IMPACTS OF THE M7.1 NOVEMBER 30, 2018 ANCHORAGE, ALASKA EARTHQUAKE ON SCHOOLS

J. Rodgers[(1)], W. Hassan[(2)], C. Motter[(3)], and J. Thornley[(4)]

[(1)] *Chief Operating Officer, GeoHazards International, rodgers@geohaz.org*
[(2)] *Associate Professor, University of Alaska, Anchorage, wmhassan@alaska.edu*
[(3)] *Assistant Professor, Washington State University, c.motter@wsu.edu*
[(4)] *Associate and Geotechnical Engineer, Golder Associates, Inc., john_thornley@golder.com*
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Abstract

The M7.1 2018 Anchorage earthquake damaged schools in the Anchorage and Matanuska-Susitna (Mat-Su) School Districts. Many remained closed for a week or more for cleanup and repairs. While major structural damage occurred in 3 of over 130 school buildings across both districts, most observed damage was to nonstructural components, including suspended ceilings, lighting, HVAC systems, piping, partitions and windows. Schools were typically built to comply with seismic design codes, which helped to limit structural damage.

Three schools in strongly shaken areas, two in Eagle River and one in Big Lake, suffered structural damage severe enough to close them for the rest of the school year. Damage to CMU partitions caused closure of the gymnasium at an additional Mat-Su school. Another Eagle River school operating in a rented building was closed for the remainder of the year by major nonstructural damage. Minor structural damage or evidence of nonlinear behavior was observed at a number of additional schools. Observed structural damage was to reinforced masonry and concrete, while wood-frame schools, including older ones, suffered little structural damage. Nonstructural damage, primarily to ceilings, caused most school closures.

Many schools were in session at the time of the earthquake. Despite ceiling damage and fallen ceiling tiles, books, and supplies (heavy furniture was anchored), both districts reported very few injuries. Statements by the school districts, media reports, available video, and field interviews with administrators indicate that most students dropped and covered as trained. Schools in both districts held regular “Drop, Cover and Hold On” drills. The combination of life-safety structural performance (with a few exceptions), anchoring of heavy furnishings, and student preparedness and drills to practice protective action appears to have protected students. Structural damage indicates that older schools in Alaska and elsewhere be seismically evaluated and strengthened or replaced if needed. If districts want to reduce lost instructional time as well, they should ensure nonstructural components such as ceilings have adequate seismic design.

Keywords: structural damage, nonstructural damage, preparedness, injuries, strong motion

1. Introduction

The area affected by the M7.1 November 30, 2018 Anchorage earthquake, shown in Figure 1, includes Alaska's two largest school districts by student population, namely the Anchorage School District (ASD) with nearly 46,000 students [1], and the Matanuska-Susitna Borough School District (MSBSD) with over 19,000 students [2]. MSBSD covers more than 25,000 square miles [3] and is the sixth-largest district in the nation in geographic area. ASD covers nearly 2000 square miles. These two school districts experienced the vast majority of the school damage during the earthquake. The earthquake epicenter was located in the southwestern part of the MSBSD. The most densely populated portions of the ASD, the Anchorage Bowl (main city area) and nearby town of Eagle River, also experienced significant shaking. Shaking was also felt across the Kenai Peninsula Borough School District (KPBSD) further south, but impacts were minor.

Figure 1 – Map of Alaska showing school district locations and USGS earthquake epicenter. Image source: Google Earth; satellite imagery IBCAO, Landsat/Copernicus; data from USGS, Alaska State Geo-Spatial Data Clearinghouse, SIO, NOAA, US Navy, NGA, GEBCO.

The earthquake occurred at 8:29am local time, when middle and high schools (secondary schools) were in session. Elementary schools (primary schools) were not yet in session, though some schools with before-school programs had some students already on site. This paper provides an overview of damage to schools and resulting impacts, and provides a more detailed discussion of structural damage at Houston Middle School, the most heavily damaged school in the Matanuska-Susitna (Mat-Su) District.

2. Background on Matanuska-Susitna and Anchorage Schools

At the time of the earthquake, the ASD had 86 school buildings, with 97 schools or programs operating in them, including 59 elementary schools, 11 middle schools, 13 high schools, 1 K-12 school, and 13 charter schools or schools with special missions. The MSBSD had 47 schools providing K-12 education, including 21 elementary schools, 5 middle schools, 8 high schools, 4 K-12 schools, and 9 charter schools or schools with special missions. Following the earthquake, three district-owned school buildings and one rented facility were closed for the remainder of the year due to damage, with students moved to other facilities.

