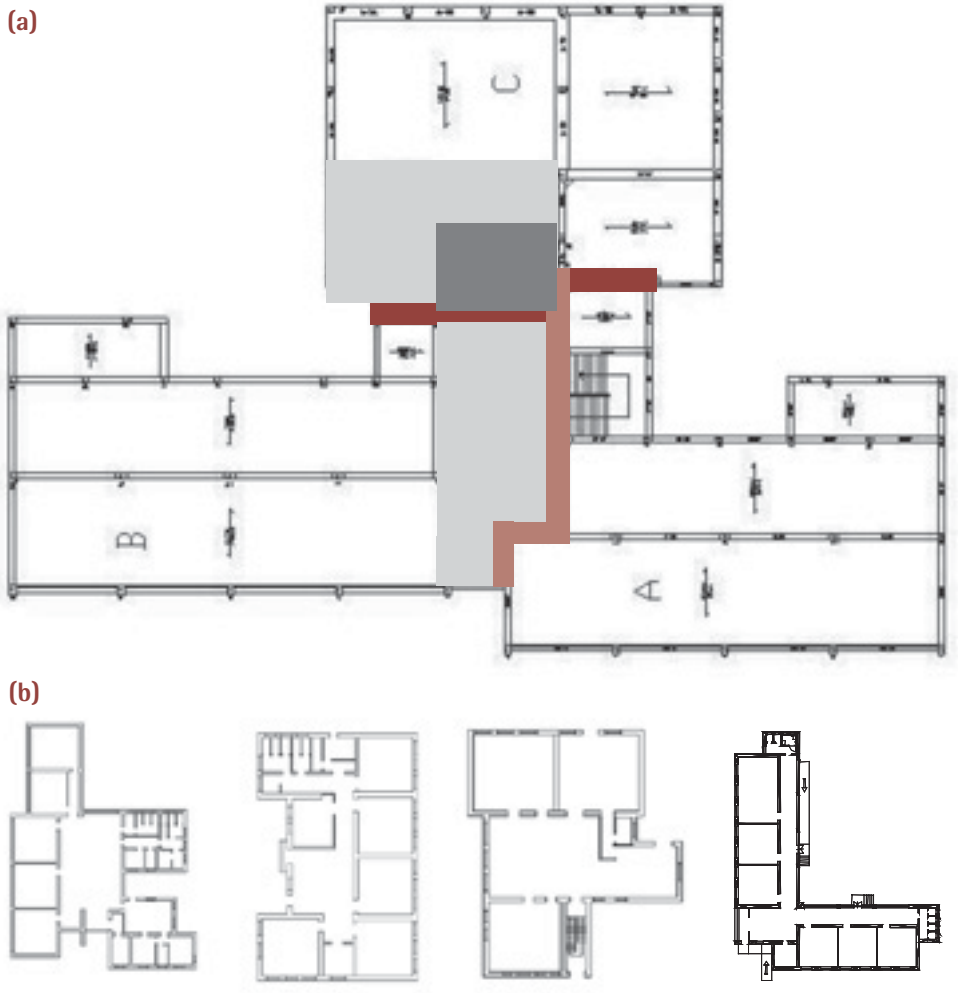
A major cause of vulnerability of school buildings is the architectural and structural layout. Most schools are composed of a number of different teaching areas, such as traditional teaching rooms, laboratories, gymnasiums and theatres. If these different areas are located in the same building, then 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)

 © OECD 2004

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.

© OECD 2004

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

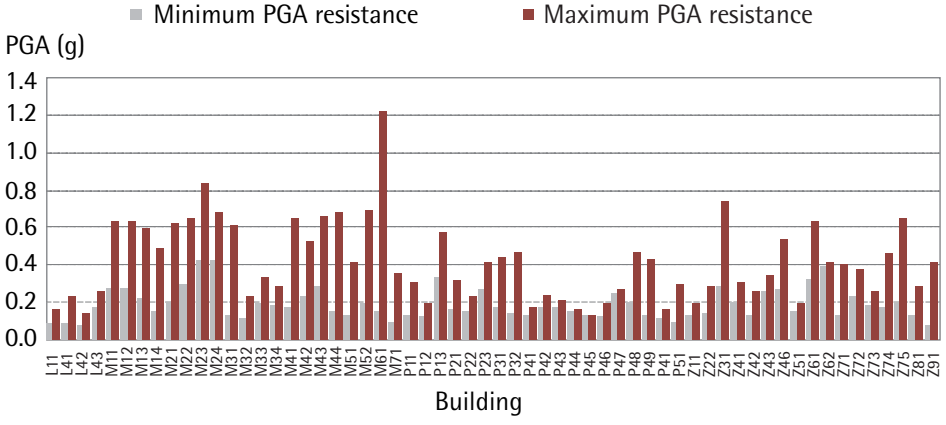
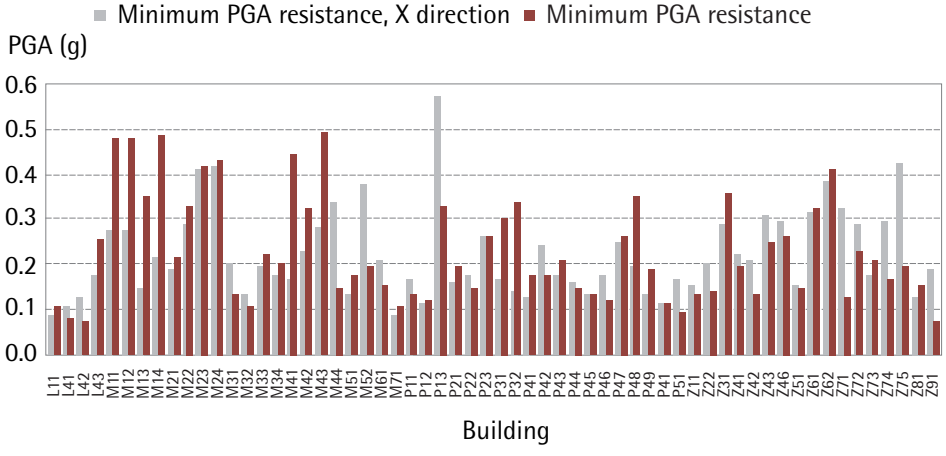


Figure 3.7. Reinforced-concrete buildings: Minimum PGA resistance in the X and Y directions



© OECD 2004

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

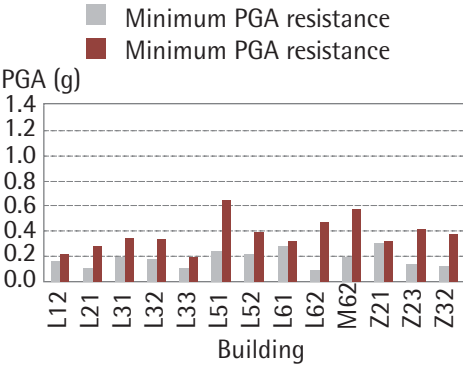


Figure 3.9. Reinforced-concrete buildings: Minimum PGA resistance in the X and Y directions

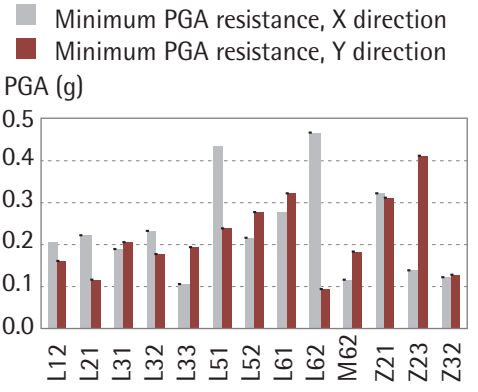
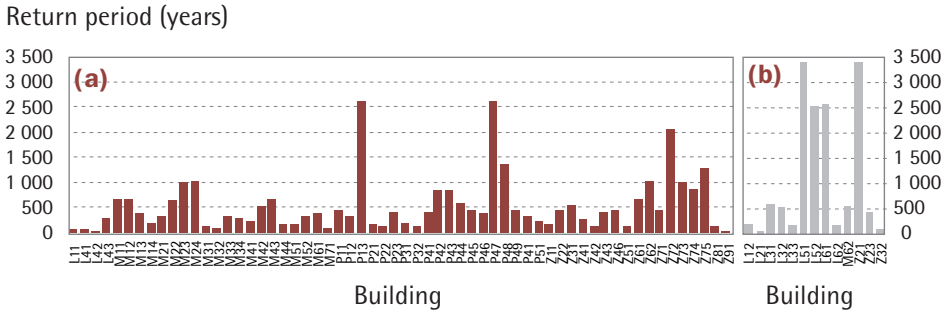


Figure 3.10. Return period of the collapse earthquake of (a) reinforced-concrete and (b) masonry buildings



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.

© OECD 2004

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.

References

Augenti, N., *et al.* (2004), "Performance of School Buildings during the Molise Earthquake of 31 October 2002", *Earthquake Spectra,* Special Issue on the Molise Earthquake.

Baranello, S., *et al.* (2004), "Criteria for Seismic Microzonation in Molise after the Earthquake of 31 October 2002", *11th Congress on Earthquake Engineering in Italy*, Genoa, Italy, 25-29 June 2004 (in Italian).

Cherubini, A., *et al.* (1999), "Vulnerability Analysis of Special Strategic Public Buildings in the Regions of Abruzzo, Basilicata, Calabria, Campania, Molise, Puglia and Sicily – Chapter 4: Results of the Project", Department of Civil Protection, Rome (in Italian).

Dolce, M., *et al.* (2004), "Examination of the Typological and Damage Characteristics of Public Buildings in San Giuliano di Puglia", *11th Congress on Earthquake Engineering in Italy*, Genoa, Italy, 25-29 June 2004 (in Italian).

Dolce, M. and G. Zuccaro (2003), *SAVE-Project: Updated Tools for the Seismic Vulnerability Evaluation of the Italian Real Estate and of Urban Systems. 1st year report*, National Group for Protection from Earthquakes (GNDT), Rome.

Ordinance 3274 (2003), *First Elements Concerning General Criteria for the Seismic Classification of the National Territory and for Technical Norms for Construction in Seismic Zones*, G.U., 8 May 2003 (in Italian).

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

 © OECD 2004

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.

 © OECD 2004

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

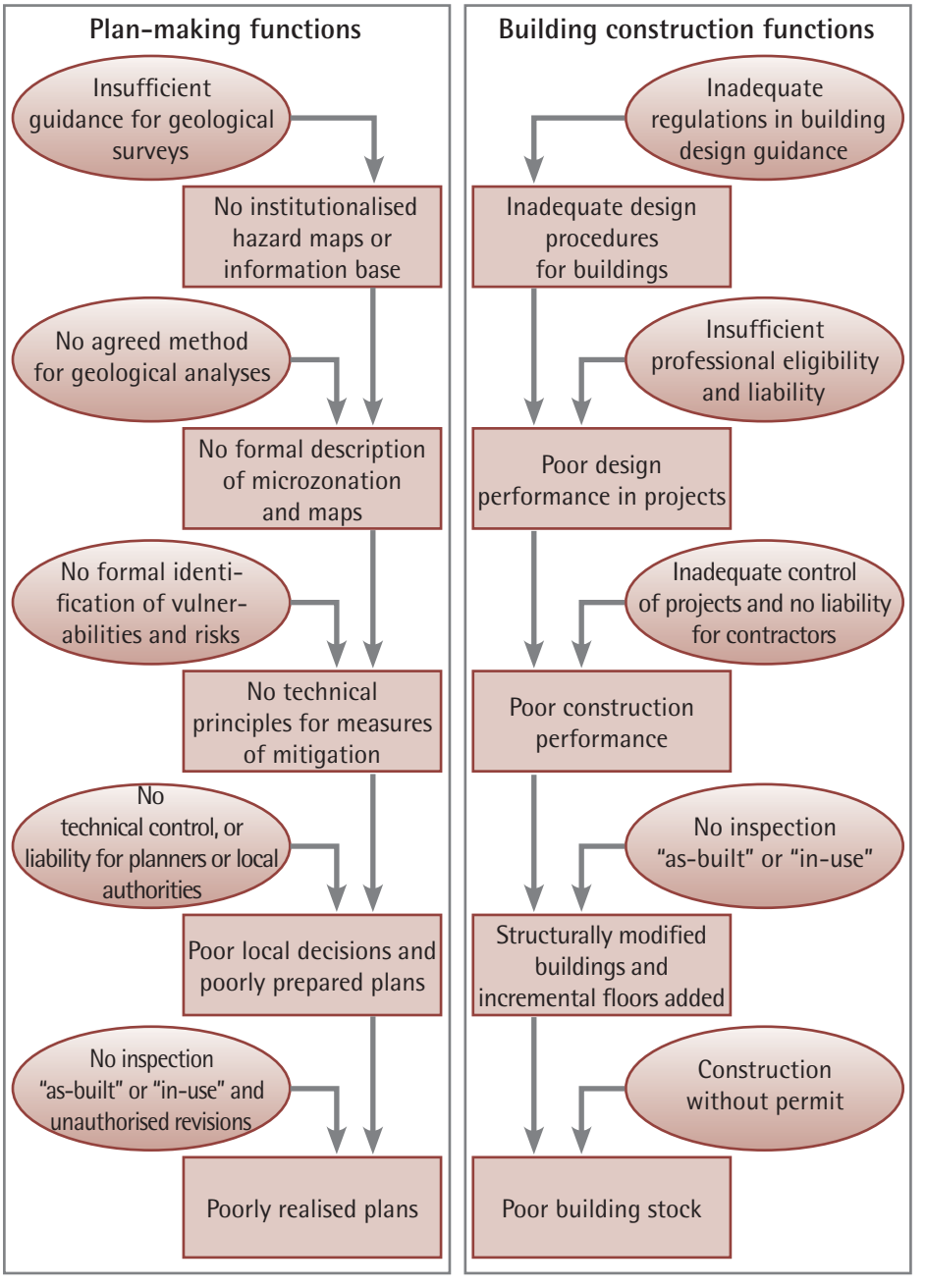
- Technical expertise, resources and knowledge of routine methods and practical standards of supervision in local authorities are insufficient to carry out reliable project supervision.
- No higher authority exists with the authority to inspect and exact penalties on local authorities that do not fulfil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

 © OECD 2004

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



© OECD 2004

- 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).

© OECD 2004

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

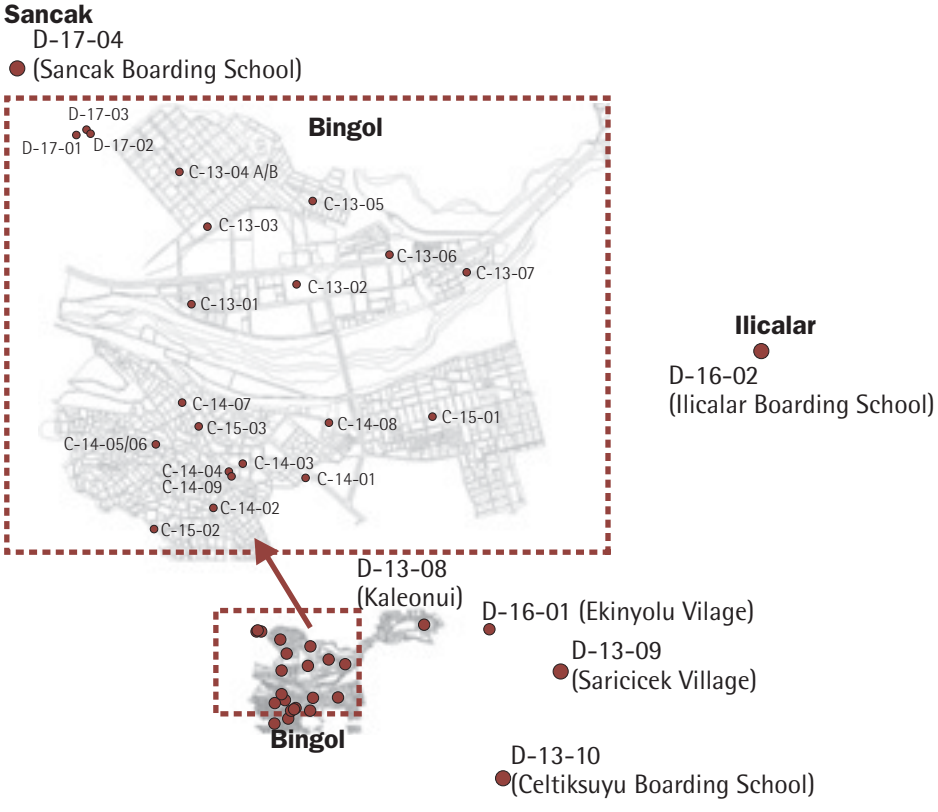


Table A4.1. Damage to school buildings in the Bingöl area

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

© OECD 2004

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).

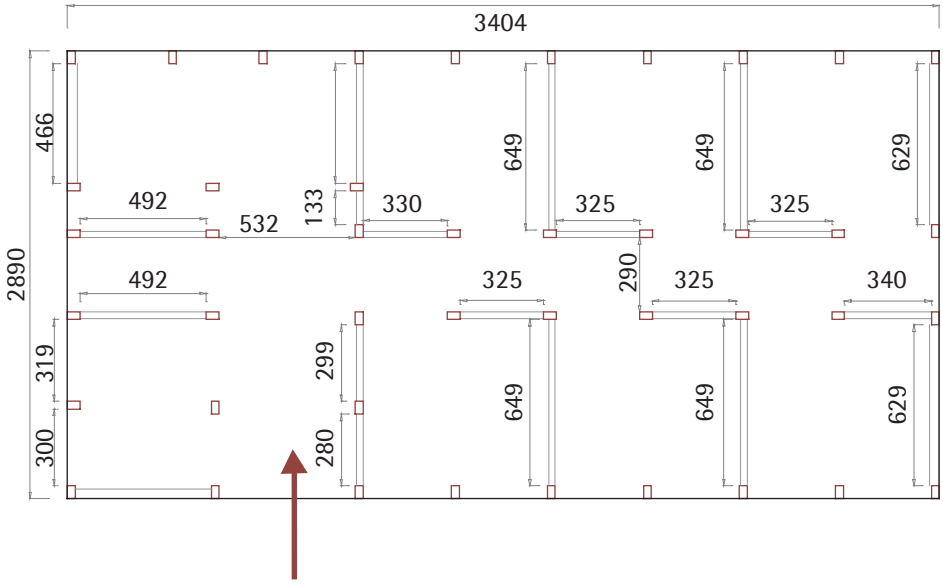


Figure A4.3. School buildings with a typical floor plan

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

© OECD 2004

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.

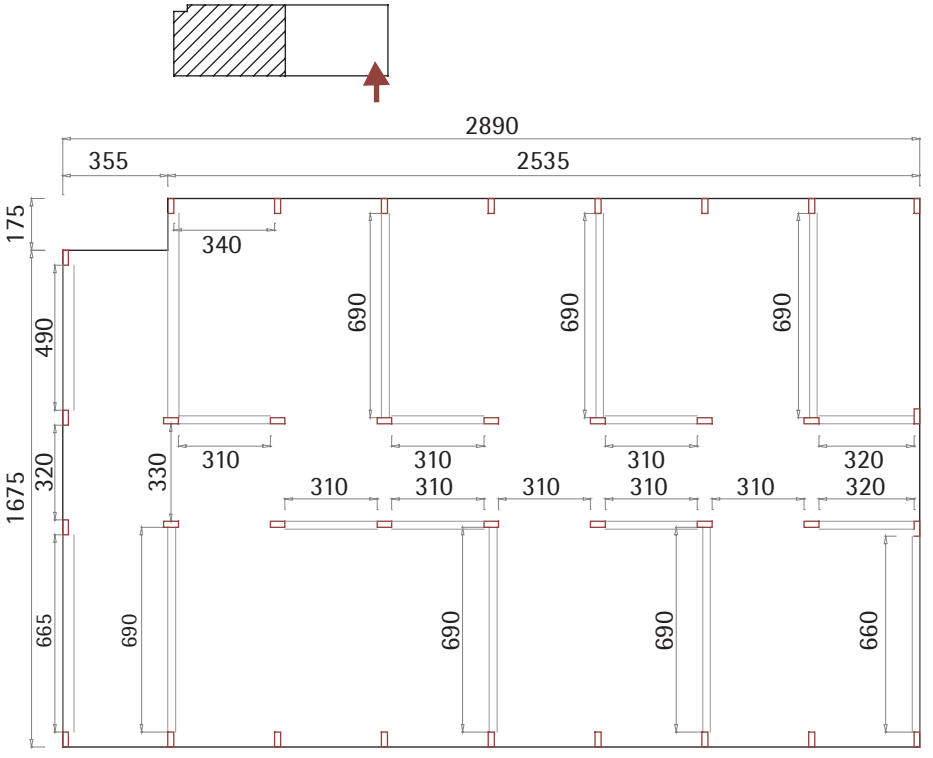
There were several construction and structural design deficiencies commonly observed in school buildings. In most of the structures surveyed, the quality of construction practices was uniform. Specific problems noted were:

- 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).

© OECD 2004

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.

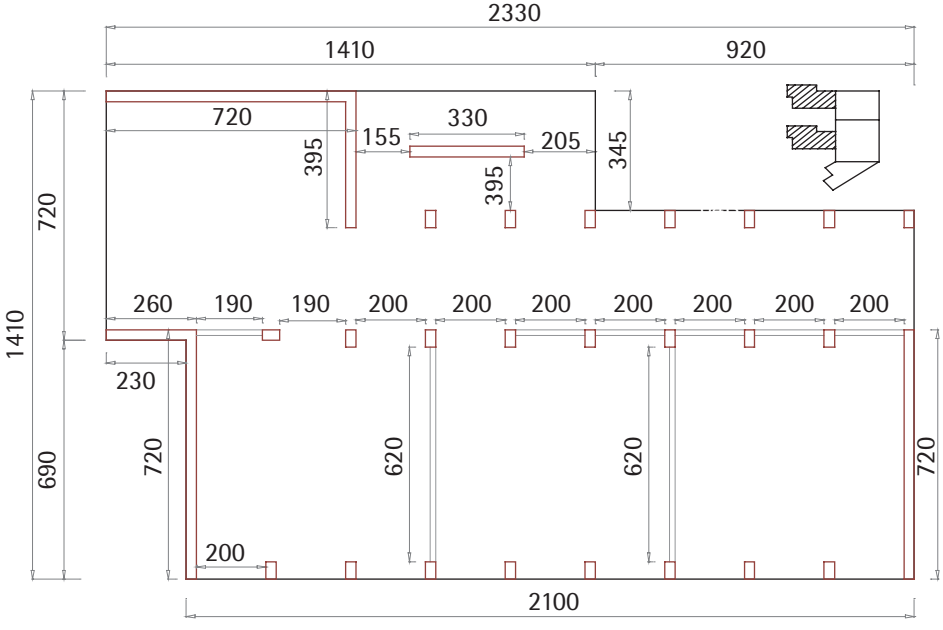
Buildings C-13-04A and C-13-04B

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).



© OECD 2004

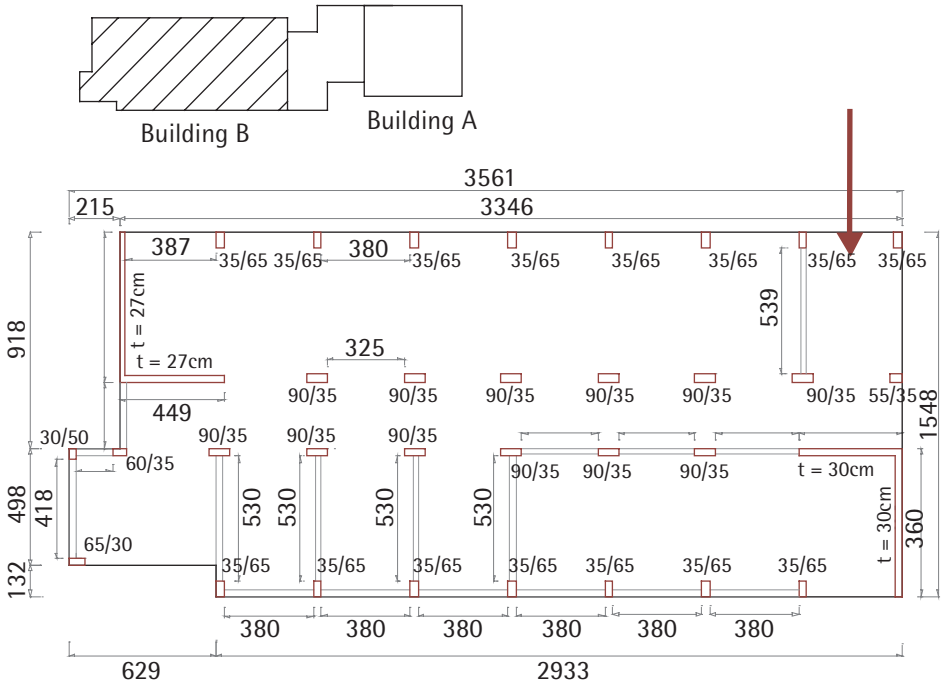
Buildings C-13-03, C-14-08, C-14-09 and C-15-03

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).

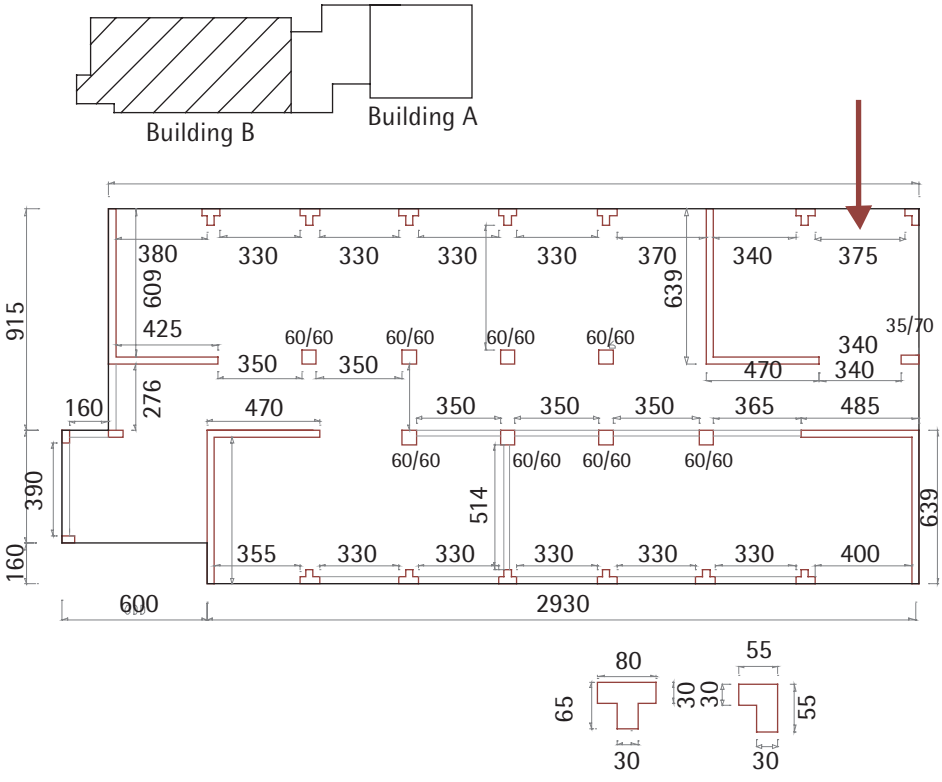


In building C-14-08, damage to the structural system was confined to significant crushing of concrete in the shear walls. No damage was observed in the columns, and a few beams had severe flexural cracks. The structural system of this building was rated as severely damaged. The masonry walls were separated 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).



