State of California
Alfred E. Alquist
Seismic Safety Commission

The Field Act and its Relative Effectiveness in Reducing Earthquake Damage in California Public Schools

October 2009

1755 Creekside Oaks Drive, #100
Sacramento, California 95833
(916) 263-5506
CSSC 09-02

Alfred E. Alquist Seismic Safety Commission

Honorable Mark Church
Chairman
Local Government

Honorable Ken Cooley
Vice Chairman
Cities Government

Andrew Adelman
Cities/Building Official

Honorable Elaine Alquist
Senate Representative

Dr. Arul Arulmoli
Geotechnical Engineer

Honorable Sam Blakeslee
Assembly Representative

Bill Chubb
Utilities

Dr. Lucy Jones
Seismology

Sharron Leaon
Emergency Services

John Littrell
Mechanical Engineer

Elizabeth Mathieson
Geologist

Gary McGavin, AIA
Architectural Planning

Dr. Dennis Mileti
Social Services

Honorable Brad Mitzelfelt
County Government

Don Parker
Fire Protection

Ali Sadre
Structural Engineer

Michael Stevens
Insurance

Christina Curry
Cal EMA

David Thorman, AIA
State Architect

Dave Walls
Bldg. Standards Commission

Field Act Research Study Ad Hoc Committee

Commissioner McGavin, Chair

Commissioner Sadre

Commissioner Adelman

Commissioner Cooley

Dan Shapiro

Larry Klein

Richard McCarthy, SSC
Executive Director

Henry Reyes, SSC
Project Manager

Fred Turner, SSC
Structural Engineer

Seismic Safety Commission Staff

Richard McCarthy
Executive Director

Fred Turner
Structural Engineer

Robert Anderson
Engineering Geologist

Henry Reyes
Special Projects Manager

Karen Cogan
Administrative Officer

Sue Celli
Executive Secretary

Meghan Sweeney
Student Assistant

Collaborative for Disaster Mitigation, San Jose State University Personnel

Guna Selvaduray, Ph.D.
Executive Director

Steven Vukazich, Ph.D., S.E.
Professor

Clare Cordero
Document Editor

David Murphy, S.E.
Consultant

Jyotheeswara Gottam
Research Assistant

Jalpa Thakkar
Research Assistant

Prashant Kalyanraman
Research Assistant

Farhad Doneshwar
Research Assistant

Larissa Clark
Research Assistant

Table of Contents

The Field Act and its Relative Effectiveness in Reducing Earthquake Damage in California Public Schools

Executive Summary

One month after the Long Beach Earthquake of March 10, 1933 the Governor of California signed the Field Act into law. Assemblyman C. Don Field, who authored this legislation, believed that the earthquake's extensive damage to public schools and its potential for causing injuries and casualties was unacceptable. Subsequent legislation such as the Garrison and Greene Acts also sought to ensure that all California public school buildings would meet Field Act standards and that school boards would take the necessary steps to ensure this by retrofitting or replacing at-risk public school buildings that were built prior to the Field Act.

The objective of this study was to determine if the Field Act has been effective in reducing structural damage in public school buildings, as compared to buildings constructed according to the Uniform Building Code, and was based on literature that has already been published; no primary data collection was intended to be part of this study. A benefit-cost analysis of the Field Act was beyond the scope of this project. The final report is intended to communicate the findings to policy makers in the executive and legislative branches and appropriate local jurisdictions such as school districts.

The primary findings from this study are that Field Act public school buildings affected by earthquakes:

- Have incurred a substantially lower level of damage as compared to other buildings of similar age and construction, in the same vicinity and experiencing similar shaking intensity, including private school buildings or pre-Field Act buildings, some of which were damaged to the point where they had to be demolished;
- Generally suffered relatively minor to no earthquake-caused structural damage;
- Showed very few instances of structural failure that could have been potentially life threatening;

- Have served as the primary source for disaster shelters in regions that have experienced significant damage, including epicentral regions that had MMI* IX or X ground shaking intensity;
- Incurred damage that was primarily limited to nonstructural items, such as ceilings and lighting fixtures, and building and classroom furniture and supplies.

In its essence, the Field Act requires the Division of the State Architect (DSA) to set standards for seismic resistant design and rigorous quality control throughout the design and construction process for public schools. Public school buildings must be designed by a California licensed architect or structural engineer and submitted to the DSA for review. The design criteria and standards for public school buildings do not significantly vary from those for other institutional buildings designed under the California Building Code, except for the more stringent and consistent DSA plan review, testing, and inspection requirements.

Since 1933 the building codes in California have improved significantly, and as these improvements have been made, the gap in design standards between Field Act and non-Field Act buildings has narrowed. However, the uniform and stringent design and construction quality control continues to be a unique feature that was set in motion by the Field Act and implemented by the DSA. An important outcome of the Field Act has been the requirement to carry out seismic evaluations and to retrofit or replace vulnerable public school buildings; this has not been the case with the general building stock in California.

Fifteen major California earthquakes that have occurred after 1933 were studied to determine if the damage to public schools was in anyway significantly different from that incurred by the general building stock, and by private schools that are not required to comply with the Field Act. Only regions that experienced ground shaking intensity greater than Modified Mercalli Intensity (MMI) VII were studied. A comprehensive bibliography consisting of more than 400 relevant documents was compiled and a data base was created. All California school sites that have experienced MMI VII or greater shaking intensity were identified and mapped.

* The Modified Mercalli Intensity (MMI) Scale is described in Appendix I

I Introduction and Purpose of Study

Among the fifty states of the USA, California has the second highest occurrence of earthquakes(†) and many of them have caused significant loss to life and property. The damage to California schools during the March 10, 1933 Long Beach Earthquake, as shown in Figure 1, resulted in the enactment of the Field Act, which went into effect on April 10, 1933 (Jephcott 1986). Recognizing that the earthquake would have caused serious harm to children if it had occurred during school hours, the Act required earthquake-resistant design and construction of all new public schools in California. The Act also gave the Division of the State Architect the authority to write design regulations for public schools and community colleges.

Significant earthquake damage to schools has occurred in many other countries. During the May 12, 2008 Magnitude 8 Wenchuan Earthquake in China, there were 69,222 casualties, 374,638 wounded, and 18,176 missing (Yan et al. 2009). Approximately 6,900 school buildings collapsed (Yomiuri Shimbun 2009). Of the 6,581 casualties in the Sichuan Province education system, 6,376 were students, 1,274 people were missing, and 1,107 people were buried (Zhang and Li 2009). There is now a movement in China proposing that China adopt practices similar to California's Field Act to ensure safety of their schools (Li H. 2009). Figure 2 shows one of many school buildings that were destroyed.