MSBSD has school facilities with a range of ages from the 1950s to 2010s, though the majority of schools were built in the 1970s, 1980s, and after 2000 [4]. Structural systems are primarily wood frame, reinforced (CMU) masonry, steel braced frame, steel moment frame, and reinforced concrete shear wall; MSBSD has no unreinforced masonry buildings [4]. Anchorage schools are a bit older, with 24 facilities over 50 years old and a range of construction types. Depending on their age, ASD and MSBSD schools were designed to the editions of either the Uniform Building Code (UBC) or International Building Code (IBC) adopted by the Municipality of Anchorage (MOA) and the Matanuska-Susitna Borough, respectively, at the time of design. The districts, MOA and Borough all inspect school construction.

3. Structural Damage to Schools

3.1 Damage Overview

Across the ASD and MSBSD, three school district buildings out of 133 suffered structural damage severe enough to render them unsafe and necessitate closing them for the remainder of the school year. Houston Middle School near Big Lake, and Eagle River Elementary and Gruening Middle School in Eagle River were heavily damaged and red-tagged. In addition, a rented facility in Eagle River shared with the University of Alaska Anchorage was closed due to extensive, primarily nonstructural damage, and students relocated to another campus. None of these schools have strong motion instruments on site, but recordings within 5-10 km [5] indicate that three school sites may have experienced peak ground accelerations in the 0.2-0.3g range or higher. We describe structural damage to Houston Middle School and its causes as well as an overview of other structural damage, in subsequent sections. We present additional damage information about other facilities elsewhere [6].

3.2 Houston Middle School

Houston Middle School, shown in Figure 2, is a reinforced CMU and steel frame building constructed in 1986. It has three main portions: a classroom wing, an administrative wing that also contains assembly and vocational education areas, and a gymnasium. It suffered the most significant structural damage of Mat-Su schools and it was declared unsafe for students and closed for the remainder of the school year.

Figure 2 – Houston Middle School, showing the three main parts of the building. Imagery: Google Earth

The classroom wing suffered the most significant damage. At the time of this report, the district had approved the replacement of the most heavily damaged wing and seismic upgrades to other portions. The area continues to have a high level of seismic hazard due to the nearby Castle Mountain Fault and other earthquake sources in this highly active plate boundary.

Houston Middle School has several design features and construction defects that contributed to the damage. The lateral load resisting system consists of partially grouted, CMU shear walls with reinforcement spacing twice that required by modern codes [7], laid in stack bond (rather than the stronger and more typical running bond), with a flexible wood diaphragm at the roof and a concrete floor on steel deck at the first floor. The steel frame system in the gymnasium wing was complete, but the gravity frame in the classroom wing was not. The classroom wing had several steel roof girders bearing directly on tall CMU walls, without a supporting column beneath. A number of girder-to-wall connections, which consisted of shear studs embedded in a grouted cell in the top course of a tall CMU block wall, failed during shaking (Figure 3), leaving the girders in danger of unseating in an aftershock, and falling into the classrooms below. The reinforced concrete bond beam at the top of the CMU walls shown on the drawings (see Figure 4), and into which the beam connections where supposed to have been made, was not installed, according to a post-earthquake engineering inspection [7]. Had it been installed, the bond beam would have resulted in a stronger connection that may have reduced observed damage, though the CMU walls and overall structural design had other significant deficiencies as well.

Figure 3 – Failed connection between steel roof girder and CMU wall in second story of classroom wing (left); similar failed connection (right). Photos: Bill Noyes (left), Janise Rodgers (right).

Engineers also determined that CMU was installed unreinforced in some isolated locations at the tops of walls and around structural steel members [7], meaning it was much more easily dislodged. Some blocks broke apart and fell, presenting a significant life safety hazard to anyone in the vicinity. Figure 5 shows fallen block in the Classroom Wing. Other damage included significant cracking of the partially grouted stack-bond CMU walls in the classroom wing, CMU cracking in numerous other locations, and cracking in the gymnasium CMU walls caused by relative motion of the steel roof members, as shown in Figure 6.