© OECD 2004

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)

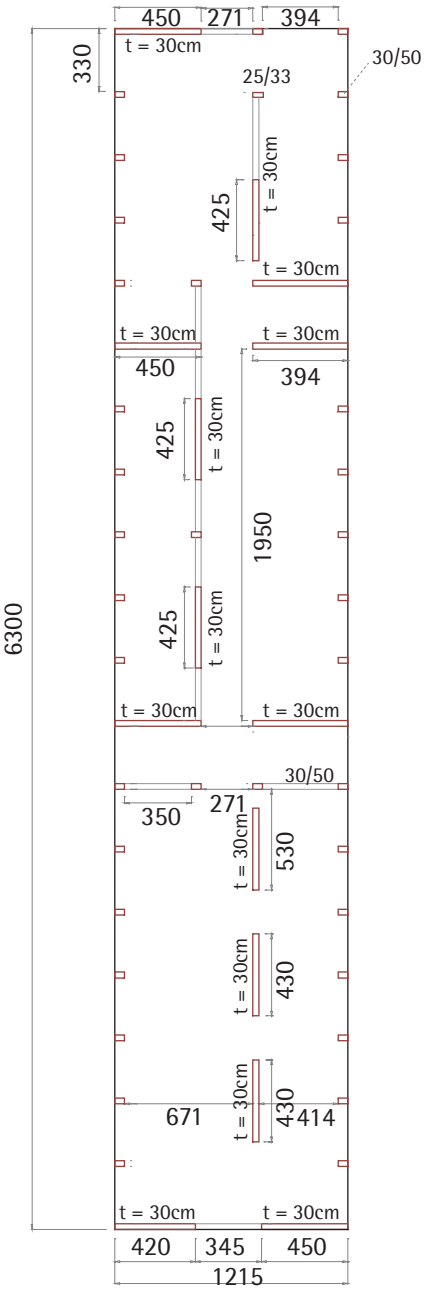
These buildings were not adjacent to other structures, had identical floor plans – as shown in Figure A4.11 – and all comprised four-storeys. Regarding the structural system, the schools had a column area of 0.7% of the floor area, and wall areas of 1.0% and 1.5% of the total floor area in the two principal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

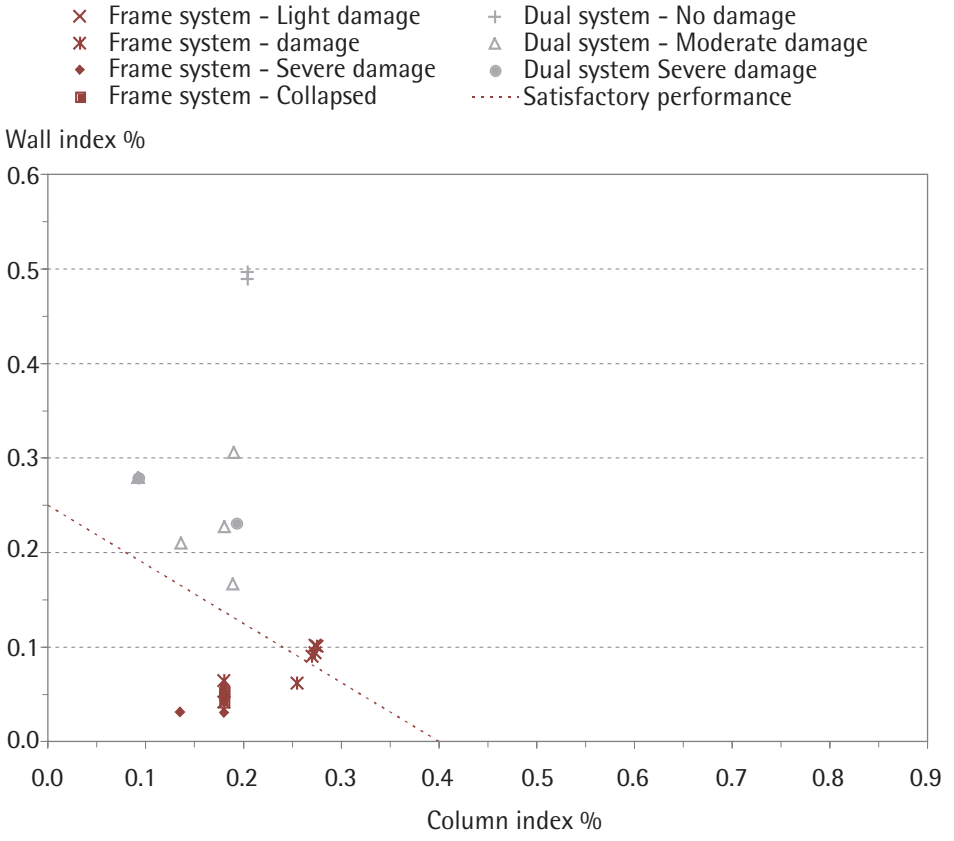
Comparison of the performance of frame and dual systems

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.

© OECD 2004

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

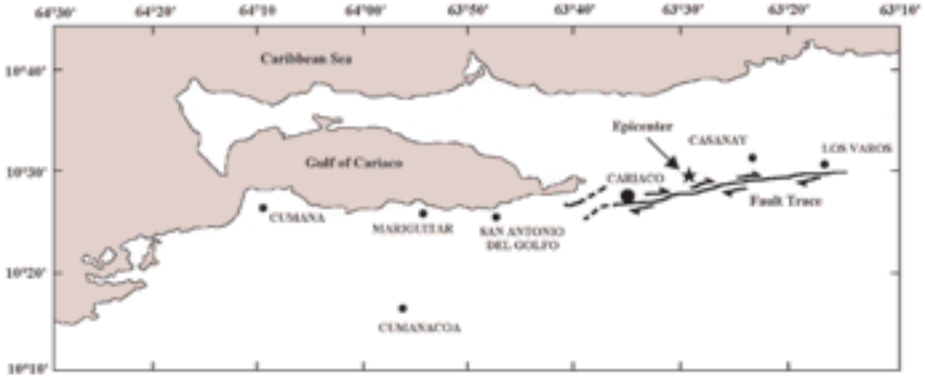
Magnolia Santamaría

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

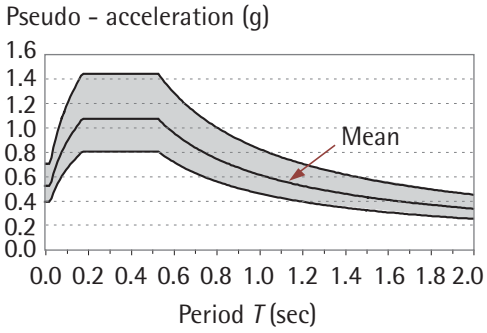
At 15:24 on 9 July 1997, an earthquake struck the north-eastern region of Venezuela, located some 300 km from Caracas. The ground motion caused five reinforced-concrete buildings – two of which were school buildings – to collapse, killing 74 people and leaving 522 wounded. The earthquake also caused 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

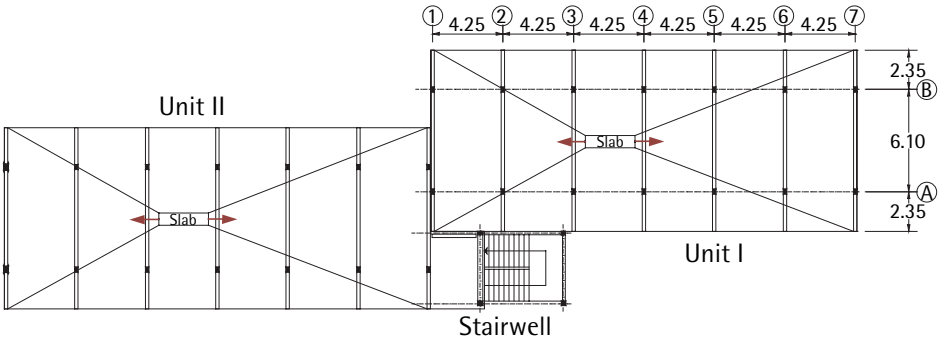
© OECD 2004

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.

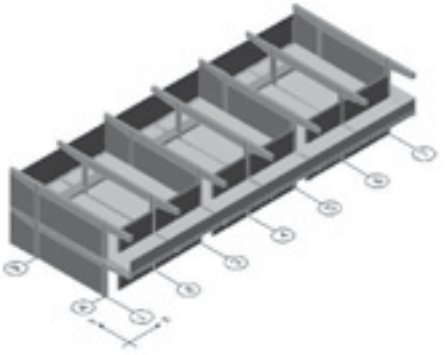
Figure 5.4. Structural plan at first storey of Valentín Valiente School (dimensions in metres)



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

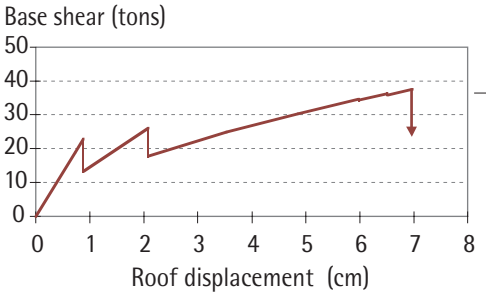
The building's capacity was determined by means of a non-linear static (pushover) analysis; lateral triangular loads were applied in the longitudinal direction until the structure became unstable. The masonry infill was modelled by diagonal compression struts. The slab concrete joists were modelled by 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.

© OECD 2004

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:

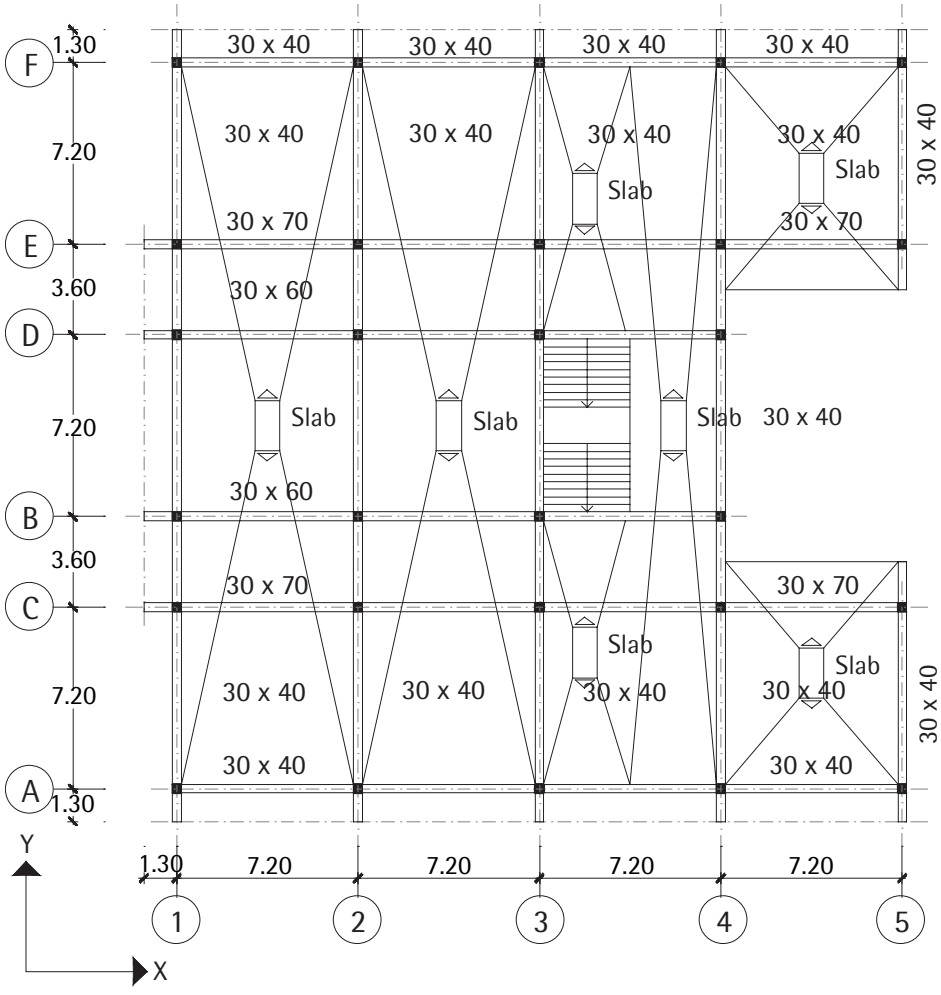
- The very low resistance and stiffness of the structure in the longitudinal direction as a result of the small size of the columns and the lack of beams.
- The presence of masonry infill connected to the columns, creating short columns and leading to brittle failures.
- The building's limited energy-dissipation 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

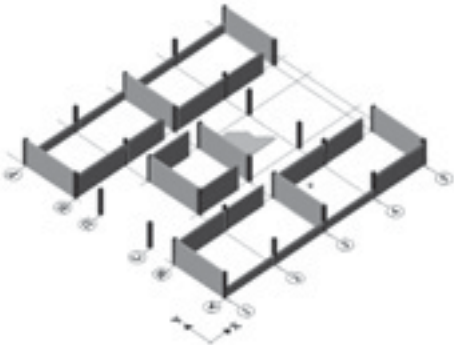
© OECD 2004

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



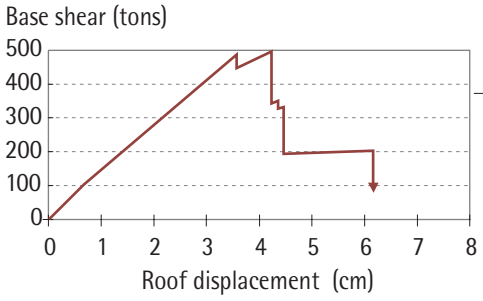
(b) Collapse of first storey of RMC school (Photo courtesy of E. Castilla)

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

 © OECD 2004

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

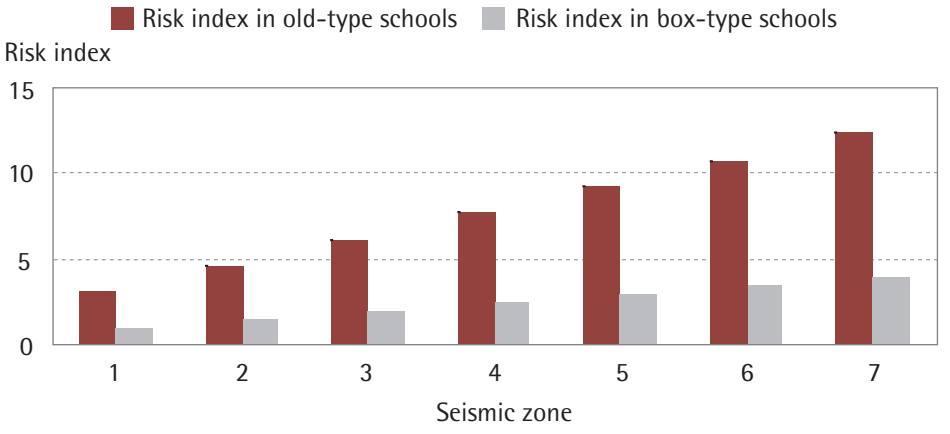
 © OECD 2004

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



References

Abrahamson, N.A. and W.J. Silva (1997), "Equations for Estimating Horizontal Response Spectra and Peak Acceleration from Western North American Earthquakes: A Summary of Recent Work", *Seismological Research Letters*, Vol. 68, No. 1, pp. 128-153.

Bonilla, R., *et al.* (2000), "The Cariaco Earthquake of 9 July 1997", *Revista Boletín IMME (Institute of Materials and Structural Models, Central University of Venezuela Technical Bulletin)*, Vol. 38, No. 2, pp. 1-50 (in Spanish).

Boore, D.M., W.B. Joyner and T.E. Fumal (1997), "Empirical Near-Source Attenuation Relationships for Horizontal and Vertical Components of Peak Ground Velocity, and Pseudo-Absolute Acceleration Response Spectra", *Seismological Research Letters*, Vol. 68, No. 1, pp. 154-179.

Campbell, K.W. (1997), "Attenuation Relationships for Shallow Crustal Earthquakes Based on California Strong Motion Data", *Seismological Research Letters*, Vol. 68, No. 1, pp. 180-189.

Castilla, E. and A. Marinilli (2000), "Structural Behaviour of the Raymundo Martinez Centeno High School in the Cariaco Earthquake on 9 July 1997", *12th World Conference on Earthquake Engineering*, Auckland, New Zealand, 29 January – 5 February 2000.

COVENIN (Venezuelan Commission for Industrial Norms) (2001), *Seismically-Resistant Construction*, Norm 1756-2001, MINDUR (in Spanish).

Fernández, N. (1998), *Sensitivity Analysis of the Causes of the Collapse of the Valentín Valiente School in the Cariaco Earthquake on 9 July 1997*, Special Project for the Degree of Civil Engineering, Faculty of Engineering, Central University of Venezuela (in Spanish).

Institute of Materials and Structural Models (IMME) (1998), *Evaluation of the Earthquake Resistance of Collapsed Buildings in the Cariaco Earthquake on 9 July 1997*, Report Nº 209209, 20 August 1998, IMME, Faculty of Engineering, Central University of Venezuela (in Spanish).

López, O.A., *et al.* (2004), "Properties of the Three Main Components of Seismic Movement", *Revista Boletín IMME (Institute of Materials and Structural Models, Central University of Venezuela Technical Bulletin)* (in Spanish).

Sadigh, K., *et al.* (1997), "SEA96-A New Predictive Relation for Earthquake Ground Motions in Extensional Tectonic Regimes", *Seismological Research Letters*, Vol. 68, No. 1, pp. 190-198.

Acknowledgements

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

 © OECD 2004

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)

 © OECD 2004

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"

© OECD 2004

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.

 © OECD 2004

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.

 © OECD 2004

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

 © OECD 2004

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.

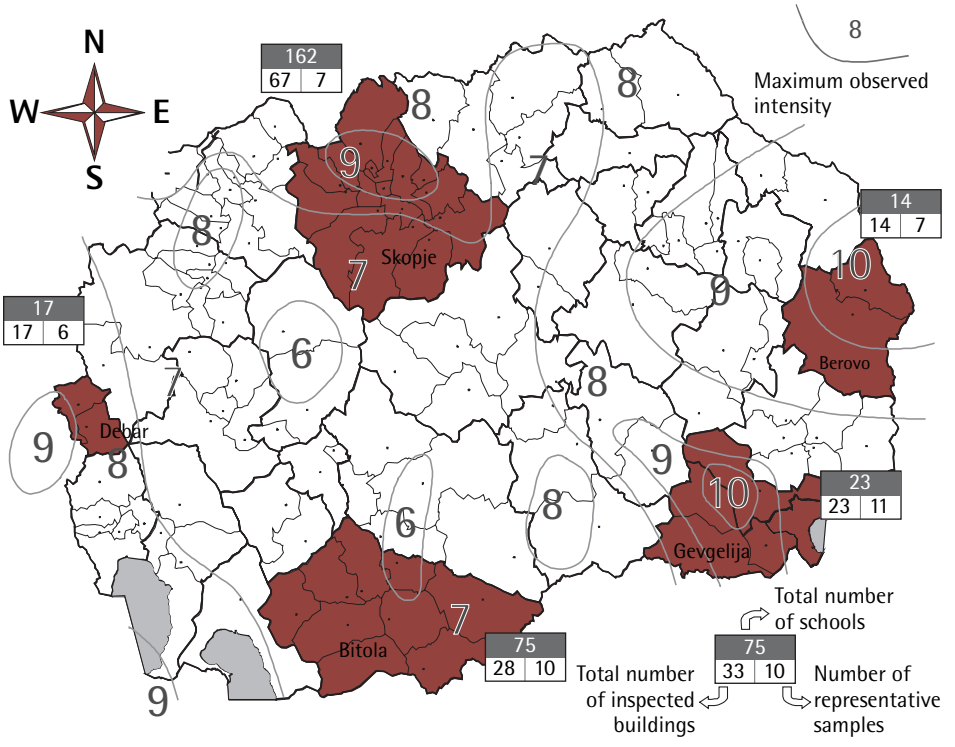
- *School Emergency Preparedness Plans (SEPP).* These plans are to be prepared at the school level. The roles and responsibilities of all stakeholders and instructions for emergency procedures will be clearly defined. Drills to test the effectiveness of SEPP will be organised regularly in co-ordination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

© OECD 2004

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

© OECD 2004

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)

© OECD 2004

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.

References

Anagnostopoulos, S.A., J. Petrovski and J.J. Bouwkamp (1989), "Emergency Earthquake Damage and Usability Assessment of Buildings", *Earthquake Spectra*, Vol. 5, No. 3.

Applied Technology Council (ATC) (1978), *Tentative Provisions for the Development of Seismic Regulations for Buildings,* Publication ATC-3-06.

Belazougui, M., M.N. Farsi and A. Remas (2003), "A Short Note on Building Damage", *European-Mediterranean Seismological Centre Newsletter,* No. 20.

Benedetti, D. and V. Petrini (1984), "On Seismic Vulnerability of Masonry Buildings: Proposal of an Evaluation Procedure", *L'Idustria delle Costruzionii,* Vol. 18.

Dandoulaki, M., M. Panoutsopoulou and K. Ioannides (1998), "An Overview of Post-Earthquake Building Inspection Practices in Greece and the Introduction of a Rapid Building Usability Evaluation Procedure after the 1996 Konitsa Earthquake", *Proceedings of 11th European Conference on Earthquake Engineering*, Paris, France, 6-11 September 1998.

Federal Emergency Management Agency (FEMA) (2002), *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook.* FEMA 154 Report.

Fukuta, T. (ed.) (1996), "Outline of Standards to Evaluate Seismic Capacity of Existing and Damaged Reinforced-Concrete Buildings", *The First Management Panel on Collaboration Research Activities Between Joint Research Centre of the European Commission-Institute for Systems, Informatics and Safety (JRC-ISIS) and the Japanese Ministry of*

Construction (JBRI), Tsukuba, Japan, 1996.

Gabrichidze G., T. Mukhadze and I. Timchenko (2003), "Damaging Effects on Education and Health Facilities in the April 2002 Earthquake in Tbilisi, Georgia", *Proceedings of International Workshop on Safety and Emergency Management of Essential Facilities*, Ohrid, FYROM, 19-21 June 2003.

Milutinovic Z.V. and G.S. Trendafiloski (1997), "Emergency Management of the Education System in the Republic of Macedonia", *International Conference on Risk Sciences: Training at School Level*, Sofia, Bulgaria, 1997.

Milutinovic Z.V. and G.S. Trendafiloski (1998), "Earthquake Preparedness of Schools in Republic of Macedonia", *Proceedings of 11th European Conference on Earthquake Engineering*, Paris, France, 6-11 September 1998.

Milutinovic, Z.V., *et al.* (2002), "Physical and Psychological Management of Earthquake-Related Emergencies in Schools in Macedonia", *Proceedings of 12th European Conference on Earthquake Engineering*, London, United Kingdom, 9-13 September 2002.

Milutinovic, Z.V. and B. Tasevski (2003), "Early Response to 1963 Skopje Earthquake: Operational and Institutional Aspects", *Proceedings of International Conference "Skopje Earthquake 40 Years of European Earthquake Engineering"*, Ohrid, FYROM, 26-29 August 2003.

Milutinovic, Z.V. and G.S. Trendafiloski (2003), "Seismic Vulnerability and Performance of School Buildings in FYROM", *Proceedings of International Workshop on Safety and Emergency Management of Essential Facilities*, Ohrid, FYROM, 19-21 June 2003.

Olumceva, T.R., Z.V. Milutinovic and G.S. Trendafiloski (2003), "Elements of Physical and Psychological Management of Emergencies in Schools", *Proceedings of International Workshop on Safety and Emergency Management of Essential Facilities*, Ohrid, FYROM, 19-21 June 2003.

Republic Bureau of Statistics (1992), *Census of Population, Households and Farm Economies in 1991. Basic Data for Population by Municipalities. Definite Data, Statistical Review No. 226*, Republic Bureau of Statistics of Republic of Macedonia, Skopje.

UNDP/UNIDO-RER/79/015 (1985), *Post-Earthquake Damage Evaluation and Strength Assessment of Buildings*, Volume 4.

 © OECD 2004

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.

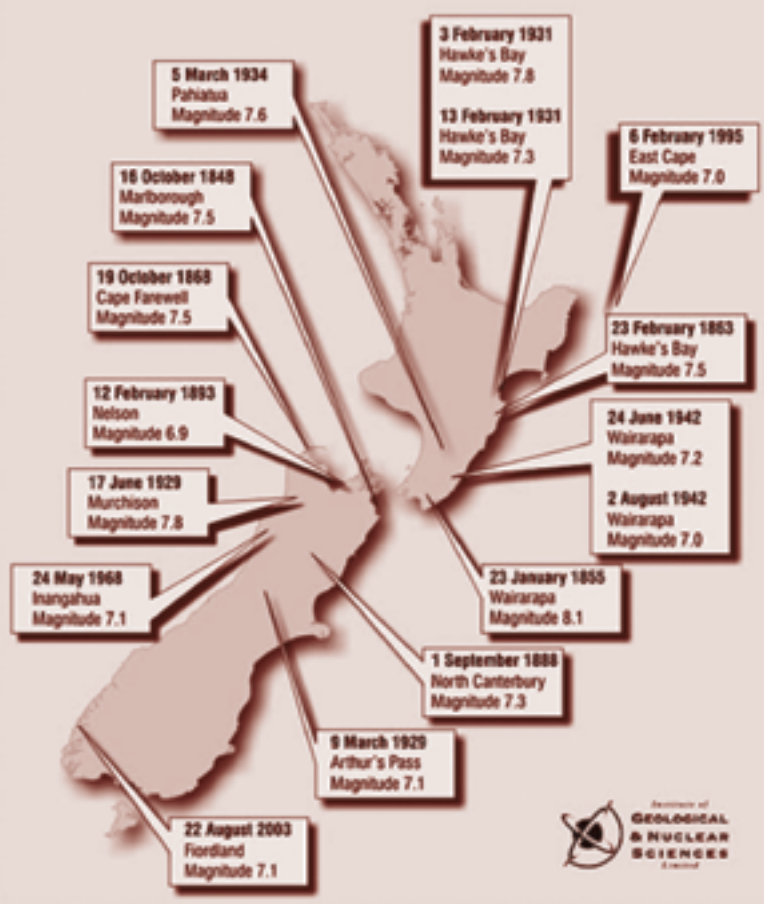
Seismic risk in New Zealand

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.

 © OECD 2004

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.

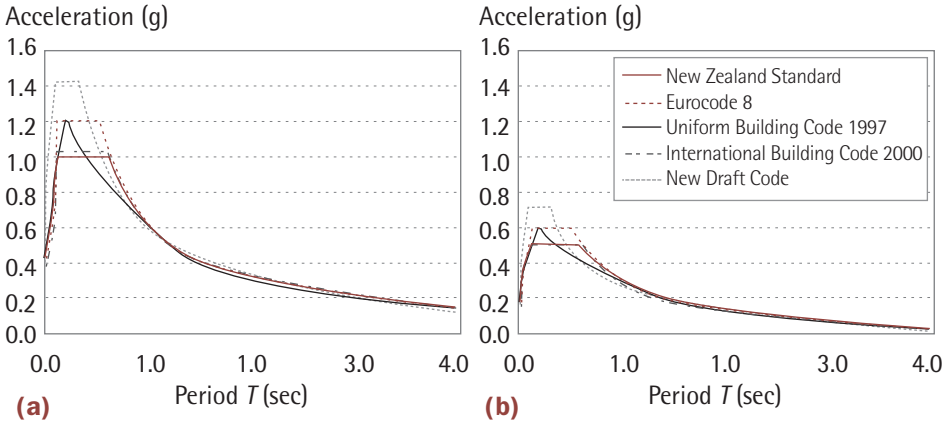
Seismic provision in design was first incorporated into legislation in 1935 following the 1931 Hawke's Bay earthquake. Subsequent improvement in design standards resulted from international experience of building performance in earthquakes and research into earthquake-resistant design. The following 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]



© OECD 2004

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.