During the 1999 Magnitude 7.6 Chi-Chi Earthquake in Taiwan, of the 186 schools in Nantou County, where the epicenter was located, 30 of them had buildings that collapsed completely, as shown in Figure 3, and another 109 schools had buildings that collapsed partially (Li W. 2008).

The last California earthquake having a magnitude close to 8 was the 1906 San Francisco Earthquake. Subsequent California earthquakes have had lower magnitudes, but major earthquakes will occur again in California in the future.

This report is a summary of an evaluation of the effectiveness of the Field Act. It addresses whether the Act avoided or reduced earthquake-caused damage to California's public schools, by comparing the performance of public schools to structures built in accordance with local government regulations but not subject to the Field Act. A synopsis of the methodology taken during the course of this study is included in Appendix A.

The Commission recognizes that additional costs and time delays are associated with the implementation of the Field Act. However, a benefit-cost analysis was beyond the scope of this study.

The intent of the Field Act is to ensure that California's public schools be safe so that the danger our children are exposed to from earthquakes, especially if they occur at times when schools are in session, is minimized.

† Alaska has experienced more earthquakes; however, due to a lower population density and fewer highly industrialized regions, the risk is lower.

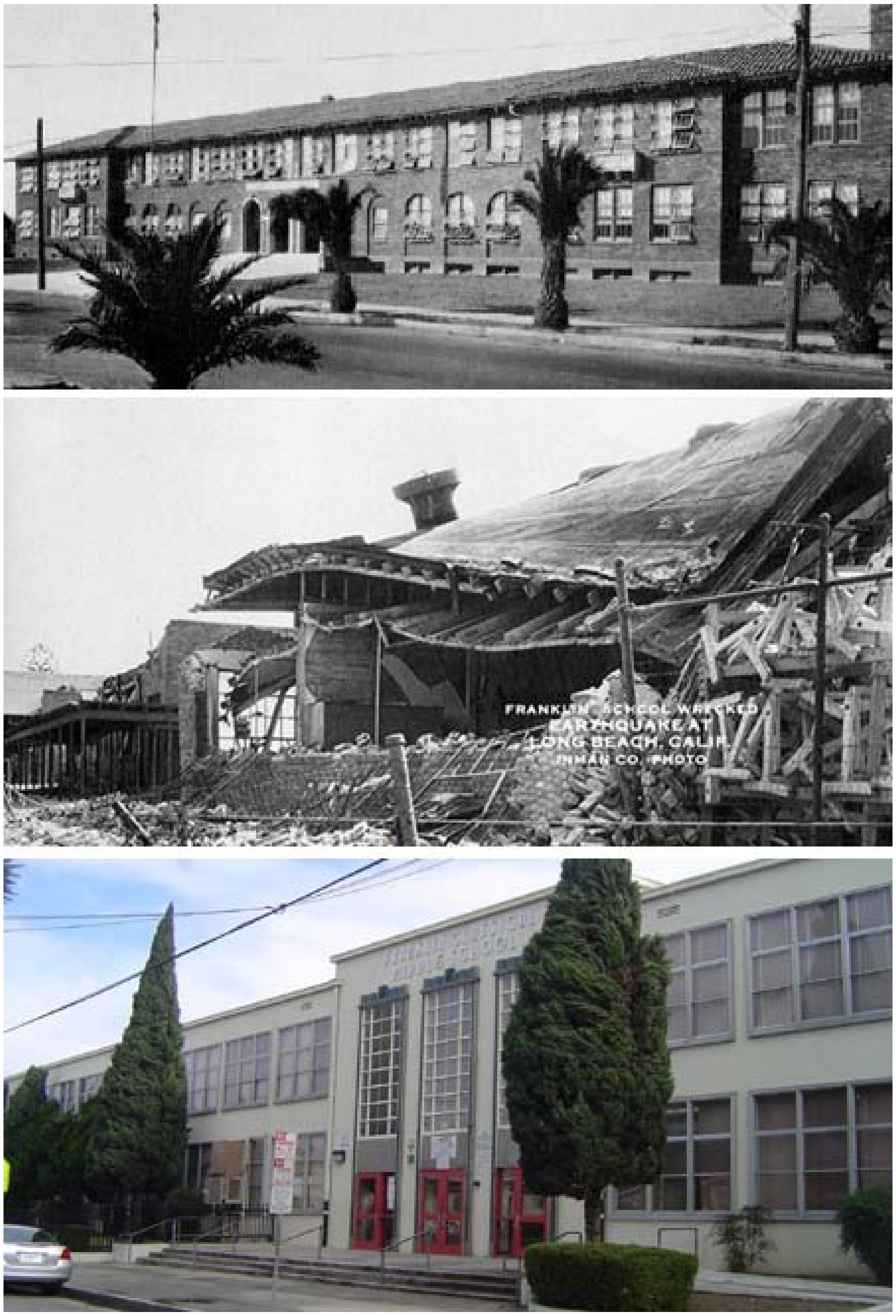

Figure 1: Pictures of the Franklin Junior High School in Long Beach. Top: before the 1933 Long Beach Earthquake; Middle: after the earthquake; Bottom: the rebuilt school today.
(Photo Credit: California Geological Survey – accessed from CGS website on May 10, 2009)

Figure 2: Damage to Elementary School in Xing Fu Township, Dujiangyan, during the 2008 Magnitude 8 Wenchuan Earthquake in China
(Photo Credit: Miyamoto International)

Figure 3: Damage to High School during the 1999 Chi-Chi Earthquake. (This collapsed school building has now been converted into a national museum.)
(Photo Credit: Wei-sen Lee, National Science and Technology Center for Disaster Reduction, Taipei, Taiwan)

II Seismicity of California

With a population of approximately 37 million, and very large agricultural and industrial sectors, the economy of California is estimated to be one of the 10 largest in the world. California is also well known for its innovative spirit and is the birthplace of several new technologies that have revolutionized the world. One factor that has played a major role in California's rise as a location for innovation has been its public education system, which is the foundation for a highly skilled workforce.

Due to the presence of several geologic faults, including the San Andreas Fault which runs practically the entire length of the state, California has experienced numerous damaging earthquakes. While no single earthquake is expected to bring devastation to the entire state, several earthquakes have caused major regional destruction in many different parts of the state. These earthquakes have also affected other parts of the state due to the intricate connections that exist among the public and private sectors. Future major earthquakes in California are likely to have global effects, not unlike the effects of the 1995 Kobe Earthquake in Japan.

