Earthquake Safety Guidelines for Educational Facilities

By Rob Jackson, P. E.

Every child has the right to attend school in safe buildings. The United States has been relatively lucky so far regarding school children and the occurrence of earthquakes. However, the United States cannot rely on such continued good fortune in the future. Governmental and educational leaders must fulfill their responsibilities for the safety of school children by implementing school safety programs that include the design and construction of seismically safe buildings. Such programs must emphasize seismic resistance and overall earthquake hazard resilience. Earthquake hazard mitigation is most readily accomplished through the improved seismic design and construction of buildings, since “earthquakes don’t kill people, unsafe buildings do.” Earthquake hazard mitigation requires an increase in the prioritization and perceived value of seismic design within the project delivery systems of the owners, construction managers, architects and engineers who operate, design and construct educational facilities in the United States.

Over the past year, the United States Geological Survey (USDI, USGS, 2012) recorded an average of nearly 1,500 earthquakes of magnitude 5 or greater worldwide. Damaging earthquakes may be infrequent when compared to seasonal natural hazards. However, earthquakes can be very high consequence events. For schools, the consequences could be catastrophic for children in seismically vulnerable school buildings should an earthquake occur during school hours. Society is learning and acknowledging the need to provide “punctuated resilience to protect against what is possible, beyond what is probable" (O’Rourke, 2012). To do so will require an increased earthquake awareness for parents, educators, school boards and students. Such an increase in awareness has been a focus of the Earthquake Engineering Research Institute’s (EERI) Seismic Safety of Schools Committee (EERI, 2012).

A typical unreinforced masonry high school in the United States. (Wang, Y., EERI, 2012a)

Similar advocacy efforts have impacted policy across the United States. In California, positive steps have been taken to increase the seismic safety of schools. The 1933 Long Beach earthquake resulted in passage of the Field and Riley Acts. In California, no school child has been killed or seriously injured since 1933. However, no major California earthquakes since 1925 have occurred during school hours. The Field Act required all public school buildings to be designed by a California licensed structural engineer and also implemented increased review and inspection requirements. The Riley Act required specific lateral force requirements for design, and effectively outlawed unreinforced masonry buildings. School buildings constructed of unreinforced masonry present a significant danger to students and teachers, but earthquakes will also find the weak areas in otherwise well designed and constructed buildings.

Even though United States schools have not yet experienced catastrophic damage and loss of life, major earthquakes in the rest of the

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world have taken a severe toll on schools. In the 2008 Wenchuan, China earthquake an estimated 19,000 died in 7,000 schools. Also, 19,000 children died while attending school during the 2005 Pakistan earthquake (Maqsood & Schwarz, 2008). In 2010, Haiti's magnitude 7.0 earthquake destroyed or damaged nearly 4,000 schools (UNOCHA, 2011). 4,000 schools were badly damaged or destroyed in the 2010 Chile earthquake (Dillard & Leon, 2010). The 2011 earthquake in Christchurch, New Zealand, resulted in 153 schools damaged, 11 seriously.

This Japanese school is in session after the 2011 Tohoku earthquake. Notice the evidence of liquefaction and settlement around the building. The building used pile foundations and was built for seismic conditions. (Wang, Y., EERI, 2012b)

The occurrence of earthquakes cannot be accurately predicted. Therefore policy must be proactive even in the least earthquake prone areas. The 2011 Virginia earthquake resulted in $30 million in damage to schools in an area that had not experienced a major earthquake since 1875 (EERI, 2011). Earthquake preparedness requires awareness training for teachers and students. School children are required to temporarily stay at the schools and essentially "shelter in place" during an earthquake; thus the need for "drop, cover, and hold" drills. In addition, the local government and school board should establish whether the school is to be used as a post-earthquake community shelter. New schools to be used as shelters should require an "immediate occupancy" or "operational" performance level of seismic resistance. As a minimum, schools should be safe and usable during repair. Schools should be able to be occupied without restriction (e.g., receive an official "green tag" by inspectors) after the expected earthquake (Maffei, 2009).