© OECD 2004

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

 © OECD 2004

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

 © OECD 2004

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.

References

British Standards (BSI) (1998), "Eurocode 8. Design Provisions for Earthquake-Resistant Structures", BSI, London.

Building Officials and Code Administrators International, Inc. (BOCA) and International Conference of Building Officials (ICBO) (1998), *International Building Code*, final draft.

International Code Council (ICC) (1997), *Uniform Building Code 97*, International Conference of Building Officials, Whittier.

Standards New Zealand (NZS), (1992), *Code of Practice for General Structural Design and Design Loadings for Buildings, NZS 4203*, Standards New Zealand, Wellington.

Standards New Zealand (NZS) (1995), *Concrete Structures Standard, NZS 3101*, Standards New Zealand, Wellington.

Standards New Zealand (NZS) (1997), *Steel Structures Standard, NZS 3404*, Standards New Zealand, Wellington.

Park, R. and T. Paulay (1975), *Reinforced-Concrete Structures*, John Wiley, New York.

Stirling, M., *et al.* (2000), *Probabilistic Seismic Hazard Assessment of New Zealand: New Active Fault Data, Seismically Data, Attenuation Relationships and Methods*, Institute of Geological and Nuclear Sciences, Wellington.

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.

 © OECD 2004

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.

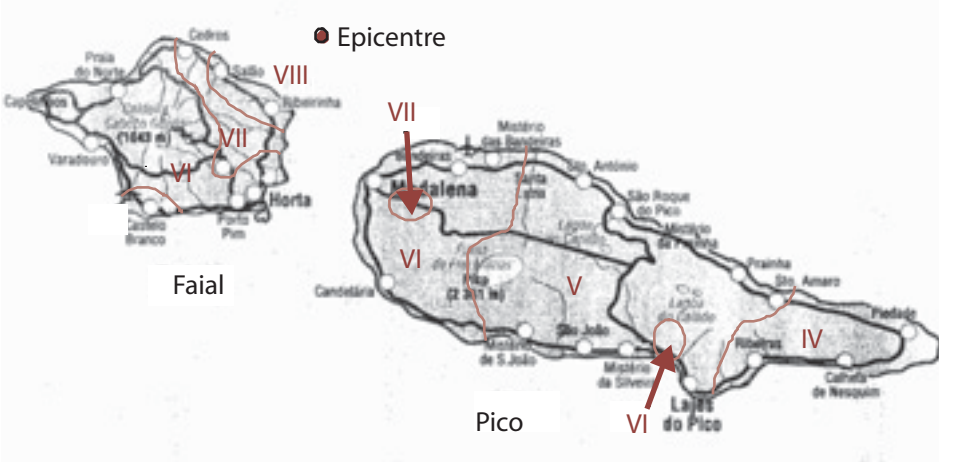
In the aftermath of the 1998 Faial earthquake, a team from the Institute of Structures, Territory and Construction Engineering at the Higher Technical Institute (ICIST/IST) in Lisbon completed damage assessments of religious and educational buildings on the

 © OECD 2004

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.

© OECD 2004

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

© OECD 2004

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.

 © OECD 2004

References

Azevedo, J., *et al.* (1998), *IST Mission to Faial and Pico after the 9 July 1998 Earthquake: Inspection of Schools and Churches*, Institute of Structures, Territory and Construction Engineering, Higher Technical Institute (ICIST/IST) Report DT Nº 8/98, IST, Lisbon (in Portuguese).

Nunes, J., *et al.* (1998), "Distribution of Seismic Intensities in Pico as a Consequence of the 9 July 1998 Earthquake, Morphological, Geological and Tectonic Influences", *Proceedings of the 1st Portuguese Association of Meteorology and Geophysics (APMG) Seminar on Meteorology and Geophysics*, Lagos, Portugal, 23-25 November 1998 (in Portuguese).

Oliveira, C.S. (1999), Personal Communication.

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

 © OECD 2004

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.

 © OECD 2004

- 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.

 © OECD 2004

PART II

DEFINING SEISMIC SAFETY PRINCIPLES FOR SCHOOLS

Introduction

In order to improve earthquake safety in schools, the fundamental concepts and principles that lead to building earthquake-resilient school must be identified. The aim of this part of the experts' meeting was not only to define these concepts and principles, taking into account cost/benefit and resource implications, but also to use them as a starting point from which to develop a programme for school seismic safety in countries.

California's 1933 Field Act illustrates how effective legislation can lead to developing and implementing a successful programme. The general principles that ensure the effective and prolonged enforcement of this legislation can be identified, although the extent to which these general principles are transferable to other countries and cultures requires further discussion.

Based on the experience of California and other successful programmes throughout the world, the *ad hoc* experts' group identified a number of broad seismic safety principles for schools.

Defining principles

- *Champions of seismic safety.* These "champions" are community members and parents, earthquake engineers, academics and politicians who are striving to promote a risk-averse society and to communicate the risks involved in the event of an earthquake.
- *Understanding of the critical role of schools in the community and as post-disaster shelters.*
- *System for assigning risk ownership and a legal or regulatory basis for action.* Legislation and enforcement mechanisms should establish clear lines of accountability and achievable performance goals with an incremental implementation strategy. An assessment of national regulations may also be useful.
- *Established financial responsibility and cost.* Economic support should be established based on the assessment and prioritisation for retrofit of new and existing school buildings.
- *Detailed and up-to-date hazard maps and building codes.*
- *Well-monitored and independent plan review, checking and approval, and construction inspection, testing and final reporting by certified professionals.*

 © OECD 2004

CHAPTER

10

FUNDAMENTAL CONCEPTS AND PRINCIPLES FOR ASSURING ACCEPTABLE PERFORMANCE OF SCHOOLS AND THE EDUCATION SYSTEM

Dennis Bellet

Division of the State Architect, California, United States

Abstract: This paper presents the principles of satisfactory school building *design*, through the use of qualified engineers, an adequate building code, independent review and hazard investigations; and satisfactory building *construction*, through the use of qualified builders and independent inspection and testing. It also discusses the history of school construction in California, including the adoption of the 1933 Field Act and its subsequent enforcement by the Division of the State Architect.

Introduction

The minimum expected performance of school buildings is that these structures do not collapse when subjected to natural hazards such as large earthquakes. The existence of adequate and enforceable codes, rules, or regulations is the first part of the structural safety equation. The second part of the safety equation involves ensuring compliance with these standards in the actual design and construction of school buildings.

Higher performance objectives for building construction include preventing collapse and providing additional protection to prevent minor injuries, limiting the amount of physical damage to the building, and assuring immediate occupancy and continuous operation for buildings that provide post-disaster emergency response. Policy-makers generally decide on the performance objective that is desirable based on risk tolerance and financial limitations. In California, the performance objective for public schools is collapse prevention and minor risk of injury to the occupants, but allows for some repairable structural damage. Since most school campuses have big assembly areas, food service capabilities for large numbers of people, restrooms and often shower facilities, the general public can seek immediate shelter in the safety of a well-constructed school building.

Provided below are a list of elements and procedures that can lead to safer building construction. In general, the level of concern about conflict of interest or capabilities of designers, contractors and users dictates the level of enforcement necessary for each element. The public and policy-makers also have a significant role to play in the provision of safe school construction. In California, in response to the public's demand that schoolchildren not be at risk at school, policy-makers enacted laws that rigorously enforce each of these elements.

Ensuring satisfactory school building design

Qualified designers and good building design

Designing buildings to resist the forces of nature, especially earthquakes, is a complex task and requires educated, experienced professionals. Colleges and universities should provide basic education for engineers. Licensing authorities can also establish a minimum competency level for structural engineers.

Correct design can be achieved with well-engineered standard plans. These drawings can be used repeatedly and thus result in saving the costs of original design and review. Similarly, designs that have been proven successful elsewhere can be re-used. An advantage of re-using plans is that some of the flaws in the original construction can be corrected. For example, a fast-growing school district in northern California has

 © OECD 2004

been using the same design for a school campus for over a decade with great success. According to the facilities planner, money is saved through steady improvements in the design based on previous construction experience, more competitive bidding and fewer corrections during construction.

Building code

Codes developed by researchers, engineers and other stakeholders establish a minimum accepted standard for safe design of buildings at a practical cost. The research and development completed to create the code is also a valuable resource for future code development; codes and standards should evolve as more cost-effective and resistant materials are developed.

Public schools in California are constructed according to the 1997 Uniform Building Code. A stricter amendment is also included in the code. While some consider that this amendment is too conservative, the real increase in materials and labour costs is less than 2% of the final cost of construction.

A good code does not need to be complicated. The Structural Engineers Association of California (SEAOC) is currently creating a simplified code for smaller, less complex structures. Current codes are generally based on the assumptions that engineers are experienced, that low-cost construction materials are available, and that builders and workers and capable. But many countries may lack the basic human and material resources to enforce a code. Thus, the code must consider all the constraints of the system, making provisions for countries or regions with limited means.

Hazard investigations

A site-specific geological hazard report can identify unacceptable locations for building construction, such as areas that are prone to landslides, on or near a surface fault, or at risk of soil liquefaction conditions. An area-wide geotechnical hazard investigation can provide substantial benefits and at a lower cost than site-specific investigations. The investigation can vary from a review of existing information to a written report based on extensive on-site drilling, testing and soil analysis.

Independent review

Independent review ensures that calculations, plans and specifications are developed in accordance with the code requirements. It also mitigates any potential conflict of interest caused by the building's stakeholders: owners, contractors and designers. Since reviewers can also be subject to a conflict of interest, the review should be conducted by an agency that is financially and politically independent from the building's stakeholders.

Code-complying documents should be stamped and signed by the independent agency. Substitution of unapproved drawings can easily occur if approved plans are not identified. The approved plans are then used by the contractor to construct the building, and by the inspector to ensure that the contractor has constructed the building correctly. Independent review, approval and identification is also required when changes are made to the building design before or during construction.

Ensuring satisfactory school building construction

Qualified builders and good building construction

All contractors, sub-contractors and workers involved in the construction process should be certified by an independent agency, which stipulates the minimum qualifications and training for all workers. In many countries, simple training of workers is required. For example, in an adobe construction, the brick makers and those who lay them should be trained, as adobe bricks can vary in strength based on the skill of the labourer and the material chosen. Simply staggering the mortar joints when laying bricks can also result in substantial increases in shear capacity.

Independent inspection and testing

The benefits of controlling the design are lost if the construction does not adhere to the approved plans. This process can add about 2% to the cost of construction. Without rigorous inspection and testing, the safety of the building can be compromised as building plans may be changed or materials substituted for lower quality, less expensive alternatives. The frequency and rigour of testing and inspection can often depend on such factors as the complexity of the project, competency of the builder, competency of the workers, financial constraints and level of risk aversion.

Experience in California

History of school construction in California

In 1933, the lateral force-resistant design of public schools and other buildings in the state was based on estimated wind loads. Engineers assumed that buildings designed to resist wind forces would also be able to withstand earthquakes. The Long Beach Earthquake on 10 April 1933 destroyed 70 schools, and another 120 schools suffered major structural damage. Fortunately, the earthquake occurred when the buildings were unoccupied.

Although other earthquakes had occurred in urban areas of California – San Francisco in 1906 and Santa Barbara in 1925 – the Long Beach Earthquake forced engineers, public officials and the general public to make the protection of public structures, particularly schools, against earthquakes a public policy goal.

On 10 April 1933, the Field Act was adopted. Following the act, buildings were to be designed according to state standards, and plans and specifications prepared by qualified and state-registered designers. The quality of construction would be enforced by independent review and inspection. In addition, design professionals, the independent inspector and the contractor had to certify under penalty of perjury that the building was constructed according to the approved plans. The Division of the State Architect (DSA) was established as the jurisdictional authority within the state of California to enforce the Field Act.

The Field Act applied to new construction and not to existing pre-1933 school buildings. Legislation relating to the continued use or abandonment of these pre-1933 school buildings was enacted under the Garrison Act of 1939. These pre-Field Act buildings

 © OECD 2004

were not retrofitted to conform to current codes until funding was made available in the 1970s, following the M6.4 San Fernando earthquake in 1971. California is now trying to evaluate and retrofit thousands of school buildings constructed before major changes were made to the building code in 1976 following the San Fernando earthquake.

Threats to the programme

Many policy-makers believe that aggressive plan review and construction inspection is too costly or time consuming. Legislation is frequently proposed and sometimes adopted that exempts certain categories of school building uses from the Field Act requirements. In response, DSA undertook a study in 1992 to determine the cost difference between a Field Act-enforced school building and a private school building constructed to the unamended code and enforced by local jurisdictions. The results showed that the cost of construction in the Field Act-enforced school building increased the project cost by less than 4%. Most of the increased costs were associated with a requirement for continuous on-site inspection and more frequent testing. Less than 1.5% of the cost was associated with the stricter building code.

There are over 500 local jurisdictions in California, and current proposed legislation may give them the authority to enforce plan review and construction inspection. This legislation would result in increased inconsistencies in review and construction inspection. It would also force local jurisdictions to contract out the plan review, as the number of structural engineers in California is insufficient to meet the needs of 500 jurisdictions. This arrangement would add another administrative layer to the process and may result in conflicts of interest, inconsistencies and errors. Local building departments may also be subject to greater political and economic pressures.

Primary barriers to success

Two principal barriers to the success of the programme can be identified. First, as funding for school construction is unstable and the quantity of work often exceeds staff capacity, schedule pressures can lead to less aggressive inspection and less rigorous plan review. Second, the 1933 Field Act does not adequately address the risk posed by non-structural elements, which often come loose and fall during moderate earthquakes. Although parts of the code do address non-structural hazards – DSA has published guides for school districts regarding anchoring and bracing televisions, bookcases, etc. to assist them in identifying and mitigating non-structural hazards – many of these protection devices are ignored as new teachers make changes in their classrooms.

Primary successes

DSA has been reviewing plans and overseeing the construction of public school buildings for over 70 years. In that time, no pupil or teacher has been injured or killed due to the failure of a building as a result of an earthquake, wind, snow or other loads. One student died due to injuries sustained when a wall collapsed (the wall had not been approved by DSA) due to wind loads and dry rot in its posts. In the history of the Field Act, few school buildings have been so severely damaged in an earthquake as to require demolition. Public awareness of the success of the school programme has discouraged any change to the programme that might threaten its safety record.

PART III

ASSESSING VULNERABILITY AND RISKS TO SCHOOLS AND OTHER PUBLIC BUILDINGS

Introduction

Is it feasible to develop norms for assessing risk and for quantifying structural and non-structural hazards, vulnerability and exposure in schools and other public buildings? If establishing and monitoring norms is realistic, to what extent are these norms transferable across cultures and countries?

Successful programmes exist that assess vulnerability and risk in public buildings. In this section, the Insurance Services Office's Building Code Effectiveness Grading Schedule (BCEGS) and the United States-Italy collaborative programme for improving seismic safety of Italy's hospitals (ATC-51) are cited as exemplary programmes. The *ad hoc* experts' group was asked to deliberate on the transferability of such programmes to an international context.

The group reached the following conclusions:

- A number of existing risk scoring and assessment systems – such as those published by the Applied Technology Council in the United States – could be adapted to schools in different countries. Likewise, common performance objectives, standard criteria for specifying expected ground-shaking severity, and standards, regulations, licensing, education and training could be realistically implemented across countries.
- The processes of code administration, plan review and field inspection used in grading systems such as the BCEGS could be adopted as standard procedures across countries.
- Adequate risk assessment methodologies and metrics currently exist to evaluate the state of school seismic safety, and to monitor the progress and success or failure of school seismic safety programmes throughout the world.

 © OECD 2004

CHAPTER

11

BUILDING CODE EFFECTIVENESS GRADING SCHEDULE: MEASURING THE COMMUNITY'S COMMITMENT TO ADOPTING AND ENFORCING BUILDING CODES

Dennis Gage

Natural Hazards Mitigation Division Insurance Services Office, Inc., United States

Abstract: Government, insurers, property owners and builders all have important roles and responsibilities to ensure that buildings are safe. However, not all communities have rigorous building codes, nor do all communities enforce their codes with equal commitment. This paper describes how the Insurance Services Office (ISO) helps distinguish between communities in the United States with effective building-code enforcement and those with weak enforcement through a comprehensive programme called the Building Code Effectiveness Grading Schedule. The ISO collects information on a community's building-code adoption and enforcement services; reviews the administration of codes, building plans and field inspections; and then assigns a Building Code Effectiveness Classification.

The stakeholders

In a free economy, there are many pressures to provide the least expensive product that will serve the customer's immediate needs; in this way, building construction is no different from any other product or service. However, buildings in which we live, learn, work or play are expected to be safe structures that serve us for many years, protecting us from the challenges of the environment and minimising the impact of the hazards that may exist within. As building construction is very expensive, there is an inherent need to minimise the cost of construction to meet the budget. However, under no circumstances should the safety of the occupants be jeopardised in order to minimise these costs.

There are essential partners in the goal of providing safer buildings. They are:

- Government.
- Insurers.
- Property owners.
- Builders.

Government

Charged with the basic responsibility of providing a safe environment for its citizens, government must set the stage for any meaningful partnership to work effectively. Modern, effective building codes must be adopted, and codes must be enforced in an unbiased manner to set a baseline of minimum expectations for building safety with which everyone must comply.

Government must provide an environment where the insurance industry can operate in a competitive manner with flexible insurance regulation, allowing insurers to develop pricing programmes that provide economic incentives for superior construction, protection and other features that reduce losses.

Government can provide the resources for the research and development of modern building and fire prevention codes if an effective, national consensus, standard-making organisation does not exist in the private sector.

Government can also provide tax incentives to property owners who comply with building construction regulations.

 © OECD 2004

Government can require that builders be qualified and certified, and provide information to consumers. Most consumers are normally unaware of proper building techniques and are dependent on the professionalism and expertise of builders. Information on builder's certification programmes can help customers to make an informed choice when selecting builders.

Insurers

Insurers can work with government to develop rating or pricing programmes that correspond to building and fire prevention codes, thus providing insurance pricing incentives for better construction designs, including hazard mitigation provisions within individual properties and at the local community level. Insurance incentives can have meaningful economic consequences to a business and will attract the attention of business people seeking to maximise their future profit potential through reduced insurance costs. Insurance companies can work with property owners to reduce potential losses.

Property owners

Property owners can work with government to ensure that their new or revised construction is code-compliant early in the planning stage. This relationship does not need to be adversarial if there is the common goal of safe construction at the least cost.

Property owners should hire only qualified and certified builders to ensure quality construction.

Property owners should be selective in choosing an insurance company that offers the most competitive coverage at the least cost for superior construction and hazard mitigation, and that provides on-going service to help reduce hazards and potential losses.

Property owners must realise that while insurance is a method of transferring the risk of financial losses to insurance companies for a premium, insurance will never cover the emotional impact of a major disaster, nor all of the indirect costs of a major loss.

Builders

Builders should be able to identify qualified workers through government or trade association certification programmes. With effective codes and enforcement, all builders can operate on an even playing field that allows them to compete on quality and service, without taking shortcuts that threaten safety.

Comparing building code adoption and enforcement

Following Hurricane Andrew in 1992, photos taken in several parts of south Florida showed homes on one side of a street that were completely destroyed and homes on the other side still standing. Later inspections revealed that, in many cases, construction of the destroyed buildings was well below the standard required by the building code in effect. Several industry studies suggest that total losses (USD 26.5 billion) might have been as much as 50% less if all structures in the area had met current building codes. These studies highlight the fact that code adoption is only part of the solution; rigorous

enforcement with adequately staffed and well-trained personnel is also required to maximise mitigation efforts.

Hurricane Andrew did not limit its destructive forces to property. Even though there was significant warning of the event, it caused 23 deaths in the United States and three in the Bahamas.

In 1994, another significant catastrophic event occurred in the United States: the Northridge earthquake in California. This earthquake caused over USD 7 billion of insured losses to properties. The actual dollar loss rose dramatically considering that only 25% of the damaged property had insurance coverage for the earthquake hazard. Once again, a correlation was evident between significant building damage and non-code compliant construction.

Building code adoption and effective code enforcement can have a major influence on the economic well-being of a municipality as well as on the safety of its citizens. However, not all communities in the United States have rigorous building codes, nor do all communities enforce their codes with equal commitment. Local building codes can have a profound effect on how the structures in a community fare in a hurricane, earthquake or other natural disaster.

The Insurance Services Office (ISO) helps to distinguish between communities with effective building code enforcement and those with weak enforcement through a comprehensive programme called the Building Code Effectiveness Grading Schedule (BCEGS).

The ISO is an independent statistical, rating and advisory organisation that serves the property/casualty insurance industry. It collects information on a community's building code adoption and enforcement services, analyses the data, and then assigns a Building Code Effectiveness Classification from 1 to 10. Class 1 represents exemplary commitment to building code enforcement, and Class 10 indicates less than minimum commitment.

The BCEGS also helps evaluate a community's building code enforcement services. The programme provides an objective, countrywide standard for agencies to use when preparing and budgeting for plan review, inspection services, public relations activities and training efforts.

Multiple benefits for communities

Municipalities with well-enforced, up-to-date codes demonstrate better loss experience, and their citizens' insurance rates can reflect that. The prospect of minimising catastrophe-related damage and ultimately lowering insurance costs gives communities an incentive to enforce their building codes. Communities can benefit with safer buildings, less damage from catastrophic events and reduced insurance premiums.

How the BCEGS works

The BCEGS assesses the building codes in effect in a particular community. The programme also evaluates how the community enforces its building codes, with special emphasis on mitigation of losses from natural hazards.

The ISO collects information on building code adoption and enforcement services by distributing a detailed questionnaire to the community's building official. Once the

 © OECD 2004

questionnaire is complete, the ISO arranges for one of more than 40 field representatives to meet at the community site with the building official. Together, the ISO representative and building official review and verify the community's capabilities. Each review usually takes between two and four hours.

The ISO field representative then tabulates the points scored on the various sections of the schedule. The total score determines the community's Building Code Effectiveness Classification.

The ISO notifies each community of the results of the evaluation before releasing the classification to subscribing insurance companies. The notification letter includes comprehensive details of the evaluation, outlining the score in each category.

The ISO field representatives are trained to gather and accurately analyse information regarding adopted building codes and enforcement efforts. Their training includes an overview of the administration of building codes and the BCEGS, and a detailed review of the questionnaire including background concepts and information gathering techniques. Each new BCEGS employee is also field mentored. It is not important that the field staff have a building official's knowledge of the building codes. The BCEGS programme's focus on the codes adopted, resources, and certification and education of the staff translate into measurable expectations of different community's commitment to effective code adoption and enforcement.

BCEGS criteria

The BCEGS analysis focuses on three critical areas.

Administration of codes

- Building code edition in use.
- Modification of the codes.
- Zoning provisions to mitigate natural hazards.
- Training of code enforcers.
- Certification of code enforcers.
- Incentives for outside education or certification.
- Qualifications of building officials.
- Contractor or builder licensing and bonding.
- Public awareness programmes.
- Participation in code development activities and the appeal process.

Review of building plans

- Staffing levels.
- Qualifications.
- Level of detail within plan review.
- Performance evaluations.
- Review of plans for residential, multi-family and commercial buildings.

Review of field inspections

- Staffing levels.
- Qualifications.
- Level of detail in field inspections.
- Performance evaluations.
- Final inspections.
- Issuance of certificates of occupancy.

In addition, the ISO collects insurance underwriting information, including natural hazards common to the area, the number of inspection permits issued, the number of inspections completed, the building department's funding mechanism and date of establishment, the size of the jurisdiction and population, and the fair-market value of all buildings.

BCEGS and property owner insurance premiums

The ISO serves the property/casualty insurance industry by classifying a community's commitment to code adoption and enforcement. Insurers subscribe to the BCEGS service through affiliation fees; the companies pay a fee proportional to their premium volume. They use the BCEGS results to help establish appropriate insurance premiums for residential and commercial properties.

The ISO has extensive information on more than 5 000 building code enforcement agencies. Insurance companies receive reliable, up-to-date information on a municipality's building code adoption and enforcement services.

The ISO provides insurers with BCEGS classifications, BCEGS advisory credits and related underwriting information. Any building constructed in the year that the ISO classifies a community, or in a later year, will be eligible for the insurance rating credits contained in the programme.

Re-evaluating a community's BCEGS classification

The ISO's trained field representatives evaluate communities at approximate five-

 © OECD 2004

year intervals. However, the ISO can survey a community sooner if its building code enforcement agency has made significant changes, or when a community requests a resurvey.

By securing lower property insurance premiums for communities with better performance, the BCEGS programme provides rewards to communities that choose to improve their building code enforcement efforts.

BCEGS programme incentives

Communities have many incentives to participate in the BCEGS programme. These incentives include:

- Promoting construction of damage-resistant buildings.
- Reducing property and human losses.
- Minimising economic and social disruption resulting from catastrophic events.
- Promoting good public policy.

The BCEGS programme recognises a community's commitment to building code adoption and enforcement and promotes mutually beneficial relationships among community leaders, private citizens, building code enforcement agencies and insurers.

CHAPTER

12

TRANSLATING EARTHQUAKE HAZARD MITIGATION MEASURES FROM ONE COUNTRY TO ANOTHER: A CASE STUDY

Christopher Rojahn

Applied Technology Council, United States

Abstract: This paper presents a collaborative programme by the Applied Technology Council in the United States and the *Servizio Sismico Nazionale* (National Seismic Service) in Italy to improve seismic safety in Italian hospitals. It describes how U.S. hazard mitigation measures and regulations were used in Italy. The paper also provides an overview of procedures for rapid visual screening of buildings for potential seismic hazards and for evaluating structural and non-structural components, including criteria for specifying the expected level of seismic shaking.

Applied Technology Council

Founded as a non-profit corporation in 1973 with the aid of the Structural Engineers Association of California, the Applied Technology Council (ATC) specialises in the development of engineering applications and resources for mitigating the effects of natural and man-made hazards on the built environment. Given its roots in seismically-active California, the vast majority of the organisation's efforts to date have focused on the means to reduce the potential impacts of earthquakes on buildings, bridges and other structures.

The ATC has essentially defined and developed the basis for the seismic design, evaluation and retrofit of buildings in the United States, as well as the assessment and repair of earthquake-damaged buildings. In addition, the organisation has served as the catalyst for introducing and implementing seismic protective systems for buildings and bridges (seismic isolation and energy dissipation devices), and has developed the current and pending specifications for the seismic design of federally-funded bridges. Key projects and publications over the last 25 years for improving seismic engineering practice in the United States are provided Text Box 12.1.[1]

The collaborative United States-Italy programme initiated in the late 1990s to improve seismic safety in Italian hospitals has provided insight into the means by which seismic hazard mitigation measures

Text Box 12.1. Key ATC publications

ATC-3, *Tentative Provisions for the Development of Seismic Regulations for Buildings* (1978), basis for seismic provisions in model codes in the United States.

ATC-6, *Seismic Design Guidelines for Highway Bridges* (1981), basis for current national standard specification.

ATC-13, *Earthquake Damage Evaluation Data for California* (1985), seminal report on earthquake damage and loss estimation.

ATC-20, *Procedures for Post-Earthquake Safety Evaluation of Buildings* (1989, 1995), *de-facto* national standard.

