Why Schools are Vulnerable to Earthquakes

J.E. Rodgers
GeoHazards International

SUMMARY:
School buildings frequently collapse or suffer heavy damage in earthquakes. In the past decade, tens of thousands of children lost their lives when their schools collapsed. Thousands more escaped injury or death solely because the earthquake that flattened their school occurred outside of school hours. This paper explores physical characteristics of schools that cause vulnerability to damage and collapse, using data from earthquake damage reports and seismic vulnerability assessments of school buildings. These data show that characteristics related to building configuration, type, materials and location; construction and inspection practices; and maintenance and modifications all contribute to building vulnerability. Physical characteristics, such as large classroom windows, when combined with poor design and construction practices, create major seismic vulnerabilities. Underlying drivers include scarce resources, inadequate seismic codes, unskilled building professionals, and lack of awareness of earthquake risk and risk reduction measures.

Keywords: Earthquake damage, vulnerability assessment

1. INTRODUCTION

Schools have distinct physical and organizational characteristics that cause them to be vulnerable to earthquakes. Seismic vulnerability manifests itself most dramatically in building collapses that kill teachers and students, but also through hazardous falling objects and inadequate exits. This paper explores vulnerability-generating physical characteristics and the underlying reasons that these characteristics manifest themselves in schools in different geographic, economic and cultural settings. Not all schools are alike: differences in number of students, available land and local building practices, among other factors, result in buildings that range from a single-room adobe structure in Peru to an eight-story concrete building in Mumbai. Despite the disparities, many schools – especially in urban areas – tend to share similar characteristics and as a result, similar seismic vulnerabilities.

2. DATA SOURCES AND METHODS

To determine the physical characteristics that create vulnerability, this study examined data from two main types of sources: reports of earthquake damage to schools, and vulnerability assessments of school buildings. These data vary greatly in quality, quantity and availability. Professional organizations, government agencies, individual authors, and private companies provided the earthquake damage reports listed in Table 1.

Table 1. School earthquake damage data sources

Year	Location	Magnitude	School Damage Data References
2010	Baja California	7.2	EERI (2010)
2010	Haiti	7.0	UNICEF (2010), Green and Miles (2011), Holliday and Grant (2011), Marshall et al (2011)
2009	Mongar, Bhutan	6.1	RGoB (2009)
2009	L’Aquila, Italy	6.3	EEFIT (2009a), EERI (2009a)
2009	Padang, Indonesia	7.6	EEFIT (2009b), EERI (2009b)
2008	Wenchuan, China	7.9	CEA (2008), Kabeyasawa et al. (2008), Miyamoto Intl. (2008),

			Xiong (2008)
2007	Pisco, Peru	8.0	EERI (2007), Taucer et al. (2008), Spence and So (2009)
2006	Yogyakarta, Indonesia	6.3	Spence and So (2009)
2005	Kashmir, Pakistan and India	7.6	ADB-WB (2005), Durrani et al. (2005), Langenbach (2005), NAS (2005), EEFIT (2006), Bothara (2007), Mumtaz et al. (2008)
2003	Bam, Iran	6.6	Parsizadeh and Izadkhah (2005) Tierney et al. (2005)
2003	Bourmerdes, Algeria	6.8	Belazougui et al (2003), Bendimerad (2004), Milutonovic and Massue (2004), Meslem (2007)
2003	Bingol, Turkey	6.4	Gulkan (2004)
2002	Molise, Italy	5.9	Augenti et al. (2004)
2002	Tblisi, Georgia	4.5	Gabrichidze et al (2004)
2001	Gujarat, India	7.7	Rai et al. (2001)
1999	Duzce, Turkey	7.2	Gur et al. (2009)
1999	Chi-Chi, Taiwan	7.7	Tsai et al. (2000), Yi (2005)
1999	Kocaeli, Turkey	7.6	Erdik (2001) Yuzugullu et al (2004)
1998	Faial, Azores, Portugal	6.2	Proença (2004)
1997	Cariaco, Venezuela	7.0	Lopez et al. (2004, 2007)
1996	Temouchent, Algeria	5.8	Bendimerad (2004)
1995	Kobe, Japan	6.9	Yomiuri Shimbun (1995), AIJ (1997), Nakano (2007)
1994	Beni Chougrane, Algeria	5.6	Bendimerad (2004)
1994	Northridge, USA	6.7	DSA (1994), LAUSD (1994)
1989	Loma Prieta, USA	6.9	EERI (1990)
1989	Chenoua, Algeria	5.7	Bendimerad (2004)
1988	Spitak, Armenia	6.8	EERI (1989), Yegian and Ghahraman (1992)
1988	Bihar, India and Nepal	6.6	Thapa (1989), Theruvengadam and Wason (1992)
1985	Michoacan, Mexico	8.0	Tena-Colunga (1996)
1980	El-Asnam, Algeria	7.3	Bendimerad (2004)
1971	San Fernando, USA	6.6	Jephcott and Hudson (1974)
1963	Skopje, Macedonia	6.0	Milutinovic and Tasevski (2003

Vulnerability assessments of school buildings come from a similarly varied set of sources, shown in Table 2. Urban and peri-urban schools provided most of the data, though several assessments conducted at the national or state/district help to rectify this bias in the dataset. More vulnerability assessments have been conducted, but the data were not obtained in time for publication.

