SEISMIC SAFETY INVENTORY OF CALIFORNIA PUBLIC SCHOOLS

(A Report to the Governor of California and the California State Legislature)

Prepared by the Department of General Services
(November 15, 2002)

Table of Contents

List of Figures

List of Tables

Executive Summary

Public school buildings in California are the safest in the nation. They exceed the seismic standards required for most other buildings and have proven to provide a level of protection that assures the safety of California's public school children. Since the passage of the Field Act in 1933, no school has collapsed due to a seismic event, and there has been no loss of life. Nonetheless, the need to constantly examine conditions, in light of a better understanding of building performance, is necessary to maintain the high standard that is historic in California.

This report conforms to the requirements of Assembly Bill (AB) 300 (Corbett, Chapter 622, Statutes of 1999) which requires the California Department of General Services (DGS) to conduct an inventory of public school buildings (Kindergarten through grade 12, inclusive) that are of concrete tilt-up construction and those with non-wood frame walls that do not meet the minimum requirements of the 1976 *Uniform Building Code* (UBC). Substantial improvements in the seismic design of buildings were incorporated into the 1976 UBC and were adopted for the design and construction of public schools on July 1, 1978.

The DGS, through the Division of the State Architect (DSA), developed a seismic-safety inventory methodology to evaluate the buildings in a meaningful way without conducting costly field investigations**.** The screening process adopted by DSA eliminated all but approximately 16,000 school building construction projects that were then evaluated using a construction documents review process to identify the lateral-force-resisting systems of these buildings.

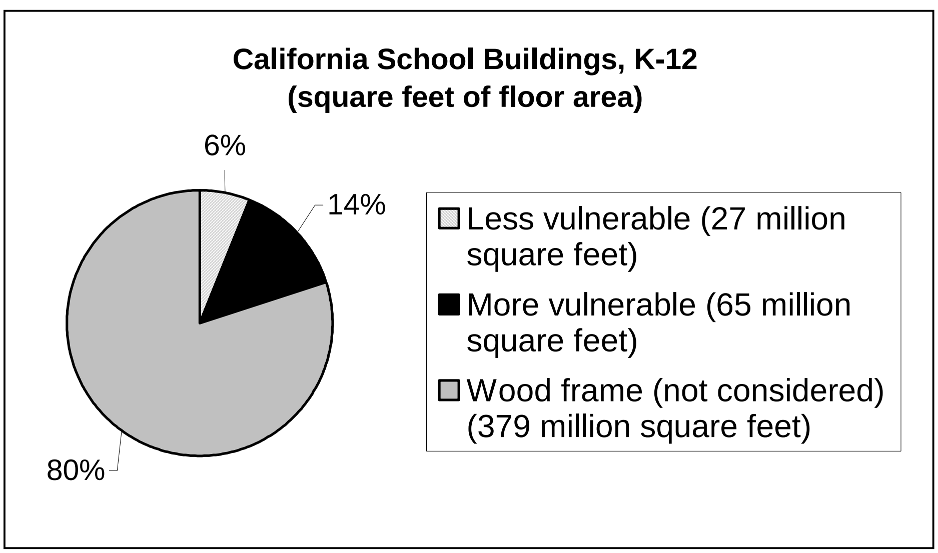
Throughout the development of this report, DSA consulted with the Seismic Safety Commission (SSC). In addition to coordinating the results and recommendations in this report, the SSC provided information on other inventory reports, the history of seismic safety legislation and regulations in California.

The resulting inventory of non-wood frame California public schools designed and built before July 1, 1978, contained 9,659 buildings (92 million square feet), which were then classified in one of the following seismic vulnerability categories:

Category 1: those building types that are likely to perform well, and are expected (but not guaranteed) to achieve life-safety performance in future earthquakes (2,122 buildings, 27 million square feet); and

Category 2: those building types that are not expected to perform as well in future earthquakes as Category 1 building types and that require detailed seismic evaluation to determine if they can be expected to achieve life-safety performance (7,537 buildings, 65 million square feet).

Category 2 buildings represent 14 percent of the current total square footage of California public schools, including wood frame buildings (see diagram below).



The report presents the results of the inventory of non-wood frame public school buildings by number, structural system vulnerability, structure type, square footage, distance from a fault, seismic forces on the building, and estimated costs for rehabilitation. The most vulnerable of Category 2 buildings represent a total cost of $800 million for seismic upgrade. This inventory demonstrates that the cost for seismic rehabilitation of all Category 2 buildings should not exceed an estimated $4.7 billion for work directly associated with the structural strengthening alone. Costs for improvements to the architectural, mechanical, electrical, plumbing or other systems of the building; damage repair costs; hazardous material costs; disabled access improvements; and fire and life safety upgrading and relocation of students may double or triple the costs for implementation of a seismic rehabilitation program.

It must be emphasized that costs at this stage are very preliminary. They are not based on site visits or detailed analysis of individual buildings and also do not take into consideration any recent alterations made through bond measures. Chapter 4 of this report provides a more thorough description of the algorithm used to assess costs at this early stage and its benefit in quantifying the extent of the problem faced.

Typical rehabilitation programs rank buildings according to the level of life-safety risk to the occupants. Buildings that pose the greatest risk are scheduled for rehabilitation first. Table A provides the number of buildings relative to distance from an active fault and the approximate cost to rehabilitate. Each building will require further evaluation to determine its specific seismic strength and extent of rehabilitation to meet the desired performance objective. Table A provides estimated costs for rehabilitation to a "Damage Control" performance objective, which is equivalent to the performance objective for new public school construction.