ATC-21, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook* (1989, 2002), FEMA 154 Report.

ATC-22, *A Handbook for Seismic Evaluation of Existing Buildings (Preliminary)* (1989), basis for current national standard for seismic evaluation of buildings.

ATC-26, seven publications defining a seismic safety programme for United States Postal Service Facilities (1990-1992).

ATC-33, *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (FEMA 273 Report), basis for current national pre-standard for seismic rehabilitation of buildings.

ATC-43, *Evaluation and Repair of Earthquake-Damaged Masonry Wall and Concrete Wall Buildings* (1998), FEMA 306, 307, and 308 reports.

and regulation are transferred from one country to another. While focused on improving seismic safety of hospitals, the programme defines a scope of collaborative activities that could serve as a model for an international programme to assess the seismic vulnerability and risks to schools and educational systems.

Collaborative United States-Italy programme to improve hospital seismic safety in Italy

The ATC-51 programme for improving seismic safety in hospitals in Italy, carried out jointly by the ATC and the Italian *Servizio Sismico Nazionale* (National Seismic Service), consisted of an initial project to develop overarching seismic hazard mitigation recommendations for adoption country-wide, followed by several focused projects under which key recommendations are being implemented. The initial project resulted in the development of a series of ten recommendations, six of which are focused on the short term, which will take place in the next few years, and four designated as long-term goals, which may require one or more decades to achieve (Table 12.1). The recommendations, published in 2000 in the ATC-51 Report, *U.S.-Collaborative Recommendations for Improving the Seismic Safety of Hospitals in Italy*, consider the seismic hazard in Italy, the characteristics of Italian hospital buildings and their performance in past earthquakes, and the existing regulations and standards applicable to the design and retrofitting of Italian hospitals. The recommendations draw on the experience in California of developing, implementing and enforcing hospital seismic risk-reduction programmes. Typical of ATC projects, the recommendations were developed by a "blue-ribbon" panel consisting of leading available specialists in the seismic design, evaluation, retrofit and regulation of hospitals from both countries. Since the development of the initial overarching recommendations for improving the seismic safety of Italian hospitals (Table 12.1), the National Seismic Service has funded two other ATC projects that provide the basis for implementing two of the recommendations (Recommendation 3, "Implement bracing and anchorage for new installations of non-structural systems"; and Recommendation 6, "Plan for emergency response and post-earthquake inspection"). The first of these follow-on projects, completed in 2002, resulted in the publication of the ATC-51-1 Report, *Recommended U.S.-Italy Collaborative Procedures for Earthquake Emergency Response Planning for Hospitals in Italy*; the second project, completed in 2003, resulted in the publication of the ATC-51-2 Report, *Recommended U.S.-Italy Collaborative Guidelines for Bracing and Anchoring Non-Structural Components in Italian Hospitals*. In both of these publications, and in the initial ATC-51 Report, the guidance includes recommendations pertaining to:

- Procedures.
- Standards of practice.
- Risk exposure jointly perceived to be suitable for Italy.

 © OECD 2004

Both countries have benefited from the collaborative ATC-51 programme: Italy has obtained fully documented and focused procedures for improving hospital seismic safety, and the United States has benefited from the development of new ideas and approaches.

Table 12.1. Summary of recommendations for improved seismic safety of Italian hospitals

Recommendation	Applicable to
Short term	
Establish consistent review and enforcement of design and construction quality, beginning with the preparation of specific guidelines for this review and enforcement	New and existing buildings
Evaluate options for seismic risk-reduction programmes, including programme and performance objectives, long-term strategies, and possible passive and active seismic retrofit programmes	New and existing buildings
Implement bracing and anchorage for new installations of non-structural systems	New buildings and remodelling
Restrict the use of unreinforced masonry in new construction, depending on the seismic zone	New buildings and remodelling
Improve the inventory of structural data by collecting and documenting information on seismic vulnerability	Existing buildings
Plan for emergency response and post-earthquake inspection	New and existing buildings
Long term	
Establish an active programme for non-structural bracing	Existing buildings
Improve seismic code provisions for new buildings	New buildings
Tie seismic design codes to performance-based design	New and existing buildings
Carry out a systematic seismic screening of existing hospitals, for an active seismic retrofit programme	Existing buildings

Source: ATC-51 Report.

Translating seismic vulnerability and risk assessment procedures from one country to another

Efforts to date on the collaborative United States-Italy programme for reducing seismic risks in Italian hospitals, in addition to those under consideration for future development, include establishing procedures for assessing the seismic vulnerability of buildings using rapid visual inspection; procedures for detailed seismic evaluation of buildings, including both structural and non-structural components; and criteria for specifying expected seismic shaking. This programme effort has also confirmed as workable the

procedures followed in adopting and adapting United States-developed procedures and criteria for hospital seismic safety in Italy. These approaches, including both the technical procedures and the translation and adoption approaches, provide constructive models for use in translating seismic vulnerability and risk assessment procedures for schools and educational systems to countries in need of such procedures.

Translating seismic hazard mitigation measures from one country to another

The approach for translating hospital seismic hazard mitigation procedures and regulations from the United States to Italy was based on a set of principles and actions identified at the outset of the project. These dictated that the seismic hazard reduction procedures and criteria recommended for Italian hospitals should:

- Be based on available procedures in the United States and on regulations known to be effective in reducing the seismic vulnerability of hospitals, in this case, those developed by the ATC, the Federal Emergency Management Agency (FEMA), the California Office of State-Wide Health Planning and Development, the Overseas Building Office (formerly the United States Foreign Building Office) and other agencies.
- Be based on the performance of Italian hospitals in previous earthquakes.
- Be consistent with existing laws in Italy.
- Consider the seismicity of Italy.
- Consider criteria for the seismic design of structural and non-structural components in hospital facilities in Italy, including new and existing structures.
- Consider the structural attributes of existing hospital facilities in Italy, including age, number of storeys, plan size and shape, and structural system materials; in this case, the extensive use of unreinforced-masonry walls.
- Consider the existing inventory of hospital facilities – that is, the number and regional distribution of facilities – relative to the regional seismicity.

The actions deemed necessary to carry out a successful project included:

- The selection of qualified consultants to develop the recommended procedures, in addition to a "blue ribbon" advisory panel consisting of leading available specialists in the seismic design, performance and regulation of hospital facilities from both countries, to overview and guide development of the recommendations.
- A field trip to Italy by members of the advisory panel and project consultants in the United States to observe the attributes and conditions of representative hospitals in Italy.
- A review by specialists in the United States of information and data provided by Italy on the historical seismicity of Italy, the performance of hospitals in previous earthquakes,

 © OECD 2004

existing laws pertaining to seismic safety of hospitals, and available inventory information containing the number, age, size, height, plan-shape and structural system materials of hospitals.

- A field trip to the United States by Italian members of the advisory panel to observe the attributes and conditions of representative hospitals in California.
- A meeting of the bi-lateral advisory panel to develop the recommended procedures.
- A review of the final report by the bi-lateral advisory panel.

Rapid visual inspection of buildings

While a procedure for rapid visual screening of buildings for potential seismic hazards has not yet been developed for the ATC-51 programme for reducing seismic hazards in Italy, the existing procedure for this process in the United States could, with some effort, be adopted and adapted for assessing the seismic vulnerability of schools and educational facilities in other countries. The existing procedure in the United States for rapid visual inspection of buildings for potential seismic hazards was originally developed by the ATC in the late 1980s and published in 1989 in the first edition of the FEMA 154 Report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook*. In 2002, the procedure was updated to include more recent seismic hazard information and a revised scoring system, based on more recently-developed building damage estimation curves; the updated version was published in 2002 as the second edition of the FEMA 154 Report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook*.

FEMA 154 rapid visual screening procedure

The FEMA 154 rapid visual screening procedure (RVS) was developed for implementation by a government agency or corporate owner of a building, or the building department of a city or other community (known as the "RVS authority") to identify, inventory and rank buildings that are potentially seismically hazardous. Although RVS is applicable to all buildings, its principal purpose is to identify:

- Older buildings designed and constructed before the adoption of adequate seismic design and detailing requirements.
- Buildings on soft or poor soils.
- Buildings with performance characteristics that negatively influence their seismic response.

Once identified as potentially hazardous, such buildings should be further evaluated by a design professional experienced in seismic design to determine if, in fact, they are seismically hazardous.

The RVS uses a methodology based on a "sidewalk survey" of a building and a Data Collection Form (Figure 12.1), which the person conducting the survey (known as the

"screener") completes based on visual observation of the building from the exterior, and if possible, the interior. The Data Collection Form provides space for documenting building identification information, including building use and size, a photograph of the building, sketches and pertinent data related to seismic performance, including the development of a numeric and seismic hazard score.

Once the decision to conduct the RVS for a community or group of buildings has been made by the RVS authority, the screening effort can be expedited by pre-planning, involving the training of screeners and careful overall management of the process. Completion of the Data Collection Form in the field begins with the identification of the primary structural lateral-load-resisting system and materials of the building. Basic Structural Hazard Scores for various building types are provided on the form, and the screener circles the appropriate one. The screener modifies the Basic Structural Hazard Score by identifying and circling Score Modifiers, which are related to observed performance attributes, and which are then added (or subtracted) to the Basic Structural Hazard Score to arrive at a final Structural Score, *S*. The Basic Structural Hazard Score, Score Modifiers and final Structural Score, *S*, all relate to the probability of building collapse, should severe ground shaking occur; that is, a ground shaking level equivalent to that currently used in the seismic design of new buildings. Final *S* scores typically range from 0 to 7, with higher *S* scores corresponding to better seismic performance.

Use of the RVS on a community-wide basis enables the RVS authority to divide screened buildings into two categories: those that are expected to have acceptable seismic performance, and those that may be seismically hazardous and should be studied further. An *S* score of 2 is suggested as a "cut-off", based on present seismic design criteria. Using this cut-off level, buildings with an *S* score of 2 or less should be investigated by a design professional experienced in seismic design.

The procedure presented in the FEMA 154 *Handbook* represents the preliminary screening phase of a multi-phase procedure for identifying hazardous buildings. Buildings identified by this procedure as potentially hazardous must be analysed in more detail by an experienced seismic design professional. As RVS is designed to be performed from the street, with interior inspection not always possible, hazardous details will not always be visible, and seismically hazardous buildings may not be identified as such. Conversely, buildings identified as potentially hazardous may prove to be adequate.

 © OECD 2004

Figure 12.1. FEMA 154 (2nd edition) Data Collection Form (high seismicity region) for use in rapid visual screening of buildings for potential seismic hazards

Rapid Visual Screening of Buildings for Potential Seismic Hazards
FEMA-154 Data Collection Form

HIGH Seismicity

Address: _____
_____ Zip _____
Other Identifiers _____
No. Stories _____ Year Built _____
Screener _____ Date _____
Total Floor Area (sq. ft.) _____
Building Name _____
Use _____

PHOTOGRAPH

Scale:

OCCUPANCY				SOIL TYPE						FALLING HAZARDS			
Assembly	Govt.	Office	Number of Persons	A	B	C	D	E	F	☐	☐	☐	☐
Commercial	Historic	Residential	0 – 10 / 11 – 100	Hard Rock	Avg. Rock	Dense Soil	Stiff Soil	Soft Soil	Poor Soil	Unreinforced Chimneys	Parapets	Cladding	Other:
Emer. Services	Industrial	School	101-1000 / 1000+										

BASIC SCORE, MODIFIERS, AND FINAL SCORE, *S*

BUILDING TYPE	W1	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC RM)	S5 (URM INF)	C1 (MRF)	C2 (SW)	C3 (URM INF)	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM
Basic Score	4.4	3.8	2.8	3.8	3.2	2.8	2.8	2.5	2.8	1.8	2.8	2.4	2.8	2.8	1.8
Mid Rise (4 to 7 stories)	N/A	N/A	+0.2	+0.4	N/A	+0.4	+0.4	+0.4	+0.4	+0.2	N/A	+0.2	+0.4	+0.4	0.0
High Rise (> 7 stories)	N/A	N/A	+0.8	+0.8	N/A	+0.8	+0.8	+0.8	+0.8	+0.3	N/A	+0.4	N/A	+0.6	N/A
Vertical Irregularity	-2.5	-2.0	-1.0	-1.5	N/A	-1.0	-1.0	-1.5	-1.0	-1.0	N/A	-1.0	-1.0	-1.0	-1.0
Plan Irregularity	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Pre-Code	0.0	-1.0	-1.0	-0.8	-0.6	-0.8	-0.2	-1.2	-1.0	-0.2	-0.8	-0.8	-1.0	-0.8	-0.2
Post-Benchmark	+2.4	+2.4	+1.4	+1.4	N/A	+1.6	N/A	+1.4	+2.4	N/A	+2.4	N/A	+2.8	+2.6	N/A
Soil Type C	0.0	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Soil Type D	0.0	-0.8	-0.6	-0.6	-0.6	-0.6	-0.4	-0.6	-0.6	-0.4	-0.8	-0.6	-0.6	-0.6	-0.6
Soil Type E	0.0	-0.8	-1.2	-1.2	-1.0	-1.2	-0.8	-1.2	-0.8	-0.8	-0.4	-1.2	-0.4	-0.6	-0.8

FINAL SCORE, *S*

COMMENTS

Detailed Evaluation Required

YES NO

* = Estimated, subjective, or unreliable data
DNK = Do Not Know

BR = Braced frame
FD = Flexible diaphragm
LM = Light metal

MRF = Moment-resisting frame
RC = Reinforced concrete
RD = Rigid diaphragm

SW = Shear wall
TU = Tilt up
URM INF = Unreinforced masonry infill

Adaptation and adoption for use in other countries

The FEMA 154 RVS procedure could be adopted and adapted to other countries. This would require a process similar to that used in the ATC-51 programme for hospital seismic safety in Italy, namely:

- The identification of representative building types in the region to be assessed.
- The development of structural hazard scores and modifiers reflecting the building's seismic-resisting attributes, and the seismicity and soil conditions in the region to be assessed.
- The use of specialists from both the United States and the region to be assessed to develop and review the adapted procedure, including revised Data Collection Forms.

Detailed seismic evaluation of structural and non-structural components

Existing procedures in the United States for detailed seismic evaluation of buildings have been developed over the last 15 years using a comprehensive research and development process involving numerous design professionals and researchers, with substantial funding from the Federal Emergency Management Agency.[2] The evaluation procedures are based on the seismic performance of buildings in previous earthquakes and focus on evaluations intended to determine if life-safety hazards exist. The procedures involve the use of a checklist approach intended to uncover weak links in both structural and non-structural components. Checklists, formatted as evaluation statements requiring a true or false response, are provided for building features common to all building types, for foundation and geologic site hazards, for non-structural components, and for the special features of 15-model, or common, building types. If the response by the evaluating engineer to any evaluation statement is false, the structural or non-structural component addressed by that evaluation statement is deemed to be potentially hazardous, and a process of simple calculation is used to determine if that component is in fact hazardous.

As is the case for the FEMA 154 procedure for rapid visual screening of buildings for potential seismic hazards, existing procedures in the United States for detailed seismic evaluation of buildings, including both structural and non-structural components, could, with some effort, be adapted for assessing the seismic vulnerability of schools and educational facilities in other countries. The process would require an approach similar to that proposed for the adoption and adaptation of the FEMA 154 RVS procedure, namely:

- The identification of common building types, in addition to seismic-resisting attributes, in the region to be assessed.
- The adaptation of FEMA 310 checklists or evaluation statements to reflect the building's seismic-resisting attributes, the seismicity and soil conditions in the region to be assessed.
- The use of specialists from both the United States and the region to be assessed to develop and review the adapted procedures and checklists or evaluation statements.

 © OECD 2004

Evaluation of non-structural components, as developed under the ATC-51 programme

The recommended procedures for bracing and anchoring non-structural components in hospitals in Italy, as documented in the ATC-51-2 Report, *Recommended U.S.-Italy Collaborative Guidelines for Bracing and Anchoring Non-Structural Components in Italian Hospitals*, comprise assessment guidelines advising that specific non-structural components be identified as requiring seismic evaluation or anchoring. These guidelines are based on four considerations:

- Seismicity, expressed as the Seismic Zone from the Italian building code.
- The seismic vulnerability of the component to earthquake damage, for a given seismicity.
- The importance of the component to hospital post-earthquake operation.
- The cost and disruption to retrofit or anchor the component.

The goal is to focus design and construction resources on the most critical and cost-effective non-structural seismic improvements. All four of the above considerations must be taken into account in any policy on non-structural seismic evaluation and design.

Specific examples are provided in the ATC-51-2 Report, which indicates when seismic evaluation and anchoring are required, considering both new and existing installations. Twenty-seven example components are presented, and each non-structural component is assessed in terms of its vulnerability, importance, and cost and disruption to retrofit. Based on these attributes, a recommendation indicates in which zones the component should be retrofitted, and in which zones seismic anchoring should be part of new installations. Each example component is summarised using photographs, a summary assessment of the component attributes, and recommendations for evaluation and anchoring (Figure 12.2).

While the non-structural component evaluation guidelines and criteria specified in the ATC-51-2 Report refer to hospitals in Italy, these simplified procedures offer a model approach for developing specifications for evaluating non-structural components in schools. The process for developing the component example guidance (Figure 12.2) was based in part on a field trip by U.S. specialists to hospitals in Italy to observe and document existing procedures for anchoring and bracing non-structural components. A similar process would be required to develop guidance for non-structural component anchoring and bracing in schools and educational systems.

Seismic loading criteria

Criteria used in the United States to specify the level of seismic shaking in seismic design of new buildings and in the seismic rehabilitation of existing buildings have evolved over the last decade from a specification of ground motions with a 10% probability of being exceeded in 50 years – which corresponds to an earthquake return period of 475 years – to a specification of ground motions with a 2% probability of being exceeded in 50 years

Figure 12.2. Seismic characteristics and recommendations for a suspended grid ceiling in Italian hospitals

Vulnerability. *Medium to High*. Ceiling panels can fall in an earthquake, although they are usually not hazardous. In some cases, panel collapse can cause panic and impair evacuation.

Importance. *Low*. Damage to ceilings typically will not seriously disrupt the hospital's post-earthquake operations.

Cost and disruption to retrofit. *Medium*. Retrofit is completed by adding bracing wires from the ceiling grid to the structure above. Ceiling spaces are often congested, making the retrofit difficult to achieve.

Recommendation for existing equipment in hospitals. Retrofit of ceilings is not required because of low importance. Adding bracing wires to suspended light fixtures may be advisable in Seismic Zone 1.

Recommendation for new equipment in existing or new hospitals. Bracing of ceilings and light fixtures is recommended in Seismic Zone 1. Bracing of light fixtures only is recommended in Seismic Zones 2 and 3.

Source: ATC-51-2 Report.

– which corresponds to an earthquake return period of 2 475 years. This change has come about largely to account for ground shaking due to large infrequent earthquakes, which are not captured by the shorter earthquake return period. Consideration of large infrequent events is only necessary, however, if the region under consideration has long fault lengths that are capable of generating such earthquakes. In the United States, such regions include California, the Pacific Northwest, Alaska and the New Madrid, Missouri region.

 © OECD 2004

It appears that seismic loading criteria for the vast majority of seismically active regions outside the United States specify ground motions roughly equivalent to those with a 10% probability of being exceeded in 50 years. The prevalence of these criteria suggest that, for the time being, the norm for quantifying the seismic shaking hazard is a specification equivalent to ground motions with a 10% probability of being exceeded in 50 years. Consideration must also be given, however, to the factors used to reduce ground motions to the level used in seismic design (called R-factors in codes in the United States). In addition, as time-dependent seismic hazard analysis capabilities improve, it may be advisable to consider time-dependent analysis results, particularly in regions where the period of time from the last large infrequent event equals or exceeds the return period for that event.

Programme costs

The cost of the ATC-51 programme for improving seismic safety of hospitals in Italy covers the development of recommendations and guidelines, as well as design and construction costs related to implementing the recommendations and guidelines. The cost of recommendation and guideline development ranged from approximately USD 80 000 to slightly more than USD 100 000, averaging approximately USD 100 000 for each of the three projects completed to date. The costs for design and construction have not yet been determined.

Notes

1. Applied Technology Council has also been involved in several international projects, including a series of ten United States-Japan Workshops on the Improvement of Structural Design and Construction Practices (ATC-15 series, held every other year since 1984), a series of United States-New Zealand workshops on seismic design of highway bridges (ATC-12 series), and in the development of a United States-Italy collaborative programme for the improvement of seismic safety of hospitals in Italy (ATC-51 series).

2. Existing procedures are based on the ATC-14 report, *Evaluating the Seismic Resistance of Existing Buildings*, published in 1987, and the ATC-22 report, *A Handbook for Seismic Evaluation of Existing Buildings (Preliminary)*, published in 1989. Subsequently, the ATC-22 *Handbook* was converted into the *NEHRP Handbook for the Seismic Evaluation of Buildings* (FEMA 178) and more recently updated to the *Handbook for the Seismic Evaluation of Buildings: A Prestandard* (FEMA 310 Report).

CHAPTER

13

SEISMIC RISK MITIGATION PRACTICES IN SCHOOL BUILDINGS IN ISTANBUL, TURKEY

Özal Yüzügüllü, Gülay Barbarosoglu and Mustafa Erdik

Kandilli Observatory and Earthquake Research Institute Boğaziçi University, Turkey

Abstract: In 1999, 820 schools were affected by the Kocaeli earthquake in Istanbul, 22 of which were subsequently demolished. This paper describes the impact of the earthquake on school buildings in Istanbul and the subsequent rehabilitation and reconstruction activities. It assesses the vulnerability of the existing school building stock in Istanbul, providing an estimated budget for strengthening buildings that predate the 1998 Building Code and a review of the methodology, criteria and priorities required to implement such a project. The paper concludes with recommendations for implementing a practical macro-project plan for improving seismic safety in schools.

Introduction

Following the two major earthquakes that struck Turkey in 1999, there has been broad recognition by Turkey's governmental, non-governmental and academic institutions of the urgent need for an appropriate seismic risk mitigation strategy, as well as systematic retrofitting of key structures, using a rationalised policy. After the 1950s, earthquake disaster risk in Istanbul increased, mainly due to the high rate of urbanisation, faulty land-use planning and construction, inadequate infrastructure services and environment degradation. Istanbul also faces an unprecedented increase in the probability of the occurrence of a large earthquake, which is 65% over the next 30 years. The inevitability of such an event – of a magnitude between M6.0 and M7.5 – requires a comprehensive approach that addresses all engineering, legal, institutional, urban and financial requirements in risk mitigation and disaster management in the Istanbul Metropolitan Area.[1]

The Building Code in Turkey was updated in 1998 to include modern earthquake provisions. However, weaknesses in construction, which were exposed in the 1999 Marmara earthquake, revealed that compliance with the intent of the code was often poor and the effectiveness of the code enforcement insufficient. Thus, legislation was enacted in April 2000 to enforce mandatory design checking and construction inspection of all buildings by government-licensed private supervision firms. For new buildings, this supervision aims to ensure compliance with earthquake-resistant design codes and nominal construction quality standards. Furthermore, in June 2000, a professional qualification expert system under certification by chambers of civil engineers and architects was established. Legal activities are still underway to enhance professional training and professional liability insurance, and to involve professionals in the official inspection and production process.

Physical impact of the 1999 Kocaeli earthquake on school buildings

Although the 1999 Kocaeli earthquake of magnitude M7.6 damaged a considerable number of primary and secondary schools in the earthquake-affected region, the performance of school buildings was on average much better than for the general building stock. A total of 22 elementary and 21 secondary schools were damaged beyond repair. Another 267 elementary and 114 secondary schools reported minor to moderate damage. In Istanbul, a total of 820 schools were reportedly affected. However, following detailed damage assessment by teams of engineers and Ministry of Education provincial authorities, it was found that 689 schools had been only slightly damaged and could be repaired quickly, without

causing any educational disruption. Educational activities were temporarily terminated in the remaining 131 schools. Among these, 13 schools were found to be heavily damaged and were replaced with new seismically safer schools. Of the remaining 118 schools, 59 were repaired, 37 were strengthened and 22 were demolished (and reconstructed) due to the high cost of foundation rehabilitation. The following rough prioritisation criteria were used for the repair and rehabilitation of these damaged schools:

- Boarding schools and facilities that provide accommodation received highest priority.
- Schools located in the 12 provinces with the highest risk zones – Avcılar, Bagcılar, Bakırkoy, Buyukçekmece, Kadıkoy, Kartal, Kucukcekmece, Maltepe, Pendik, Silivri, Tuzla and Zeytinburnu – were given high priority. Schools situated close to Marmara Sea, which is on the fault line, were also prioritised.

Costs for rehabilitating Istanbul schools

In Istanbul, due to the certainty of a major earthquake occurring, it was necessary to assess the seismic vulnerability of existing school buildings and to develop a project plan to facilitate their technical inspection, strengthening or reconstruction. During the initial phase of the project, the existing data on school building stock in Istanbul (Figure 13.1) was improved by collecting additional information on the year of construction, number of floors, total construction area, availability of design projects, and the geological and soil condition of the region. Special attention was paid to the inventory of school buildings that pre-date the 1998 Building Code. This is summarised in Table 13.1.

Table 13.1. A general overview of school building stock in Istanbul

	2003		Pre-1998 code		Already retro-fitted	Already rebuilt	To be retrofitted according to 1998 code	Post-1998 code
School type	No. of schools	No. of buildings	No. of schools	No. of buildings	No. of buildings	No. of buildings	No. of buildings	No. of buildings
Primary (ages 6-14)	1 329	1 692	1 028	1 305	24	27	1 254	387
Secondary (ages 14-17)	402	674	362	603	14	8	581	71
Other	133	138	31	28	2	0	26	112
Total	1 864	2 504	1 421	1936	40	35	1 861	570

The total cost of the project, including design and construction, was estimated at approximately USD 320 million. The computations (Table 13.2) are based on the total construction area of the buildings that pre-date the Code.