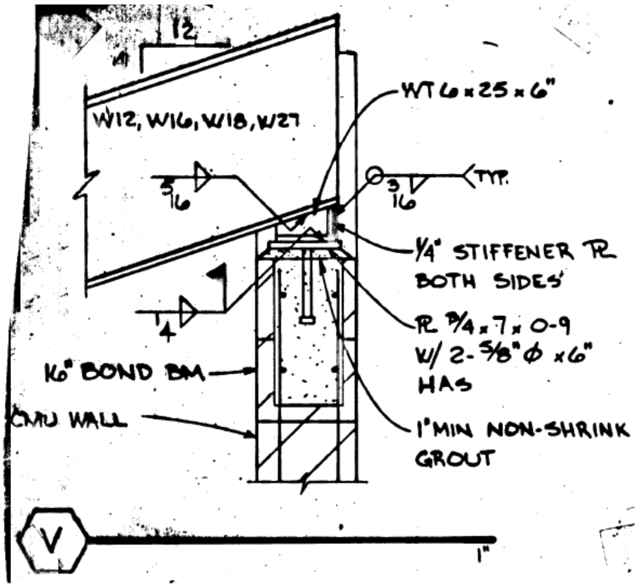

Figure 4 – Structural drawing of roof girder-to-CMU wall detail that failed (courtesy MSBSD). Post-earthquake inspections revealed that the bond beam at the top of the CMU wall had not been installed.