The significant earthquakes that have occurred in California in the 20th Century are listed in Table 1 and Appendix B**,** which contains more details. It should be noted that all of these earthquakes, with the exception of the Daly City Earthquake of 1957 that had a magnitude of 5.3, occurred at times when schools were not in session, thus sparing school children from injuries and fatalities.

In the future, the timing of earthquakes might not be quite so fortuitous. The only means available to engineers and legislators, to prevent a catastrophe in California's public schools, is to ensure that school buildings are constructed with designs and quality control standards that minimize the potential for casualties.

Table 1: Significant California earthquakes since 1900 (CalEMA 2007)

Earthquake	Date	Magnitude	Injuries	Fatalities
San Francisco[(a)]	Apr 18, 1906	7.8		~ 3,000
Santa Barbara[(a)]	Jun 29, 1925	6.8	65	13
Long Beach[(a)]	Mar 10, 1933	6.4		115
Imperial Valley	May 18, 1940	7.0	20	9
Kern County	Jul 21, 1952	7.3	35	12
Daly City	Mar 22, 1957	5.3	40	1
San Fernando	Feb 9, 1971	6.6	2000	65
Santa Barbara	Aug 13, 1978	5.1	65	-
Imperial County	Oct 15, 1979	6.5	91	-
Mammoth Lakes	May 25,1980	6.2	9	-
Coalinga	May 2, 1983	6.4	47	1
Whittier Narrows	Oct 1, 1987	5.9	200+	9
Loma Prieta	Oct 17, 1989	6.9	3757	63
Petrolia	Apr 25, 1992	7.2	356	-
Landers & Big Bear	Jun 28, 1992	7.3, 6.5	402	1
Northridge	Jan 17,1994	6.7	11,846	57
San Simeon	Dec 22, 2003	6.5	47	2

Note: *a: indicates earthquakes that occurred prior to the enactment of the Field Act*

III History of the Field Act

The Magnitude 6.4 Long Beach Earthquake of 1933 resulted in 70 schools being destroyed entirely, as was shown in Figure 1, and another 120 schools experiencing major damage and 300 schools incurring minor damage (Meehan 1982). It was fortuitous that the earthquake occurred at 5:54 p.m., outside school hours, thus minimizing injuries and fatalities of children. This poor performance of, and the extensive damage to, public school buildings resulted in the enactment of Assembly Bill 2342, later officially titled *The Field Act*, after then Assemblyman C. Don Field. This act was signed by the Governor of California on April 10, 1933 – one month after the earthquake.

The intent of the Field Act was to protect California's public school children from injuries and fatalities from building damage during earthquakes, while acknowledging that some architectural damage can be expected (California Code of Regulations). It applied only to public school buildings, and required all construction projects of $1,000 or more (currently $25,000 for structures and $100,000 for nonstructural construction) to go through a more rigorous state-regulated oversight process as compared to other locally-regulated buildings.

Subsequent California laws that built upon the Field Act, to further address the seismic safety of school buildings that were constructed prior to enactment of the Field Act, include the Garrison Act of 1939, the Greene Act (I) of 1967, and the Greene Act (II) of 1968. These acts acknowledged the costs for seismic retrofitting or replacement of buildings, raised personal liability issues for school board members, required structural examination of buildings and identification of unsafe school buildings, and provided timelines for buildings to be abandoned if they failed structural evaluations. In particular, the Greene Act (II) required that all pre-Field Act school buildings needed to be abandoned or retrofitted by June 30, 1975. A 1974 amendment extended this deadline to June 30, 1977. As a result, by 1977, with some rare exceptions, all pre-Field Act school buildings were either replaced or retrofitted to substantially comply with the Field Act.

Other California laws that have had a direct impact on improving the seismic safety of schools include the School Building Sites Act and the Alquist-Priolo Act, both of 1972. The Private Schools Act of 1986 called for similar life-safety protections for private schools as for public schools, although it did not subject them to Field Act compliance. The Charter Schools Act of 1992 authorized the establishment of charter schools; however, it left unclear what seismic safety regulations would apply to them.

In the mid-1970s DSA amended its regulations to include comprehensive requirements for the seismic safety of nonstructural systems in public school buildings. Further, by 1978 DSA prohibited construction of new non-ductile concrete buildings and other types of construction that may be vulnerable to collapse. However, there remained vulnerabilities in buildings that had been constructed according to pre-1978 Field Act regulations.

In 1999, the State of California directed the Department of General Services to conduct an inventory of K-12 public schools built before 1978 and not consisting of wood frame construction, to identify the most vulnerable school buildings in the state (AB 300 1999). The inventory, completed in 2002, found that 7,537 buildings consisting of 64 million square feet required detailed seismic evaluations (Department of General Services 2002). The Legislative Counsel issued an opinion that school district officials would have enhanced liability if they did not request information about this inventory and begin to take actions to mitigate earthquake-caused collapse risk in these early Field Act schools.

What is notable is that since the 1933 Long Beach Earthquake, California has experienced 15 damaging earthquakes. However, the damage to school buildings, especially structural damage,[‡] has been minimal. Even more notable is that while there have been 221 casualties in California earthquakes since 1933, there have been minimal life-threatening structural failures of Field Act buildings.

There are approximately 16,000 public schools and 3,500 private schools in California. 2,848 of the public schools and 1,042 of the private schools have experienced ground shaking of MMI VII or greater. The California counties that have been affected by MMI VII or greater ground shaking are shown in Appendix C. The school sites within these counties were then identified, as shown in Appendix D, and mapped as shown in Appendix E. Some schools have experienced MMI VII or greater ground shaking more than once because they have experienced more than one earthquake.

[‡] The term "structural" refers to the elements of the building that support its weight and that resist external loads, such as those arising from wind, snow, rain, and earthquakes, among others. Buildings also have non-structural components such as ceilings and light fixtures; and building contents such as filing cabinets, bookshelves, desks, etc.

IV The Field Act and the Building Code: Similarities and Differences

The Field Act is not a building code but a state statute that gives the Division of the State Architect (DSA) the authority to develop rules and regulations it deems necessary to carry out the provisions of the Act to improve seismic safety in the design and construction of public schools, from kindergarten through community colleges.[§] Amendments to Title 24, Part 2, California Code of Regulations (CCR), commonly known as the California Building Code (CBC), as they relate to public schools, are written by DSA. The CBC has historically consisted of the Uniform Building Code (UBC) with California amendments. In 2008 the UBC was replaced with the International Building Code (IBC); future CBCs will therefore be based on the IBC model code.