Table 2. School vulnerability assessment data sources

Location	Assessment description
Asia and Pacific	
Suva, Fiji	Vulnerability assessment of 6 schools (Rokoveda, 2006)
Ahmedabad, Baroda and Surat, India	Modified rapid visual screening (RVS) of 42 schools (Ahmedabad), 58 schools (Baroda) and 53 schools (Surat); GHI (2005)
Delhi, India	Walk-through vulnerability assessment of 10 government schools (GHI, 2008)
Shimla, India	Vulnerability screening of 6 representative schools near Shimla (UNCRD, 2009)
Indonesia	Study of common vulnerabilities in government schools (ADPC)
Indonesia	Vulnerability assessment of 4 schools (UNCRD, 2009)
Japan	125,000 public school buildings nationwide assessed (Japan Times, 2009; Nakano, 2007)
Ota City, Japan	91 schools (340 buildings) assessed (Nakano, 2007; Ohba et al., 2000)
Kathmandu Valley, Nepal	Inventory of Kathmandu Valley schools (643 schools, ~1100 buildings), vulnerability surveys of 378 schools (695 buildings) (Dixit et al., 2000; Kandel et al., 2004)
Lamjung, Nawalparasi, Humla Districts, Nepal	Vulnerability screening of 745 school buildings (Lamjung), 636 school buildings (Nawalparasi); detailed assessments of some buildings; small sample of mountain schools screened in Humla (Archarya et al., 2011)
Seti Zone, Nepal	Qualitative overview of community built schools (Tamang and Dharam, 1995)
New Zealand	Rapid survey of 2361 state schools (21,000 buildings) (Mitchell, 2004)
Tashkent,Uzbekistan	Detailed vulnerability assessment of 3 schools; general overview (UNCRD, 2007, 2009)
Uzbekistan	Over 10000 schools assessed (Khakimov et al., 2006)
Europe and Mediterranean	
Algiers, Algeria	190 schools (526 buildings) in 9 municipalities of Algiers (Meslem, 2007)

Emilia-Romagna,Italy	Assessment of 2700 important buildings including schools (Consentino et al., 2004)
Italy	General observations; 78 school buildings assessed in Potenza province (Dolce, 2004)
Istanbul, Turkey	Detailed assessment of 33 school buildings from ISMEP inventory (Kalem, 2010)
Latin America and Caribbean	
Quito, Ecuador	Initial screening of 340 buildings, ATC RVS of 60, detailed analyses for 20 (GHI, 1995)
Lima, Peru	28 schools (Barranco district) and 80 schools (Chorrillos district) screened using ATC-21 and EMS-98 (Meneses and Aguilar, 2004)
Venezuela	National vulnerability assessment of ~28,000 schools; (Lopez et al., 2007, 2008)
North America	
Vancouver, Canada	All 108 Vancouver School Board schools (302 buildings) surveyed (TBG, 1990)
Charleston, South Carolina, USA	Detailed vulnerability assessments of 6 schools after prioritization exercise for all district schools (CCSD, 2010)
Oregon, USA	Collapse risk assessment of 2185 K-12 public school buildings (DOGAMI, 2007)
Kodiak Island, Alaska, USA	Detailed seismic and tsunami vulnerability assessments all 14 Kodiak schools (26 buildings) (Eidinger, 2006)
Utah, USA	RVS of 128 public school buildings sampled from 1085 schools in state (Siegel, 2011)
Memphis, Shelby Counties, Tennessee	Screening of 202 schools (349 buildings) using ATC-21 plus locally developed method (Chang et al., 1995)

Where possible, the author obtained quantitative information on the relative prevalence and severity of various vulnerability-creating characteristics. However, most reports provide only qualitative assessments of the most important vulnerability creating characteristics. The relative prevalence of the various characteristics was determined by counting the number of times particular characteristic was cited as a cause of damage in damage reports or as a cause of vulnerability in vulnerability assessments. (Each characteristic was counted only once for each earthquake or vulnerability study.) The level of detail in the earthquake damage reports varied significantly with the scope of the damage investigation, with many reports coming from brief reconnaissance missions. Consequently, published damage reports may omit some causes of damage, due to incomplete coverage of the damaged area, lack of access, or simply because the report authors viewed them as less important. In particular, damage to finishes and contents inside the building, and objects that fell from the building exterior, may have been omitted for these reasons. Due to insufficient data, this paper does not attempt to quantify whether school buildings are more vulnerable to earthquake damage or collapse than are other types of buildings. The relative vulnerability of schools compared to other buildings will likely depend on the context, especially the types of buildings used for schools, and how they are designed and built, versus buildings used for other purposes.

Quantitative information on the underlying drivers that are responsible for vulnerability-creating characteristics is much less readily available. In most locations, a set of complex and interrelated social, economic, political, cultural and technical factors combine to generate an environment that creates or perpetuates school seismic vulnerability. Due to the complexities involved and the lack of quantitative information, the author relies on the judgment of local professionals as expressed in the literature, in order to identify the major underlying drivers affecting school earthquake safety. Because the literature covers a limited number of countries, it is difficult to assess relative importance.