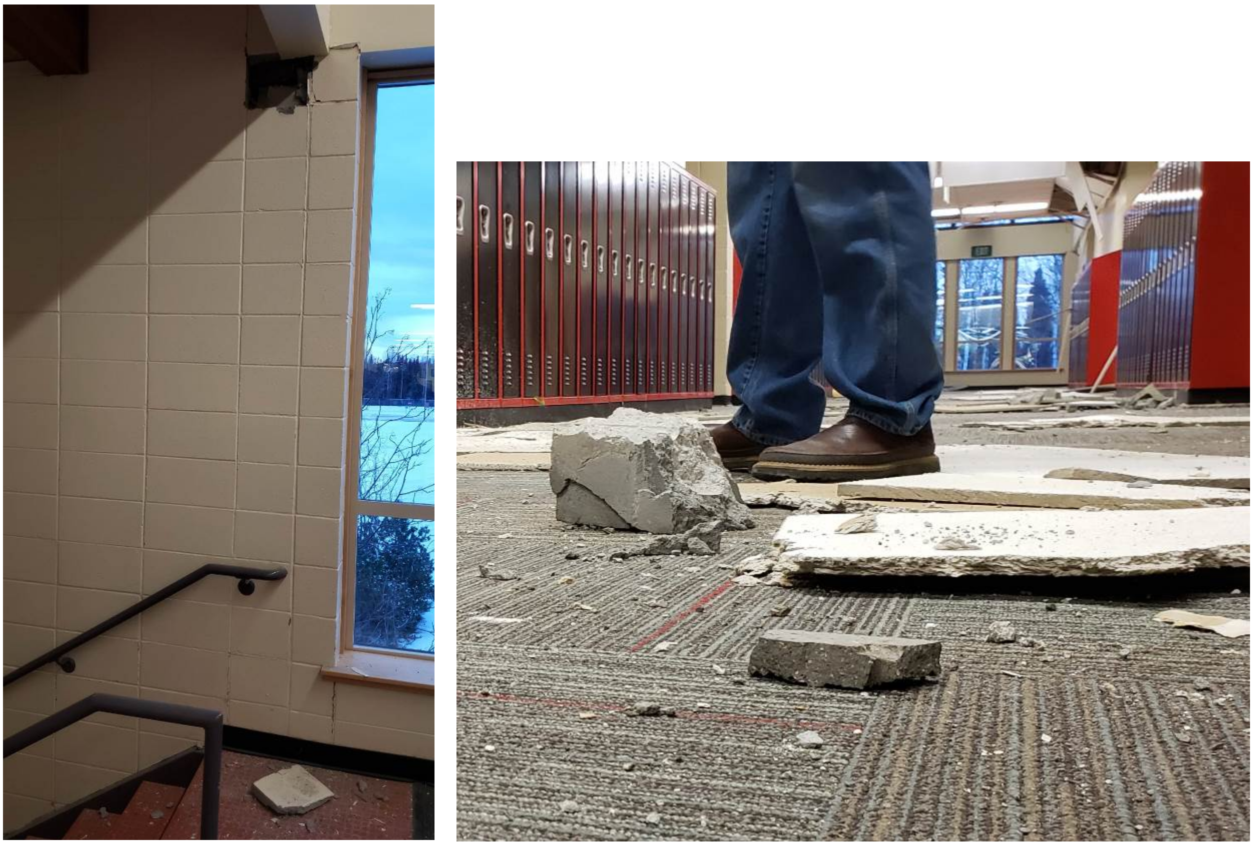

Figure 5 – Fallen block at stairs (left) and in hallway (right), Classroom Wing. The latter was dislodged by damage to the steel-girder to CMU wall connections shown in Figure 3. The classroom wing also suffered extensive damage to the suspended ceiling grid and tile, and many tiles fell. Photos: MSBSD

Figure 6 – CMU block at top of wall cracked and loosened due to differential motion of steel roof framing, Houston Middle School. Loose blocks pose a falling hazard to those below. Photo: MSBSD

3.2 Other Matanuska-Susitna Schools

In addition to Houston Middle School, three other schools suffered structural damage or required additional structural evaluation before re-opening. Colony High School and Wasilla Middle School experienced some CMU wall cracking that required further structural investigation. Mat-Su Central School experienced some cracking that necessitated further evaluation. Minor structural damage or evidence of inelastic structural behavior, such as hairline cracking in joints of reinforced CMU masonry, occurred in 14 schools, including Finger Lake Elementary, Goose Bay Elementary, Meadow Lakes Elementary, Wasilla Middle, Palmer Junior Middle, Palmer High and Colony Middle. At Colony Middle School, built at the same time as Colony High (designed 1996, completed 1988) but with a reinforced concrete shear wall lateral system, the team observed a 1/32 inch to 1/16 inch (0.8 to 1.6 mm) diagonal crack in a shear wall. This was the only wall the team could observe; others were covered by finishes, lockers or were otherwise inaccessible.

Damage due to differential movement and interaction between flexible steel frame systems and stiff but inadequately braced or reinforced CMU walls occurred at Colony High School as well. Reinforced CMU walls in the Colony High gymnasium, at the upper running track and in a stairwell, suffered cracking. CMU blocks dislodged by differential movement with the roof fell down into the stairwell, which was fortunately empty at the time of the earthquake. According to a district-provided engineering evaluation [8], the CMU walls were intended to be partitions providing a hard surface; however, in the case of the running track walls, they interfered with lateral motion of the steel frame. Some walls appear not to have been built per the design drawings. The 30 ft (9.14m) tall stair wall did not have the top lateral bracing details shown in the drawings. However, the evaluation determined this detail would be insufficient to restrain such a tall heavy wall under strong shaking, even if had it been installed, and recommended replacement with lightweight materials.

3.4 Anchorage and Eagle River Schools

Two schools in Eagle River, Eagle River Elementary School and Gruening Middle School, which are part of the Anchorage School District, suffered structural damage sufficiently severe that they were red-tagged and closed for the remainder of the school year. Eagle River Elementary School is a timber and reinforced CMU building built in several phases in 1961, 1962, 1970 and 1984. The gymnasium, which was part of the 1984 addition, suffered failure of the roof-to-wall connection along the north and south walls. Per engineering inspection report provided by the district [9], the wood nailer atop the north CMU wall failed in cross-grain tension, and the timber I-joists along the south wall slipped from their hangers, allowing the CMU wall to tilt outward and the external masonry veneer to separate.

Gruening Middle School is a stack-bond CMU and timber building, with some steel members, including columns supporting long-span steel trusses in the gymnasium. It was built in 1981 and has complicated geometry. It has had numerous modifications and renovations, due to deficiencies in the original seismic design that were discovered when construction was nearly complete [10]. The building had a Tier 3 ASCE 41 assessment in 2015, and a number of measures were recommended but were not implemented at the time of the earthquake. Damage included a failed top of wall connection between the CMU walls and wood diaphragm at two known locations, causing the CMU walls to separate from the floor and lean. Shaking also caused damage and spalling of CMU around steel columns, as well as cracking in the stack bond CMU walls [10]. Other structural damage includes permanent residual drift in two steel columns supporting the gymnasium roof. Earlier assessments had identified the following deficiencies: CMU walls were inadequately reinforced; plywood shear walls were not connected between floors, continuous or adequately nailed; unblocked diaphragm spans were too long, with unreinforced openings, among other deficiencies [10]. Damage to CMU masonry infill included crushing of masonry and exposure of rebar along the interface between these walls and steel columns. No integrity reinforcement was observed between the steel columns and the CMU walls. As occurred at Houston Middle and Colony High, deformation incompatibility between the flexible steel framing and stiff CMU masonry likely caused the observed damage to the stiffer masonry infill.