Design requirements for buildings in California have evolved since 1933 with advancements in the field of earthquake engineering due to knowledge gained from studying the behavior of structures in subsequent earthquakes. A history of significant building code changes, including seismic design forces, is presented in Appendix F (Strand 1984, Porush and Zacher 1987, Bellet 1989, Mahaney and Freeman 1996, CSSC 2004). While seismic design requirements, including those for construction materials, have evolved over the years, ***the principal differences between the design of public school buildings and other buildings in California have always been in the administrative regulations, which enhance quality by professional oversight, that are found in Part 1 of Title 24, CCR.***

The Field Act is essentially a means of standardized quality assurance of the entire process of constructing a school, from the design stage through completion of construction and occupation. The major differences between the Field Act administrative regulations and the IBC lie in the rigor of quality control during the plan approval and construction processes (Hackett 2009):

- An architect's or structural engineering license is required for professionals preparing school building construction plans under the Field Act; an architect’s or civil engineering license is adequate for preparing building construction plans for engineered non-Field Act buildings;
- The plan approval process is more rigorous under the Field Act; plans are checked to ensure they comply with the CBC by licensed structural engineers for Field Act buildings while, in some cases, plans may be checked by non-licensed professionals for non-Field Act buildings;
- Changes to public school plans during construction must be reviewed and approved by the DSA;
- Continuous construction inspection by DSA-approved inspectors is required under the Field Act, whereas periodic inspection by certified local inspectors, at certain construction milestones, is allowed for non-Field Act buildings;
- Independent testing of materials used in construction by DSA-certified laboratories is required under the Field Act; independent testing, by certified laboratories, of materials used in construction may or may not be effectively enforced by local building authorities;

[§] Proposition 1D, 2006, allowed community colleges to opt out of the Field Act requirements, at their discretion, but they are still regulated by DSA.

- All parties (architects, engineers, inspectors, testing laboratories, and contractors) must file compliance reports under penalty of perjury under the Field Act; similar reports are not required under the IBC, except for the recent exception for regions of high seismicity.

In addition to inspections during construction for non-Field Act buildings being periodic, there can also be significant variations in the rigor of inspections, based on the capabilities of the building inspectors. California has some of the best local building departments in the U. S. However, inspections by some local jurisdictions are subject to the vagaries of the economy and other factors, as a result of which the actual time building inspectors have to carry out inspections, and the technical qualifications of the inspectors, can vary significantly from jurisdiction to jurisdiction. In this report, a public school building referred to as a Field Act building is one that has been designed according to the administrative regulations found in Title 24, CCR. Buildings referred to as non-Field Act buildings have been designed to the CBC but have not been held to these administrative regulations. A side-by-side comparison of the major differences of the administrative requirements for Field Act and non-Field Act buildings can be found in Appendix G.

The Field Act has been used as the model to improve the performance of other buildings that must be capable of being occupied in the event of an emergency. Prior to 1972, the design and construction of hospitals in California were regulated by local governments. After the poor performance of several hospitals in the 1971 San Fernando Earthquake, the rigorous plan approval and construction quality assurance of the Field Act was used as the model for the 1972 Hospital Act which set new rules and regulations covering hospital design and construction. Similarly, the 1986 Essential Services Seismic Safety Act called for stricter quality control standards for essential services buildings such as fire stations, police stations, sheriff's offices, highway patrol offices, and emergency operations centers.

After evaluating building performance during the 1994 Northridge Earthquake, the Structural Engineers Association of California (SEAOC), sought to develop guidelines for performance-based engineering of buildings. The 1995 SEAOC guidelines used the Field Act and the Hospital Act as examples to illustrate the importance of rigorous plan review and construction inspection with regard to building performance in earthquakes, as evidenced by the following quote (SEAOC 1995):

> *"Schools and hospitals in California are designed to very similar standards as other buildings in California, yet they tend to perform much better in earthquakes, largely because of the rigor of the plan review during design and the quality assurance provided during construction."*

In California there are over 500 jurisdictions that review building designs and enforce building code requirements. As described previously, the staffing and resources of these jurisdictions, including the technical qualifications of the staff, vary considerably from jurisdiction to jurisdiction, resulting in inconsistencies in the depth and breadth of enforcement for non-Field Act buildings. In contrast, the existence of the Field Act and its requirements ensure that all public schools in California are constructed to a more uniform interpretation and implementation of the California Building Code, and with more consistent oversight, since one regulatory agency, the Division of the State Architect, is responsible for enforcement.

V Comparison of the Performance of Field Act Structures with Non-Field Act Structures

As discussed previously, the performance objectives of Field Act (FA) and non-Field Act (non-FA) buildings are similar, but the quality control of Field Act buildings is more rigorous. This section is a summary of the performance of public schools in major California earthquakes, since the Field Act went into effect. It should be noted that for the earthquakes occurring prior to the 1977 Greene Act (II) deadline, some public school campuses still had pre-Field Act buildings that, in most cases, were not designed to resist earthquake forces. This contributes to the large gap in damage percentages between FA and non-FA buildings in these pre-1977 earthquakes. Table 2 is a brief summary of public school performance in California earthquakes since 1933 and the subsequent paragraphs in this section are organized chronologically in order to present the narrowing performance gap between FA and non-FA buildings. This study does not specifically account for age differences between specific Field Act buildings and comparable non-Field Act buildings. However, generally, communities built after 1933 contain Field Act public school buildings that are of comparable age to nearby non-Field Act buildings. A more detailed performance summary can be found in Appendix H and a description of the Modified Mercalli Intensitiy (MMI) scale is contained in Appendix I.

A common comparative measure of building damage in earthquakes is to express loss as a percentage of the cost of repairs or reconstruction, as compared to the replacement value of the buildings, ***at the time of the earthquake***. Unless noted otherwise, this is the comparative measure used in this report, and in Table 2, when losses are expressed as a percentage.

The 1940 Imperial Valley Earthquake was the first significant test of the effectiveness of the Field Act. Although this earthquake was larger than the 1933 Long Beach Earthquake, the 16 school buildings that had been built according to Field Act standards between 1933 and 1940 suffered no significant damage. In contrast, there were pre-Field Act school buildings in the area that suffered significantly more damage (Jephcott 1986). Thirty-nine years later, the 1979 Imperial County Earthquake shook approximately the same area with little damage to the 52 public school sites inspected (EERI 1980).