3. CHARACTERISTICS THAT CREATE VULNERABILITY

The data sources used in this study mention many characteristics that either contribute to earthquake damage or are presumed to create the potential for earthquake damage, based on the collective past experience of the earthquake engineering community in observing earthquake damage in the field and simulating it in the laboratory. Some characteristics, such as those directly related to schools' functional requirements, affect schools specifically, while others affect broader classes of buildings. Table 3 shows the prevalence of each identified characteristic in the datasets.

Table 3. Prevalence of vulnerability-creating characteristics

Category	Vulnerability-creating Characteristic	No. Earthquakes	No. Vuln.

		where Observed	Assessments Observed
Configuration	Large rooms - no cross walls	3	2
	Large rooms – no diaphragm	2	1
	Plan irregularity due to one-bay wide	3	4
	Plan irregularity general	0	11
	Captive columns due to partial height infill walls	10	8
	Torsion due to windows on one side	1	3
	Torsion, general	0	6
	Weakness due to windows - masonry	2	5
	Soft or weak story	3	8
	Vertical irregularity, general	0	5
	Masonry gable walls	0	3
	Heavy roofs	3	2
Structural system type and construction materials	Vulnerable traditional construction	3	1
	Vulnerable non-engineered non-ductile RC frame	2	0
	Vulnerable non-engineered brick or block masonry	2	3
	Vulnerable non-engineered poorly confined masonry	2	0
	Vulnerable engineered non-ductile RC frame	11	8
	Vulnerable engineered brick or block masonry	6	9
	Safer traditional building types abandoned	1	0
	Standard types / plans have major seismic deficiencies	4	2
	Lack of seismic design understanding by engineers	6	2
	Local materials generate weak or brittle buildings	3	3
	Poor quality engineered materials general	10	4
Location	Vulnerable sites / poor soil conditions	3	2
	Liquefaction	1	2
	Sloping site / landslides	0	1
	Cultural practices for site selection	0	1
Construction practices	Unskilled / low-skilled local labor	4	3
	Builders not aware of earthquake-resistant practices	2	2
	Public contracting low bid rules	0	1
	Reducing quality to save money or time	3	0
	Poor construction quality, general	9	5
Construction inspection	Lack of inspection	4	0
	Corruption of inspection mechanisms	0	0
Maintenance	Deferred / not done, general	1	9
	No provision by builder or operator	0	1
Modifications	Subsequent structural modifications	2	2
	Ineffective retrofits	1	1
Falling hazards	Façade and exterior	4	10
	Interior / contents	6	6
Exit pathways	Inadequate doors, windows, halls/corridors or stairs	1	9

Note: Data set contains reports for 32 earthquakes; reports were aggregated for each earthquake. Data set contains 31 vulnerability assessments; for space reasons Table 2 combines assessments in similar locations.

Characteristics cited as causes of earthquake damage in damage reports for 25% or more of the earthquakes in the data set (eight or more citations) were captive columns due to partial height masonry infill walls under windows, non-ductile reinforced concrete frame construction, generally poor construction quality, and poor quality engineered materials. Characteristics cited in 25% or more of the vulnerability assessments (eight or more citations) were general plan irregularity, exterior falling hazards, unreinforced masonry construction, poor maintenance, non-ductile reinforced concrete frame construction, soft or weak stories and captive columns due to partial height masonry infill walls under windows. Characteristics cited in damage reports for 15% to 24% of the earthquakes in the dataset (five or more citations) were unreinforced masonry construction, lack of seismic design understanding by engineers or architects, and interior architectural and contents hazards. Characteristics cited in 15% to 24% of the vulnerability assessments (five or more citations) were torsion, interior falling hazards, general vertical irregularities, generally poor construction quality, and weakness due to numerous windows reducing solid wall area in masonry buildings.

Though the earthquake damage reports and the vulnerability assessments agree on most of the major causes of vulnerability, some notable differences exist. In particular, plan irregularities and torsion were commonly cited in vulnerability assessments but rarely mentioned in the earthquake damage reports. Possible reasons for this discrepancy include: (a) that damage caused by plan irregularities and torsion may not typically be as severe as previously assumed; (b) the incomplete nature of most earthquake damage reports, and (c) a tendency for damage observers to focus (understandably) on primary causes of collapse and major non-repairable damage. Systematic post-earthquake damage surveys that identify the causes of damage, rather than solely the damage grade or damage level, would be extremely helpful in quantifying the relative importance of different vulnerabilities.

3.1 Configuration

The majority of schools throughout the world are organized in the same way: each teacher leads a class of students in a separate classroom. This way of organizing instruction, along with concerns for occupant comfort such as natural lighting and ventilation, generates certain architectural configurations and characteristics that support the school's function but increase seismic vulnerability. Other characteristics such as weak or soft stories and heavy roofs are not unique to schools.