 © OECD 2004

Figure 13.1. School building stock in Istanbul overlain on Code Hazard Map, with 50% probability of exceedance in 50 years

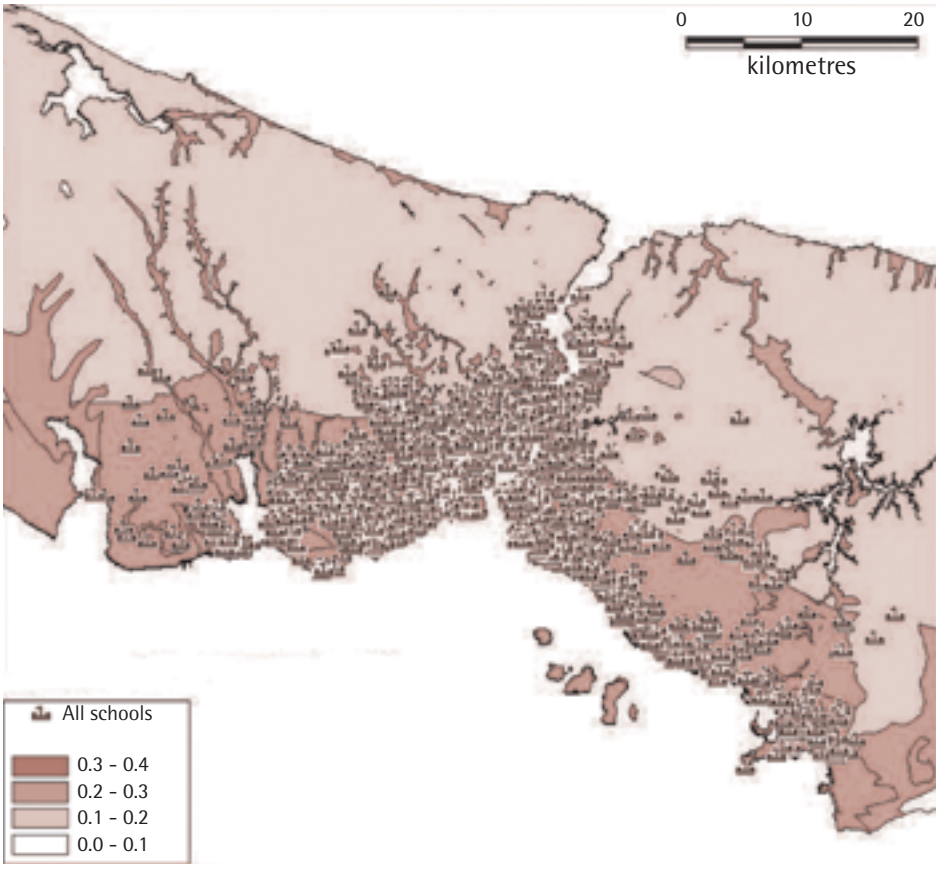


Table 13.2. Estimated strengthening cost of school buildings in Istanbul in 2003

(P = USD 4/m2; G = USD 200/m2; USD 1 = TL 1 500 000)

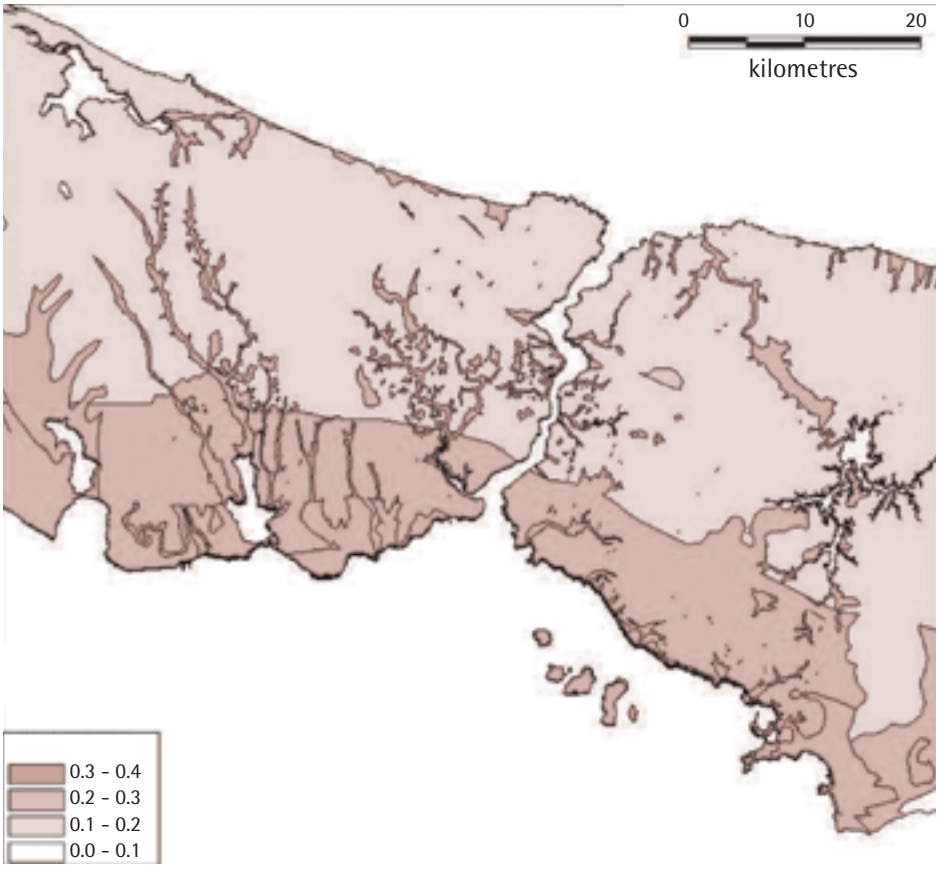
	Total area (m²)	Project cost (USD)	Construction cost (USD)	Total cost (USD)
School type	A	B = (P) x (A)	C = 0.4 x (G) x (A)	(B) + (C)
Primary (ages 6–14)	2 130 000	8 520 000	170 400 000	178 920 000
Secondary (ages 14–17)	1 663 000	6 652 000	133 004 000	139 656 000
Total	3 793 000	15 172 000	303 404 000	318 576 000

Current seismic rehabilitation practice used in Turkey

At present, any repair or rehabilitation work should follow the requirements of the 1998 Earthquake Code, which is normally used for new buildings. According to the provisions of the 1998 Code, the performance of school buildings is improved through the use of *I*, the importance factor. Earthquake hazard is expressed in a more general sense as earthquake zones, essentially based on probabilistic hazard assessment that corresponds to 10% probability of occurrence in 50 years. The probability of a damaging earthquake occurring was increased because of stress migration after the 1999 earthquake and also due to non-Poissonian characteristics of the North Anatolian Fault.

The expected earthquake performance of school buildings in Istanbul is "immediate occupancy", which is an enhanced rehabilitation objective described in FEMA 356 for earthquakes that have a high probability of occurrence (about 50%) during the economic life of the school (about

Figure 13.2. Earthquake hazard map for Istanbul, with 50% probability of exceedance in 50 years

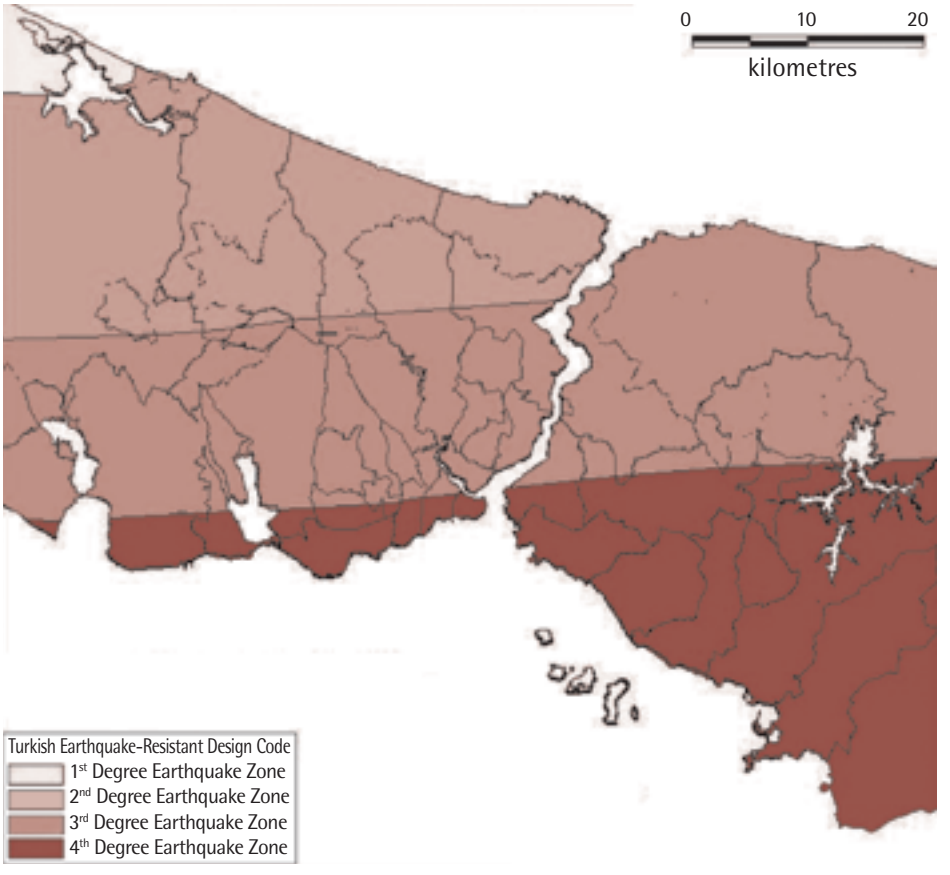


© OECD 2004

50 years). It should be noted that with this earthquake exposure, the school building should perform almost linearly with a Seismic Load Reduction Factor of Ra(T) less than or equal to 1.5. Erdik *et al.* (2004) have prepared an earthquake map for Istanbul that corresponds to 50% probability of occurrence in 50 years (Figure 13.2) using sophisticated state-of-the-art techniques. Hazard information is provided in terms of peak ground accelerations at 0.2 s and 1 s periods. Figure 13.3 presents the seismic hazard zoning map currently used for the retrofit design of school buildings.

To illustrate the application of the present code using this approach, in Bakırkoy, a district in a first-degree earthquake zone with Ao = 0.4, the spectrum co-efficient is S(T) = 2.5 (Figure 13.4). For a reinforced-concrete frame structure with shear walls, the code allows the use of a seismic load reduction factor Ra(T) = 7. The importance factor for schools is specified as *I* = 1.4 in the code. Therefore, the spectral acceleration co-efficient A(T) specified in the code is A(T) = Ao. I. S(T) or A(T) = (0.4) (1.4) (2.5) = 1.4, and

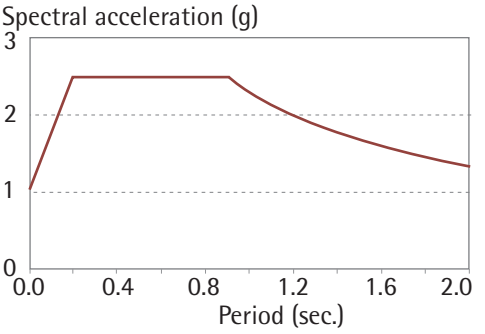
Figure 13.3. 1998 Code Hazard Map



the corresponding total equivalent seismic load Vt = W.A(T)/Ra(T) or Vt = (1.4) / 7 * W or Vt = 0.2 * W, where *W* is the total weight of the structure.

If a similar computation is carried out, but instead using the spectrum developed for the same district corresponding to an earthquake hazard of 50% probability of occurrence in 50 years, with a spectral acceleration of 0.78 (Figure 13.5): Ra(T) = 1.5, the total equivalent seismic load becomes Vt = (0. 78) / 1.5 * W or Vt = 0.52 * W.

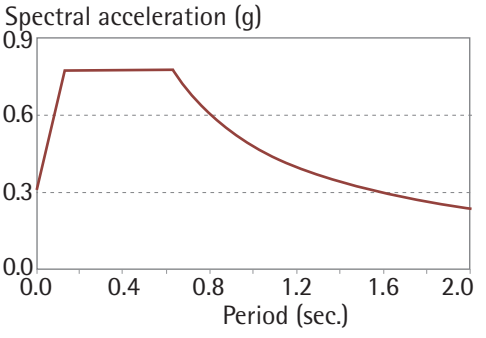
Figure 13.4. Site-specific spectrum for Bakirkoy (1998 Code)



Conclusion

As the overall school rehabilitation project budget is high and financial resources are limited, a comprehensive cash retrofitting should be completed with minimum disruption and temporary relocation of on-going educational activities. Furthermore, *advanced prioritisation and cost effective and rational rehabilitation methodologies* should be used. The FEMA 356 Pre-standard serves this purpose until a similar standard or guideline is developed that is specific to Turkey.

Figure 13.5. Site-specific spectrum for Bakirkoy, with 50% probability of exceedence in 50 years



For the rehabilitation of schools in Istanbul, the minimum performance level of school buildings is "*immediate occupancy*", with an earthquake hazard of 50% probability of occurrence in 50 years.

Additional retrofit design approaches (base isolation, energy absorption, etc.) – taking into account cost, building use, architectural value and location criteria – should be introduced.

The concept of cost-benefit analysis in the design process of retrofitting should be established, in addition to more effective design-review mechanisms for retrofitted structures.

© OECD 2004

Notes

1. Erdik, M. (2002), "Rehabilitation and Construction Activities after the 1999 Kocaeli and Duzce Earthquakes", Working Paper.

American Red Cross and Boğaziçi University (ARC-BU) (2002), *Earthquake Risk Assessment for Istanbul Metropolitan Area*, Kandilli Observatory and Earthquake Research Institute, Istanbul.

Istanbul Metropolitan Municipality (IMM) (2003), *Earthquake Masterplan for Istanbul*. IMM, Istanbul.

Japan International Co-operation Agency and Istanbul Metropolitan Municipality (JICA-IMM) (2002), *The Study on a Disaster Prevention/Mitigation Basic Plan in Istanbul Including Seismic Microzonation in the Republic of Turkey*, IMM, Istanbul.

Republic of Turkey Ministry of National Education (MEB) (2003), *Seismic Risk Mitigation for School Buildings in Istanbul*, MEB, Istanbul (in Turkish).

World Bank (2002), *Observations on Earthquake Risk and Engineering Practices in Istanbul,* World Bank, Washington, D.C.

Reference

Erdik, M., *et al.* (forthcoming), *Soil Dynamics and Earthquake Engineering*.

PART IV

IDENTIFYING STRATEGIES AND PROGRAMMES FOR IMPROVING SCHOOL SEISMIC SAFETY

Introduction

The practical obstacles to promoting school seismic safety concepts and principles are numerous, and the stories recounted in this report demonstrate that in many cases there are more impediments than incentives to achieving a culture of safety. In developing countries, implementing a strategic programme is further complicated by such factors as lack of local expertise, shortage of finances, disagreement between external experts and scarcity of materials. In a European context, while the material, financial and human resources exist to establish a number of programmes for screening, evaluating and strengthening existing buildings in earthquake-prone countries, much greater regulatory effort is required in all countries to significantly reduce the highest risks to public buildings.

In this section, the experts were invited to describe the application of known seismic safety concepts and principles to existing strategies and programmes for school safety, and to consider the most effective ways to encourage, facilitate and assess progress made towards seismic safety goals. The experts were also asked how best to make countries and political leaders recognise that it is in their interest to establish programmes that build seismically-resistant schools. Awareness-raising through the dissemination of knowledge and data regarding school seismic safety using both formal and informal channels plays an important role in empowering and motivating individuals for change. Examples given here of formal channels include a National Programme on Earthquake Engineering Education in India (see Jain) and establishing criteria and procedures to compare the vulnerability national building typologies in Italy (see Cosentino). Informal channels include delivering lectures to school communities on seismic resistance improvements to school buildings and simply distributing leaflets on better construction practices to workers at construction sites.

Seismic strengethening

In some cases, improving the earthquake resistance of a school, particularly a new school, can be a simple and inexpensive procedure. For many existing schools, however, the financial and technical implications of seismic strengthening – by retrofitting or other means – are considerable and can require a long-term commitment. In all programmes, decisions must be made concerning the most appropriate and effective strengthening action. In order to consider all factors, Smyth *et al.* applied a cost-benefit analysis to a hypothetical school structure, taking into consideration the costs of retrofitting for each damage state, building replacement cost and the cost of loss of human lives. Similarly, Spence estimated the costs of strengthening the entire school building stock in six European Union countries with a significant seismic risk. Both studies illustrate that earthquake strengthening of school building stock in many countries is technically and financially feasible, and that concerted efforts are required on the part of decision-makers to ensure that the necessary measures are carried out.

 © OECD 2004

CHAPTER

14

A BRIEF REVIEW OF SCHOOL TYPOLOGIES IN ITALY: SPECIFIC VULNERABILITY AND POSSIBLE STRATEGIES FOR SEISMIC RETROFITTING

Nicola Cosentino and Giovanni Manieri

Emilia-Romagna Regional Administration

Andrea Benedetti

DISTART, University of Bologna, Italy

Abstract: This paper outlines the four main distributive typologies of school buildings in Italy, which are strongly characterised by their periods of construction: stand-alone masonry buildings, reinforced-concrete framed structures, university buildings and historical or monumental buildings. The seismic reliability of each typology – which is generally low for all school buildings in Italy – is described, and some possible retrofit strategies are outlined. A brief note about the cost-benefit balance is presented based on the experience of the Emilia-Romagna Regional Administration, which completed a vulnerability analysis of 2 700 strategic buildings, including schools, between 1989 and 1990.

School typologies in Italy

The typologies of school buildings in Italy are strongly characterised by the construction period and the evolution of the teaching system. In particular, four main distributive typologies can be recognised.

- *Stand-alone masonry buildings* (Figure 14.1) have timber roofs and two to three storeys, with a rectangular plan and regularly spaced windows. Most of these buildings constructed between 1900 and 1940 are primary schools and are owned by the city administration. The rooms are approximately 3.5 m tall, placed along two rows on the facade and connected by a central isle. Foundations are typically made of non-reinforced concrete beams aligned under the main walls. Floors were originally constructed using steel beams and hollow brick units, but due to schools' maintenance or widening, it is possible to find different constructions, often in the same building. The roofs, in general, do not present a rigid diaphragm and are composed of light timber elements. The mechanical properties of materials, though not very good, are usually similar in the different buildings of this category.

Figure 14.1. A stand-alone masonry school building in Ferrara County

Figure 14.2. A reinforced-concrete framed school building in Bologna

- *Reinforced-concrete framed structures* (Figure 14.2), built after 1950, mainly serve as secondary schools and are owned by the county or regional administrations. They are completed with in-filled masonry walls or prefabricated panels. Following "rational

© OECD 2004

architecture", these buildings are irregular in plan and elevation and usually have strip windows. Often the first floor is an open space. A wide range of details and quality of materials can be found in these structures as construction has been improved from 1950 to the present. Technical documentation is frequently lacking for these buildings, even for those recently constructed.

Figure 14.3. The Faculty of Engineering at the University of Bologna

- *University buildings* (Figure 14.3) have been constructed over different time periods and are defined by their complex organisation of space. These structures vary greatly in size and are usually owned by the university administration. These buildings are, in general, stand-alone constructions, although they often comprise several connected blocks.

- *Historical or monumental buildings* (Figure 14.4) were built before 1900 and can house a number of educational activities, from elementary school to university, or cultural activities in general. These buildings normally form part of a more complex urban environment and have a strong structural interaction with neighbouring buildings, often allowing for easy escape in case of an earthquake. The structural element typology and material properties range widely as a result of centuries of architectural evolution and recent maintenance. In this sense, the Cultural Heritage Ministry plays an important role in maintaining the original style of the buildings.

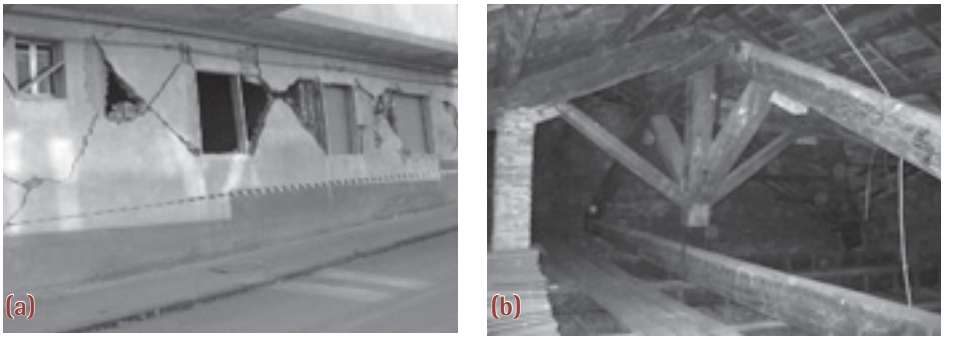
Figure 14.4. The interior court of the San Giovanni in Monte building of the University of Bologna

Characteristic seismic vulnerability of school typologies

The seismic reliability of all of these buildings is generally low, not only due to the lack of seismic code requirements in most areas of Italy, but also as a consequence of the low design sensitivity to protection against earthquake effects. Moreover, peculiar deficiencies can be seen in each of the four typologies.

- *Stand-alone masonry buildings* are characterised by a very low ductility, tall and large-span rooms that give rise to buckling sensitivity, high shear stress peaks, and flexible floor slabs and roofs. One of the main vulnerability factors is the numerous and wide window openings, which introduces a stress amplification into the reduced width shear-resistant panels. The experimental evidence of damage in recent earthquakes shows that these panels fail in shear with a brittle behaviour (Figure 14.5(a)). Other vulnerability factors are:
  - Out-of-plane instability due to the large-span rooms that have no adequate wall restraint.
  - Perimeter wall failure due to roof element pushing actions (Figure 14.5(b)).
  - Failure of the links at orthogonal wall intersections, often weak due to construction sequences.
  - Weak connections between walls and slabs.
  - Poor quality materials.
- *Reinforced-concrete framed structures* do not adhere to the detailed rules presently included in seismic codes. In addition, materials used between 1950 and 1970 were low-grade, and the architectural shapes developed after 1970 were irregular, leading to poor seismic behaviour. The combination of low column ductility due to the inadequate use of stirrups, and high shear forces usually determined by torsional effects, resulted in brittle collapse susceptibility. In this typology, the in-filled walls play an important role in global resistance and energy dissipation, the effect of which is significantly reduced by strip windows in school buildings.

Figure 14.5. (a) Typical seismic damage and vulnerability (absence of a rigid plane at the roof level) of a masonry building, showing the failure of panels in shear with brittle behaviour (b) Perimeter wall failure due to roof element pushing actions



© OECD 2004

- *University buildings,* also rendered more vulnerable due to building age, are characterised by large spaces and window openings. The complexity of space distribution increases the seismic vulnerability. In addition, equipment used in some laboratories, such as chemical laboratories, can lead to dangerous secondary effects in the presence of large displacements (even without structural collapse), inducing leakage of vessels and pipelines.

- *Historical or monumental buildings* are often highly seismically vulnerable. Retrofitting can present problems due to the historical value of the buildings and/or the urban context. The most common vulnerability issues concern the weak stiffness of timber floors, composite rubble walls, poor level of material maintenance, structural form alterations, unrestrained roof planes and foundation settlements.

Retrofit strategies

Possible retrofit strategies for the four building typologies are presented below.

- *Stand-alone masonry buildings* can be suitably retrofitted by using external cantilever walls or bracing frames at a relatively small cost. It is necessary to explore the architectural feasibility of adding external structures, selecting the most appropriate shape. Floor slab stiffening is generally required and can usually be achieved by grouting a concrete layer above the slab or adding a steel truss beneath the slab. Usually, safety codes require a global structural retrofit. However, a different strategy could involve introducing very stiff external elements that carry all the seismic forces.

- *Reinforced-concrete framed structures* require both reducing irregularities and correcting material and detailing problems. One of the most promising strategies is the use of composite fibre-reinforced materials (FRP) to improve both the strength and ductility of the frames. In addition, the shear stiffness and ductility can be increased by using bracing systems eventually coupled with dissipative devices. An additional foundation system is usually required for these added stiffening/dissipative elements.

- The general rules that apply to retrofitting *university buildings* are similar to those for the previous two building typologies, although these buildings suffer from amplification due to large structural spans. To reduce the vulnerability of laboratories, a fully elastic seismic strategy is required in order to avoid large displacements caused by a ductility-based design.

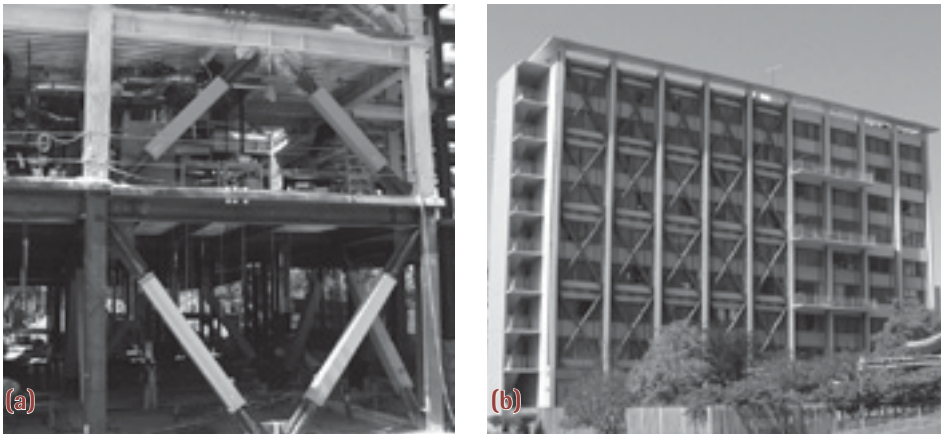
- *Historical or monumental buildings* do not allow for the definition of a general strategy, and it is perhaps necessary to accept a lower seismic protection level for these structures. In the past, at least in Italy, the codes did not require any quantitative evaluation of the seismic improvement produced by the retrofit activity when the structural behaviour was not strongly modified. Nevertheless, experience has shown that such retrofits are not always successful. Hence, guidelines should provide some information concerning experimental investigations and evaluation techniques to quantitatively estimate the effectiveness of the planned works.

Figure 14.6. (a) Retrofit work, Berkeley University Campus (b) Barrows Hall, Berkeley University Campus

Some interesting pilot seismic retrofits, employing a wide range of possible techniques transferable to school buildings, have been carried out at the Berkeley University Campus (United States). The following examples are taken from *www.nisee.berkeley.edu*.

- Figure 14.6(a) shows the construction of new concrete footings and external shear walls, which are attached to existing walls on a new base at Berkeley University Campus.
- Barrows Hall, an eight-storey reinforced-concrete frame and wall building that was rated seismically "poor", was one of the first buildings to be retrofitted in a recent campus-wide initiative (Figure 14.6(b)). The retrofit consisted of new anchored reinforced-concrete walls and foundations, which wrap around each end of the building and are

Figure 14.7. (a) New central dining and office facility on Bowditch Street, Berkeley University Campus (b) Student residences, Berkeley University Campus



© OECD 2004

linked by collector beams extending along the north and south faces of the building on the upper floors. New construction was complicated by requirements to keep the building in full use during work and to preserve window arrangements.

- Figure 14.7(a) presents a new four-storey central dining and office facility on Bowditch Street. This steel-frame building used unbounded braced or "buckling restrained braced frame" (BRBF).
- The student residences shown in Figure 14.7(b) comprise an externally retrofitted, concentrically braced steel frame and shear wall. The older reinforced-concrete framed building is now rated seismically "good".
- The building shown in Figure 14.8(a) is located close to surface tracings of the Hayward Fault. It was rated seismically "very poor" before the retrofit. The reconstruction used high-damping rubber base isolation bearings and preserved most of the building's original details.
- South Hall (Figure 14.8(b)), designed by David Farquharson, is a fine example of late Victorian architecture. South Hall was constructed between 1870 and 1873 using fired brick made of local Bay clay. The original design incorporated a bond-iron framework on granite foundations and some diagonal bracings for earthquake resistance. Interior walls comprise unreinforced masonry. In the 1980s, the building was declared hazardous and a "centre coring" reconstruction scheme was developed to preserve historic wall surfaces and ceilings.