The 1952 Kern County Earthquake (also referred to as the Tehachapi Earthquake) provided another significant test of the performance of school buildings designed under Field Act regulations. The U. S. Department of Commerce studied 37 schools, which represented about three-quarters of the school damage in the area. The losses suffered by Field Act schools were found to be less than 1% while the pre-Field Act school buildings suffered a loss of 50% (Crumlish and Wirth 1967, Jephcott 1986).

The 1971 San Fernando Earthquake was similar in size to the 1933 Long Beach Earthquake and was the first to occur in a large metropolitan area after the Field Act had been enacted. By this time nearly all of the buildings in the Los Angeles Unified School District, where most of the shaking occurred, were built in compliance with the Field Act or had been retrofitted. A study of losses incurred in 636 school sites within the 25-mile radius of the epicenter found damage of less than 1% (Barclay 2003). Nearly all of the damage was nonstructural, which at that time was just beginning to be addressed by codes.

Table 2: Public school performance in California earthquakes since 1933

Earthquake	Year	Max MMI	Public School Performance
Long Beach	1933	VIII	Severe damage, Field Act (FA) enacted immediately
Imperial Valley	1940	X	No significant damage to all 16 FA buildings, significant damage to pre-FA buildings
Kern County	1952	VIII	FA schools suffered damage of less than 1%, pre-FA schools suffered 50% damage
Daly City	1957	VII	No structural damage to FA schools
San Fernando	1971	XI	8600 FA school buildings suffered damage of 0.3%. Most of the public school damage occurred in the few remaining pre-FA school buildings
Santa Barbara	1978	VII	No structural damage to FA schools
Imperial County	1979	IX	52 FA school sites suffered little damage
Mammoth Lakes	1980	X	2 FA school sites suffered no structural damage
Coalinga	1983	VIII	77 FA buildings on 9 sites suffered losses of about 3%, with most of the damage being nonstructural
Whittier	1987	VIII	No structural damage to FA schools
Loma Prieta	1989	IX	4 of 1544 FA buildings surveyed suffered severe damage
Petrolia	1992	X	Mattole Elementary in MMI X suffered no structural damage and was used as a shelter
Landers	1992	X	Landers Elementary in MMI X suffered no structural damage, minimal nonstructural damage, and was used as a shelter
Big Bear	1992	IX	No structural damage to all 5 FA schools
Northridge	1994	IX	127 school sites surveyed (about 1600 buildings) with few permanent buildings suffering structural damage; most damage was to lunch shelters, walkways, and older portable buildings, with the notable exception of Kennedy HS Admin/Classroom Building and Van Gogh Elementary; most damage was nonstructural.
San Simeon	2003	VIII	No observed structural damage to 9 FA schools inspected. One exception was the main building at Flamson Middle School, built in 1924 and retrofitted to comply with the FA in 1959, which suffered damage and was demolished and replaced in 2005.

A juvenile facility constructed in 1965 and subjected to MMI X shaking in the San Fernando Earthquake contained Field Act and non-Field Act buildings since it was both an educational and a correctional facility. The Field Act and non-Field Act buildings were built by the same architects, engineers and contractors. The school buildings at the site survived the earthquake well whereas the non-Field Act buildings suffered major damage. The following quote is from a report on this facility by the U. S. Department of Commerce:

> “*The better behavior of the school buildings can be attributed to the more restrictive rules and regulations of the Field Act since the other factors (Architects, Engineers, Contractors and Inspectors) were the same for both types of buildings. The school buildings could be economically repaired; however, the entire facility has been vacated and may be abandoned.*” (Lew et al. 1971).

Hospitals were another class of publicly owned structures that were not built to Field Act standards, and suffered extensive damage. The poor performance of hospitals in the San Fernando Earthquake led to the 1972 Hospital Act which set rules and regulations covering hospital design and construction that were nearly identical to the Field Act (Bellet 1989).

An approximate comparison of public school performance and the general building stock can be found from a study funded by the National Science Foundation that reported the total percentage of losses incurred by the Los Angeles Unified School District, due to the 1971 earthquake, was 0.16% of the 1971 assessed value. In comparison, data from the U. S. Department of Commerce on building damage incurred in Los Angeles County yields losses of about 1.8% of the 1971 assessed value (Lew et al. 1971, ATC 1993, Cuenca 2009).

A study of 9 school sites in the 1983 Coalinga Earthquake, that contained 77 Field Act buildings, estimated that the damage to these buildings was about 3% and was mostly nonstructural. Private buildings averaged a loss in the range of 18%; however, most of the damage was to older unreinforced masonry buildings which tend to perform poorly in earthquakes (EERI 1984, Jephcott 1986, Barklay 2003).

The Loma Prieta Earthquake was the largest earthquake to occur in Northern California since the 1906 San Francisco Earthquake and caused damage that ranged from Watsonville and Santa Cruz to Oakland and San Francisco. A survey of 1,544 public school buildings showed that only four school buildings sustained severe damage: a portable classroom near Santa Cruz, a woodframe building built in the 1950s at Loma Prieta Elementary School near Los Gatos, a San Francisco High School building that was built in 1920 and retrofitted to comply with the Field Act in 1947, and a Watsonville High School building constructed prior to the Field Act in 1917 and strengthened in 1935 (Bellet 1989, National Clearinghouse for Educational Facilities 2004). Significant building damage occurred in the Marina District of San Francisco with most of the damage to woodframe apartment buildings due to poor soil conditions. Winfield Scott School, built in 1930 and retrofitted in the 1970s under the state school strengthening program, is located in the area of the Marina District with the poorest soil and suffered only minor damage. The Marina Middle School served the Marina District as a shelter and disaster center immediately following the earthquake (Harris and Egan 1990, Meehan 1990, EERI 1990).

Mattole Elementary School experienced ground shaking of MMI X in the 1992 Petrolia, Cape Mendocino Earthquake with no structural damage and some minor nonstructural damage. This elementary school was used as the initial shelter and disaster assistance center, for approximately one week (Selvaduray 2008). A similar case is Landers Elementary School that was subjected to MMI X shaking in the 1992 Landers Earthquake. The school experienced only minor nonstructural damage and was used as an emergency shelter for local residents whose homes suffered heavy damage (ATC 1993, CSSC 2007).