In order to accommodate a cost-efficient number of students per teacher and to provide unobstructed sight lines between students and teacher, classrooms tend to be larger rooms without interior supports. Requirements and preferences for cross-ventilation and natural light lead to school buildings that are one or at most two classrooms wide, with classrooms placed next to each other with a corridor or hallway and exterior windows on the other two sides. Irregular plan shapes result from packing more classrooms into available land, and more importantly there are few if any cross walls outside the classroom to reduce the span of walls. When the building has a type of structural system that relies on the number and placement of walls for earthquake resistance (such as masonry bearing wall), this weakens the building. In buildings without a proper diaphragm, the long spans of the floor and roof allow the walls to move more and increase the chances that the floor or roof will pull apart and collapse. In the 2008 Wenchuan, China earthquake, the Hanwang Primary School main building collapsed, while the adjacent dormitory of the same construction type, which had smaller rooms and more cross walls, did not. Both buildings had a type of precast concrete plank flooring system where the planks were not well connected and came apart if the walls moved much at all (Miyamoto International, 2008). Many other schools built with this system collapsed also, killing thousands.

The large classroom windows that let in light and air also create several vulnerabilities. Many concrete frame buildings have stiff partial-height masonry walls below the windows, which create captive columns above the wall which fail in shear. Earthquake damage reports cited captive columns as one of the most common causes of school building earthquake damage. In masonry buildings, the building is weak in the direction parallel to the windows, and narrow piers between windows can crack and fail. Classrooms often have large windows on only one side, with more substantial walls on the other side, which can create torsion in some buildings.

3.2 Structural system and construction materials

School buildings that utilize a structural system or material that is inherently weak or brittle will be less earthquake resistant. Vulnerabilities related to structural system and construction material are often prevalent throughout the local built environment, rather than being specific to the schools. For example, seismically vulnerable forms of vernacular construction (meaning buildings built without input from design professionals), both traditional and modern, are common in many areas of the world. Traditional vernacular construction often uses readily available local materials, such as Adobe (unfired clay) bricks and rubble stones, which may be inherently weak or brittle.

Many school jurisdictions use standard building designs for multiple schools, in order to reduce the costs involved in building design and to generate efficiencies in construction. In cases where a national or state level authority designs and builds schools, this practice results in many similar or identical school buildings. If standard building plans have major seismic weaknesses, then many schools will be at risk of severe damage or collapse. In the former Soviet Union, certain types of standard school building designs created by the central government collapsed in large numbers in the 1988 Armenia earthquake (Yegian and Ghahraman 1992; Khakimov and Tursonov 2006).

Schools may be built with poor quality engineered materials such as concrete, fired clay bricks, and reinforcing steel. Though the data sources used in this study do not typically provide insight into the reasons why poor quality engineered materials were used, possibilities include cost pressures, good quality materials not locally available, and an inadequate or complete lack of materials testing and quality control. In the case of concrete buildings, unskilled or low-skilled construction workers may produce poor quality concrete despite good quality cement, sand and aggregate, simply because they are not aware of how to properly mix and place concrete, or lack proper equipment.

3.3 Location

Schools may be located on sites vulnerable to amplified earthquake ground motions, landslides, liquefaction, lateral spreading or fault rupture, as well as earthquake-triggered secondary hazards such as landslides, tsunamis, fires and dam or levee failures. Schools are most often located in communities near housing, which restricts the choice of available sites. If the community cannot (or will not) make good land available, the school may be built on marginal land such as a hillside or in a flood plain.

3.4 Construction and inspection practices

School construction by unskilled or low-skilled workers is problematic, because these workers are often unaware of proper earthquake resistant practices, and may not have the skills to build good quality buildings. Selection of the lowest bidder, a cornerstone of public contracting used for building schools in many locations, can create unintended construction quality problems. If the construction contractors are not properly qualified during the bid process, less-qualified or unqualified contractors will build the schools, resulting in poor quality workmanship. In addition, the cost pressures involved with trying to win a low-bid competition can force the contractor to reduce quality in order to make the job financially viable. Lack of proper construction inspection removes incentives to follow plans and specifications and often leads to poor quality construction. In areas with high levels of corruption in the construction sector, the prevalence of corrupt practices such as the paying off of inspectors to approve poor quality or non-code-compliant work can lead to poor quality construction.

3.5 Falling hazards and inadequate exit pathways

Many school buildings have objects on the exterior or inside that can fall during shaking and injure or kill people. On the exterior, common falling hazards include unreinforced masonry parapets, masonry chimneys and rooftop water tanks. Inside the building, large bookshelves, pendant lights and fans, and chemicals in chemistry labs can fall on students or block exit pathways. In some areas, many school buildings have inadequate exit pathways, and students may not be able to exit the building safely and quickly following an earthquake, or during a fire or other emergency. Corridors and stairwells can be too narrow, poorly lit or used for storage. Classrooms may have only one door which opens inward rather than outward. Exit doors and gates may be locked for security purposes.

4. UNDERLYING DRIVERS

Local professionals well versed in school design and construction in their location identified a number of underlying drivers that help create an environment where unsafe school buildings either continue to be built or continue to be used; Table 4 provides a snapshot of their observations. The diversity of these drivers indicates that the reasons for school earthquake vulnerability are complex, inter-related and vary by context. However, some drivers seem to be present in diverse settings. The scarcity of resources for education affects prosperous and less-prosperous countries alike, as does the presence of inadequate building codes and the tendency to underestimate the seismic hazard. Drivers such as rapid school construction under Education for All initiatives, unskilled or unaware building professionals, and a lack of code enforcement occur predominately in developing countries regardless of geography.

