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PANEL ON SEISMIC SAFETY OF SCHOOLS

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ABSTRACT

Panelists in the panel session on Seismic School Safety will address or comment on the following questions:

1. What is the expected earthquake damage to public (elementary through high school) schools in the U.S. and British Columbia?
2. What is the worst case earthquake scenario in terms of student fatalities (in the U.S. and British Columbia)?
3. What level of seismic safety of schools is acceptable?
4. What actions are needed to achieve that level of safety?
5. What new state, provincial or national programs (or policies) are needed?

As a practicing architect specializing in K-12 design in California and a Professor of Architectural Structures at CSU Pomona, I am only qualified to discuss my knowledge of California's K-12 Schools with respect to these questions.

1. What is the expected earthquake damage to public (elementary through high school) schools in the U.S. and British Columbia?

An answer to this question requires a slight diversion into the history of the code and its basic philosophy for schools in CA.

The first mention of seismic issues in the UBC followed the 1925 Santa Barbara Earthquake. Prior to that, wind loads addressed the earthquake issues. California enacted the "Field Act" in 1933 following the Long Beach Earthquake and was specifically intended to address a higher level of design, inspection and construction for public schools (K-14 at the time) mainly due to the poor performance of unreinforced masonry in the earthquake. Initially, the Act did not require the replacement of pre-Field Act schools within any particular time frame. Subsequent legislation set time requirements for strengthening or abandonment for educational purposes that were essentially required to by met by the middle 1970's. There are very few remaining "non-Field Act" buildings on public school campuses at this writing where these facilities remain in use for educational purposes.

Early seismic provisions in the Uniform Building Code (UBC) which served as the model code

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in California for the CA Building Code (CBC) had low estimates by today's standards for ground accelerations of about 0.1g which was also the base shear value at the time. As the CBC was revised on its tri-annual cycle from knowledge obtained during earthquakes, these ground acceleration values were increased and yielded base shear in schools that eventually rose to about 0.2g in the early 1990's for Zone 4 locations (CA only had Zone 3 and Zone 4 with Zone 4 using 0.4g ground acceleration and then being modified by other parameters which lowered the Base Shear). The 1997 UBC/1998CBC substantially increased the calculated base shear values for sites within earthquake Near Source Zones. California finally shifted to the IBC in 2007 (2006IBC/2007 CBC) following prolonged political turmoil that severely delayed the implementation of the IBC. The Near Source philosophy is retained in the IBC with the much more accurate and detailed acceleration values.

There is no current mandate to upgrade early Field Act approved schools that have lower acceleration design values than currently in use for modern design/construction or to mitigate older construction techniques such as non-ductile reinforced concrete that is in some cases a severe collapse hazard in the earthquake environment (Mujumdar and McGavin, 1999).

Consequently, California has a wide range of potential performance for its stock of K-12 schools (Community Colleges are no longer required to meet the Field Act Provisions).

Historically, California's Field Act schools have performed structurally very well in earthquakes (CSSC, 2007 and 2009) including in the recent 7.2 M_w Baja Earthquake southwest of Mexicali, Mexico as evidenced by the performance of Calexico USD schools. The CA Seismic Safety Commission recently conducted an in depth research literature survey of the performance of California K-12 schools that have been subjected to damaging earthquakes since the enactment of the Field Act. Very few public K-12 schools that were designed and constructed under the Field Act have had severe damage as a result of strong ground motion. One can literally count the severely damaged public school buildings on their hands. The Field Act has been a resounding success in the dozen or so damaging earthquakes examined in our research project. Consequently, we can answer the question based on performance rather than speculation. Field Act approved public schools have performed well and they are expected to continue to perform well in future earthquakes. Private schools that are not subject to the requirements of the Field Ach have not performed as well.

As an example, this panelist was the architect for the Landers Elementary School and several other schools in the vicinity of the Landers/Big Bear Earthquakes of 1992. All of the schools had been designed and completed within 6 years of the earthquakes with Landers Elementary being completed about one year prior. Specifically, the Landers Elementary School was located 0.4 miles from between 8 and 12 ft of horizontal offset on the rupture. This school was clearly within the near source rupture zone and sustained very strong ground shaking (although no strong motion records are available from the school site). The damage to the Landers Elementary School was minimal and all of the sustained damage was nonstructural in nature.