The 1994 Northridge Earthquake was the largest earthquake in the urban Southern California area since the 1971 San Fernando Earthquake. The more than $40 billion in total property losses and nearly $7 billion in Federal Emergency Management Agency (FEMA) funding makes the Northridge Earthquake the most costly earthquake disaster, and the second most costly natural disaster, in the nation's history. The Northridge Earthquake was the first strong earthquake in which the Applied Technology Council Rapid Evaluation procedures (ATC-20), described in Appendix J, were employed to assess the safety of a large number of damaged buildings.[**] Table 3 presents a summary of some of the ATC-20 data that was collected. Note that the number of green-tagged buildings does not represent the total number of undamaged buildings but only those inspected.

Table 3: ATC-20 Tagging data for the Northridge Earthquake

Type of building	**Red (Unsafe)**	**Yellow (Limited Entry)**	**Green (Inspected)**	**% Red Tagged**	**% Yellow Tagged**
Private school buildings (City of Los Angeles 2003)	6	21	141	3.6 %[(c)]	12.5%[(c)]
Public school (Field Act) buildings (DSA ATC-20 Reports 1994)	17[(a)]	89[(a)]	1500[(b)]	1.1 %	5.5 %
One- and two-story commercial buildings (non-Field Act) in Los Angeles of similar construction to schools (City of Los Angeles 2003)	100	322	1746	4.6 %[(c)]	14.9 %[(c)]
Residential and commercial buildings in the City of Los Angeles (Deppe 1994)	1900	8800	82,500	2.0 %[(c)]	9.4 %[(c)]
Residential and commercial buildings in Los Angeles, Ventura, and Orange Counties (Governor's Office of Emergency Services 1999)	3000	11,500	90,400	2.9 %[(c)]	11.0 %[(c)]

Notes: *(a)* Of the 17 red tags; 5 are permanent buildings, 4 relocatable buildings, and 8 other structures (arcades, walkways, lunch shelters, pavilions, bridges between buildings). Of the 89 yellow tags; 62 are permanent buildings, 14 relocatable buildings, and 13 other structures.

(*b*) Approximate, based on an average of 13 buildings per school campus. (Jephcott 1974)

(c) The percentages contained in Columns 5 and 6 are based on the number of buildings that were inspected, and NOT the total number of buildings.

[**] The ATC-20 damage evaluation process was developed shortly before the Loma Prieta Earthquake, and first used after the Loma Prieta Earthquake (Applied Technology Council (ATC) 1989). Based on this experience the evaluation process was revised significantly and the revised evaluation process was employed more comprehensively after the Northridge Earthquake.

An approximate damage comparison for the Northridge Earthquake can be found by dividing the claim of the Los Angeles Unified School District (LAUSD) for FEMA disaster assistance funds by the 1994 assessed value of the LAUSD school properties which yields a ratio of about 0.11% (LAUSD 1994, FEMA 2009).[††] The equivalent loss ratio for the general building stock, based on FEMA claims and 1994 assessed value, for Los Angeles County, is approximately 1.3% (County of Los Angeles 1994-1995, FEMA 2009). Since FEMA claims are relevant only for public and non-profit sector structures, and not the for-profit sector, the actual loss ratio for the general building stock would have been much higher than 1.3%.

The ATC-20 data from 8 zip code areas, in an approximately 100 square mile area surrounding the epicenter of the Northridge Earthquake and subjected to some of the strongest shaking, were analyzed. In this area the urban growth was from South to North and thus public schools and buildings nearby were generally built at the same time (between 1950 and 1970) (OES 1995). A summary of the results of this analysis is presented in Table 4.

Table 4: ATC-20 Tagging data for the Northridge Earthquake epicentral area

Type of building	**Red (Unsafe)**	**(Yellow) Limited Entry**	**Green (Inspected)**	**% Red Tagged**	**% Yellow Tagged**
Private school buildings (City of Los Angeles 2003)	4	12	26	9.5 %[(c)]	28.6 %[(c)]
Public school (Field Act) buildings (DSA ATC-20 reports 1994)	7[(a)]	37[(a)]	463[(b)]	1.4 %	7.3 %
One- and two-story commercial buildings (non-Field Act) of similar construction to schools (City of Los Angeles 2003)	28	96	342	6.0 %[(c)]	20.6 %[(c)]
All Residential and commercial buildings (City of Los Angeles 2003)	267	1401	14,305	1.7 %[(c)]	8.8 %[(c)]

Notes: *(a)* Of the 7 red tags; 3 are permanent buildings and 4 other structures (arcades, walkways, lunch shelters, pavilions, bridges between buildings). Of the 37 yellow tags; 17 are permanent buildings, 11 relocatable buildings, and 9 other structures.
(b) Approximate, based on an average of 13 buildings per school campus (Jephcott and Hudson 1974).
(c) The percentages contained in Columns 5 and 6 are based on the number of buildings that were inspected, and NOT the total number of buildings.

All of the public schools in this area, except for John F. Kennedy High School, were capable of receiving students after post-earthquake debris was cleared. In some schools, portions of the campus and certain structures needed to be closed to students until further evaluations could be performed but the schools were able to open (McGavin 1994).

[††] Based on data received from California Office of Emergency Services (currently CalEMA) regarding post Northridge Earthquake claims paid by FEMA.

In all of the earthquakes studied, nonstructural damage was reported in many public school buildings. After the Northridge Earthquake, it was reported that nonstructural damage could have caused injuries if the earthquake had occurred during school hours. In 1995 the California Seismic Safety Commission recommended that *"a percentage of future school bond proceeds be used to abate life-threatening nonstructural and building contents deficiencies in public schools"* (CSSC 1995). In 1999, legislation was passed for public schools to address securing nonstructural elements and in 2003 detailed guidelines were published to aid public schools in identifying and correcting nonstructural hazards (CalEMA 2003).

Significant earthquakes that have occurred since 1933 in states outside California are summarized in Appendix K. It is important to note that similar legislation to the Field Act does not exist outside California. Reports from the 1935 Helena Montana Earthquake and the 1964 Anchorage Alaska Earthquake mention cases of unacceptable building performance due to poor plan review and quality control during construction (Engle 1936, National Clearinghouse for Educational Facilities 2004, National Board of Fire Underwriters and Pacific Fire Rating Bureau 1964). The effects of the 2001 Nisqually Earthquake on public school buildings was examined in depth and the findings are also included in Appendix K. The maximum level of shaking intensity was MMI VII in a very limited region.