A program that provides for evaluation, ranking and rehabilitation of those buildings most vulnerable and nearest to active faults is recommended. The costs for a comprehensive rehabilitation program can, therefore, be distributed over several years. Bond financing of public school construction has in part contributed to seismic upgrade of California's public schools. The passage on November 5, 2002, of Proposition 47, a 13 billion dollar measure for school construction, will provide much needed funds for continuing to make California schools the safest in the nation.

A number of school districts throughout California have independently undertaken reviews of the seismic condition of their facilities built prior 1978 and of these some have implemented seismic retrofit programs. Among these are Fremont, San Mateo, Santa Clara, Beverly Hills, Charter Oaks, Glendale and Newport Mesa. Some of the buildings identified in this inventory may be included in current work underway or recently completed. The State Architect and the Department of General Services have always and will continue to work in partnership with local school districts to assure the protection of California's children.

Table A Number of School Buildings and Total Estimated Costs for Seismic Evaluation and Rehabilitation for Category 2* Buildings for "Damage Control" Performance Objective. (Seismic Safety Inventory of California Public Schools)**

Seismic Vulnerability Category 2	*Less than 2 km from Active Fault*	*Between 2 and 5 km from Active Fault*	*Between 5 and 10 km from Active Fault*	*More than 10 km from Active Fault*	*Total All Buildings*
Number of Buildings	1,229	1,602	1,896	2,810	7,537
Cost in Millions	$808	$1,051	$1,204	$1,636	$4,699

*Category 2: Cost includes evaluations, structural rehabilitation, removal and replacement of finishes, project design and administrative costs, and contingencies.

**Non-wood-frame schools designed before July 1, 1978.

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Chapter 1. INTRODUCTION

The California Legislature passed AB 300, (Corbett, Chapter 622, Statutes of 1999) which requires the Department of General Services (DGS) to conduct an inventory of public school buildings that are of concrete tilt-up construction and those with non-wood frame walls, that do not meet the minimum requirements of the 1976 *Uniform Building Code* (UBC) (International Conference of Building Officials, 1976). AB 300 also requires the DGS to submit a report to the Legislature and the Governor by December 31, 2001, summarizing the department's findings and making recommendations regarding the seismic safety of public school buildings (Kindergarten and grades 1 through 12). A copy of the bill is provided in Appendix A.

The Legislature noted that seismic safety studies have been completed for hospitals, bridges, state and local governments, and community colleges, and that it is reasonable to conduct similar studies, using similar methodology, for schools that house pupils enrolled in Kindergarten and grades 1 to 12, inclusive.

This report summarizes the results of the recently completed seismic-safety inventory of public school buildings built prior to July 1, 1978, Kindergarten through grade 12, inclusive, by the DGS, mandated in AB 300. It also recommends actions that should be taken to improve the seismic safety of existing California public school buildings. The report begins with an overview of seismic safety surveys and programs by other state agencies, followed by a brief history of the Field Act and other legislation, regulations, and factors affecting the seismic safety of California public schools, including the benchmark date of July 1, 1978, when the significantly improved seismic provisions contained in the 1976 UBC were adopted for the design and construction of California public schools.

1.1 Seismic-Safety Surveys and Programs by Other Agencies

Over the last three decades, city and state government agencies throughout California have conducted a variety of inventory surveys and programs aimed at improving the seismic safety of facilities within their jurisdiction. These have included programs by statewide municipal programs aimed at specific types of seismically hazardous buildings, programs to improve the seismic resistance of state owned buildings and local government essential services buildings, programs to improve the seismic safety of facilities at higher education facilities, including Community Colleges, the California State University (CSU) system, and the University of California (UC) system, and a statewide program to improve the seismic safety of acute-care hospitals. Following, listed in the chronological order of their start date, are brief descriptions of each of these programs and the current seismic-safety status of the buildings they govern:

1. The UC system has been evaluating and retrofitting its facilities since the 1970s and continues to place a top priority on seismic risk reduction in its capital outlay program. While

a leader in seismic safety in many respects, UC's building stock tends to be the oldest and most vulnerable compared to other state government buildings. Recently billions in modernization funds have been estimated to be needed on UC's oldest campuses.

2. In 1986, the state required local governments to identify potentially hazardous brick or masonry buildings and establish loss-reduction programs. To date, more than half of the 25,000 buildings inventoried have been retrofitted or demolished. Since 1986, a number of pioneering local governments have developed and adopted mandatory or voluntary retrofit ordinances for tilt-ups, concrete frame buildings, and certain residential wood frame buildings. Many local governments have undertaken voluntary seismic evaluations and retrofits of essential services buildings, including firehouses, police facilities, and communications facilities.

3. In 1990, the Proposition 122 bond measure, sponsored by the Seismic Safety Commission provided $250 million for the retrofit of state buildings and $50 million for local government essential services buildings. Nearly all of these funds have been expended and the remaining funds earmarked for projects. As of 1999, the DGS estimated that between $800 million and $1.7 billion remained in unmet seismic retrofit needs for state buildings excluding UC and CSU buildings.

4. In 1992, the CSU system established a Seismic Review Board to assess more comprehensively CSU's seismic risk and to develop a retrofit program that is now well underway. In CSU's inventory of 1,364 facilities, 145 were identified as potentially hazardous and deserving further evaluation and, retrofits, in many cases. Most of these facilities now have retrofit projects undergoing design and construction, or are completed.

5. In 1994, based on surveys of 2,673 buildings at 490 acute care hospital sites (Applied Technology Council, 1991), Senate Bill 1953, (Chapter 40, Statutes of 1994) was enacted and the state began an effort to require hospital owners to evaluate and, if needed, retrofit or relocate acute care hospitals. Since then, hospital modernization projects have been identified at costs in the tens of billions of dollars.