Priorities for Earthquake Hazard Mitigation in Educational Facilities

1) **Establish the project management approach for the design and construction of the school including seismic resilience as a necessary measure of quality.** A successful project must meet the requirements for quality, budget, and schedule. If budget and schedule are prioritized over quality, the long term success of the project is at risk. Quality cannot be judged only on operational efficiencies and aesthetic aspects. Form follows function. What is behind the walls and beneath the building can ultimately determine whether the school meets all its intended purposes for use and occupancy over the life of the building.
    a) **Prepare estimates considering life-cycle costs.** Consider the embodied energy (the initial energy provided from all materials and construction in building the school) and include the benefits of seismic resistance over the life of the school building.
    b) **Include all Special Inspection requirements in the contracting process.** It is important that the various roles and responsibilities required to implement Special Inspections are identified and the scopes of work included in the appropriate contracts early on in the contracting process. The Owner is

    responsible for ensuring that Special Inspections are performed and documented to the code authority.

2) **Hire a structural engineer with seismic design experience.**
3) **For new schools, the site selection process must include geological considerations** up front including obtaining a Geological Survey review.
4) **Design and construction of all schools, at a minimum, should be in full compliance with the provisions of appropriate building codes** (ASCE, 2010; FEMA, 1998; ICC, 2012a) even if, for whatever reason, building codes have not been adopted in their locale.
    a) **Require a thorough geotechnical report** that addresses all the building code requirements and includes foundation recommendations and all seismic design parameters such as the liquefaction potential at the site. The Site (soil) Class should be determined based on the shear wave velocity (v_s) in the upper 30m (100 ft).
    b) **Establish the Seismic Design Category (SDC)** based on the hazard maps, the Risk Category and the Site Class. The Risk Category is a function of the occupancy group of the building. Schools are normally considered Risk Category III, but if used as shelters they should be considered to be Risk Category IV. The SDC ranges from A (virtually no seismic design is performed) to SDC F. SDC D is the default if soils information is inadequate to properly establish the shear wave velocity.
    c) **Non-structural elements require anchorage to the primary seismic force resisting structural system of the building.** These components of the school building include mechanical, electrical and plumbing systems, equipment, partitions, cladding, and ceilings. Although bracing and anchorage should always be provided where necessary, the code design requirements for seismic anchorage and equipment performance are also a function of the Risk Category and Seismic Design Category. The building code may exempt these requirements in lower seismic hazard areas.
5) **The challenge of existing buildings is initially one of risk assessment**. The **seismic risk** is a function of the level of earthquake hazard vs. the vulnerability of the building. With the help of structural engineers, **develop vulnerability assessments** of the existing buildings by screening the buildings for seismic deficiencies. Utilize the “Rapid Observation of Vulnerability and Estimation of Risk” software (ROVER, FEMA P-154) (FEMA, 2002; FEMA, 2011) or seismic safety checklists such as are included in ASCE 31 (ASCE, 2003) and ASCE 41 (ASCE, 2006)
    a) **Prioritize the assessment of existing buildings** that were not designed to modern building codes, generally considered to be 1976 and later. In some places, such as Oregon and parts of the central US, modern seismic codes were not adopted until decades later. Changes in the hazard maps and/or the “zones” of the older codes should also be considered in determining to what extent a building meets current seismic design requirements.
    b) **Prioritize the identification of and risk reduction for unreinforced masonry buildings** (FEMA, 2009).
    c) **Prioritize the identification** of and **risk reduction** for non-ductile concrete buildings, multi-story schools with weak stories, and those

with significant landslide, liquefaction or tsunami hazards.

d) **Seek examples when developing a seismic needs assessment.** See how Oregon has developed a statewide seismic needs assessment. http://www.oregongeology.org/sub/projects/rvs/default.htm#overview

e) **Develop a retrofit plan** based on the seismic hazard and the vulnerability, for improved seismic performance of the building(s). Use ASCE 41 or the International Existing Building Code (ICC, 2012b) for procedures and criteria.

f) **Consider incremental seismic rehabilitation** in order to start the improvements sooner (FEMA, 2003). The seismic vulnerability of an existing school building may be such that the anticipated seismic performance is not even at the life safety level. A retrofit project for such a building should consider meeting a level beyond life safety, if not immediately then as part of an incremental program.

g) **Inspections should still be made,** and improvements documented on the facilities "as-built" construction documents, even though some non-structural retrofit work can be performed by school maintenance personnel.

h) **Get support** of local parents, educators, and legislators for fund raising and increasing preparedness and awareness (FSSSBC, 2012).