The success of K-12 public schools since 1933 during earthquakes does not mean that "all is well" and that we should rest on our success. As noted in the *Earthquake Spectra* Opinion Paper (Mujumdar and McGavin, 1999) coauthored by this panelist, there is a very large stock of

older Field Act approved schools that may be in jeopardy due to a number of factors. These factors include non-ductile reinforced concrete structures; light framed wood structures with the potential for dry rot and lower design acceleration values in light of what has been learned from earthquakes over the decades and the potential for severe nonstructural damage.

As another case in point, the Jefferson Elementary School within the Calexico USD performed well structurally in the 2010 Baja Earthquake. There was however some significant nonstructural issues with this school. One building had approximately 1200 SF of covered walk stucco soffit that collapsed onto the sidewalk, which in turn blocked exit doors and sheared off some doorknobs. Had students been in the walkways at the time of the earthquake, there would have been a high likelihood of serious injury and death. Had students been in their classrooms at the time of the earthquake, they would have been trapped inside because the soffit blocked the swing of the doors. The nonstructural issues such as the heavy stucco soffits and suspended ceilings were not rigorously plan checked by DSA in the 1960's. for the seismic environment. Figures 1 and 2 below show the nonstructural soffit collapse.

Figure 1 Jefferson Elementary Stucco Soffit Collapse in the Baja Earthquake

Figure 2 Soffit collapse blocked the classroom doors and sheared off some doorknobs.

Nonstructural damage in California remains the largest potential for casualties in California schools.

2. What is the worst-case earthquake scenario in terms of student fatalities (in the U.S. and British Columbia)?

I don't think that I am qualified to predict the numbers of dead or injured students and staff as asked by the question.

It is my personal and professional opinion as an architect, that the worst case scenario for death and injury for students and staff in K-12 Field Act schools in California will be due to several factors:

- A severe earthquake occurring during school hours in an urban/suburban area
- Nonstructural damage issues such as the toppling furniture and equipment that is not addressed by the building codes including teachers that install tall unsecured filing cabinets next to exit doors, science teachers that inappropriately store chemicals such as oxidizers and organics in the same vicinity (believe it or not, often storing them in the same cabinets), unattached book shelves, teachers that hang heavy objects from t-bar ceilings, etc.
- Older nonstructural issues schools that have not been modernized where the code under which the school was designed and constructed did not address nonstructural issues (prior to the 1980's)
- Non-ductile reinforced concrete construction that is a collapse hazard (not all non-ductile reinforced concrete is guaranteed to be a collapse hazard as unreinforced masonry was) which has not been structurally upgraded
- Deteriorated (dry rotted and/or termite damaged) older wood structures
- Older tilt-up structures that have not been structurally upgraded

California is used to experiencing earthquakes outside of school hours. We in California will have a very rude awakening when we finally experience a strong earthquake during school hours. We had a single student killed during the Whittier Earthquake at a Community College. We will not deal well as a society when we realize the reality of hundreds if not thousands of student fatalities and injuries due to an earthquake at an inopportune time.

We have experienced "neighborhood earthquakes" for the most part in California since the enactment of the Field Act. There will come an event that is a regional earthquake rather than a neighborhood earthquake in the future. This event will likely cause wide spread death and injury the likes of which we do not expect in California. We have become too complacent with our neighborhood earthquakes that seem to always occur outside of school hours.

3. What level of seismic safety of schools is acceptable?

As a member of the CA Seismic Safety Commission and an architect specializing in public school design for thirty years, it is my opinion that the Field Act was pivotal legislation. The legislation demanded that we do better than had been done in the past. We as a society mandate that our students attend school and the legislature proclaimed in 1933 that students and staff are thus entitled to a higher and better standard of design, inspection and construction. I personally believe that the legislature acted wisely at the time by dictating that changes were necessary so

as to prevent catastrophic death and injury to students and staff. We have maintained that position in California ever since for our public schools.

The code says that under most expected earthquake scenarios, construction should not suffer either full or partial collapse and that the occupants should be able to exit the buildings safely when strong motion ceases. This is a reasonable expectation in my opinion. Achieving it is another matter.

From time to time, there proposals in California to "save money" by eliminating the requirements of the Field Act. One of the arguments for these proposals are that over the decades, the local building codes have become very close to the requirements of the Field Act. There is truth in this argument that can't be denied. The Field Act goes much beyond the letter of the basic building code. The Field Act, however, is not code. It is "enabling legislation". The details of this enabling aspect are discussed under question 4 below that the basic building code does not meet.