6. In 1996, the state's Community College Chancellor's Office undertook a $900,000 initial seismic risk assessment of Community Colleges statewide. About 1,600 out of 4,000 buildings surveyed were slated for more detailed seismic evaluations. Community Colleges are integrating this information into future capital outlay plans.

Similar seismic evaluation and retrofit programs are underway for bridges, dams, and other infrastructure systems throughout California.

1.2 History of Legislation and Other Key Factors Affecting the Seismic Design and Construction of Public Schools

1933 - Enactment of the Field Act. Recognizing the gravity of the widespread damage, within a few days after the 1933 Long Beach earthquake, California State Assembly Member C. Don Field, a contractor from Glendale who personally witnessed the collapse of buildings from the earthquake, together with a fellow Assembly Member and a Senator sponsored a bill authorizing the State Architect to develop a statewide building code to make all buildings and especially school buildings safe from earthquakes. At that time, there were no statewide building regulations of any kind except a few regulations on housing concerning general issues such as area and lighting. It was soon recognized that the public would object to spending their own money for such safety measures, particularly during the Great Depression, and the bill would be difficult to enforce properly throughout the state. A bill of this nature would have considerable opposition within the legislative process. However, because of the following items: schools are funded with public money, schools house the children of the electorate, statutes require children to attend schools, and school buildings had performed poorly in prior earthquakes, it was believed that the legislators, as well as the Governor, would support legislation requiring public school buildings to be constructed with earthquake resistance.

The original Field Act passed through the Legislature and was enacted as an emergency measure on April 10, 1933, only one month after the 1933 Long Beach earthquake.

1939 – Enactment of the Garrison Act. The California Legislature, soon after enactment of the Field Act, realized that the new laws regulating school construction did not protect public school children who were still studying in unsafe structures built before 1933. In 1939, the Legislature passed the Garrison Act, which states if a pre-1933 school building was reported by a structural engineer to be unsafe, then it must be upgraded to the lateral-load-resisting requirements of the California Building Code (CBC) or abandoned for school use. There were no requirements in the Garrison Act requiring school districts to make the necessary structural examination. Many school districts, lacking funding or a clear vision of the risks, chose not to investigate their pre-1933 schools. Not until 1967 did the Legislature pass a law requiring pre-1933 school buildings be examined for seismic safety. In 1968, amendments to the Garrison Act required seismic retrofitting or abandonment of the structures found unsafe, with retrofit construction to be completed by June 30, 1975. This amendment to the Garrison Act provided funding for school districts that did not have sufficient funds available for the repair. Under special circumstances, some school buildings were not required to have the seismic retrofit work completed until June 30, 1977.

1967 - Geologic Hazards Legislation. Geological hazards investigations were not required for school construction projects until legislation was passed in 1967. The 1967 statutes required that geological hazards studies be made for all new school sites prior to acquisition for school construction. A 1976 amendment made geological studies mandatory only if the site to be acquired was within the boundaries of any special studies zone (an Alquist-Priolo zone) or within an area designated as geologically hazardous in the seismic safety element of the local general plan. The 1976 amendment prohibits the construction or reconstruction of a school building within 50 feet of the trace of a geological fault along which surface rupture can reasonably be expected to occur within the life of the school building. Geological hazards information is required as part of the California Department of Education's approval of a school site. Since these laws came into effect after most of the buildings in this inventory were constructed, it is likely that there are school buildings in the inventory that may be on or very near the trace of an active fault.

1.3 DSA Plan Review and Inspection Procedures

The Field Act provides for establishment of a procedure to be followed in the design and construction or alteration of public school buildings. The Field Act has been updated several times, but the following principal provisions and procedures have not been changed:

- DSA was given the authority to approve or reject plans for construction of all new school buildings and for the reconstruction, alteration, or addition to existing school buildings for the protection of life and safety and to resist future earthquakes insofar as possible.

- Required plans, specifications, and estimates are to be prepared by a California-licensed architect or registered structural engineer.

- The application, drawings, specifications, geologic report, and calculations are submitted to DSA for review. The documents are marked to ensure compliance with the current CBC and returned to the architect. California-registered structural engineers provide the review of the structural aspects of the design.

- After corrections are made and back-checked by DSA, the documents are stamped for identification. When DSA receives copies of the stamped documents, the application is approved and a letter is sent to the school board indicating approval. No construction contract may be let before the approval of the construction documents is issued by DSA.

- Competent, adequate, and continuous inspection is required during construction by a qualified, state-approved inspector to verify that the work has been executed in accordance with the plans, specifications, addenda, and change orders approved by DSA. Visits to the construction site are required of the design professionals, who are required to observe the construction as it progresses. DSA structural engineers also visit the site to observe the construction and ensure the inspection is comprehensive.

- The architect and registered engineer, the inspector, and the contractor must each make a duly verified report to DSA indicating that the work has been performed and the materials have been used and installed, in every important respect in compliance with the approved plans and specifications.

- When all the final verified reports indicating conformance with the approved documents are received by DSA, a letter of certification of compliance with the Field Act is issued to the school board.

- Any person found to have violated any provision of the Act or to have made any false statement in any verified report is guilty of a felony.

1.4 History of the Changes to the Building Codes Affecting Public School Construction

The Field Act is a state statute and is not a building code. However, the Field Act gives DSA the authority to make rules and regulations it deems necessary to carry out the provisions of the Act. Those rules and regulations are found in Title 24, California Code of Regulations (CCR), commonly known as the CBC. The CBC has historically consisted of the UBC with California amendments.