Additional Recommendations:

Consider a second opinion on budgets and schedule. The owner (school district) may benefit by hiring a cost estimator. The Federal Emergency Management Agency (FEMA) has a web site that provides some assistance in doing preliminary seismic cost estimating for retrofit projects. See Seismic Rehabilitation Cost Estimator at http://www.fema.gov/srce/index.jsp

In lower seismic hazard regions the International Building Code (ICC, 2012a) may allow the use of Seismic Design Category A (minimal requirements). Some municipalities have amended the code to prohibit the use of SDC A. Since uncertainties in the seismic hazard maps are often high in the lower seismic regions, the use of SDC A is discouraged for schools. Risk is substantially increased when seismic design is not performed. The Western States Seismic Policy Council recommends a minimum of Risk Category IV and Seismic Design Category C as part of their policy recommendation for the design of new schools (WSSPC, 2012).

To ensure non-structural components are anchored and designed appropriately for schools, attention must be given to the outcomes that are achieved through the use of the various Risk Categories and Seismic Design Categories. Consideration should be given to maintaining more robust seismic design criteria for components by ignoring component design exemptions that may be available within the code. Certain components, including fire protection systems for school buildings, should always be required to function after an earthquake. For Risk Category IV buildings, such as schools that are required for shelters, all seismic component anchorage and performance design must provide for continued operation of the facility.

Earthquake preparedness drills and curricula are important. Using a variety of relevant scenarios helps to increase interest and keep awareness focused.

Additional Resources:

1) ACEF – "Earthquake preparedness. [Audio Podcast]" – 2011. Retrieved from http://online.tarleton.edu/ACEF/EarthquakePreparednessPodcast.mp3
2) California Emergency Management Agency, "Guide and Checklist for Nonstructural Earthquake Hazards in California Schools", January, 2011
3) FEMA E74 – "Reducing the Risks of Nonstructural Earthquake Damage", September 2010
4) FEMA P-420 – "Engineering Guideline for Incremental Seismic Rehabilitation", May 2009
5) FEMA 454 – "Designing for Earthquakes: A Manual for Architects", December 2006
6) FEMA 547 – "Techniques for the Seismic Rehabilitation of Existing Buildings", September 2006
7) FEMA P-424 - "Design guide for improving school safety in earthquakes, floods, and high winds," 2010.
8) Federal Emergency Management Agency. FEMA Webinar: "Earthquake safety & mitigation for schools", 2012. Retrieved from https://fema.connectsolutions.com/nehrp-webinar/
9) New York Times, Andy Revkin, http://dotearth.blogs.nytimes.com/2010/01/23/building-safer-schools-in-poor-shaky-places/
10) Tracy Monk – "The importance of Community Involvement and Engineering Advocacy on the Road to School Seismic Safety in British Columbia", 9th Canadian Conference on Earthquake Engineering, Ottawa, Ontario, Canada, June 2007
11) Wolf, Edward C, and Wang, Yumei, in preparation, "URM-Free by 2033: Toward a National Safe Schools Agenda, American Society of Civil Engineers, Council on Disaster Reduction Monograph 7, Jim Beavers Editor, http://www.asce.org/uploadedFiles/Technical_Groups_and_Institutes/Technical_Activities_Committees_(TAC)/CDRM/Safe%20School%20ProgramsToward%20A%20National%20AgendalV2.pdf
    Presentation: http://2012am.eeri.org/wp-content/uploads/2012/05/4-Wang-2012-NEC-memphis-recent-eqs-YW-ECW.pdf

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