VI Value of Schools as Shelters

Schools have been used as emergency shelters in areas that were badly damaged by earthquakes. For example, after the 1989 Loma Prieta Earthquake, the Marina Middle and John Swett Schools, both located in San Francisco's heavily damaged Marina District, were used as emergency shelters and disaster assistance centers (CSSC 2007). Similarly, after the 1992 Petrolia (Cape Mendocino) Earthquake, the Mattole Elementary School, located in an area that experienced ground shaking equivalent to MMI X was the emergency shelter for the community of Petrolia (Selvaduray 2008). Landers Elementary School, completed in 1991, was situated approximately 0.4 miles from the epicenter. The 1992 earthquake caused a horizontal ground offset of approximately 8 ft to 10 ft. On the day of the earthquake this school was occupied by the California Department of Forestry as a base of operations, and within 3 days of the earthquake it was an emergency shelter for the American Red Cross (McGavin, 2009).

The types of facilities that the American Red Cross (ARC) has identified as shelters in 23 counties that have experienced earthquakes were examined. The majority of shelters are schools, with most located in public schools. Notably:

- Of the 3,448 Red Cross shelters, 2,204 (63.9 %) are in schools.
- Of the shelters in schools, 2,141 (97.1 %) are in public schools and 63 (2.9 %) are in private schools.
- In some counties no private schools are used as shelters (Busk 2009).

A summary of the total number of shelters in each of the counties and the distribution among public and private schools is presented in Appendix L.

The main issue in the selection of shelters is safety, followed by proximity to potential disaster zones. Public schools are most desirable as shelters *"because they are known to be built to a higher standard, as compared to other buildings"* (Busk, 2009). Schools of more recent construction are even more desirable as shelters because they have a higher level of Americans with Disabilities Act (ADA) compliance. The level of comfort available for evacuees, e.g., the availability of showers, privacy, parking spaces, and ease of finding the location, are other considerations, which make public high schools a preferred choice. The effect of the impact of the shelter being occupied for the duration of the disaster is also considered, with the intention of minimizing that impact. ARC has a Memorandum of Understanding (MOU) with each school district and sometimes with the City. Each school is individually inspected to determine features such as the facilities available, number of evacuees that can be accommodated, and age of construction, among others. The ARC cooperates with the facility owner to the fullest extent possible (Busk 2009).

VII Findings

1. Since the inception of the Field Act, school buildings constructed according to the Field Act have performed significantly better than comparable non-Field Act buildings with regard to life safety and limiting property damage. In particular, the amount of structural damage reported in public schools in all of the earthquakes studied was relatively small and there was not one incidence of structural collapse in any Field Act building. Five earthquakes (Imperial Valley, San Fernando, Mammoth Lakes, Landers, and Petrolia) since 1933 resulted in shaking intensities of MMI X or greater. All 13 public school sites reported to have been subjected to MMI X shaking performed well.

2. Despite the difficulty of making direct comparisons between Field Act and similar non-Field Act buildings, there is ample evidence that Field Act buildings have achieved a consistently higher level of performance with regard to structural integrity as compared to similar non-Field Act buildings at shaking intensities that can cause significant structural damage. However, improvements in requirements for the general building stock have resulted in a narrowing of the performance gap between Field Act and non-Field Act buildings.

3. The enactment of the Field Act in 1933 has resulted in public schools in California being constructed with uniform code enforcement and quality control, from design through completion of construction. Related legislation has also ensured that pre-Field Act public school buildings were either retrofitted or rebuilt, to improve their seismic safety.

4. The enforcement of the Field Act by a central agency, the Division of the State Architect, results in relatively consistent quality control throughout the design, including plan check, and construction inspection processes. Having one agency oversee public school design and construction also allows seismic safety programs, such as the Seismic Safety Inventory of California Public Schools under AB 300, to be more easily utilized because building records and data are under the control of one agency.

5. The recognized likelihood of public schools performing better than the general building stock during a damaging earthquake is a significant factor in the extensive selection and use of these facilities as temporary emergency shelters and places to assist communities during the recovery phase.

6. Significant nonstructural damage was reported in nearly all earthquakes. In some cases, it was noted that this damage could have caused injuries if schools had been in session. Code requirements began addressing this issue in the 1970s. The dislodging of building contents, which are added after construction, poses significant risks to occupants; these warrant a higher level of safety. Students will remain at risk due to toppling of furniture and equipment such as filing cabinets, shelved items, computers, and laboratory contents. A 2003 publication providing guidance to mitigate nonstructural earthquake hazards in California's public schools was prepared by the Governor's Office of Emergency Services and the Division of the State Architect and issued to school districts.

References

AB 300, 1999. *Seismic Safety: Schools*. California Assembly Bill 300, Introduced by Assembly Member Corbett.

Applied Technology Council (ATC), 1989. *Procedures for Postearthquake Safety Evaluation of Buildings (ATC-20),* Applied Technology Council, Redwood City, CA.

Applied Technology Council (ATC), 1993. *NSF/ATC-59 Task 4 Report*, Applied Technology Council, Redwood City, CA, unpublished.

Barclay, D., 2003. The Field Act: History and issues of California schools, *Seismological Research Letters*, Volume 74, No. 1, 27-33.

Barclay, D., 2004. Assessing seismic safety policy, *MIT Undergraduate Research Journal (MURJ)*, Volume 10, 17-23.

Bellet, D. E., 1989. *Impact of Seismic Safety Legislation on Schools, Hospitals, and Essential Services Buildings*, Office of the State Architect, Sacramento, CA, 14 pages.

Busk, T. 2009. *Personal Communication*, American Red Cross, San Jose Chapter, June 12.

California Code of Regulations. (2007-). *Title 24, Part 1, Section 4*. California Building Standards Commission, Sacramento, CA, 301 pages.

California Emergency Management Agency, 2003. *Guide and Checklist for Nonstructural Earthquake Hazards in California Schools.* Governor's Office of Emergency Services, Mather, CA, 56 pages.

California Emergency Management Agency (CalEMA), 2007. *State of California: Multi-Hazard Mitigation Plan*. Governor's Office of Emergency Services, Mather, CA, 620 pages.

California Seismic Safety Commission (CSSC), 1995. *Northridge Earthquake: Turning Loss to Gain*, California Seismic Safety Commission, Sacramento, CA. Report No. CSSC 95-01.

California Seismic Safety Commission (CSSC), 2004. *Seismic Safety in California's Schools: Findings and Recommendations on Seismic Safety Policies and Requirements for Public, Private, and Charter Schools,* California Seismic Safety Commission, Sacramento, CA. Report No. CSSC 2004-04.

California Seismic Safety Commission (CSSC), 2007. *The Field Act and Public School Construction: A 2007 Perspective,* California Seismic Safety Commission, Sacramento, CA. Report No. CSSC 2007-03.