<u>Before 1933</u>: Previous to the Field Act, school buildings were constructed according to the codes used by a local jurisdiction. The first UBC was not published until 1927. The design of buildings to resist earthquake forces is commonly based on applying a horizontal load on the structure equal to a percentage of the weight of the structure. Most buildings were designed to resist horizontal wind loads instead of earthquake forces. For heavy masonry and concrete buildings the equivalent earthquake force was as low as two percent of the building weight.

<u>1933 to 1978</u>: The first building code for school buildings was *Temporary Regulation Number 5, Appendix A* that went into effect on April 10, 1933, the same day that the Field Act was enacted. This code was much more detailed than the 1927 UBC. Subsequently the UBC was improved. Although the UBC was changed several times and the methods of calculations revised from 1933 to 1976, the earthquake force on the typical school building varied from two to 10 percent of the building weight, dependent upon the structural system and soil strength. Earthquake forces on masonry and concrete buildings increased to about 10 percent of the building weight.

<u>After July 1, 1978</u>: Following the 1971 San Fernando earthquake, which caused extensive damage to numerous buildings in the Los Angeles region that were designed in accordance with the UBC, engineers identified language and requirements in the seismic provisions of the UBC that required revision. While many of these items were changed in the 1973 UBC, all of the needed changes did not appear until the 1976 UBC. The major changes in the 1976 UBC included:

- increased design force levels (an increase of 40 percent in the earthquake forces for masonry and concrete buildings);
- more realistic requirements for the distribution of forces in buildings (for design purposes);
- improved requirements to reduce the horizontal swaying of the building when subjected to earthquake shaking;
- further requirements for the use of ductile connections of exterior elements (such as precast panels) to the structure; and
- an expansion of the earthquake zone map from three zones to four zones.

Most of the changes made to the 1976 UBC were adopted, effective July 1, 1978, by the Building Standards Commission and are included in Title 24 of the California Code of Regulations, which has regulated school design and construction under the jurisdiction of the DGS since the mid 1970s.

Public school buildings in California are the safest in the nation. They exceed the seismic standards required for most other buildings and have proven to provide a level of protection that assures the safety of California's public school children. Since the passage of the Field Act in 1933, no school has collapsed due to a seismic event, and there has been no loss of life. Nonetheless, the need to constantly examine conditions, in light of a better understanding of building performance, is necessary to maintain the high standard that is historic in California.

Chapter 2. INVENTORY METHODOLOGY

The budget constraints dictated by AB 300 stipulated that the DGS complete its seismic-safety inventory of public school buildings at a cost not to exceed $500,000. This required that the DGS develop a means to reduce the number of buildings to be inventoried and to evaluate buildings in a meaningful way without conducting field investigations. Gathering detailed seismic evaluation information at a practical cost for nearly 10,000 non-wood frame school buildings required that the data collection method be efficient and meaningful (see Chapter 4 for the costs of detailed evaluations). The Department of Finance raised concerns about site verification of the inventory results. Field verification is part of the recommended next phase of the survey. This would occur during the more detailed seismic evaluation as part of the mitigation strategy described in Section 4.1. The method selected must also be consistent with the legislative requirement that the report **not** identify individual school sites.

Initially, the DGS reviewed the seismic inventory procedures of other agencies, including the survey of acute-care hospital buildings by the Office of Statewide Health Planning and Development in the early 1990s. The DGS also reviewed available procedures and guidelines for detailed seismic evaluation of buildings with the intent of selecting a seismic-safety inventory approach that would be compatible with commonly used detailed seismic evaluation methods. Based on the review of inventory procedures and available seismic evaluation methods, the department selected an approach that would eliminate from consideration as many apparently safe buildings as possible and would incorporate a building classification scheme that would be consistent with the Federal Emergency Management Agency (FEMA) 310 *Handbook for the Seismic Evaluation of Buildings – A Prestandard* (American Society of Civil Engineers**,** 1998). (The FEMA-310 *Handbook* is a nationally applicable document, accepted by the engineering profession, that is based on more than a decade of research and development funded by the National Science Foundation (NSF) and the FEMA to reduce the seismic effects on existing buildings [**ATC, 1987; ATC, 1989; BSSC, 1992]**). The advantage of developing a FEMA-310-compatible seismic-safety inventory approach offered a framework for further seismic evaluation of potentially hazardous buildings in a systematic and hierarchical way. Further, the FEMA 310 building classification offered a framework for identifying building types having the greatest seismic vulnerability.

Based on these decisions and consistent with AB 300, the DGS eliminated from consideration (1) all school buildings designed on July 1, 1978, and thereafter, and (2) all retrofit projects (and other projects not for new construction) designed before July 1, 1978. The new construction projects built before July 1, 1978, were further screened to eliminate from consideration all wood-frame buildings. Wood-frame buildings are known to perform well in earthquakes. The remaining buildings namely, new construction in steel, concrete, reinforced masonry or mixed systems, designed between 1933 and July, 1, 1978, were then evaluated in a construction document review process, the purpose being to identify the lateral-force-resisting system for each building. The building lateral-force-resisting classification system adopted for this process is consistent with the classification system described in the FEMA-310 *Handbook*, adapted in certain instances to fit the special characteristics of California public schools.

2.1 An Overview of Construction Records and Files Maintained by the Division of the State Architect

Since 1933, the DSA has kept records for each school construction project, including approved plans and specifications, calculations, correspondence, and change orders. The approved plans for each project, which are used by contractors for the construction of school buildings, consist of site layouts and architectural, mechanical, electrical and structural drawings, including details.

Each project is identified by an application number that is supplied at the time of submittal of the project to DSA. The application number is assigned sequentially in the order received the DSA's records include 41,658 school construction projects submitted before the 1976 UBC was adopted on July 1, 1978.