Some others make the argument that the Field Act increases the cost of public education facilities unreasonably. Clearly, the mandates of the Field Act are more expensive than construction of a lesser quality. Many claims have been made over the years about just how much the cost increase is. In the 1990's, the then State Architect, Harry Hallenbeck, FAIA, conducted a study in an attempt to answer the question. Some had claimed the cost increase due to the Field Act was on the order of magnitude of 100%. While this magnitude of cost didn't seem to make sense to architects involved with both Field Act school projects and private school design, there was no existing data to support the actual magnitude of the cost increase. The State Architect assembled several sets of plans from several architects and had contractors "mock bid" the projects based on Field Act compliance and local building codes. These were real schools that had recently been bid and constructed. The results of the study were surprising. The increase in costs due to the requirements of the Field Act were about 1.5 to 2% for "soft costs" such as the IOR and special inspection and another 1.5 to 2% for added construction requirements of the State Architect. This study is currently about fifteen years old. It is time to revisit the study to determine if it is still valid.

California's public schools have been shown in numerous actual earthquakes to perform better than many private schools designed and constructed under the local building codes based on the 2009 CA Seismic Safety Commission research report[4]. A cost increase of three to four percent seems to be a small price to pay as an investment in school safety.

4. What actions are needed to achieve that level of safety?

When the California Legislature enacted the Field Act, they departed from the "norm" for design-bid-build type projects in the public works realm.

- First, the Legislature said that either a licensed architect or structural engineer must design schools. Civil engineers were restricted from designing schools.
- Second, the Legislature assigned plan check authority for public schools to the State Architect and DSA only uses licensed structural engineers to perform plan checking for

structural safety. Many local California jurisdictions did not and still do not employ licensed structural engineers in their building departments nor do they have always them assigned to plan checking responsibilities if they are employed by the jurisdiction.

- Third, the Legislature required continuous and fulltime inspection as well as special inspection by an independent inspector that is hired and reports to the owner. This is in my personal opinion the real "genius" of the Field Act. The independent, continuous and fulltime inspection is not replicated with "normal" construction. Instead, inspection occurs at infrequent intervals. Infrequent inspection is simply not good enough for public education. The cost vs. benefit of full time and continuous inspection is clearly well worth the added effort as can be seen by the performance of California's schools in earthquake after earthquake.
- Fourth, the Legislature required that the State Architect approve all change orders.
- Lastly, the architect, engineers, IOR and contractor must certify that the facility was completed per the approved plans and specifications (and allowed change orders).

5. What new state, provincial or national programs (or policies) are needed?

The recent Baja Earthquake as well as other past earthquakes has shown that California needs a program for granting Public School Safety Assessment Authority to DSA first and local Government second in the event that DSA can not be deployed in a timely manner following a damaging earthquake. Currently, local school districts are the only entity authorized to perform safety assessments and many local district personnel are not trained or qualified for these assessments.

In my opinion, we NEED IMMEDIATE IMPLEMENTATION of an "Earthquake Early Warning System" in ALL schools where strong ground motion is possible (not just in California) based on P-wave technology. Early warning is similar in concept to smoke detectors providing an early warning for fire in facilities. They don't "predict" an earthquake. They simply warn occupants that fast moving P-waves have been detected and that slower moving strong motion is imminent. There are commercially available systems in use at this writing. For example, an Early Warning P-wave technology system is currently being designed for the Coachella Valley that will provide instrumentation for schools, police stations, fire stations, communication centers, civic centers, etc. This P-wave early warning system can provide between 2 and 20 seconds of early warning for rupture along either the southern leg of the San Andreas Fault Zone (Bombay Beach Northward) or the San Jacinto Fault Zone. Between two and twenty seconds is sufficient time for staff and students to implement "Drop-Cover-Hold" procedures before severe ground shaking begins based on P-wave analysis.

Early warning is not controversy free. Some argue that there are "shadow zones" with some earthquakes that prevent any effective early warning. Others say that just a few seconds is not enough time. There is also the possibility of false alarms with early warning. I believe that we need early warning technology now in our schools. Their technology and performance will improve over time. That is what the marketplace does. We make a mistake by waiting until any technology is perfect before deploying it.

Implementation of effective early warning systems for all school districts *will in my opinion* be as big a step forward for the safety of school children in the earthquake environment today as the Field Act was in 1933.

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