4. Damage to Architectural Elements, Building Systems and Equipment, and Contents

In both districts, far fewer schools suffered structural damage than damage to architectural elements, building systems, other nonstructural components, and contents. Damage to architectural finishes, particularly suspended ceilings and gypsum wallboard, was widespread across both districts. Schools in both districts also reported numerous leaks from pipes carrying water and glycol (a fluid used in heating systems). Unanchored equipment in mechanical rooms also shifted, causing further leaks and damage. Figure 7 shows examples of damage to suspended ceilings and piping.

Figure 7 – Example of major ceiling damage, Houston Middle School (left) and glycol leak due to pipe connection damage, Gruening Middle School (right). Photos: MSBSD (left) and Wael Hassan (right)

Both districts had a large variety of ceilings, ranging from completely unbraced to newly built using current code. Most newer ceilings performed well, with the exception of some newer designs with especially heavy acoustical panels. A great deal of additional information about damage to nonstructural components and systems is located in the Earthquake Engineering Research Institute reconnaissance report for this earthquake [6].

5. Impacts of School Damage on School Function, Students and Staff

5.1 School Closures and Disruption of Instruction

ASD and MSBSD closed all schools the day of the earthquake, sending home students already at school. Primarily due to the need to clean up fallen contents and repair damage to architectural finishes (especially ceilings) and building utility systems, all ASD schools remained closed the week following the earthquake, and almost all reopened at the same time. Due to the greater disparity in levels of shaking in the much larger Mat-Su district, schools there re-opened in staggered fashion, as shown in Figure 8. Students at red-tagged schools that did not re-open were shifted to open school sites within two weeks of the earthquake in ASD and three weeks in MSBSD.

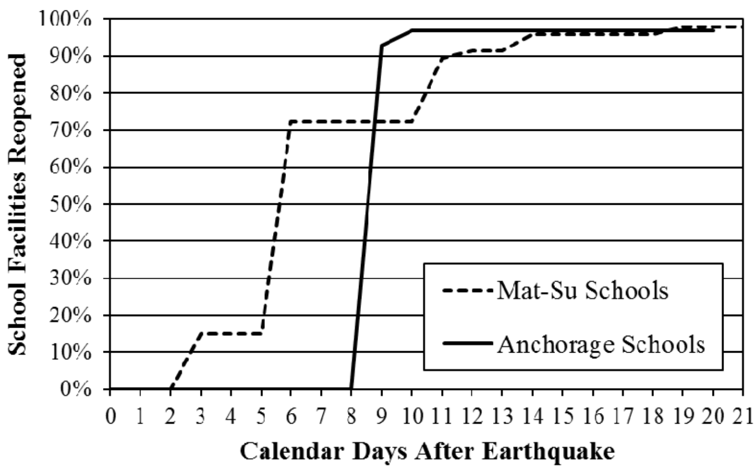

Figure 8 – School facility reopening curves

5.2 Student and Staff Injuries

Middle and high schools were in session at the time of the earthquake, and despite extensive ceiling damage, including falling ceiling tiles, metal light fixtures, books and supplies (heavy furniture was typically anchored), both school districts reported very few injuries. According to injury data provided by the districts, MSBSD schools reported 13 student injuries and 2 staff injuries, while ASD schools reported 3 student injuries and 11 staff injuries, out of a of an estimated 2,200-2,300 students in MSBSD and over 19,000 students in ASD at the time of the earthquake. The most serious injury was a concussion suffered by a student who was hit by falling books, and then hit their head on a desk. Other student injuries included being struck by falling objects and asthma from dust, as well as reports of shock, stress, dizziness, and low blood pressure. Staff injuries were primarily bruises and muscle pulls from getting under desks, or being struck by falling debris. Even in schools with substantial ceiling damage, few injuries occurred because most students were underneath their desks and protected by the desktops from falling ceiling tiles, pieces of the ceiling grid, and lighting components, and were out of the way of swinging air diffusers.