For purposes of retrieval of the records, hand written "register sheets" list each project in the order received. The name of the school and a brief description of the project, including the cost of construction, are provided on the register sheet for each application number. The descriptions provide the scope of the project in simple terms such as "alteration to classroom building", "construction of gym", or "bleachers".

2.2 The Seismic-Safety Inventory Process

Projects designed on or after July 1, 1978, and those that did not appear to be new school building construction were eliminated from further consideration, leaving projects such as new gyms and new classroom buildings for further evaluation. Relocatable buildings constructed before 1978 were small one-story wood structures, and were eliminated from further evaluation pursuant to AB 300. The process for eliminating projects designed before July 1, 1978, was carried out by DSA staff, who were familiar with typical project and construction descriptions used between 1933 and 1978 and who reviewed the register sheets to evaluate project scopes and costs. Of the 41,658 projects designed before July 1, 1978, nearly 16,000 projects were identified as likely new construction of a school building.

In the next stage of the inventory process, construction drawings for these 16,000 projects were retrieved from the DSA archives for further evaluation. Structural engineers, most of whom had extensive experience in the design and construction of public school buildings, carried out the construction document review process. When it was determined that a building was wood frame, no further action was taken other than recording the number of wood school buildings on the campus. Other applications, such as sites with multiple non-wood buildings or complicated structures, required two or three hours of review time. After each set of plans was reviewed, the surveyors completed a Data Collection Form (Figure 1) to document the plan review results.

STRUCTURAL SYSTEMS
S1 Steel Moment Frame With Rigid Diaphragm
S1A Steel Moment Frame With Flexible Diaphragm
S2 Steel Braced Frame With Rigid Diaphragm
S2A Steel Braced Frame With Flexible Diaphragm
S3 Steel Light Frame Metal siding and/or Rod Bracing
S4 Steel Frames with Concrete Shear walls and diaphragms
S5 Steel Frames w/ Infill Masonry Shear Wall/Conc Diaphragms
S5A Steel Frame w/ Infill Masonry Shear Wall/Wood Diaphragms
C1 Concrete Moment Frame
C2 Concrete Shear Wall Rigid Diaphragm
C2A Concrete Shear Wall Flexible Diaphragm
C3 Conc. Frame w/ Infill Masonry Shear Walls/Conc. Diaphragm
C3A Conc. Frame w/ Infill Masonry Shear Walls/Flex. Diaphragm
PC1 Precast/Tilt-up Concrete Shear Wall with Conc. Diaphragm
PC1A Precast/Tilt-up Conc. Shear Wall with Flex. Diaphragm
PC2 Precast Conc. Frame Conc. Shear Walls/Rigid Diaphragm
PC2A Precast Conc Frame No Conc. Shear Walls - RigidDiaphragm
RM1 Reinforced Masonry Bearing Wall - Flexible Diaphragms
RM2 Reinf Masonry Bearing Wall - Stiff Diaphragms
URM Unreinforced Masonry Wood Diaphragms
URMA Unreinforced Masonry Rigid Diaphragms
M Mixed –indicate systems here

Remarks:	
FILE NUMBER	
APPL. NUMBER	
Firm	Initials

Wood Frame Buildings Questions:
Does this appl. have only wood buildings? **Yes**___ **No**___
Number of Wood Bldgs. on this **Application** ____
No. of Stories ____
If any building is 2 stories or more, provide rough approximate of the sq. ft. per floor in remarks section.
This box must be completed even if there are no wood buildings.

Does this application appear to be for an entire campus?
Yes___ **No**___
This box must be completed for all projects

ZONE 3	ZONE 4	AP ZONE	10Km	5Km	2Km
These	**boxes**	**will be**	**filled**	**by**	**CDMG**

Fill in the box below only for non-wood frame buildings

Bldg. No. →	1	2	3	4	5	6
Struct. Sys. →						
No. of Stories						
Classroom						
Multipurpose						
Library						
Auditor/theater						
Administration						
Shop						
Science						
Gym						
Cafeteria						
Greenhouse						
Equip./storage						
Lunch Shelter						
Canopies						
Other						
Sq. Ft. → Combine the Sq. Ft. for all floors and enter. In remarks describe setbacks if any.						

Figure 1. Data Collection Form used in California public school seismic-safety inventory.

The Data Collection Form provided space to document:

- the file number, which indicates the county and school district for the project;
- the application number;
- for each non-wood-frame building, the following information:
  – lateral-force-resisting system, inserting the appropriate alpha-numeric code per Section 2.3 and Figure 1;
  – number of stories;
  – use (classroom, multipurpose, library, auditorium or theatre, shop, science, gym, cafeteria, greenhouse, equipment or storage, lunch shelter, canopy, or "other");
  – the combined square footage for all floors;
- for each wood-frame building (to build a database on those projects for possible future requests for project information):
  - the number of wood-frame buildings on the application, with the number of stories;
  - the approximate square footage per floor of buildings with two or more stories;
  - an indication if the application was for an entire campus;
- space for potential ground motion data for the site was provided; however, this data was later collected using geo-coding (see Section 2.4):
  - if the application was in Seismic Zone 3, or Seismic Zone 4, as defined by the 1997 CBC;
  - if the application was in an Alquist Priolo fault zone;
  - the distance to the nearest active fault (in km, as defined by the 1997 CBC, if the application was equal to or less than 10 km from the fault; and
- remarks.

To facilitate the use of the Data Collection Form, it contained a listing of all of the lateral-force-resisting systems (structural systems) in the building classification system adopted for the inventory (see Section 2.3). Later, the data on each Data Collection Form were entered into an electronic database for long-term archival and data analysis (see Section 2.4 for additional information).