City of Los Angeles, 2003. *Database of Northridge Earthquake Information (EQ1-94),* Department of Building and Safety.

County of Los Angeles, 1995. *Assessor's Report*.

County of Los Angeles, 1995. *Assessor's Roll Release, 1994-1995.*

Crumlish, D. C., and Wirth, G. W., 1967. *A Preliminary Study of Engineering Seismology Benefits*, U.S. Department of Commerce, Washington, D.C., 46 pages.

Cuenca, Ventura, 2009. *Email Communication*, Data courtesy of the Los Angeles County Office of the Assessor, Department of IT Financial and Property Data Sales, July 15.

Department of General Services, 2002. *Seismic Safety Inventory of California Public Schools: A Report to the Governor of California and the California State Legislature.* Sacramento, CA, 37 pages.

Deppe, K., 1994. "Northridge Earthquake overall damage review," *Proceedings of the 63rd Annual Convention of the Structural Engineers Association of California*, Lake Tahoe, CA, pp. 51-67.

Division of the State Architect (DSA), 1994. Northridge Earthquake: Public school buildings preliminary report, *The Inspector*, Volume 6, No. 2.

Division of the State Architect (DSA), 1994. *ATC-20 Reports*. Reviewed by Steven Vukazich on July 8, 2009.

Earthquake Engineering Research Institute (EERI), 1980. *Imperial County, California, Earthquake*, EERI, Berkeley, CA.

Earthquake Engineering Research Institute (EERI), 1984. *Coalinga, California, Earthquake of May 2, 1983*, EERI, Report No. 84-03, Berkeley, CA.

Earthquake Engineering Research Institute (EERI), 1990. *Loma Prieta Earthquake Reconnaissance Report*, EERI, Berkeley, CA.

Engle, H. M., 1936. The Montana Earthquake of October, 1935: Structural Lessons, *Bulletin of the Seismological Society of America*, Volume 26, No. 2, 99-109.

Federal Emergency Management Agency (FEMA), 2009. *Email Communication*, Data provided by Johanna Fenton, August 3.

Governor's Office of Emergency Services, 1999. *Five-Year Anniversary Northridge Earthquake: Anniversary Recap,* Office of Emergency Services News.

Hackett, J. P., 2009. "Quality assurance for seismic safety in California's schools," *Proceedings of the Sixth International Conference on Urban Earthquake Engineering*, Tokyo Institute of Technology, Tokyo, Japan, pp. 395-400.

Harris, S. K., and Egan, J. A., 1990. *Effects of Ground Conditions on the Damage to Four-Story Corner Apartment Buildings (Marina District),* U.S. Geological Survey Paper 1551-F, Department of Mines and Geology, F181-F194.

Jephcott, D. K., and Hudson, D. E., 1974. *The Performance of Public School Plants during the San Fernando Earthquake,* California Institute of Technology, Pasadena, CA.

Jephcott, D. K., 1986. Fifty-Year Record of Field Act Seismic Building Standards for California Schools, *Earthquake Spectra*, Volume 2, No. 3, 621-629.

Lew, H. S., Leyendecker, E. V., and Dikkers, R. D., 1971. *Engineering Aspects of the 1971 San Fernando Earthquake*, U.S. Department of Commerce, Building Science Series 40, Washington, D.C.

Li H., 2009. *Improve Earthquake-Resistant Performance of School Buildings Through Legislation: The Establishment, Enforcement and Effectiveness of "Field Act" in California*, manuscript received from F. Turner, California Seismic Safety Commission, unpublished.

Li W., 2008. *Personal Communication*, National Center of Science and Technology for Disaster Reduction, Taipei, Taiwan.

Los Angeles Unified School District (LAUSD), 1994. *Financial Report*.

Mahaney, J. A., and Freeman, S. A., 1996. "Evolution of performance-based design: A historical perspective," *Proceedings of the 65th Annual Convention of the Structural Engineers Association of California,* Maui, HI.

McGavin, G., 1994. *Observations of Public Educational Facilities within the Epicentral Area of the January 17, 1994, Northridge, California Earthquake*, HMC Group.

McGavin, G., 2009. *Personal Communication*, February 19.

Meehan, J. F., 1982. "Public schools and hospital building geologic hazards considerations," in *Proceedings of the Conference on Earthquake Hazards in the Eastern San Francisco Bay Area, California*, Division of Mines and Geology, Sacramento, CA, Special Publication No. 62, pp 387- 391.

Meehan, J. F., 1990. *Performance of Public Schools in the Loma Prieta Earthquake of October 17, 1989,* Office of the State Architect, Sacramento, CA, 19 pages.

National Board of Fire Underwriters and Pacific Fire Rating Bureau, 1964. *The Alaska Earthquake, March 27, 1964.*

National Clearinghouse for Educational Facilities, 2004. “Earthquakes and Schools,” adapted from *Design Guide for School Safety Against Earthquakes, Floods, and High Winds*, FEMA Publication 424, January 2004.

Office of Emergency Services (OES), 1995. *The Northridge Earthquake of January 17, 1994: Report of Data Collection and Analysis*, Prepared by EQE International, Inc. and the Geographic Information Systems Group of the Governor’s Office of Emergency Services, State of California, May.

Porush, A. R., and Zacher, E. G., 1987. “The Blue Book and seismic codes: Past, present, and future,” *Proceedings of the Convention of the Structural Engineers Association of California.*

Rymer, M. J., and Ellsworth, W. L., 1990. *The Coalinga, California, Earthquake of May 2, 1983*, U.S. Geological Survey Professional Paper 1487, Washington, D.C.

Structural Engineers Association of California (SEAOC), 1995. *Framework for Performance Based Engineering (Vision 2000 Report).*

Selvaduray, G., 2008. *Petrolia Cape Mendocino Earthquakes Trip Report*, August 15, unpublished.

Strand, D., 1984. “Code development between 1927 and 1980,” *Proceedings of the Convention of the Structural Engineers Association of California.*

Yan W., Inaba Y., and Oba A., 2009. “Relief, reconstruction and rehabilitation from the Sichuan Earthquake, China,” *Proceedings of the 6th International Conference on Urban Earthquake Engineering*, Tokyo, Japan, 370 pages.

Yomiuri Shimbun, Japan, 2009. *Personal Communication*, Received from F. Turner, California Seismic Safety Commission, Sacramento, CA.

Zhang Y., and Li W., 2009. *300 Days After the Wenchuan Earthquake Death Toll is Still not Confirmed*. Web site accessed March 20, 2009: http://www.caijing.com.cn/2009-03-08/110114939.html