Figure 14.8. (a) Exterior view of excavation, showing temporary supports and scale of the project, Berkeley University Campus (b) Oldest building still standing on the campus, South Hall, Berkeley University Campus

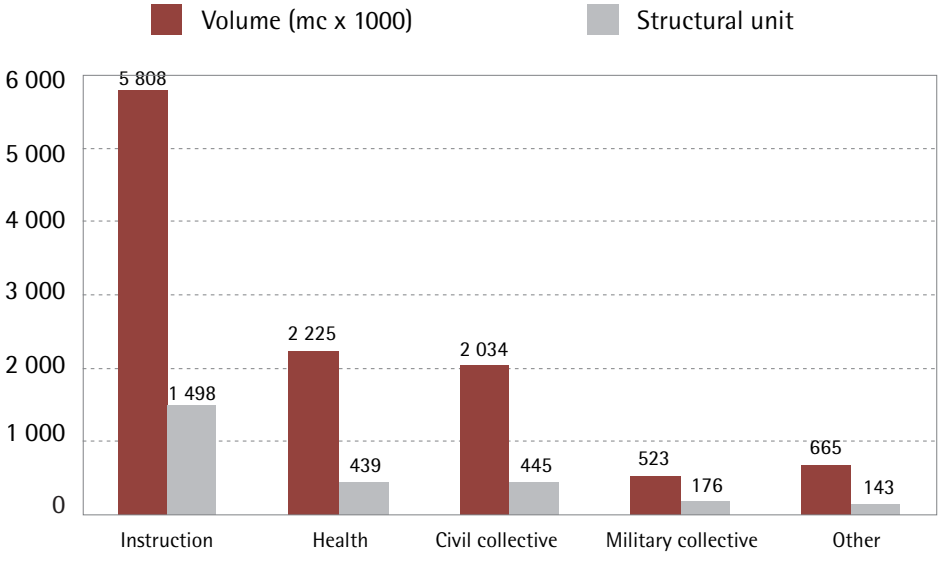
A public administration perspective: The Emilia-Romagna experience

The public administration is usually faced with two challenges related to earthquakes: first, managing a post-earthquake emergency; and second, reducing the seismic risk level of buildings for the purposes of prevention. The reduction of the seismic risk level must also be the main goal during the post-earthquake "reconstruction", after the first emergency phase. In both cases, the first task is to prepare a "priority list" and a retrofit cost programme in order to adequately assign the economic resources required.

In the post-earthquake case, the problem is partially simplified. A post-earthquake damage analysis can provide additional information to evaluate surviving buildings' seismic vulnerability. However, in a purely preventive programme, the vulnerability analysis is usually more difficult as it must take into account the risk related to building use.

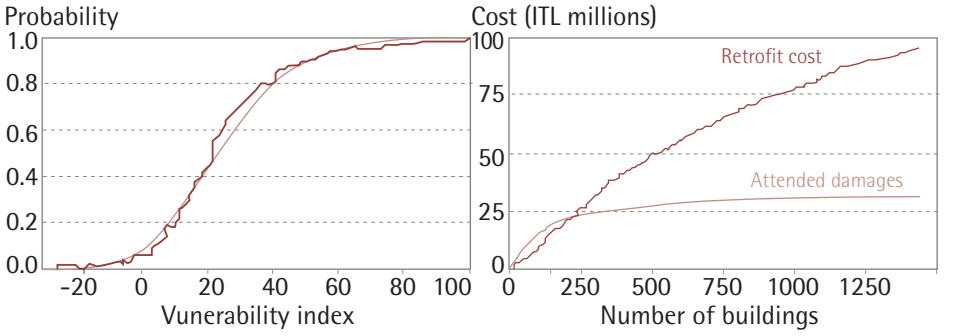
The experience of the Emilia-Romagna Regional Administration (see *www.regione.emilia-romagna.it/geologia/Sismic.htm*) began in 1986 in 12 municipalities located in Emilia Appennino. It continued between 1989 and 1990 with the completion of a vulnerability investigation of about 2 700 strategic buildings – hospitals, schools and town halls – in 76 municipalities that were classified as seismically prone in 1983 (Figure 14.9). Currently, the regional administration is preparing to update and extend this analysis. A substantial agreement between all Italian regional administrations was reached recently concerning the necessity of having a common simplified but validated method to select buildings and create a priority list for seismic retrofit.

Figure 14.9. Vulnerability analysis from 1989 to 1990



© OECD 2004

Figure 14.10. (a) Distribution of the buildings' vulnerability index (b) Cumulative curves of attended damages and preventive seismic retrofit costs



In the course of these investigations, vulnerability was estimated by means of fragility curves, which relate the damage index *d(y,V)*, expressed as a percentage of the building value, to the vulnerability index *V* and the peak ground acceleration *y*. y_i and y_c are the first damage and the collapse accelerations, respectively. Details on the procedure and the parameters used in the numerical models can be found at *www.gndt.ingv.it → Strumenti → Schede di Rilevamento*. The user manuals can be downloaded at *www.regione.marche.it/terremoto/VulnEntry.htm*.

$$
d(y,V) = \begin{cases} 0 & \text{for } y \le y_i \\ (y - y_i) / (y_c - y_i) & \text{for } y_i < y < y_c \\ 1 & \text{for } y_c \le y \end{cases}
$$

The first result of this analysis is a curve showing the cumulative distribution of the examined buildings it terms of its vulnerability (Figure 14.10(a)). The attribution of a "cost model" to each building typology allows for the definition of an "attended damage" vs. "cost" curve. Figure 14.10(b) shows the result of applying this procedure to school buildings in Emilia-Romagna. It can be seen that a significant percentage of buildings can be retrofitted. In the model, indirect damages and "human damages" – that is the seismic exposure – have not been taken into account: a corrected damage curve can be obtained whenever these factors are considered and the equilibrium point moves up.

Some aspects could be improved by applying this procedure. A joint effort between interested countries – in developing European guidelines for example – could be profitable in this sense. In particular, the following points can be elucidated from our experience:

- The vulnerability evaluation should take into account construction details, which are often the source of failures.
- The criteria and the procedure used to compare the vulnerability of different building typologies should be better clarified.
- Indirect damages should be defined and evaluated.

- The seismic exposure – especially in terms of human resources – should be considered. Since this is typically a "political" task, the technical role is to define a set of parameters to facilitate political decisions.

Evidently, economic interests can create conflicts between different administrations when applying a risk evaluation procedure: the role of a control authority is important.

Finally, it is clear that the economic effort involved in seismic retrofitting is huge. Moreover, after a careful reliability analysis, the cost-benefit evaluation could suggest strategies other than retrofitting. A radical decision could be the demolition of some building parts or floors – to reduce masses and/or to achieve a greater regularity – or, an extreme solution, the restriction of school activities.

 © OECD 2004

CHAPTER

15

IMPLEMENTING SCHOOL SEISMIC SAFETY PROGRAMMES IN DEVELOPING COUNTRIES

Sudhir K. Jain

Indian Institute of Technology, India

Abstract: This paper discusses some of the challenges of implementing successful seismic safety initiatives in developing countries. Two Indian initiatives are presented – the National Programme on Earthquake Engineering Education and licensing of engineers – that can provide lessons for planning school seismic safety programmes in developing countries. A number of strategy issues are discussed in the light of these programmes, which focus on the need for having realistic expectations, giving priority to areas and components that are likely to succeed, focusing on new buildings first and retrofitting later, considering the broader context of education provision and infrastructure, promoting effective communication and developing local leadership.

Introduction

It has long been recognised that schools require special attention with regard to seismic safety. Spectacular collapses of a number of school buildings in the 1933 Long Beach earthquake in California (M6.3, with a maximum MMI of IX) resulted in the implementation of the Field Act by the state of California, which required special seismic safety provisions in all new public schools. This law not only required good seismic design features, but also superior construction supervision (Steinbrugge, 1970).

During the 2001 Bhuj earthquake in India (M7.7, with a maximum MMI of X), 971 students and 31 teachers died, and 1 051 students and 95 teachers were injured. Fortunately, this earthquake occurred on the Republic Day holiday, when classrooms were empty. Another tragic event took place when about 300 schoolchildren marching in the Republic Day procession in a narrow lane in the town of Anjar were killed when buildings on both sides collapsed on them (Rai, Prasad and Jain, 2002).

In addition to protecting lives during damaging earthquakes, seismic safety of schools has two important post-earthquake implications:

- School buildings can be used to provide temporary shelter.
- To restore normalcy to the lives of the affected population, schools should be re-opened soon after an earthquake disaster.

Challenges for developing countries

What is a developing country? In the opinion of the author, the difference between a developed and developing country is not the availability of natural resources, but rather the quality of governance and utilisation of available resources. Thus, any seismic safety initiative has to factor in the issues of governance. The best-laid plans will not work without the consideration of the country's socio-political context.

In addition to issues of governance, developing countries offer several major challenges to any programme aimed at school safety. Some countries are still grappling with the task of sending every child to school. India, for example, recognises that basic education is the right of every child, but this goal is still far from being achieved; numerous schools have too few teachers, the building infrastructure of most publicly-owned schools leaves much

 © OECD 2004

to be desired and many schools are run in temporary shelters. In such a scenario, how does one argue with a well-meaning administrator about the need for seismic retrofitting of schools when the administrator is frustrated at not being able to provide shelter for children from the rain?

Developing countries lack mechanisms to effectively ensure that new constructions comply with all safety regulations, not only those that are earthquake-related. India on the one hand has design and construction firms that can compete internationally; on the other hand the country has no system to control poor quality design and construction of ordinary buildings.

In India, awareness about seismic threat – even in seismically active areas – is poor. In a workshop in Ahmedabad several months ago, city officials in two cities in seismic zones IV and V (the highest zone is V) admitted publicly that prior to the workshop they were unaware of the seismic threat to their own cities. Finally, the professionals connected with the construction industry (structural engineers, architects, construction engineers, etc.) are generally not competent in the seismic safety-related aspects of their respective professions.

Two Indian experiences

This section describes two experiences in India that can provide some lessons for planning school seismic safety programmes in developing countries.

National Programme on Earthquake Engineering Education

After the 2001 earthquake, India's Ministry of Human Resource Development launched a comprehensive National Programme on Earthquake Engineering Education (NPEEE) (*www.nicee.org/npeee*). In the project, eight premier institutes of technology provide training for teachers from colleges of engineering, architecture and polytechnics. Components of the project include short-term (one to four weeks) and medium-term (one semester) training programmes for faculty members; international exposure for faculty members; development of resource materials and teaching aids; development of library and laboratory resources; and organisation of conferences and workshops. The programme is open to all recognised engineering colleges/polytechnics and schools of architecture – both public and private – with related academic degrees or diploma programmes.

The programme commenced in April 2003, initially for three years, with a budget of about INR 137.6 million (about USD 3 million). This amount does not include institutional overheads, salaries, buildings or other infrastructure as the eight premier institutes are publicly funded.

- About 13 short courses, each of one or two weeks duration, have been conducted for faculty member to date.
- A group of 17 faculty members from around the country have completed a one-semester certificate programme at IIT Kanpur in Earthquake Engineering, while another group of 22 faculty members are completing a similar programme at IIT Roorkee.

- Several workshops have been held to develop curriculum.
- Some progress has been made towards modifying curricula to include adequate coverage of earthquake engineering.

The programme, within its first year, has received tremendous support from administrators and others. The components that are the key to its success include:

- The entire project is totally transparent in terms of finances and activities. The Programme Implementation Plan (PIP) – which outlines budget and norms for various activities, checks and balances – is available on the Web site and has been distributed by e-mail and post to college teachers and others.
- All concerned colleges are included regardless of their source of funding.
- The programme is kept at a manageable size in terms of human resources and subject area. For example, it focuses on technical education, which does not include support for research or training programmes for professional engineers. No attempt is made to solve the entire problem in the short three-year period; it is expected that such a programme must operate for ten to 20 years to fully tackle the problem.
- The programme is managed by a young group of employees, who over the years have developed a good rapport and understanding.

Licensing of engineers

In the past, India has not had a system for competence-based licensing of structural and other engineers. In recent years, it has been understood that significant opportunities will be lost without a proper licensing system. The Engineering Council of India (ECI) was formed after the Gujarat earthquake as an umbrella organisation for a number of professional bodies. It aims to develop a comprehensive licensing system for different disciplines of engineering. However, efforts are being made to simultaneously license all engineering disciplines (civil, electrical, aerospace, etc.), although clearly, there is a greater need to license disciplines such as civil or structural engineering (aerospace and automobile industries have enough checks and balances to ensure competence of their engineers).

More recently, the All India Council for Technical Education (AICTE) declared its intention to initiate the licensing of engineers. The AICTE is primarily charged with regulating the technical education sector, but it is not clear if this is the appropriate body for licensing engineers. Moreover, it is a duplication of efforts as both the AICTE and the ECI try to achieve the same objective.

 © OECD 2004

Strategy issues

In view of the above discussion, the following key issues of strategy emerge.

Having realistic expectations

Making schools earthquake safe is a lengthy process, and the problem cannot be eliminated in a short period of time. The school seismic safety effort in a developing country should be based on what can be achieved in the short and medium term, rather than what is needed in the long term. Small activities enable concerned stakeholders to gain confidence and to learn to work together for a common cause, in preparation for involvement in larger initiatives. When discussing a new initiative, an administrator tends to prefer that the entire problem be tackled at once. For an administrator, the effort is the same for managing a grant of USD 100 000 or USD 10 million; hence, there is pressure to develop a comprehensive package that includes everything, regardless of practicability, which leads to unrealistic expectations. The NPEEE was launched with a one-day workshop in April 2003 on "Earthquake Engineering Curriculum". A wide cross-section of participants attended, including more than 100 faculty members and professional engineers. Most speakers chose to address what needs to be done to ensure the safety of buildings and what should have been, and is not, included in this programme. It was clear that in an environment where everyone had been talking about the problem but nothing was being done, the participants saw a new hope in the form of this NPEEE project, and they expected it to solve the entire problem. In order to ensure that this project is not negatively affected by unduly large expectations, the project's goals should be commensurate with the available management and technical manpower capabilities.

Giving priority to regions and components that are likely to succeed

There is a wide variety of opinions and attitudes in different cities, regions, states or countries, depending on the individual or entity responsible for managing the earthquake safety project. Similarly, the manpower available for its implementation can vary greatly. This situation has two implications.

- A programme for a city, regions, state or country should ideally be tailor-made, bearing in mind what is likely to succeed. If the entire programme requires five components, and it appears that only three of them can be effectively implemented, it is best to omit the other two, even though they may be important. As the system successfully implements or starts to implement the three attainable components, capacity and motivation to take up the remaining two may improve and it may become possible to undertake them at a later stage.

- Choosing a city, region, state or country in which to implement a school safety programme should depend more on the attitude of leadership and the availability of resource manpower, than on the seismic risk. For example, the states in the north-eastern part of India are far more prone to earthquakes than most other parts of the country. However, if a state with lower risk can provide better opportunities for a successful programme, it may be better to give priority to that state. As experience and expertise is gained on

what works and what does not, it may be easier in future to start a programme in one or more of the north-eastern states. To take another example, in India, the Central Board of Secondary Education (CBSE) oversees a large number of schools in the country. It should be possible to put in place a system that will ensure that every new building in every CBSE school complies with seismic safety standards in letter and spirit.

Focusing first on new buildings, then on retrofitting

Retrofitting projects can be effective tools in drawing attention – both of the public and of decision-makers – to seismic safety; however every day, developing countries are constructing new but unsafe buildings, which will be candidates for future retrofitting. The resources available in terms of manpower, money and management skills are limited, but it is best to focus them first on setting up systems to ensure that all new constructions are seismically safe. Once there is a level of confidence in new constructions, efforts can be directed towards seismic retrofitting programmes. This is particularly important for school safety in developing countries, which as part of the development agenda, are currently investing heavily in new schools. For example, in April 1999 and December 2000, the government of Gujarat built about 6 000 new schools across the state using pre-cast technology; about three-quarters of these either collapsed or were seriously damaged during the 2001 earthquake (Rai, Prasad and Jain, 2002).

Considering education and construction issues

A school seismic safety programme must consider the overall school education environment and the construction scenario of the region.

Hence, it is important that some attention be paid to the issues of good education (*e.g.* "Are there teachers?", "Do schools have adequate classrooms and blackboards?") and to the entire construction industry (*e.g.* regulatory mechanisms, capacity building for professional engineers associated with schools, quality training for masons).

Improving communication

An effective communication system is essential to ensure the success of a school seismic safety programme. A programme should be transparent and complete details should be provided on the Internet, including financial provisions. While school safety initiatives have been undertaken in the last ten years in a number of developing countries, information and details of these initiatives are unfortunately disseminated only through presentations in international workshops. All resource materials developed for such initiatives should be placed on a common Web site, and public domain dissemination of information should be a requirement of funding agencies.

A good example of using the Internet effectively is the World Housing Encyclopaedia project of the Earthquake Engineering Research Institute (EERI) in the United States and of the International Association for Earthquake Engineering (IAEE) (*www.world-housing.net*). This Web site compiles information on different types of housing across the world. It has achieved a good amount of success with rather limited funds. It should be possible to develop a similar site for school safety programmes.

 © OECD 2004

Developing local leadership

Outsiders are rarely able to effectively contribute single-handedly to safety programmes in developing countries. It is rare to find outside experts with a good understanding of the local situation who can work in developing countries for long periods of time. Hence, the best results are achieved when the problem is tackled by local experts, with outsiders providing a guiding role: developing local leadership is the key to success.

Closing remarks

Most of the remarks above could apply not only to school safety programmes but to any other seismic safety activities. However, since schools involve children – a hopeful, optimistic and enthusiastic community – this hope and enthusiasm is transferred to teachers. Students and teachers can have a strong influence over the seismic safety of their own schools. For example, if simple facts about earthquake risk and seismic safety are covered in the school curricula, more questions will be asked about the safety of the schools, putting pressure on the school management. Efforts are being made in this direction: recently, the Central Board for Secondary Education in India introduced the subject of natural disasters in class eight, and a textbook has been published.

Working in India for the last 20 years on capacity-building projects (*e.g.* Jain and Murty, 2003) has taught the author that grand plans do not often work, that it is best to embark on a project that can be managed with available resources, and that it is possible to increase the volume and size of operations only after the project has obtained credibility and confidence in the initial phase.

References

Jain, S.K. and C.V.R. Murty (2003), "Some Innovative Education and Outreach Projects in India for Earthquake Risk Reduction", *Seismological Research Letters*, Vol. 74, No. 5, pp. 545-551.

Rai, D.C., A.M. Prasad and S.K. Jain (2002), "Hospitals and Schools", in S.K. Jain, W.R. Lettis, C.V.R. Murty and J.P. Bardet (eds.), *2001 Bhuj, India Earthquake Reconnaissance Report, Earthquake Spectra*, Supplement A to Volume 18, Earthquake Engineering Research Institute, pp. 265-277.

Steinbrugge, K.V. (1970), "Earthquake Damage and Structural Performance in the United States", in R.L. Wiegel (ed.), *Earthquake Engineering*, Prentice-Hall, Inc., Englewood Cliffs.

CHAPTER

16

SUPPORTING LOCAL SEISMIC EXPERTS: EXPERIENCES IN NEPAL AND INDIA

Richard Sharpe

Beca Carter Hollings and Ferner, Ltd., New Zealand

Abstract: This paper discusses the development of local expertise in Nepal and India. The obstacles to the development of local expertise in Nepal are presented, in addition to the work of the National Society of Earthquake Technology, which has used local and international knowledge and experience to advance earthquake safety in Nepal. Concerning India, which has well-developed local networks of professionals in universities and the private sector, the case study of Bhuj Hospial in Gujurat is described.

Introduction

In every country, there are a small number of individuals who are very knowledgeable about the likelihood and consequences of earthquakes and who struggle to make people listen. Identifying these people is key to developing the *modus operandi* for providing external assistance to improve seismic safety within the country. These people often work in education or in civil service; they are rarely politicians at the national or municipal level. Those who are subject to political re-election, or who have many and changing responsibilities, may appear to be interested in promoting seismic safety; the reality is, however, that these people move on to other positions with other priorities and agendas.

Local expertise in Nepal

Local and international experts need to work together to empower communities to improve earthquake safety. Following the 1988 earthquake in Nepal, the United Nations Development Programme (UNDP) launched the Nepal National Building Code Development Project. The driving force behind the project was a senior civil servant from the Ministry of Housing and Urban Planning, who had the knowledge and ability within the government to promote the code and gain the support of international donors. The project's aim was to assess the seismic hazard and seismic risk of building construction in Nepal, including the development of earthquake design strategies.

Obstacles to developing local expertise

A number of obstacles to developing local expertise in Nepal can be identified.

- *Past lessons forgotten.* Nepal was struck by devastating earthquakes in 1934 and 1988. By 1998, the lessons of the 1934 earthquake had unfortunately been long forgotten. Many practices had deteriorated as new materials were introduced (*e.g.* reinforced concrete) without appropriate design and construction practices. In Kathmandu, for example, traditional Newari houses were built with pairs of vertical pegs in the roof rafters, which fixed the rafters to the support walls. This practice, largely discontinued, had the effect of mobilising the opposite walls to resist seismic loads generated by the roof. A decade ago in Nepal, high-strength non-ductile reinforcing steel replaced lower strength ductile steel in the market because steel manufacturers promoted it as providing more value for money. In effect, the safety net provided by ductile action – even in structures with no formal design – was eliminated.

- *Disagreement between experts.* Problems can arise when experts disagree with each other, and this often provides a justification for inaction. For example, a short time after the first seismic hazard map was published in Nepal in 1994 – an outcome of the UNDP code project – two organisations announced plans to undertake seismic microzonation of the Kathmandu Valley, without consulting the original developers of the hazard map. These organisations obtained different values of hazard and risk from the original developers.

- *Lack of empowerment of local experts.* In many cases, national experts have the technical knowledge to undertake project work. During the author's time in Nepal, this fact was regrettably ignored because the presence of a foreign "expert" was considered necessary to influence higher levels of government, which otherwise would have been difficult to achieve. Affirmation by the foreign expert of the local experts' technical competence improved the latter's credibility among the political and social hierarchy, further demonstrating a lack of regard for local experts.

- *Disregard for simple solutions.* In some cases, simple, inexpensive solutions can solve common problems. As in many countries, it is common practice in Nepal to bend hoop steel for reinforced-concrete columns, without using the hooks necessary to make the hoops effective in large earthquakes (this is similar to having the belt in one's trousers constantly undone). After failing to persuade the authorities to undertake a simple campaign of distributing leaflets on best practice to local construction sites, one of the national project team members decided to produce the leaflets privately, which he distributed from his motorcycle bag.

National Society of Earthquake Technology

In Nepal, the National Society of Earthquake Technology (NSET), a non-governmental organisation established in 1993, has used local and international knowledge and experience to significantly advance earthquake safety within the country, including implementing a pilot schools retrofit project (*www.nset.org.np*). Students, teachers, head teachers, parents, local masons and the wider community have been motivated by enthusiastic lectures and demonstrations by NSET to finance pre-engineered retrofit seismic resistance improvements for school buildings. Communities have responded positively though financial contributions, and masons have been asked by some members of the community to apply their new skills to their own houses. The NSET is now supplying teams of masons experienced in seismic-resistant construction to teach other Himalayan communities.

Local expertise in India

India can be perceived as a conundrum with respect to earthquake engineering. It has produced some of the finest structural engineers in the world yet has not solved some of the fundamental problems common to other countries in the area. India has a reasonable building code but also has the generic problem of enforcing compliance from both design

 © OECD 2004

professionals and builders. The country has a seismic zoning map that is not probabilistically based and has experts that could construct such a zoning map. However, it appears that there is currently a lack of consensus about the correct approach to be taken.

Seismic engineering expertise is mainly based in universities – Sudhir Jain from the Indian Institute of Technology in Kanpur and his team are making great efforts in many sectors to improve the standard of structural engineering in India – but there are a growing number of highly motivated private consultants who are producing state-of-the-art designs and working for clients who will accept only their advice regarding seismic resistance. In the disaster management area, one engineer in the northern state of Uttaranchal is almost single-handedly encouraging remote villages to produce their own village vulnerability assessments. He is networking internationally and allocating foreign resources to meet the specific requirements of the communities in the area.

The January 2001 earthquake in the Kutch region of Gujarat affected a middle-class community situated some 300 km from the epicentre. There has been a sustained reaction to this event, in that some residents are considering investing in houses with improved seismic resistance.

The effect of the base isolation of the new Bhuj Hospital in Gujarat, which replaced the hospital that collapsed during the Kutch earthquake, is an interesting case study. The Indian architect convinced the officials of the prime minister's department, who financed the construction of the hospital, to accept that the New Zealand Ministry of Foreign Affairs provide assistance and the author identify and arrange the base isolation of a replacement hospital in Bhuj. While the leading earthquake engineers provided the required endorsement of the technology, it was the non-engineer officials who understood the possible significance of an application to the wider community. Since construction commenced, there was clearly an empowerment effect amongst a number of structural engineers who realised that a non-traditional solution was possible.

CHAPTER

17

EVALUATING EARTHQUAKE RETROFITTING MEASURES FOR SCHOOLS: A COST-BENEFIT ANALYSIS

A.W. Smyth, G. Deodatis, G. Franco , Y. He and T. Gurvich

Department of Civil Engineering and Engineering Mechanics, Columbia University, United States

Abstract: Based on a cost-benefit approach for evaluating seismic mitigation options for apartment buildings in Istanbul, Turkey, this paper presents a demonstration study for a hypothetical vulnerable school building. A probabilistic cost-benefit analysis provides a useful framework for assessing seismic mitigation measures, taking into consideration limited resources and social costs. The hypothetical school is analysed over a variety of time-horizons to determine the break-even point for investments for several seismic retrofitting options.

Introduction

In Smyth *et al.* (2004), a simple cost-benefit analysis was performed to evaluate seismic retrofitting measures of an apartment building in Istanbul, Turkey. The study combined probabilistic seismic hazard estimates, sophisticated structural analysis techniques and economic cost-benefit principles to select the best of three retrofitting options proposed by local contractors. Actual cost estimates for the retrofitting measures, in addition to the direct dollar losses due to a potential collapse, were considered. In addition, to translate all of the losses into one common metric, the dollar cost of human lives lost in the event of a structural collapse was also considered.

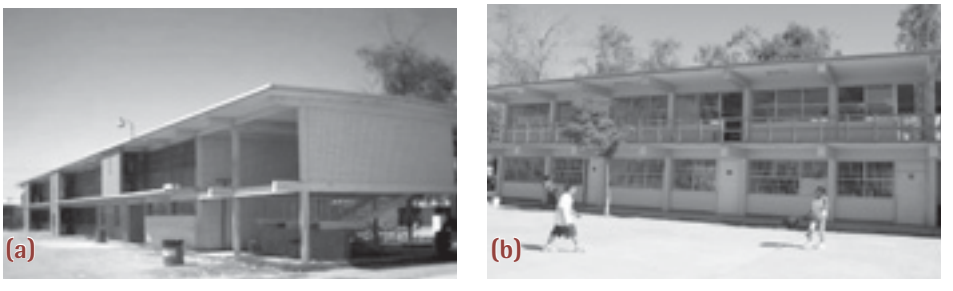
While the approach is promising for apartment structures, its potential application to school buildings is even greater. This is simply because in many regions schools are designed using similar building methods, with similar geometries. Therefore, it would not be necessary to perform a detailed analysis for each individual structure. Rather, a probabilistic structure could be considered to represent a class of school structure type. Given the demonstration nature of this study, a deterministic and hypothetical school structure will be considered. The results of this analysis should not be used to draw major conclusions for practice; the presentation of the methodology in the context of schools is the purpose of this paper.

The structure to be considered

A prototype school model was developed based on rough descriptions, photographs and other qualitative information (Figure 17.1).