2.3 Building Classification System

The DSA adopted with some minor changes the building classification system provided in the FEMA 310 *Handbook*, which is based on a building classification system first introduced by the ATC in the NSF-funded ATC-14 Report, *Evaluating the Seismic Resistance of Existing Buildings* (ATC, 1987). The classification system was developed following an extensive review of building structural system types nationwide to identify building types that were prevalent in the nation's building stock. The classification system adopted for the seismic-safety inventory of California public schools uses all of the building types included in the FEMA 310 *Handbook*, excluding wood-frame buildings; in addition, several building types dominant in California public school construction but not included in the FEMA 310 *Handbook* were added. The list of building types adopted for this inventory, and their alpha-numeric codes, is provided in Table 1. This list is similar to that in the left column of the Data Collection Form (see Figure 1) but includes two additional types (S1B and C1B) not considered when the form was first developed, yet were identified by the surveyors in the remarks section. Descriptions of each building type are provided in Appendix B.

2.4 Electronic Database

Concurrent with the review of the construction documents, DSA developed an in-house web-based, relational electronic database to archive the data being collected on the Data Collection Forms. In addition to inputting the information provided on the form[1] (see list of attributes in Section 2.2), DSA also compiled and imported address information for use in geo-coding the construction project locations. Geo-coding was required to compare locations with seismic hazard maps prepared by the California Department of Conservation, Division of Mines and Geology (CDMG). Using a geographic information system (GIS), CDMG compared project locations from the DSA database with the level of ground shaking in the current building code. That level is the ground shaking that has a 10 percent chance of being exceeded in 50 years, or, stated another way, the ground shaking that occurs on average every 475 years. Ground motion values corresponding to this level were obtained from the published statewide map by CDMG (Map Sheet 48 by Petersen and others, 1999). The CDMG also compared the location information from the DSA database with the maps of "known active fault near-source zones" prepared by CDMG for use with the 1997 UBC. The "near-source zones" show areas within two, five, and 10 kilometers of active faults, including faults that do not break the ground surface and so are not included within Alquist-Priolo active fault zones. Values for level of ground shaking and for distance from seismic sources were added by CDMG. Future studies of the relation of schools to Alquist-Priolo earthquake fault zones (where faults break the ground surface) and to zones established for liquefaction or seismically induced landslide hazards will also benefit from the DSA geo-coded database.

[1] All data were entered except information pertaining to the Alquist Priolo zone, which were excluded because the data duplicated information contained in the fields pertaining to distance from an active fault.

Table 1. Building Classification System for Seismic-Safety Inventory of California Public Schools

Alpha-Numeric Reference Code	Brief Description
C1	Concrete moment frames
C1B	Reinforced concrete cantilever columns with wood roofs
C2	Concrete shear wall with rigid floor and roof diaphragms
C2A	Concrete shear wall with flexible floor and roof diaphragms
C3	Concrete frame with infill masonry shear walls and concrete floor and roof diaphragms
C3A	Concrete frame with infill masonry shear walls and flexible floor and roof diaphragms
M	Mixed construction containing a combination of two or more of the other structure types defined in this table
PC1	Precast tilt-up concrete shear wall with concrete floor and roof diaphragms
PC1A	Precast tilt-up concrete shear wall with flexible floor and roof diaphragms
PC2	Precast concrete frame with concrete shear walls and rigid floor and roof diaphragms
PC2A	Precast concrete frame without concrete shear walls and with rigid floor and roof diaphragms
RM1	Reinforced masonry bearing wall with flexible floor and roof diaphragms
RM2	Reinforced masonry bearing wall with stiff floor and roof diaphragms
S1	Steel moment frame with rigid floor and roof diaphragms
S1A	Steel moment frame with flexible floor and roof diaphragms
S1B	Steel cantilever columns with wood roofs
S2	Steel braced frame with rigid floor and roof diaphragms
S2A	Steel braced frame with flexible floor and roof diaphragms
S3	Steel light frame with metal siding and/or rod bracing
S4	Steel frames with concrete shear walls
S5	Steel frames with infill masonry shear walls and concrete floor and roof diaphragms
S5A	Steel frame with infill masonry shear walls and wood floor and roof diaphragms
URM	Unreinforced masonry bearing wall with flexible floor and roof diaphragms
URMA	Unreinforced masonry bearing wall with rigid floor and roof diaphragms

Chapter 3. INVENTORY RESULTS

3.1 Building Seismic Vulnerability Categories

As the initial step in analyzing and interpreting the results from the seismic-safety inventory of California public schools, the Project Advisory Panel reviewed the list of building types included in the inventory (Table 1) and divided them into two seismic vulnerability categories:

Category 1: those building types that are likely to perform well[2], based on their performance in prior earthquakes, and are expected to achieve life-safety performance in future earthquakes; and

Category 2: those building types that are not expected to perform as well as Category 1 building types in future earthquakes and that require detailed seismic evaluation to determine if they can be expected to achieve life-safety performance when subjected to earthquake ground motions equivalent to those specified for new design in the 1997 UBC.

If, after detailed seismic evaluation, it is determined that a Category 2 building will not achieve life-safety performance when subjected to the specified ground motions, several risk reduction options are available, including (1) seismically rehabilitating the building to meet DSA's life-safety requirements, (2) a change in use, or (3) demolition.

Table 2 contains a listing of the building types in each seismic vulnerability category.

Table 2. Building Types by Seismic Vulnerability Category*
(Seismic-Safety Inventory of California Public Schools)**

Category 1: Building Types Expected to Perform Well in Future Earthquakes	Category 2: Building Types Requiring Detailed Seismic Evaluation
	C1, C1B, C2A, C3A,
C2, C3	M
S1, S1A, S2, S2A, S4, S5, S5A	S1B, S3
RM2	PC1, PC1A, PC2, PC2A
	RM1, URM, URMA

*Excludes consideration of the seismic performance of nonstructural components.
**Non-wood-frame schools designed before July 1, 1978.