Except for drivers related to building code content and professional competence, the drivers are outside the direct control of the engineers and scientists that make up the majority of the earthquake professional community. Social, economic and political factors create the remaining drivers and necessitate a broad and multifaceted approach to improving school seismic safety.

Table 4. Observations of underlying drivers

Underlying driver	Location	Specific observations
Community built buildings	Nepal	Construction quality poor because communities forced to build schools without technical support. (Tamang and Dharam, 1995)
	Bhutan	Community built school buildings damaged by 2009 earthquake (RGoB, 2009)
Scarcity of resources	Global	Other pressing demands limit education department resources (Kenny, 2009)
	Canada	Retrofit or replacement of unsafe schools perceived to compete with basic educational needs of children for same limited funds (Monk, 2006)
	India	School administrators struggle to provide basic facilities (Jain, 2004)
Inadequate codes or seismic zoning	Italy	Inadequate codes before 1996; inadequate zoning (Dolce, 2004)
	Algeria	Seismic hazard underestimated (Bendimerad, 2004)
	China	Seismic hazard underestimated; codes inadequate prior to 1992 (CEA, 2008)
Lack of code enforcement	Algeria	Little enforcement after centralized govt construction ended (Bendimerad, 2004)
	Turkey	No construction site inspections (Gulkan, 2004)
Corruption of enforcement	Global	Corruption circumvents regulatory mechanisms intended to provide safe buildings and renders them ineffective (Kenny, 2009)
Unskilled or unaware building professionals	Algeria	Rural contractors less skilled; most professionals can't design and build properly detailed RC frame buildings (Bendimerad, 2004)
	India	No licensing or proficiency requirements for engineers; building professionals generally not competent in seismic safety related aspects (Jain, 2004)
	Nepal	Most new schools built by convention, not designed (Bothara and Sharpe, 2003)
	Pakistan	Unskilled builders built poorly despite good materials (Mumtaz et al., 2008)
	Turkey	No requirements for engineers, architects or contractors (Gulkan, 2004)
Lack of accountability	Turkey	Engineer of record is paid by developer, no independent inspection, no liability (Gulkan, 2004)
Lack of risk awareness	Algeria	Those responsible for school safety not aware of earthquake threat; parents unaware but very interested in seismic safety once informed (Meslem, 2007)
	India	Many government officials unaware of earthquake threat (Jain, 2004)
	Pakistan	Professionals and builders unaware of earthquake threat (Mumtaz et al., 2008)
Failure to prioritize schools	Canada	Schools not considered critical infrastructure, politicians uninterested; many other buildings retrofitted before schools (Monk, 2006)
Urgent need for large numbers of new schools	Global	Education for all initiatives create demand for many new schools in developing countries; earthquake safety not usually mentioned Wisner (2006), Kenny (2009)
	Algeria	Rapid expansion of education system led to poor construction (Bendimerad, 2004)
	India	2001 earthquake badly damaged governmt precast schools built rapidly (Rai, 2001)

5. CONCLUSIONS AND RECOMMENDATIONS

A review of school earthquake damage and vulnerability assessment data shows that a number of characteristics contribute to school buildings' earthquake vulnerability, including those related to configuration, structural type and construction materials, location, construction and inspection practices, maintenance, and subsequent modifications. Of these characteristics, earthquake damage reports cited non-ductile reinforced concrete frame construction, captive columns due to partial height masonry infill walls under windows, generally poor construction quality and use of poor quality construction materials most often as causes of damage. Vulnerability assessment reports cited unreinforced masonry construction, poor maintenance, non-ductile reinforced concrete frame construction, soft or weak stories and captive columns due to partial height masonry infill walls under windows most often. Other commonly cited vulnerability generating characteristics were lack of seismic design understanding by engineers or architects, torsional irregularities, vertical structural system irregularities, and weakness due to numerous windows reducing solid wall area in masonry buildings. In addition to these characteristics affecting the structure, schools often have exterior falling hazards, inadequate exit pathways and unrestrained contents or fixtures.

Some local professionals have, in the literature, provided insight into the underlying drivers that create the environment where unsafe school building are built or used, and which feed many of the vulnerability-creating characteristics not directly tied to school function. Scarce resources, inadequate seismic building codes, unskilled building professionals, and a lack of awareness of earthquake risk and risk reduction measures were the underlying drivers cited most often.

The terrible consequences of school collapses make it crucial to better understand the characteristics and underlying drivers that generate seismically vulnerable school buildings. Thus far, efforts to collect and make available detailed data on earthquake damage to school buildings have fallen far short of what is needed. Schools should receive focused attention in post-earthquake damage inventories, beyond the often cursory chapter in a reconnaissance report. School jurisdictions should share earthquake damage data they collect with the earthquake engineering community. Furthermore, the earthquake professional community should support research that provides quantitative information on the underlying drivers generating conditions that create or perpetuate school vulnerabilities.

ACKNOWLEDGMENT
The author thanks Surya P. Archarya, Jeannette Fernandez, Hari Kumar, Brian Tucker, L. Thomas Tobin and Carlos Ventura for their assistance in gathering data and information for this paper.