Figure 17.1. Typical school structures in Mexico

(a) School in Guerrero (b) School in Mexicali
(Photos courtesy of Brian Tucker, GeoHazards International)

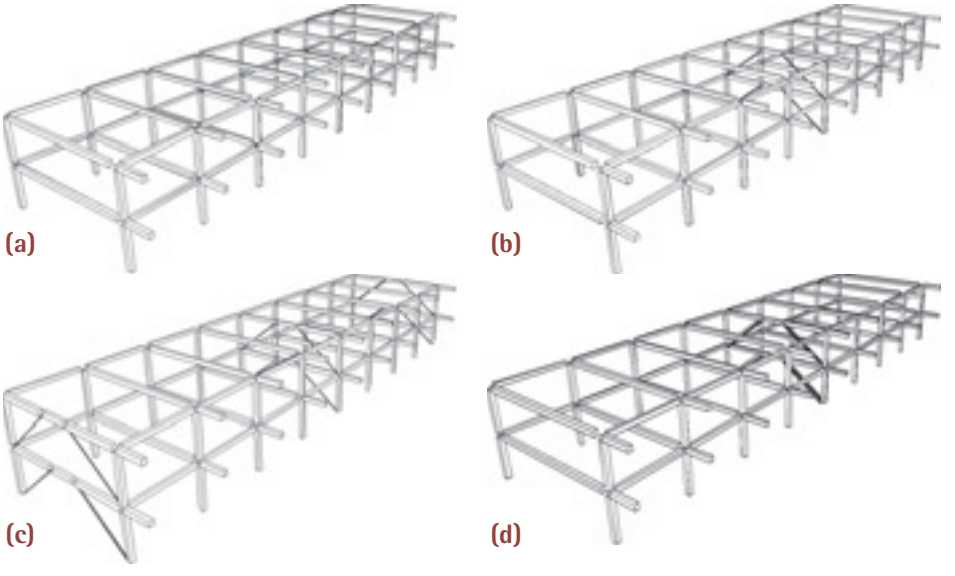


This structural model consists of a two-storey building with a footprint of 10 m × 40 m and a storey height of 3 m. The structure, the frame of which is shown in Figure 17.2(a), is divided into eight bays with a width of 5 m in the long direction and one bay with a width of 10 m in the short direction. A 2 m cantilevered slab on each floor acts as an access corridor for the different classrooms.

To mimic possible poor design practice in developing countries, no lateral loads such as seismic loading were considered in the design. The structure was designed for gravity loads, which include the weight of the structural elements (beams and columns), the weight of the slab, and permanent elements estimated at about 2.50 kN/m^2. A live load of about 1.91 kN/m^2 was also considered. These loads are applied on both storeys to allow for the typical practice of constructing additional floors. The material is assumed to be reinforced concrete of average quality with a concrete compressive strength of 20 684 kN/m^2 and a yield strength of 413 686 kN/m^2 for the steel. The mass of each of the elements is considered, and additional masses are added on each floor to simulate the slabs. The Eurocode 1999 is used for dimensioning the steel reinforcement with the appropriate safety factors for loads and materials. As designed, the structure is vulnerable; it is capable of appropriate standard service loads but unfit to sustain any strong loads other than gravity.

Figure 17.2. Model of the structural frame for the original and retrofitted structures

(a) Original structure (b) First steel bracing option
(c) Second steel bracing option (d) Reinforced-concrete bracing retrofit



© OECD 2004

While this design is appropriate for highlighting in general terms the effectiveness of retrofitting and the economic analysis methodology, should a study of this type be completed for actual school buildings, a survey of designs and materials used in existing structures must be carried out to model these buildings more accurately. The three retrofitting measures considered are shown in Figures 17.2(b) to 17.2(d). The first involves the addition of light steel bracing at the central bay to stiffen the weak axis of the structure. The second is a more aggressive steel bracing retrofit that also braces the end walls. Finally, a more substantial reinforced-concrete bracing alternative is considered. This reinforced concrete option – while somewhat more labour intensive – is assumed to be cheaper than the second option simply because steel shapes are not always readily available in rural regions in developing countries.

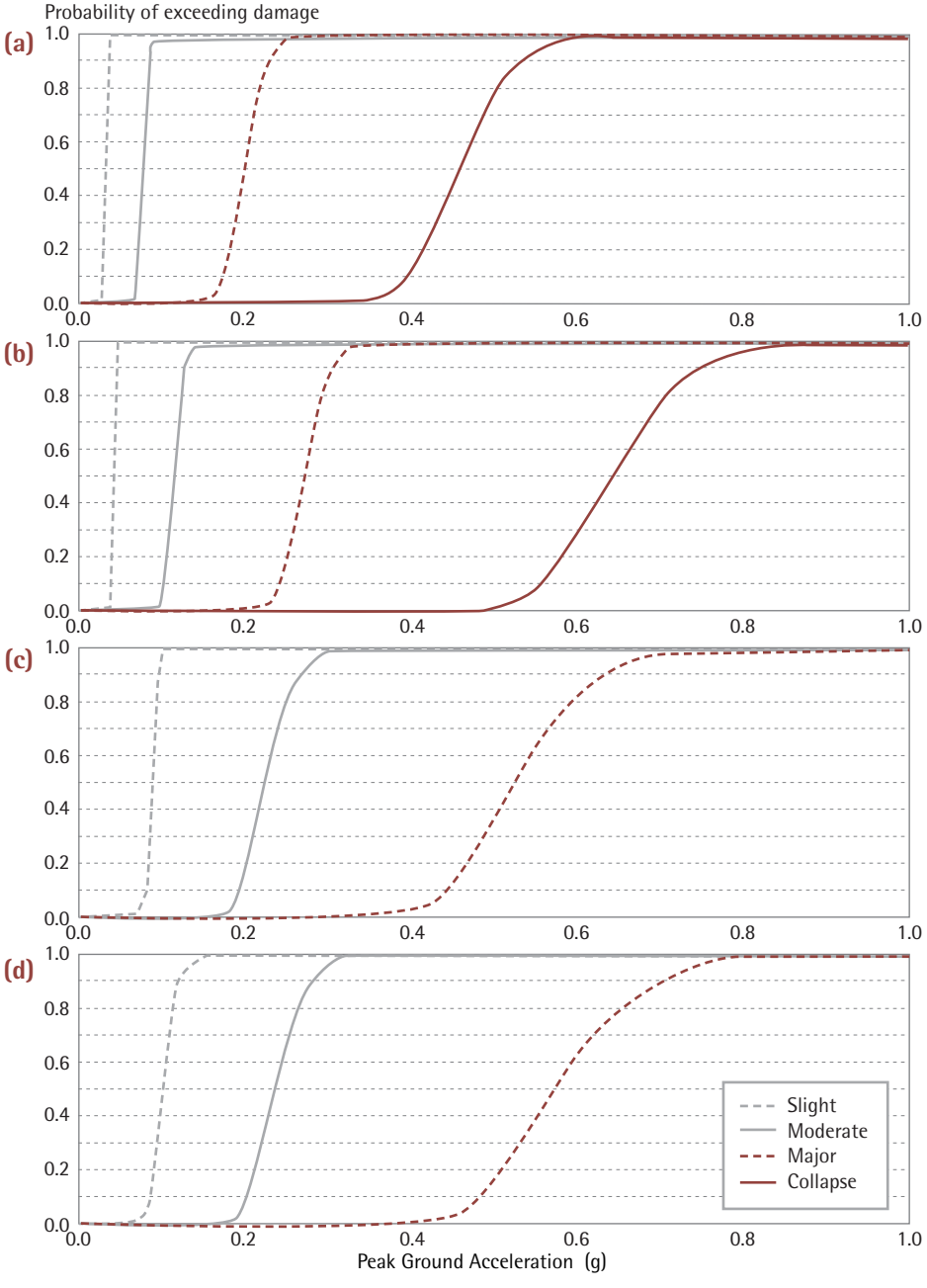
Note that in developing countries, it is not uncommon to find that a substandard structural analysis was undertaken prior to a building's construction, and that little if any quality control was carried out in the manufacturing of materials. It is also typical to find evidence of poor construction practices – *e.g.* insufficient cover for the rebar or insufficient spacing between the steel reinforcement bars – in collapsed buildings after earthquakes (EERI, 2000). From this perspective, the design carried out in this paper is sound; the cover for the rebar is no less than 5 cm and the spacing is consistent with the Eurocode 1999 norm. This model is designed with the help of the software package SAP2000 v.7.40, which is a standard tool for structural calculations. The dynamic analysis was also undertaken using this software.

Fragility analysis

The fragility of a given structure is defined as the probability that for a given ground motion shaking level (peak ground acceleration), the structural response will exceed a given threshold level corresponding to a particular damage level. The structural response is probabilistic in terms of peak ground acceleration (PGA) because the structural response deformations will, in general, be different for different ground motion time histories with the same PGA. For each of the structural configurations, the fragility curves are shown in Figure 17.3. Four damage levels E_i are considered: slight, moderate, major and total collapse. These damage levels are defined by inter-storey drift ratios in accordance with the HAZUS99-SR2 Technical Manual. Note that retrofit strengthening has the effect of pushing the fragility curves to the right, *i.e.* for the same PGA value, the probability of exceeding a given damage state is lower.

Figure 17.3. Derived fragility curves for the four structural configurations

(a) Original structure (b) First steel bracing option
(c) Second steel bracing option (d) Reinforced-concrete bracing retrofit



© OECD 2004

Loss estimation procedure

In order to perform a basic cost-benefit analysis, the expected losses for arbitrary time horizons must be computed. The basic equation to calculate the present value of losses using a real (social) discount rate *d* is:

Total loss in present value for a given time horizon *T** (in years) =

$$\sum_{T=1}^{T^*}\sum_{i=1}^{4}\int_{a_{\min}}^{a_{\max}}[\hat{R}(a+da,T)-\hat{R}(a,T)]\,P(E_i \text{ only} \mid a)\,\frac{C_i^D}{(1+d)^{T-1}}\,da$$

where

$\hat{R}(a,T)$ = the probability of exceeding the PGA value *a*, given that no earthquake has occurred in the previous years

= (the probability of exceeding the PGA value *a* in year *T*) x (the probability that no earthquake has occurred in the previous (*T-1)* years)

$= R(a)\times e^{-R(a_{\min})(T-1)}$

$e^{-R(a_{\min})(T-1)}$ is the probability that no earthquake has occurred in the previous (*T-1*) years, assuming a Poisson distribution of earthquake occurrence. The term $a_{\min}$ denotes the lower limit of PGAs considered, so if this value is not exceeded, then a (significant) earthquake will not have occurred. In this study, the lower limit $a_{\min}$ is set equal to 1% of *g*. The annual hazard curve *R*(*a*) was the same as that used in Smyth *et al.* (2004). This information is region-specific and requires the input of seismological experts.

The additional probability in the above expression is:

$P(E_i \text{ only} \mid a)$ = the probability of only event E_i occurring for a given PGA value *a*. This probability is needed so that damage levels which are lower than (or fall within the set of) more severe damage levels will not be counted twice. This expression is easily related to fragility curves.

C_i^D = The losses associated with damage state *i* are summarised in Table 17.1.

Table 17.1. Losses associated with damage state *i*

Damage level	Cost (C_1^D)	Comments
E_1 Slight damage	$C_1^D = (s_1 \times S) + (0 \times V)$	$0\% \le s_1 \le s_2 \le 100\%$ (s_1 = 1%)
E_2 Moderate damage	$C_2^D = (s_2 \times S) + (0 \times V)$	$0\% \le s_1 \le s_2 \le 100\%$ (s_2 = 10%)
E_3 Major damage	$C_3^D = (s_3 \times S) + (0 \times V)$	s_3 = 100%
E_4 Total collapse	$C_4^D = (s_4 \times S) + (N_L \times V)$	s_4 = 100%

Results of the economic cost-benefit analysis

In order to perform a cost-benefit analysis, realistic estimates of the costs of the retrofitting measures as well as the losses C_i^D for each damage state must be established. As this is not a real building, assumed values were selected without the usual consultation with local experts. The replacement cost of the entire structure is assumed to be S = USD 160 000, and the costs of each retrofit C_i^M are:

- Retrofit 1: Steel bracing in 1 bay C_i^M = USD 8 000.
- Retrofit 2: Steel bracing in 3 bays C_2^M = USD 20 000.
- Retrofit 3: Reinforced-concrete bracing C_3^M = USD 13 000.

The social discount rate is assumed to be 3% (Weinstein *et al.*, 1996). The fact that children would typically only occupy a school for one-third of the day (eight hours) was also factored into the calculation. Therefore in the loss calculations above, the assumed number of lives lost N_L is actually one-third of the number of actual lives lost in the event of collapse. The net present value is the benefit minus the certain cost of retrofit. The benefit is simply the difference in expected losses with and without mitigation.

Table 17.2 illustrates the cost-benefit analysis results for an assumed value of human life V = USD 400 000, and an assumption that 15 lives would be lost if collapse occurred. The table lists net present values for different retrofitting decisions. Negative values indicate

Table 17.2. Expected net present value with 15 fatalities and V = USD 400 000 (NPV(5))*

Alternative (A_i) Time horizon	i=1 Steel bracing 1 (USD)	i=2 Steel bracing 2 (USD)	i=3 Reinforced-concrete bracing (USD)
1	-3 110	-11 899	-4 794
2	1 366	-4 480	2 719
3	5 466	2 313	9 600
4	9 221	8 535	15 903
5	12 661	14 234	21 674
6	15 810	19 452	26 959
7	18 694	24 231	31 799
8	21 335	28 607	36 232
9	23 754	32 615	40 291
10	25 969	36 285	44 009
25	43 620	65 531	73 632
50	49 344	75 016	83 238

* Negative values (unshaded) indicate economically undesirable choices for the given time-horizon, while positive values (shaded) indicate economically desirable choices.

 © OECD 2004

economically undesirable choices for the given time-horizon, while positive values indicate an economically desirable choice. Note that the second steel bracing retrofitting option only "breaks even" after three years of hazard exposure. The reinforced-concrete bracing option, which is about as effective as the more expensive three-bay steel bracing option, naturally hits its break-even point sooner. In all cases, the break-even point occurs rather quickly simply because the retrofitting options are inexpensive relative to the potential loss of life due to collapse.

From this hypothetical and simplistic example one can begin to appreciate the types of decision-making information that the cost-benefit approach yields. For other combinations of parameters, costs, etc., the conclusions would change. This also permits analysts to perform sensitivity analyses to test the robustness of decisions.

Conclusions and further work

As mentioned at the outset, in order for this approach to be applied to a particular stock of school buildings, more careful modelling of the particular construction type is required. To apply this approach to an ensemble of different structures of the same type, some randomness also needs to be introduced in the structural model. This will have the effect of making the fragility curves ascend more gradually because of the increased uncertainty. The authors are currently working on a framework to introduce randomness to capture material, geometric and workmanship uncertainties.

Another limitation of this demonstration study is that only direct losses are considered. In the case of a school building, the obvious disruption caused by a building collapse and time required to rebuild should be considered. The modular framework presented here can easily accommodate estimation of indirect losses.

References

Earthquake Engineering Research Institute (EERI) (2000), "1999 Kocaeli, Turkey Earthquake Reconnaissance Report", *Earthquake Spectra*, Supplement to Volume 16.

SAP2000 (2000), *Integrated Finite Element and Design of Structures, Analysis Reference Manual*, Computers and Structures, Inc., Berkeley.

Smyth, A.W., *et. al.* (2004), "Probabilistic Benefit-Cost Analysis for Earthquake Damage Mitigation: Evaluating Measures for Apartment Houses in Turkey", *Earthquake Spectra*, Vol. 20, No. 1, pp. 171-203.

Weinstein, M., *et al.* (1996), "Recommendations of the Panel on Cost-Effectiveness in Health and Medicine: Consensus Statement", *Journal of the American Medical Association*, Vol. 276, pp. 1253-1258.

Acknowledgements

This work was supported in part by a grant from the Columbia University Academic Quality Fund. The Columbia Earth Institute also provided support for this work.

© OECD 2004

CHAPTER

18

STRENGTHENING SCHOOL BUILDINGS TO RESIST EARTHQUAKES: PROGRESS IN EUROPEAN COUNTRIES

Robin Spence

University of Cambridge and European Association for Earthquake Engineering, United Kingdom

Abstract: This paper reviews progress in programmes for screening, evaluating and strengthening existing vulnerable buildings, including schools, in high-risk areas in Europe. It is argued that legislation is needed to ensure the long-term financial commitment that is required for strengthening programmes. The experience of a lethal earthquake – as in Italy in 2002 and Turkey in 2003 – is the most effective catalyst for action, but computed scenarios can also motivate action. Data available on the extent and possible scope of a programme for the retrofit strengthening of school buildings for the six most at-risk countries in the European Union are presented. The costs are substantial but reasonable when distributed over a period of years with some adjustment of capital expenditure priorities.

Introduction

On 15 January 2003, the following written question – drafted in consultation with the Executive Committee of the European Association for Earthquake Engineering – was presented to the European Parliament by Mihail Papagiannakis, European Parliament member for Greece:

> In San Giuliano di Puglia, Italy, on 31 October 2002, a recently modified school building collapsed in a moderate-sized earthquake, resulting in the death of 27 occupants (25 of them schoolchildren). According to the European Association of Earthquake Engineering this is not an isolated incident. Similar incidents could happen in many European countries; however, the problem is preventable and the risk can be substantially reduced by a programme of expert assessment of the older and more vulnerable existing structures and a programme of strengthening works in the highest-risk areas. The rules for the assessment and strengthening of structures are available in the European Standard, Part 1-4 of Eurocode 8, prEN 1998-3. In the interest of preventing further loss of life and considering that in many member states there is considerable earthquake activity, could the Commission formulate a directive requiring the member states to establish programmes of assessment (according to the above-mentioned European Standard) of all buildings and structures in areas known to be prone to damaging earthquakes and of strengthening the ones which are found to be inadequate?

A few weeks later, on 24 February 2003, the response from the European Union Environment Commissioner Margot Wallström on behalf of the Commission was presented on the European Parliament Web site (*www.europarl.eu.int*) as follows:

> The Commission deeply regrets the loss of human lives and the damages caused to the population of San Giuliano di Puglia. At this stage, the Commission does not envisage any specific proposal for legislation in the field of earthquake mitigation.

The reply also mentions other initiatives which the Commission has and will take to stimulate action for risk mitigation against natural disasters. The urgency of the question posed was dramatically and tragically confirmed on 1 May 2003 when another school collapsed, trapping over 100 schoolchildren in an M6.4 earthquake in Bingöl, Turkey.

Whose responsibility is it to formulate and enact the legislation to ensure that school buildings, and indeed all other buildings used by the public, are earthquake safe? Certainly the European Commission has some powers in this area. Many regulations already exist at the European level in areas affecting the health and safety of the public, and particularly

 © OECD 2004

the workforce, and are seen as a necessary means to ensure a uniform level of protection for the citizen and a level playing field for business throughout Europe. Regulation has a special validity in circumstances where decisions affecting the risks to peoples' life and health are taken by others (for example their employers); where individuals are not readily aware of the risks associated with their actions; and where action to mitigate the risks must be taken at a community, regional or even international level. All of these circumstances are true of earthquake risk, and this is of course recognised in the regulations covering the design of new buildings, which are now in the process of being unified at European Union (EU) level through the adoption of the Eurocodes. There is also a special validity, which can be widely supported, in legislation to protect the lives of schoolchildren who have no choice over which buildings they use and little awareness of the risks involved.

It is not surprising, though, that the European Commission does not appear to favour the idea of regulation on this issue at the European level. Among the possible tools for government action, regulation tends to be losing popularity in the EU – in common with other advanced economies of the world – in favour of various other kinds of incentives to achieve desirable social and environmental goals. Supporting underpinning research, demonstrating best practice, proposing voluntary codes and even providing tax incentives are today preferred to regulation because of the perceived costs to the economy and the additional problems of enforcement that new regulations often bring. And, in any case, the principle of *subsidiarity* makes the European Commission reluctant to initiate action in any matter in which effective action can be taken by member states individually.

Necessary action for earthquake protection can easily become a victim of this kind of thinking. For the building stock at large, regulation would impose obligations on property-owners to strengthen their buildings, thus increasing rents and reducing the stock of cheap accommodation; and this would certainly be opposed by many of those owners, and perhaps by the business community at large. For publicly-owned buildings, the introduction of such regulations would impose additional burdens on national budgets, which would have to be met by increasingly tax-averse electorates. And it can also be argued that each country – and each city – has its own separate risks and set of social conditions, which means that uniform legislation across the whole EU would be inappropriate.

The aim of this paper is to argue the contrary, that the logic which applies to protecting life through the design of new buildings should also apply to the much more difficult issue of protecting life in existing older buildings. All kinds of activities are needed at an EU and at a national level to support this, including research, public awareness-raising, and the drafting of model documents. But experience from other countries suggests that unless these activities are underpinned by legislation – primarily concerned with strengthening, demolishing and replacing existing high risk-buildings – resistance will be strong and little progress will be made (Spence, 2003). Without underpinning legislation, other supporting actions will simply lack the "teeth" to be really effective in reducing the highest risks. Whether this legislation should be at an EU or individual country level is an open question, but EC support for such work could be a powerful stimulus to action.

To support this argument, the paper first looks at actions taken or in progress in some of the European Association for Earthquake Engineering (EAEE) countries to achieve this type of risk mitigation. It then considers the costs and benefits of strengthening existing high-risk buildings, and examines the possible scale of the programme of work needed to bring Europe's school buildings up to an acceptable standard of earthquake safety.

Risk mitigation action in the European area

The ESC-SESAME Seismic Hazard Map shows that Europe is a seismically diverse area (Giardini, Jiménez and Grünthal, 2003). Converting the hazard map into a map of relative risks is a difficult task because much depends on the population density and the relative vulnerability of the building stock, both of which change over time. One way to look at relative risks is by examining the number of earthquake casualties over a long time period on a country-by-country basis. Such a study (Spence, 2003) for the 29 current member countries of the EAEE shows that the three highest risk countries – Iran, Italy and Turkey – had long-term annual fatality rates over the 20th century that were greater than 15 per million of the 2001 population; while several others, including Algeria, Cyprus, Greece and Romania, some of the countries of the former Soviet Union and Yugoslavia (but here recent changes in political geography make exact comparisons complicated), had annual fatality rates of between 1 and 6 per million of the 2001 population. The remainder, including most of the 23 existing and potential EU countries, have lower long-term risk rates. As would be expected, countries with the highest risk rates – and the most recent experience of a damaging earthquake – are currently most active in risk mitigation, and are also those that require most help. Activities in a number of countries will be discussed briefly.

Greece

In Greece, frequent damaging earthquakes in the last 25 years, including those in Thessaloniki (1978), Corinth (1981), Kalamata (1986), Aegion (1995), Kozani (1995) and Athens (1999), have created a highly developed national consciousness of the earthquake problem. Improved economic performance has also led to a general rise in the standards of buildings. Most of the buildings which collapsed in recent earthquakes were identified as older buildings, which were built prior to the present-day building code. But many such buildings remain, and in the last two years a framework for the pre-earthquake assessment of public buildings was developed and approved by the national earthquake mitigation authority (OASP) (Penelis, 2001). It is recognised that the cost of bringing these buildings – which include public schools, hospitals and public administration buildings – to a satisfactory standard of earthquake resistance will be substantial. For schools in Thessaloniki alone, it was estimated that the cost would be equal to the entire budget of the region for new schools over the next six years. Thus a lengthy programme for action is envisaged, of perhaps 15 years.

A three-stage process is envisaged, beginning with a rapid visual screening procedure (RVSP), followed by the calculation of a seismic score. This will be followed by an approximate seismic evaluation of those buildings with a low seismic score. For those buildings that do not pass this evaluation, a third more detailed assessment will be performed, leading to

 © OECD 2004

recommendations for strengthening. An attempt to validate the RVSP for a large sample of buildings in Thessaloniki, by comparing the seismic score with their actual performance in the earthquake of 1978, showed poor correlation building by building. Nevertheless, a clear trend of reduced average repair costs with increasing seismic score was established for reinforced-concrete buildings (Penelis, 2001).

Italy

In Italy, a substantial programme of repair and strengthening of older buildings followed the 1976 Friuli, 1980 Irpinia, 1997 Umbria-Marche and 1998 Pollino earthquakes, and a number of other post-earthquake projects have begun to tackle the problem of the existing building stock at risk in these areas. Progress towards reducing risks in Italy as a whole has been supported by a new system of tax incentives introduced in 2001 for private owners for upgrading their buildings. Most recently, following the tragic loss of schoolchildren's lives, the 31 October 2002 Molise earthquake provided a large stimulus to earthquake risk mitigation throughout Italy, with important implications for older building stock. Within months, a new earthquake code was drafted and is now proceeding into law, which among other changes introduces a new seismic zonation – including for the first time the whole of the Italian territory, many parts of which were not previously designated as seismic areas – and will set out detailed procedures for evaluating and strengthening existing structures. In parallel with this initiative and without precedent, the 2003 allocation of funds from central government to the regions provides funds for the evaluation of public buildings, leading to the creation of a list of priorities for strengthening, and with an emphasis on school buildings at risk. Further legal instruments will set deadlines of a few years to carry out this large strengthening programme (Dolce, 2003; Zuccaro, 2003).

Portugal

In Portugal, while there has been no earthquake on the mainland in recent years, the Azores islands of Terceira and Faial were badly affected by the earthquakes of 1980 and 1997, respectively, which claimed 70 lives. The memory of the 20th century earthquakes in 1909, 1941 and 1969, in addition to the historical memory of the devastating 1755 Lisbon earthquake, provides an incentive for risk mitigation activity. At the government level, the regional government of the Azores is at a relatively advanced stage in terms of policy to intensify efforts to rehabilitate and maintain the existing housing stock, creating credit lines (including earthquake insurance) aimed at strengthening older housing while maintaining architectonic characteristics, and introducing special measures for protecting people living in high-risk locations. Subsidies are also available for houses damaged in the 1998 earthquake. At a national level, the Portuguese Association of Earthquake Engineering (SPES, 2001) has formulated a National Plan for Reducing the Seismic Vulnerability of Constructions, which is modelled on the National Earthquake Hazards Reduction Programme (NEHRP) in the United States. This plan envisages a series of activities, including implementing surveys of housing stock to assess the risk; defining and developing intervention strategies; creating support legislation; training; preparing master plans; and carrying out the rehabilitation. A 25-year programme is envisaged,

with a cost of around 1% of gross national product over that period. The legislation has several dimensions, including certifying designers, improving building control, defining situations that require compulsory seismic rehabilitation, and creating tax incentives. However, to date this plan remains a proposal, supported in terms of research work, but lacking the government backing to bring it to fruition.

Turkey

In Turkey, the tragic 1999 earthquakes in Kocaeli and Düzce, which killed about 18 000 people, were primarily caused by the collapse of relatively recent buildings, built without proper design or building control. Much of the action taken in recent years has been aimed at improving control of new buildings, including those built in Turkey's reconstruction phase. A study of the causes of poor quality construction in Turkey (Gülkan *et al.*, 1999) pointed to deficiencies in both the nature and implementation of laws and regulations concerning the planning system, the project supervision at the design stage, and the system of on-site supervision, and recommended a range of government actions, some of which have been implemented.

Fresh impetus for mitigation action in Turkey has been provided by a forecast that a major earthquake (M>7.5) can be expected in the area of the North Anatolian fault closest to Istanbul, with a 60% probability of occurrence within 30 years (Parsons *et al.*, 2000). A study of the effects of this scenario conducted by JICA-IMM (2002) estimated that 7.1% (51 000) of buildings in Istanbul will be heavily damaged, and casualties will reach 0.8% (73 000). While not all seismologists accept the assumptions behind this prediction, it has prompted consideration of the special risk problem of Istanbul, where a high proportion of the population (73%) live in the type of apartment blocks that suffered so badly in the Kocaeli earthquake, few of which are built to satisfactory earthquake-resistant standards.

A proposed Istanbul Rehabilitation Project conducted for the Istanbul Metropolitan Municipality (Sucuoglu, 2003) will attempt to take action on the vast number of sub-standard buildings in a three-stage process. In the first stage, street surveys will identify the most at-risk buildings; in the second stage, these buildings will be surveyed by dimensional measurements at ground floor to determine action needed for the third stage, which is seismic rehabilitation for those in the highest risk category. In some cases, where high-risk buildings are scattered, the process will take the form of simplified strengthening interventions; but in other cases, where whole housing estates are in a state of deterioration, it is envisaged that wholesale redevelopment will be undertaken on existing or new sites.