3.2 Summary and Interpretation of Inventory Data

Because the seismic-safety inventory data are archived in a relational database, it is possible to summarize the data in a wide variety of ways. Table 3 provides a summary of the number of school buildings by building type, vulnerability category, and square footage. Based on this table, 78 percent of the buildings, and 71 percent of the square footage, are building types in

[2] Performance in future earthquakes is estimated, not guaranteed, and not to be construed to be a warrant.

Category 2, which require detailed seismic evaluation to determine if they can achieve life-safety performance when subjected to the specified ground motions.

Table 3. Distribution of Building Types by Seismic Vulnerability Category*, Number of Buildings, and Square Footage (School Seismic-Safety Inventory of California Public Schools)**

Building Type	Number of Buildings	Total Square Footage
Category 1: Building Types Expected Perform Well in Future Earthquakes		
C2	452	8,851,000
C3	20	236,000
S1	57	1,179,000
S1A	685	5,332,000
S2	34	1,180,000
S2A	294	2,347,000
S4	2	65,000
S5	3	25,000
S5A	15	114,000
RM2	560	7,154,000
Total Category 1:	2,122	26,483,000
Category 2: Building Types Requiring Detailed Seismic Evaluation		
C1	189	3,304,000
C1B	216	1,486,000
C2A	760	8,695,000
C3A	11	61,000
M	361	3,941,000
S1B	450	2,436,000
S3	181	932,000
PC1	234	3,442,000
PC1A	1,077	10,766,000
PC2	60	583,000
PC2A	18	115,000
RM1	3,980	28,716,000
Total Category 2:	7,537	64,477,000
Total Inventory	9,659	90,960,000

*Excludes consideration of the seismic performance of nonstructural components.
**Non-wood-frame schools designed before July 1, 1978.

Twenty-two percent of the buildings, and 29 percent of the square footage, are building types in Category 1, which are expected to perform well in future earthquakes. Fifty-three percent of Category 2 buildings are of the RM1 type, reinforced masonry bearing wall buildings with flexible floor and roof diaphragms. For buildings constructed between 1933 and 1978, diaphragms were generally wood and therefore flexible. Other prevalent types in Category 2 include PC1A, precast tilt-up concrete shear wall buildings with flexible floor and roof diaphragms (14 percent), and C2A, concrete shear wall buildings with flexible floor and roof diaphragms (10 percent).

Figure 2. Map of California showing Title 24 Seismic zones.

A summary of California public schools in Seismic Zone 3 and Zone 4 (Figure 2), as specified by the 1997 UBC, is provided in Table 4. Zone 4 specifies the region of highest expected ground shaking. Zone 3 ground motions are expected to be less severe than Zone 4, and the equivalent static force level for design is 3/4 of that for Zone 4. Within Zone 4, which contains 79 percent of the school buildings in the seismic-safety inventory, there are 1,596 public school buildings in seismic vulnerability Category 1 and 6,061 public school buildings in seismic vulnerability Category 2. In Zone 3, which contains 21 percent of the school buildings in the seismic-safety inventory, there are 526 public school buildings in seismic vulnerability Category 1 and 1,476 public school buildings in seismic vulnerability Category 2.

Of the 9,659 public school buildings in the seismic-safety inventory, 1,569 school buildings are located within two km of an active fault, 2,004 school buildings are located between two km and five km of an active fault, 2,417 school buildings are located between five km and 10 km of an active fault, and 3,669 buildings are located more than 10 km from an active fault (Table 5). The distribution of school buildings within areas having various ranges of expected seismic shaking (with a 10 percent chance of being exceeded in 50 years) is shown in Table 6.

Table 4. Number of Buildings, and Square Footage by Seismic Vulnerability Category* and Seismic Zone (Seismic-Safety Inventory of California Public Schools)**

Seismic Vulnerability Category	Seismic Zone 3	Seismic Zone 4
Number of Buildings		
Category 1	526	1596
Category 2	1476	6061
Total Buildings	2002	7657
Total Square Footage		
Category 1	4,177,000	22,306,000
Category 2	11,523,000	52,954,000
Total Square Footage	15,700,000	75,260,000

*Category 1: Buildings Expected to Perform Well in Future Earthquakes
Category 2: Buildings Requiring Detailed Seismic Evaluation
Excludes consideration of the seismic performance of nonstructural components.

**Non-wood-frame schools designed before July 1, 1978.

Table 5. Number of Schools Within 2, 5, 10 and More Than 10 Km of an Active Fault, by Seismic Vulnerability Category*
(Seismic-Safety Inventory of California Public Schools)**

Seismic Vulnerability Category**	Within 2 km of Active Fault	2 km to 5 km from an Active Fault	5 km to 10 km from an Active Fault	More than 10 km from an Active Fault
Number of Buildings				
Category 1	340	402	521	859
Category 2	1,229	1,602	1,896	2,810
Total Buildings	1,569	2,004	2,417	3,669

*Category 1: Buildings Expected to Perform Well in Future Earthquakes
Category 2: Buildings Requiring Detailed Seismic Evaluation
Excludes consideration of the seismic performance of nonstructural components.
**Non-wood-frame schools designed before July 1, 1978.