REFERENCES

ADB-WB (2005). *Preliminary damage and needs assessment – Pakistan 2005 earthquake*. Prepared by Asian Development Bank and World Bank, Islamabad, Pakistan, November 12, 2005.

Archarya, S.P., Joshi, N., Shakya, A., Parajuli, B., and Upadhyay, B. (2011). *Volume II: Survey and vulnerability assessment of school buildings*. NSET-Nepal, Kathmandu, Nepal.

Augenti, N., Cosenza, E., Dolce, M., Manfredi, G., Masi, A., and Samela, L. (2004). Performance of school buildings during the 2002 Molise, Italy earthquake. *Earthquake Spectra*, **20(S1),** S257-S270.

Bendimerad, F. (2004). Earthquake vulnerability of school buildings in Algeria. *Keeping Schools Safe in Earthquakes*, Organisation for Economic Co-operation and Development (OECD), Paris, France, 35-44.

Bothara, J.K., Sharpe, R.D. (2003). Seismic protection in developing countries: where are the gaps in our approach? *Pacific Conference on Earthquake Engineering 2003*, Christchurch, Paper 73.

Bothara, J. K. (2007). Social intervention required for sustainable seismic safety after the Pakistan earthquake, *Eighth Pacific Conference on Earthquake Engineering*, Singapore, Paper 049.

CCSD (2010). *Recommendations: schools with life safety issues information packet*. Charleston Country School District. Available online at http://www.ccsdschools.com/Departments_Staff_Directory/ Capital_Improvements/ seismic/documents/SeismicPacketPresented20100322.pdf.

CEA (2008). General introduction to engineering damage during Wenchuan earthquake. *Journal of Earthquake Engineering and Engineering Vibration,* **28 Supplement**, China Earthquake Administration, Harbin, China.

Chang, T.S., Pezeshk, S., Yiak, K.C. and Kung, H.T. (1995). Seismic vulnerability evaluation of essential facilities in Memphis and Shelby County, Tennessee. *Earthquake Spectra*, **11**, 527-544.

Consentino, N., Manieri, G. and Benedetti, A. (2004). A brief review of school typologies in Italy: specific vulnerability and possible strategies for seismic retrofitting, *Keeping Schools Safe in Earthquakes*, OECD, Paris, France, 187-196.

Dixit, A.M., Samant, L.D., Nakarmi, M., Pradhanang, S. and Tucker, B. (2000). The Kathmandu Valley earthquake risk management project: an evaluation. *12th World Conference on Earthquake Engineering*, Auckland, New Zealand, paper 788.

DOGAMI (2007). Statewide seismic needs assessment: implementation of Oregon 2005 Senate bill 2 relating to public safety, earthquakes and seismic rehabilitation of public buildings, *Open File Report O-07-02*, State of Oregon Department of Geology and Mineral Industries, Portland, Oregon.

Dolce, M. (2004). Seismic safety of schools in Italy. *Keeping Schools Safe in Earthquakes*, OECD, Paris, France, 53-63.

DSA (1994). *Northridge earthquake (January 17, 1994): performance of public school buildings, final report*. State of California, Division of the State Architect, Office of Regulation Services.

Durrani, A.J., Elnashai, A.S., Hashash, Y.M.A., Kim, S.J., and Masud, A. (2005). The Kashmir earthquake of October 8, 2005: a quick look report. *MAE Center Report No. 05-04*, Mid-America Earthquake Center.

EEFIT (2006). *The Kashmir, Pakistan earthquake of 8 September 2005: a field report by EEFIT*. Earthquake Engineering Field Investigation Team, Institution of Structural Engineers, London.