Other countries

France and Romania have also established programmes to evaluate and strengthen important high-risk buildings. In France, the programme is concerned with the protection of public buildings – schools and hospitals – in the high-risk Antilles islands of Guadeloupe and Martinique (French Government, 2001). In Romania, the scope is limited to a relatively small number of multi-storey reinforced-concrete buildings in the capital, Bucharest, which were shown by the 1977 earthquake to be highly vulnerable and in some cases were inadequately repaired following the earthquake (Lungu, 2003).

 © OECD 2004

Costs of strengthening

Table 18.1. Typical reconstruction cost ratios for strengthening interventions

Country	Building type	Construction type	Technique	Strengthening-cost ratio	Source
French Antilles	Public buildings	Masonry and reinforced concrete		up to 50%	French Government
Greece	Schools	Masonry and reinforced concrete	Varies	10-20%	Penelis, 2001
Portugal	Apartments	Rubble masonry	Wall ties	5%	Cóias e Silva, 2001
Turkey	Apartments	Reinforced concrete	X-bracing Part shear wall Full shear wall	16% 20% 34%-40%	Altay *et al.*, unpublished
Eastern Turkey	Houses	Rubble masonry	Adding ties	27%	Coburn and Spence, 2002
California, United States	Apartments	Unreinforced masonry	Wall anchors, etc.	25%	Alesch *et al.*, 1986
Missouri, United States	Houses	Masonry Reinforced concrete		25% 30%	Cóias e Silva, 2001

Table 18.1 shows a compilation of recent studies of the costs of retrofit strengthening buildings to improve earthquake resistance. A useful way to present these costs is as a percentage of the total rebuilding costs of the same facility. Since both strengthening and rebuilding depend on building costs, the ratio tends to remain stable as prices rise. Table 18.1 shows a wide range of strengthening-cost ratios: from 5% to 50%. The cost ratio depends on a number of factors including:

- The type of building considered and its existing resistance.
- The intended level of strengthening.
- The cost of design and preliminary studies.
- Only structural costs or other associated refurbishment.
- The cost of taking the building out of use while work is undertaken.

In many cases, the strengthening-cost ratio for the structural intervention required to achieve an adequate degree of life safety tends to be in the range of 20% to 30%. This may be taken as a starting point for estimating the costs of a general strengthening programme. However, not all buildings would need strengthening.

The only study listed in Table 18.1 which specifically relates to schools is that carried out by Penelis *et al.* (2001) for the city of Thessaloniki. Costs of carrying out the three-stage procedure described below for the 500 schools in the region have been estimated in national currency; the figures converted into euros are shown in Table 18.2. The preliminary procedure, which would amount to 0.04% of reconstruction costs, would be carried out in all 500 schools. Of these, 400 schools would require the second-stage evaluation, which costs 0.4%. A detailed assessment would perhaps be needed for about 300, comprising 2% of reconstruction costs. Then, strengthening work would be carried out, meaning that 150 buildings would require work costing 10%, and 150 further strengthening work costing 20%. The cost of the whole programme would therefore be about 10.5% of the total reconstruction cost.

Table 18.2. Proposed strengthening programme for 500 school buildings in the Thessaloniki region

(after Penelis, 2001)

	Number of schools	Unit cost (euros)	Cost ratio	Total cost (million euros)
Preliminary rapid visual screening procedure	500	587	0.04%	0.3
Approximate evaluation	400	5 869	0.40%	2.4
Detailed assessment	300	29 347	2.00%	8.8
Strengthening work, 1	150	293 470	20.00%	44.0
Strengthening work, 2	150	146 735	10.00%	22.0
Total cost				77.0
Value of existing building stock	500	1 467 351	100.00%	733.0
Percentage of reconstruction cost				10.5%

Based on this study, a crude preliminary estimate was made of the possible costs of a strengthening programme for all of the school building stock (primary and secondary) in the six European Union countries with a significant seismic risk (Table 18.3). It is based on the following assumptions:

- Each of the six countries are divided into four seismic zones, using the ESC-SESAME map, by the expected 475-year peak ground acceleration (PGA) level, and its population is assumed to be uniformly distributed.[1]
- For the highest risk zone (PGA > 0.24 g) the average strengthening-cost ratio is estimated at 10% (as for Thessaloniki); for the second zone (0.24 g > PGA > 0.16 g) the average strengthening-cost ratio is estimated at 5%; and for the third zone (0.16 g > PGA > 0.06 g) the cost is estimated at 1%. The school population is estimated for the 11 years of compulsory schooling, which is standard in EU countries.

© OECD 2004

Table 18.3. Likely cost of school strengthening programmes in high-risk countries in the European Union

	Strengthening-cost ratio unit	Austria	France	Greece	Italy	Portugal	Spain
% of population in Zone 3 (0.16 g > PGA > 0.06 g)	0.01	1.0	0.3	0	0.4	0.8	0.5
% of population in Zone 2 (0.24 g > PGA > 0.16 g)	0.05	0.05	0.05	0.25	0.49	0.20	0.05
% of population in Zone 1 (PGA > 0.24 g)	0.1	0	0	0.75	0.16	0	0
Estimated number of schoolchildren	million	0.94	7.97	1.11	5.84	1.23	4.31
Space requirements at 6 m^2 per child	million m^2	5.65	47.83	6.66	35.03	7.39	25.86
Cost of building schools per m^2		1235	942	600	1 100	598	903
Total rebuilding cost	million euros	7 000	45 000	4 000	38 000	4 400	23 000
% expected strengthening costs		0.012	0.0055	0.0875	0.044	0.018	0.0055
Total strengthening costs	million euros	84	250	350	1670	80	130
% of GDP spent on education		5.9	5.9	3.6	4.5	5.7	7.5
Education capital expenditure (ECE)	million euros	614	6 297	751	3 513	376	3 725
Strengthening costs as % ECE...		13.6%	3.9%	46.5%	47.6%	21.2%	3.5%
...or annually as a 20-year programme		0.7%	0.2%	2.3%	2.4%	1.1%	0.2%

- Data on school-age population, school enrolment, expected space requirements for each child, rebuilding costs and national budgets spent on school building are taken from a variety of statistical sources (DfEE, 1996; Eurostat, 2003; UNDP, 2001; Langdon *et al.*, 2000).

The resulting estimates of strengthening costs for each of the six countries are shown in millions of euros, then as a percentage of each country's annual capital expenditure on education, and finally as an annual percentage, assuming a programme of 20 years' duration. The data show that Italy is the country with the highest relative cost (47.6% of the annual capital budget for education at current levels),[2] followed by Greece (46.5%), Portugal (21.2%) and Austria (13.6%). The costs do not seem completely unmanageable

given that the estimated length of the programme is 20 years and also considering that these costs are offset by the reductions in damage, disruption and human casualties that such a programme would entail.

In practice, a 20-year programme could be designed in such a way that retrofitting work would be carried out alongside other necessary maintenance or refurbishing work; and the natural process of replacing older school buildings already planned and budgeted for would avoid the need for upgrading some of the oldest and most vulnerable school buildings. Thus, the real additional costs would be significantly less.

Conclusions

This paper has argued that legislation is necessary to ensure that the work needed to make public buildings earthquake-safe is carried out. The paper has also described the required scope of a programme of work that would bring school buildings up to acceptable life-safety standards in the six most earthquake-prone countries in the European Union. Such a programme is certainly affordable for EU countries over a 20-year period, although it would involve some revision of national capital expenditure priorities over that time.

The extension of this retrofitting approach to poorer countries is likely to be more problematic, both because of the limited resources available for public expenditure, and also because strengthening in many existing school buildings may not be technically feasible. In the most earthquake-prone countries, most effort should be devoted to ensuring that new school buildings are built to adequate standards, and that unsafe buildings are replaced. El Salvador, which suffered an earthquake in 2001 in which over 60% of the school buildings in the entire country suffered damage, has already adopted such an approach.

An urgent and preliminary task is to define a set of life-safety standards that could be adopted internationally. With such a definition, it would be a straightforward, if laborious, task for structural engineers to define more precisely the scope of the building programme needed in any country or region. Pressure must be placed on the EU and national governments to adopt regulations and to put in place the programmes necessary to protect the lives of future generations of schoolchildren worldwide. A clear set of guidelines, which establishes what can be achieved, will help to create a situation in which governments and their ministers will be forced by their electorates to take responsibility for the consequences of their inaction.

Notes

1. This assumption leads to an overestimation of the exposure to seismic risk, since the highest risk areas are generally mountainous and relatively lightly populated.

2. An estimate by the Italian government assumed that all schools constructed before 1979 in the three highest seismic risk zones defined in the Italian seismic code would

 © OECD 2004

require strengthening to two-thirds of the full code resistance, which resulted in significantly higher assumed overall costs. However, this estimate was not based on a detailed vulnerability survey, and it used operational cost data from a post-earthquake situation (Goretti, 2004). The estimate covers students aged between three and 18 in public schools.

References

Alesh, D.J. and W.J. Petak (1986), *The Politics and Economics of Earthquake Hazard Mitigation*, Institute of Behavioural Science, University of Colorado.

Altay, G., *et al.* (unpublished), "Benefit Cost Analysis for Earthquake Mitigation: Evaluating Measures for Apartment Houses in Turkey".

Coburn, A.W. and R.J.S. Spence (2002), *Earthquake Protection*, John Wiley and Sons, Hoboken.

Cóias e Silva, V. (2001), "Technical Feasibility of the National Programme for Reducing the Seismic Vulnerability of the Building Stock", *Conference on Reducing the Seismic Vulnerability of Constructions*, National Laboratory of Civil Engineering (LNEC), Lisbon, Portugal, 2001.

Department for Education and Employment (DfEE) (1996), *Area Guidelines for Schools, Building Bulletin 82*, Architects and Building Branch Department for Education and Employment, London.

Dolce, M. (2003), Personal communication.

Eurostat (2003), "Public Expenditure on Education in the EU in 1999", *Statistics in Focus, Theme 3 –22/2003*, Eurostat, Quebec.

French Government (2001), Personal communication from Pierre Mouroux, Office of Geological and Mining Research, France (BRGM).

Giardini, M., J. Jiménez and G. Grünthal (2003), *European-Mediterranean Seismic Hazard Map,* European Seismological Commission, International Geological Correlation Programme, Project No. 382, SESAME, *http://wija.ija.csic.es/gt/earthquakes/imatges/ESC-SESAME_poster_A4_75q.jpg*.

Goretti, A. (2004), Personal communication.

Gülkan, P., *et al.* (1999), *Revision of the Turkish Development Law No. 3194 and its Attendant Regulations with the Objective of Establishing a New Building Construction Supervision System Inclusive of Incorporating Technical Disaster Resistance-Enhancing Measures* (3 Volumes), Turkish Ministry of Public Works and Settlement, Istanbul.

Japan International Co-operation Agency and Istanbul Metropolitan Municipality (JICA-IMM) (2002), *The Study on a Disaster Prevention/Mitigation Basic Plan in Istanbul Including Seismic Microzonation in the Republic of Turkey*, IMM, Istanbul.

Langdon, D., *et al.* (2000), *Spon's European Construction Costs Handbook*, Routledge mot E F and N Spon.

Lungu, D. (2003), Personal communication.

Parsons, T., *et al.* (2000), "Heightened Odds of Large Earthquakes Near Istanbul: An Interaction-Based Probability Calculation", *Science*, Vol. 268, pp. 661-665.

Penelis, G. (2001), "Pre-Earthquake Assessment of Public Buildings in Greece", *International Workshop on Seismic Assessment and Rehabilitation of Structures*, Athens, Greece, January 2001.

Portuguese Association of Earthquake Engineering (SPES) (2001), "Contributing to a National Programme for Reducing Seismic Vulnerability of Constructions", *Conference on Reducing the Seismic Vulnerability of Constructions*, National Laboratory of Civil Engineering (LNEC), Lisbon, 2001.

Spence, R. (2003), "Earthquake Risk Mitigation in Europe: Progress towards Upgrading the Existing Building Stock", Keynote paper for 5th Turkish National Conference on Earthquake Engineering, July 2003.

Sucuoglu, H. (2003), Personal communication.

United National Development Programme (UNDP) (2001), *Human Development Report 2001*, UNDP, New York, *http://hdr.undp.org/reports/global/2001/en/*.

Zuccaro, G. (2003), Personal communication.

Acknowledgements

The ideas of many people active in earthquake protection issues in Europe have contributed to this paper. Special thanks are given to Mihael Papagiannakis MEP, Polat Gülkan, Panayotis Carydis, Andrew Coburn, Giulio Zuccaro, Antonios Pomonis, Julian Bommer, Mary Comerio, Carlos Oliveira, Artur Pinto, Haluk Sucuoglu, Pierre Mouroux, Dan Lungu, Agostino Goretti and Mauro Dolce for fruitful discussions and valuable comments on earlier drafts.

 © OECD 2004

PART V

TAKING AN INITIAL STEP TOWARDS IMPROVING EARTHQUAKE SAFETY IN SCHOOLS: AD HOC EXPERTS' GROUP REPORT ON EARTHQUAKE SAFETY IN SCHOOLS

The *ad hoc* Experts' Group on Earthquake Safety in Schools unanimously recommends to the Organisation for Economic Co-operation and Development that it undertake urgent action to establish mandatory national programmes for the seismic safety of schools and education systems.

Rationale for the recommendation

All too frequently, strong earthquakes strike OECD member countries, causing the collapse of school buildings and the death of innocent children. Although earthquakes are natural and unavoidable events, school buildings need not collapse during earthquakes. The knowledge presently exists to significantly lower the seismic risk of schools and to help prevent further injury and death of school occupants during earthquakes.

Experts from 14 countries and five continents representing international organisations, government, academia, business and non-governmental organisations deliberated for two and one-half days regarding possible measures to assure the seismic safety of schools and education systems. During these deliberations, scientific, technical, economic, social, political and public policy issues related to earthquake safety of schools were examined. The recommendations contained in this document represent the strong and unanimous view of the *ad hoc* experts' group.

The *ad hoc* experts' group finds it unconscionable that schools built world-wide routinely collapse in earthquakes due to avoidable errors in design and construction, causing predictable, unacceptable and tragic loss of life. In the last few decades alone, thousands of school children have died because existing knowledge was not applied to make their schools safe from earthquakes. It is only by chance that there has not been much greater loss of life since many earthquakes have occurred outside of school hours. Unless action is taken immediately to address this problem, much greater loss of life of school children and teachers will occur. Currently available technology can resolve this problem at reasonable cost and in a reasonable time frame.

The motivation for school seismic safety is much broader than the universal human instinct to protect and love children. The education of children is essential to maintaining free societies, the social and economic progress of nations, and the welfare of individuals and their families. As a result, most nations make education compulsory. However, a state requirement for compulsory education, while allowing the continued use of seismically unsafe buildings, is an inconsistent and unjustifiable practice. The school seismic safety initiative recommended herein is based on the premise that the very future of society is dependent upon the safety of the children of the world.

The *ad hoc* experts' group believes that any meaningful effort to improve the seismic safety of schools and education systems must involve national programmes that are mandatory.

 © OECD 2004

Role of the OECD in achieving school seismic safety

Earthquake safety of schools can only be achieved through long-term efforts sustained by participating nations, and understood and supported by all stakeholders. The OECD is ideally suited to play a leadership role in such efforts. The *ad hoc* experts' group strongly recommends that the OECD take steps to encourage the establishment of mandatory programmes of school seismic safety among its member countries, and also in OECD partner countries.

The OECD should consider establishing a responsible organisational entity to co-ordinate and manage this effort. This entity would fit well within the OECD Programme on Educational Building (PEB). It should have an advisory committee consisting of earthquake safety experts, code enforcement officials, and school facility managers from participating countries, and national advisory committees.

The OECD should work with member countries and partner countries to help them develop and sustain effective school earthquake safety programmes. The OECD organisational entity should be charged with establishing a procedure for accreditation of national school seismic safety programmes and a means for assessing and validating the status, progress and effectiveness of these programmes. Participating countries should regularly submit updated school seismic safety implementation plans and progress reports for review and acceptance by the OECD organisational entity. This entity should periodically evaluate national programmes by conducting reviews of reports and inspection of practices within the nations. OECD should publicise the results of its evaluations and possibly issue certificates of compliance, publicly recognising those nations that meet or exceed the expectations established for acceptable national programmes. The OECD organisational entity should develop recommendations for how to reward exemplary programmes, and improve programmes that are less than exemplary.

Participating countries will have common needs for school risk management tools and programme materials to increase the effectiveness of their school seismic risk reduction programmes. The OECD entity should provide information, facilitate international information sharing, develop and disseminate informational materials and tools, and advise participating countries on effective strategies to develop support for programmes. It may develop some tools and materials using its own resources, but should also disseminate best practices selected from participating national programmes. Examples of the products needed are vulnerability assessment tools, priority-setting tools, cost evaluation tools, school curricula, and preparedness and awareness information. Some of these tools may be developed by nations whose programmes for school seismic safety are more advanced, by experts drawn from groups of nations, or by the OECD organisational entity directly using its own staff and/or contractors.

The OECD should also seek to find ways to enhance the support provided to non-member countries to facilitate the achievement of the targets and goals set forth in this report globally, in line with the objectives of other relevant international organisations.

Guiding principles for mandatory national school seismic safety programmes

National programmes for seismic safety in schools should recognise the safety of children in schools as a basic human right and formally establish this as a national policy. Such programmes, to be established on an urgent basis to assure earthquake safety of new and existing schools, should be based on the following guiding principles:

1. Establish clear and measurable objectives for school seismic safety based on the level of risk that can be implemented and supported by the affected residents of communities and agencies at the local government level, and provide adequate resources and realistic timelines to achieve these objectives.

2. Define the level of the earthquake hazard for the country in order to facilitate the development and application of construction codes and standards. At a minimum, natural hazard zones should be established and, where possible, seismic hazard maps should be based on probabilistic analysis.

3. Set forth expectations or objectives that define the desired ability of school buildings to resist earthquakes. All school buildings should be designed and constructed, or retrofitted, to prevent collapse, partial collapse or other failure that would endanger human life when subjected to specified levels of ground shaking and/or collateral seismic hazards such as surface fault rupture, landslide or inundation from tsunami waves or dam failure. However, some countries may desire that school buildings have additional seismic resistance to the extent that damage is limited and the buildings can be occupied immediately after earthquakes and used for shelter or emergency operations.

4. Address all schools regardless of ownership, as preservation of the educational system is vital to the continuity of society, and as the functioning of schools as emergency shelters and cultural centres provides an important point of community convergence.

5. Give initial priority to making new schools safe. Efforts to identify vulnerable existing schools, to establish standards for retrofitting or replacing dangerous buildings, and to develop a list of priority actions can be made over a short period of time. A longer timeframe will likely be needed to correct seismic weaknesses of existing school buildings.

6. Establish the programmes as long-term undertakings with a strong commitment to sustained effort rather than one-time actions.

7. Adopt a multi-hazard approach to school safety, with earthquake mitigation strategies that complement disaster countermeasures for other hazards.

8. Employ advisory committees as needed to assure that policy and technical decisions are consistent, and to provide long-term independent support and evaluation for the seismic safety effort.

 © OECD 2004

Major elements of effective national school seismic safety programmes

An effective national school seismic safety programme should include the major elements described below:

Seismic safety policy element

A national policy should be established by law with well-defined and measurable objectives. Priorities and strategies for satisfying the objectives should be established by the appropriate authorities. The policy must be clear and should have adequate governmental authority to enforce its scope and objectives and to carry out the plan over a specified number of years. The policy should:

- Recognise the safety of school children as a basic human right.
- Recognise the need for the safety of school buildings.
- Establish minimum standards for protection of human life.
- Adopt sustainable standards to guide design for new and existing school infrastructure based on prescribed performance objectives, knowledge of the ground shaking severity in different regions, quantification of site specific hazards, and the ability of the community to educate, train and license its members to effectively achieve established objectives.
- Establish programmes for seismic risk reduction of school buildings and their components.
- Provide adequate funding and human resources for the protracted duration of the programme.
- Be supported by committed and competent leaders with sufficient legal and moral authority to ensure the effectiveness, sustainability and continuity of the programmes that derive from the policy.

Accountability element

There should be a legal basis for action with clear lines of accountability of the different members of society who are given responsibility for implementing earthquake safety programmes. To achieve the objectives of these programmes there should be:

- A clear definition of the roles and responsibilities of the various individuals, agencies and organisations involved in school seismic safety.
- A process for making all planning, design, regulation and enforcement decisions transparent.
- Qualification requirements for professionals engaged in the design of school facilities.
- A responsible enforcement agency – independent of the organisations responsible for designing, constructing and financing school facilities – charged with overseeing and approving proper design, construction and maintenance of school facilities including:

  - Conducting assessments of existing school facilities.
  - Reviewing and approving construction documents prepared for new structures and the retrofit of existing structures.
  - Inspecting and approving construction.
  - Qualifying personnel for design, plan review and inspection, materials testing and support functions.

- A clearly identified jurisdiction in terms of the area and the type of school systems and buildings affected.

Building codes and code enforcement element

The primary objective of school building codes and regulations should be to protect the life of occupants of a school building. Other objectives could include minimising damage to allow rapid occupancy of buildings after earthquakes. Building codes should govern the design of new and retrofitted school buildings. Design earthquake ground motions may be based on a probabilistic approach, a deterministic approach, or on a map of seismic zones. Individual nations should determine the most appropriate design criteria, based on a review of their country's seismic hazard and other pertinent factors.

An effective school building code and enforcement element should establish:

- Clear building performance objectives based on:
  - Ground motion characteristics and geology of the region.
  - Collapse prevention and structural damage control criteria.
  - Secondary effects such as tsunamis, landslides and surface rupture.
  - Socio-economic impacts to the community.
- A process for periodic review and revision of codes and guidelines by knowledgeable individuals to reflect current understanding of good earthquake engineering practice.
- Enforcement procedures for school building code and construction regulations that take into account community needs but provide clear provision for:
  - Checking of design plans for school buildings by qualified reviewers.
  - Review and certification of constructed school facilities.

 © OECD 2004

- A regulatory body with a responsible official who is independent of those who finance, design and construct the buildings to assure that enforcement activities are not compromised by overt or subtle pressures due to project-specific cost, deadlines or other financial considerations.

The mere existence of a building code in a community can give the false impression that buildings are being constructed safely and that their seismic performance will be satisfactory. While extremely important, the writing and adoption of building codes and regulations can be an incomplete strategy if they are not enforced at every step of the design and construction process. Steps should be taken to ensure that code regulations are implemented and enforced consistently and have equal priority to code development.

Training and qualification element

Building safety relies on regulations and laws that require proper training and qualification of professionals, builders and technicians involved in the different aspects of the design and construction process. Building safety training programmes should be carried out within the context of each individual country. Training programmes must accommodate governmental structure and division of responsibilities, perception of risk to the institution and its stakeholders, community values and economic conditions. Training and licensing should be required for design professionals, code enforcement officials, plan checkers, inspectors and contractors.

- *Engineers and architects* should be properly trained on current practices of seismic design and should pass rigorous tests to obtain a license to design and prepare school construction documents.

- *Qualifications of contractors* should be considered in awarding construction projects. For instance, contractors could be tested and licensed to assure minimum levels of competence. This would require the establishment of training programmes on best constructions practices for contractors and trades.

- *Building officials, plan-check professionals and inspectors* should be certified through a process of adequate training and experience.

Preparedness and planning element

Effective national programmes should require each school organisation and every individual school to take measures to reduce risks and to prepare employees and students to react in safe ways during emergencies. These school safety elements should include the following:

- *Education.* Develop and teach curricula for primary and secondary school students on earthquakes, societal issues relating to earthquakes and preparedness actions. Use the school curricula to promote a culture of prevention in future generations of the community.

- *Risk reduction measures.* Undertake measures to improve the safety of the physical environment by bracing and anchoring furnishings, bookcases, and equipment and building components such as lights, heaters and water heaters.

- *Emergency plan.* Prepare and maintain plans that identify the actions, decisions and responsibilities needed before, during and following an earthquake; the organisation and responsibilities to carry out these plans, including determining whether to shelter or release students or to use school facilities as community shelters; and the equipment and supplies needed to carry out these decisions.

- *Safety assessments.* Establish standards, line of responsibility and procedures to assess the safety of buildings following earthquakes, and decide on evacuation, repair and re-occupancy procedures.

- *Training.* Provide training and materials for employees and students on earthquake hazards and actions to take to improve personal safety.

- *Drills.* Hold periodic drills simulating realistic conditions of earthquake events to reinforce training and to test the adequacy of plans and safety assessments.

Community awareness and participation element

Paramount to the success of a programme to improve the seismic safety of schools is the understanding and involvement of the community. All members of the community should understand the seismic hazard of the region, the vulnerability of existing school buildings, the consequences of not properly constructing new school buildings or improving the resistance of existing buildings, and the feasibility of improving seismic safety. In particular, those members of the community who are involved in the construction of school buildings need to understand why they are required to follow prescribed practices, and the consequences of their failing to do so. An effective community awareness effort should include:

- Programmes to raise public awareness and knowledge of the risk from earthquakes and other natural hazards.

- Educational programmes to transfer and disseminate technical knowledge and to explain risk in terms understandable to community stakeholders.

- Activities to empower the community to be part of, and contribute to, the reduction of seismic risk of schools.

- Use of school curricula to promote a culture of prevention in the future generations of community members.

Risk reduction element for *new* facilities

Verified procedures currently exist to ensure good seismic performance of school buildings and their contents, and the implementation of such procedures is feasible. The following components are needed in a risk reduction element for *new* facilities:

- Determination of seismic hazard in the region and development of seismic hazard maps.

- Development of performance criteria and codes suitable to the culture and economic

 © OECD 2004

conditions of the region with recognition of the fundamental societal importance of schools and the shelter function of school structures in post-disaster emergencies.

- Development of simple regulations, or best construction practices, for regions where such an approach may have an immediate impact on seismic safety (*e.g.* simple, low-cost education facilities in rural regions of developing countries).
- Training and education of professionals, technicians and the construction workforce.
- Target dates for implementation of construction standards recognising the different levels of current practice in different countries.
- Effective building codes and regulations, and rigorous enforcement of these regulations.

Risk reduction element for *existing* facilities

To reduce the seismic risk of *existing* school buildings, it is important to understand why this risk exists and what actions can be taken by the community to eventually reduce the risk. Community values, economic conditions, financial possibilities and the type of building materials available in the region should be considered when developing and implementing a risk reduction plan.

Key ingredients for an effective risk reduction element for existing facilities include:

- Determination of the seismic hazard and preparation of hazard maps.
- Assessment of risk to existing schools and their contents.
- Evaluation of the consequences of not taking corrective action.
- Development and implementation of technical guidelines to improve performance of existing facilities during earthquakes (*e.g.* methods and procedures to estimate forces and displacements of the structure and predict damage, acceptable margins of safety or confidence, proper use of building materials, and monitoring of the construction processes).
- Formulation of an action programme based on availability of funding, human resources and their qualifications, existing infrastructure and the operational structure of the community.
- Prioritisation and risk reduction plan implementation, considering financial and human resources and the role of school buildings in post-disaster emergency management.
- Monitoring of effectiveness of plan implementation.

Given the magnitude of the retrofitting task in many countries, responsible officials should establish time schedules and priorities to retrofit at least those facilities deemed to be at the highest risk. While several decades may be needed to completely implement a school seismic retrofit programme, work on the facilities at greatest risk can be undertaken on a priority basis over a much shorter period.

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

© OECD 2004

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)

© OECD 2004