5.3 The Role of Preparedness and Pre-Earthquake Mitigation

Statements by the school districts, media reports, and field interviews with administrators, as well as review of available social media footage [11] indicate that students quickly taking protective action under desks, as they had been trained to do during "Drop, Cover and Hold On" drills at least once per semester, was a key reason for the low number of injuries. A number of middle and high schools suffered extensive ceiling damage that caused tiles, portions of the grid, light fixtures and air diffusers to fall and swing into the space students would normally occupy. Also, classroom environments in both districts had been made much safer by anchoring large and heavy furnishings such as bookshelves, and classroom equipment such as smartboards, which reduced hazards to students from heavier items and from toppling items striking from the side.

Structural performance that kept buildings standing and in many cases structurally undamaged (or with minimal damage / nonlinear behavior) was the most important factor in protecting students. It is worth mentioning, however, that several schools experienced serious structural damage that might have led to partial collapse had shaking been just a bit stronger or of longer duration. It was fortunate that no collapses or fatalities occurred. The varied nature of school structural performance in this earthquake underscores the essential role of earthquake-resistant new buildings, and of seismic retrofits of older, deficient buildings in protecting students. Even the most effective preparedness programs will not protect students in a collapse.

Preparedness programs do appear to have had a key role in protecting students during this earthquake in buildings that were already structurally life safe. By the time they reached middle and high school, students who had been in ASD and MSBSD for years would have participated in numerous "Drop, Cover and Hold On" drills. During this earthquake, the effectiveness of drills and contents anchoring in elementary schools did not receive a similarly rigorous test, because elementary schools were not in session. It is likely, though, that most elementary students, with training and practice, could also "Drop, Cover and Hold On" quickly underneath desks and tables, which would similarly protect them from falling objects. This earthquake clearly shows the effectiveness of protective actions taught in preparedness programs and practiced in drills, combined with contents anchoring, to protect middle and high school students from falling objects in classroom environments, even if significant nonstructural damage occurs.

It is noteworthy, however, that of the incidents of heavy objects falling (CMU blocks, heavy acoustical tile, and other items), most occurred in areas without safe cover nearby, such as stairs, hallways and gymnasiums. Few to no students, mercifully, were in these locations at the time of the earthquake. Had they been, serious injuries and even loss of life could have resulted. It is particularly important to identify and mitigate the threat from heavy objects overhead in these areas.

6. Lessons Learned and Conclusions

The combination of overall life-safety structural performance (with some exceptions), anchoring of heavy furnishings, and student preparedness and drills to practice protective action appears to have protected most students. As trained, students took action immediately to take cover under classroom desks or in other safer places. Even in schools with substantial ceiling damage, few injuries occurred because students were protected by their desks in most cases from objects falling or swinging from the ceiling. This earthquake provides direct evidence that school earthquake safety programs that include building structural safety, mitigation, and preparedness drills protect students.

Despite limited structural damage due to earthquake resistant design and code-compliant construction, a small number of older buildings experienced serious structural damage that could have become life-threatening in a modestly larger or longer-duration earthquake. In addition, some schools experienced potentially-life threatening damage, such as falling CMU block, but no students were in those areas at the time. Schools with flexible steel framing surrounded by CMU walls proved vulnerable to this type of damage. Other schools of this construction type need to be assessed, because this type of damage can occur at moderate levels of shaking and creates falling debris that is dangerous to students.

These observations point to the need to expand current and recent vulnerability assessment programs to cover all schools in Alaska's areas of high seismic hazard. Older schools must be seismically evaluated, and strengthened or replaced if needed. Continued vigilant oversight of new school design and construction is needed to prevent poor design and shoddy construction from putting students at risk. Furthermore, if districts want to reduce lost instructional time, and prevent injuries, more attention must be paid to addressing seismic vulnerabilities in existing architectural elements, building utility systems and other nonstructural components, and ensuring new nonstructural components have adequate seismic design. These lessons apply equally to schools elsewhere in the United States and internationally. This earthquake provides strong evidence that school earthquake safety programs work and should be implemented in all schools in areas of significant seismic hazard worldwide.

7. Acknowledgements

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