EEFIT (2009a). *The L'Aquila, Italy earthquake of 6 April 2009: a preliminary field report by EEFIT*. Earthquake Engineering Field Investigation Team, Institution of Structural Engineers, London.
EEFIT (2009b). *The Padang, Sumatra - Indonesia earthquake of 30 September 2009: a field report by EEFIT*. Earthquake Engineering Field Investigation Team, Institution of Structural Engineers, London.
EERI (1989). Armenia Earthquake Reconnaissance Report. *Earthquake Spectra*, **5(S1).**
EERI (1990). Buildings, Loma Prieta Earthquake Reconnaissance Report. *Earthquake Spectra*, **6(S1)**, 127-149.
EERI (2007). The Pisco, Peru earthquake of August 15, 2007. *Special Earthquake Report – October 2007,* Earthquake Engineering Research Institute, Oakland, California.
EERI (2009a). The Mw 6.3 Abruzzo, Italy earthquake of April 6, 2009. *Special Earthquake Report – June 2009*.
EERI (2009a). The Mw 7.6 Western Sumatra earthquake of September 30, 2009. *Special Earthquake Report – December 2009*.
EERI (2010). *The El Mayor Cucapah, Baja California Earthquake April 4, 2010: reconnaissance report.*
Eidinger, J. (2006). Kodiak Island Borough school vulnerability assessment, *G&E Report 87.01.05*, G&E Engineering Systems Inc. Available online at http://www.kodiakak.us/ DocumentView.aspx? DID=4
Gabrichidze, G., Lomidze, G., Mukhadze, T., Odisharia, A., Timchenko, I. (2004). April 2002 epicentral earthquake in Tblisi, Georgia. *13th World Conference in Earthquake Engineering*, Vancouver, Canada.
GHI (1995). *Investing in Quito's Future*. GeoHazards International, Palo Alto, CA.
GHI (2005). *Identifying earthquake-unsafe schools and setting priorities to make them safe: a case study in Gujarat, India*. Available online at www.geohaz.org.
Green, R. and Miles, S. (2011). Social impacts of the 12 January 2010 Haiti earthquake. *Earthquake Spectra*, **27 (S1)**, S447-S462.
Gulkan, P. (2004). Obstacles to improving seismic safety of school buildings in Turkey. *Keeping Schools Safe in Earthquakes*, Organisation for Economic Co-operation and Development, Paris, France, 65-87.
Gur, T., Pay, A.C., Ramirez, J.A., Sozen, M.A., Johnson, A.M., Irfanoglu, A. and Bobet, A. (2009). Performance of school buildings in Turkey during the 1999 Duzce and the 2003 Bingol earthquakes. *Earthquake Spectra*, **25(2)**, 239–256.
Holliday, L. and Grant, H. (2011). Haiti building failures and a replicable building design for improved earthquake safety. *Earthquake Spectra*, **27 (S1)**, S277-S298.
Jain, S. (2004). Implementing school seismic safety programmes in developing countries. *Keeping Schools Safe in Earthquakes*, OECD, Paris, France, 198-203.
Japan Times (2009). Education on Earthquakes – Editorial. *Japan Times*, July 5, 2009. Available online at search.japantimes.co.jp/print/ed20090705a2.html. Retrieved August 10, 2011.
Jephcott, D.K. and Hudson, D.E. (1974). Performance of public school plants during the 1971 San Fernando earthquake. *EERL Report*, Earthquake Engineering Research Laboratory, Pasadena, California.
Kabeyasawa, T., Kabeyasawa, T., Kusunoki, K., and Li, K. (2008). An outline of damage to school buildings in Dujiangyan by the Wenchuan earthquake on May 12, 2008. *14th World Conference on Earthquake Engineering, Beijing, China*, paper S31-002.
Kalem, I. (2010). Capacity related properties and assessment of school buildings in Turkey, *M.S. Thesis*, Middle East Technical University, Ankara, Turkey.
Kandel, R.C., Pandey, B. H., and Dixit, A. M. (2004). Investing in future generation: the school earthquake safety program of Nepal. *13th World Conference on Earthquake Engineering*, Vancouver, Canada.
Kenny, C. (2009). Why do people die in earthquakes? The costs, benefits and institutions of disaster risk reduction in developing countries. *Policy Research Working Paper 4823*, World Bank, Washington, DC.
Khakimov, S. and Tursonov, K. (2006). Earthquake safety of school children in Uzbekistan. *International Workshop on Keeping Schools Safe from Earthquakes*, Kathmandu, Nepal.
Langenbach, R. (2005). *Survey report on northern Kashmir earthquake of October 8, 2005 from the Indian Kashmir side of the line of control*. Available online at: www.conservationtech.com.
LAUSD (1994). *Report on the status of earthquake damage repairs*, Facilities Asset Management Division, Los Angeles Unified School District. Presented to the Committee of the Whole December 5, 1994.
Lopez, O.A., Hernandez, J.J., Del Re, G., and Puig, J. (2004). Seismic risk in schools: the Venezuelan project. *Keeping Schools Safe in Earthquakes*, OECD, Paris, France, 88-100.
López O. A., Hernández, J.J., Del Re, J., Puig, J. and Espinosa, L.F. (2007). Reducing seismic risk of school buildings in Venezuela. *Earthquake Spectra*, **23(4)**, 771-790.
Lopez, O.A., Hernandez, J.J., Marinilli, A., Bonilla, R., Fernandez, N., Dominguez, J., Baloa, T., Coronel, G., Safina, S. and Vielma, R. (2008). Seismic evaluation and retrofit of school buildings in Venezuela. *14th World Conference on Earthquake Engineering,* Beijing, China.
Marshall, J., Lang, A.F., Baldridge, S.M., and Popp, D.R. (2011). Recipe for disaster: construction methods, materials and building performance in the January 2010 Haiti earthquake. *Earthquake Spectra*, **27 (S1)**, S323-S344.
Meneses, J., and Aguilar, Z. (2004). Seismic vulnerability of school buildings in Lima, Peru. *13th World*

Conference on Earthquake Engineering, Vancouver, Canada. Paper No. 1683
Meslem, A. (2007). Seismic vulnerability evaluation of existing Algerian school buildings, *Final Report to ProVention Consortium*, Geneva, Switzerland. Available online at www.proventionconsortium.org.
Mitchell, B. (2004). Making schools safer: the New Zealand experience. *Keeping Schools Safe in Earthquakes*, Organisation for Economic Co-operation and Development, Paris, France, 119-130.
Miyamoto International (2008). *Earthquake field investigation report: Sichuan, China M8 earthquake May 12, 2008.* Available online at www.miyamotointernational.com
Mumtaz, H., Mughal, S.H., Stephenson, M., and Bothara, J. (2008). The challenges of reconstruction after the October 2005 Kashmir earthquake. *New Zealand Society of Earthquake Engineering Conference*, Paper 34.
Nakano, Y. (2007). Seismic rehabilitation of seismically vulnerable school buildings in Japan, *Proceedings, Regional Development Dialogue*, United Nations Centre for Regional Development, Kyoto, Japan.
Ohba, T., S. Takada, Y. Nakano, H. Kimura, Y. Owada, and T. Okada (2000). Seismic capacity of existing reinforced concrete school buildings in Ota City, Tokyo, Japan, *12th World Conference on Earthquake Engineering* (CD-ROM).
Parsizadeh, F. and Izadkhah. Y.O. (2005). Impact of the 2003 Bam, Iran earthquake on the personnel and functioning of local government organizations. *Earthquake Spectra*, **21(S1)**, S30-31.
Proença, J.M. (2004). Damage in schools in the 1998 Faial earthquake in the Azores Islands, Portugal. *Keeping Schools Safe in Earthquakes*, OECD, Paris, France, 131-139.
Rai, D., Prasad, A., and Jain, S. (2002). Hospitals and Schools, in Bhuj, India Earthquake of January 26, 2001 Reconnaissance Report, *Earthquake Spectra*, **18(Supplement A)**, July 2002.
RGoB (2009). *Bhutan earthquake September 21, 2009: Joint rapid assessment for recovery, reconstruction and risk reduction*. Royal Government of Bhutan (RGoB), the World Bank and the United Nations.
Rokovada, J. (2006). Fiji case study: assessing ongoing initiatives/ our children are our future. *International Workshop on Keeping Schools Safe from Earthquakes*, Kathmandu, Nepal.
Siegel, L.J. (2011). *Utah students at risk: a preliminary survey by the Utah seismic safety commission and structural engineers association of Utah.* Utah Seismic Safety Commission, Salt Lake City, Utah.
Spence, R. and So, E. (2009). Estimating shaking-induced casualties and building damage for global earthquake events. *Final Technical Report*, NEHRP Grant No. 08HQGR0102, available online at earthquake.usgs.gov.
Tamang, H.D., and Dharam, K.C. (1995). Innovation in primary school construction: community participation in Seti Zone, Nepal. *Educational Building Report 20*, UNESCO Regional Office, Bangkok, Thailand.
Taucer, F., Alarcon, J., and So, E. (2008). 2007 August 15 Magnitude 7.9 earthquake near the coast of central Peru, *Final Report, Earthquake Field Investigation Team (EEFIT) Field Mission, 5-12 September 2007.* Institution of Structural Engineers, London.
TBG (1990). *Seismic risk assessment of Vancouver School Board schools*, Transit Bridge Group, Vancouver.
Tena-Colunga, A. (1996). Some retrofit options for the seismic upgrading of old low-rise school buildings in Mexico. *Earthquake Spectra*, **12**, 883-902.
Thapa, N. (1989). *Bhadau Panch Ko Bhukampa*. Central Disaster Relief Committee, Kathmandu (in Nepali).
Thiruvengadam, V. and Wason, J.C. (1992). Postearthquake damage studies on performance of buildings during Bihar (India)-Nepal earthquake on 21st August 1988. *10th World Conference on Earthquake Engineering*.
Tierney, K. Hhazai, G., Tobin, L.T. and Krimgold, F. (2005). Social and public policy issues following the 2003 Bam Iran earthquake. *Earthquake Spectra*, **21(S1)**, S521.
Tsai, K.C., Hsaio, C.P., and Bruneau, M. (2000). Overview of building damages in 921 Chi-Chi earthquake. *Earthquake Engineering and Engineering Seismology* **2(1)**, 93-108.
UNCRD (2009). *Reducing vulnerability of schoolchildren to earthquakes: school earthquake safety initiative*, United Nations Center for Regional Development.
UNCRD (2007). *Preliminary field survey of school buildings in Tashkent*. UN Centre for Regional Development, available online at: http://www.hyogo.uncrd.or.jp.
UNICEF (2010). Updated list of damaged schools – Ouest and Sudest Departments, spreadsheets, available online at: http://oneresponse.info/Disasters/Haiti/Education/Pages/default.aspx.
Wisner, B. (2006). *Let Our Children Teach Us! A Review of the Role of Education and Knowledge in Disaster Risk Reduction.* ISDR Thematic Cluster on Knowledge & Education. Books for Change, Bangalore.
Xiong, Z.H. (2008). Lessons learned from Wenchuan earthquake: to improve the seismic design of school buildings. *14th World Conference in Earthquake Engineering, Beijing, China*, paper S31-053.
Yegian, M.K. and Ghahraman, V.G. (1992). The Armenia earthquake of December 1988: engineering and reconstruction aspects. *Report No. CE-92-11*, Northeastern University, Boston, Massachusetts.
Yi, Z.L. (2005). A database of the compulsory school buildings and comparison between seismic evaluation methods in Taiwan. *M.S. Thesis*, Department of Construction Engineering, National Taiwan University.
Yüzügüllü, Ö., Barbarosoglu, G., and Erdik, M. (2004). Seismic risk mitigation practices in school buildings in Istanbul, Turkey. *Keeping Schools Safe in Earthquakes*, OECD, Paris, France, 176-183.