Table 6. Number of Schools in Areas With Specified Levels of Expected Ground Shaking, by Seismic Vulnerability Category*
(Seismic-Safety Inventory of California Public Schools)**

Seismic Vulnerability Category**	Horizontal Acceleration Response of Buildings with Short Periods of Vibration (With 10% Chance of Being Exceeded in 50 Years)			
	Less Than 0.6 *g*	0.6 *g* to less than 1.0 *g*	1.0 *g* to less than 1.4 *g*	1.4 *g* or more
Number of Buildings				
Category 1	557	182	793	590
Category 2	1,645	917	2,993	1,982
Total Buildings	2,202	1,099	3,786	2,572

*Category 1: Buildings Expected to Perform Well in Future Earthquakes
Category 2: Buildings Requiring Detailed Seismic Evaluation
Excludes consideration of the seismic performance of nonstructural components.
**Non-wood-frame schools designed before July 1, 1978.

Chapter 4. MITIGATION STRATEGIES

School buildings in seismic vulnerability Category 1 are likely to perform well, based upon their performance in prior earthquakes, and are expected to achieve life-safety performance in future earthquakes. Category 1 buildings, however, need to be evaluated to determine if their nonstructural components will achieve life-safety performance in future earthquakes.

School buildings in seismic vulnerability Category 2, as defined in Chapter 3, require detailed seismic evaluation to determine if they can be expected to achieve life-safety performance when subjected to earthquake ground motions equivalent to those specified for new design in the 1997 UBC. If after detailed seismic evaluation it is determined that a Category 2 building, including its nonstructural components, will not achieve life-safety performance when subjected to the specified ground motions, the building should be seismically rehabilitated to meet life-safety requirements for the specified ground motions. Other options include a change in use to one where life-safety is not an issue, change in ownership to another party, or demolition.

This chapter provides estimated costs for detailed seismic evaluation and seismic rehabilitation of Category 2 building types, as listed in Table 2. Costs for this evaluation will be done in accordance with the FEMA 310 *Handbook*. The building classification types adopted for the seismic-safety inventory were adapted principally from the FEMA 310 *Handbook*, which is the national consensus standard for detailed seismic evaluation. Costs for carrying out the various levels of evaluation described in FEMA 310 *Handbook* are based on information developed by the ATC for the U. S. Postal Service in 1990 (ATC, 1990). Evaluation costs for seismic rehabilitation are estimated from data generated in an earlier FEMA study on the costs of seismic rehabilitation and published in the FEMA 156 Report, *Typical Costs for Seismic Rehabilitation of Existing Buildings*, dated December 1994.

4.1 An Overview of the FEMA 310 Seismic Evaluation Procedures

The FEMA 310 *Handbook* describes three levels, or tiers, of seismic evaluation. Tier 1 evaluations are carried out using checklists to evaluate on a rapid basis, the structural, nonstructural and foundation elements of the building and the site geologic hazards. Unique checklists for structural evaluation are provided for a broad range of building types, most of which are included in the list in Table 2 (C1B and S1B types are not included in the FEMA 310 Handbook). The goal of a Tier 1 evaluation is to screen out buildings that comply with the FEMA 310 *Handbook*, to exclude from further evaluation buildings that do not have the seismic deficiencies identified in the checklists of FEMA 310. In some cases, “quick checks” of strength and stiffness may be required. There are several possible outcomes from a Tier 1 evaluation:

- The building is acceptable and no further review is necessary;
- The building needs minor seismic rehabilitation work;
- The building has marginal capacity and a Tier 2 seismic evaluation is warranted; or
- The building requires major seismic rehabilitation work.

In a Tier 2 evaluation, a complete analysis of the building that addresses all of the seismic deficiencies identified in Tier 1 is performed. Analysis in Tier 2 is limited to simplified linear analysis methods, and again the goal is to identify buildings not requiring seismic rehabilitation. There are several possible outcomes from a Tier 2 evaluation:

- The building is acceptable and no further review is necessary;
- The building needs minor seismic rehabilitation work;
- The building has marginal capacity and a Tier 3 detailed seismic evaluation using nonlinear analysis procedures is warranted; or
- The building requires major seismic rehabilitation work.

The use of Tier 3 detailed seismic evaluation is recommended for certain building types and configurations that research has indicated can be shown to be seismically adequate using nonlinear analysis procedures, even though other common procedures do not validate their seismic adequacy (ASCE, 1998).

4.2 Cost Estimates for Seismic Evaluation of School Buildings in the Seismic-Safety Inventory

Two broad categories establish the framework for estimating the cost of seismic evaluation:

1. engineering evaluation costs; and
2. program administrative costs.

Engineering Cost Basis. The cost of engineering evaluations relates to the level and type of evaluation. Tier 1 evaluations that include structural, nonstructural, and geologic hazard evaluations are less time intensive than Tier 2 evaluations, which require less time than Tier 3 evaluations. In some cases, only nonstructural components are evaluated at the Tier 1 and Tier 2 levels.

Based on the U.S. Postal Seismic Program estimates, which used a range of 14 hours to 41 hours for the equivalent of Tier 1 evaluations (ATC, 1990), it is assumed that 28 hours of engineering time is required per building for Tier 1 structural evaluations, including evaluation of nonstructural components and geologic hazards. For Tier 1 nonstructural evaluation only, it is assumed that 8 hours are required per building. The hourly cost rate for engineering services is assumed to be $100 per hour (based on an assumed annual inflation rate of four percent since the 1990 U.S. Postal Service study was published).

Tier 2 evaluations, including evaluation of nonstructural components and geologic hazards, are assumed to require 96 hours to complete. If only Tier 2 evaluations of nonstructural components are conducted, 20 hours are required per building. The hourly cost rate for engineering services for Tier 2 evaluations is assumed to be $115 per hour (higher than for Tier 1 evaluations because a higher level of expertise is required).

For purposes of this cost estimation, it is assumed that none of the buildings in seismic vulnerability Category 2 will require a Tier 3 evaluation.

Administrative Cost Basis. The experience of other organizations that have conducted building seismic evaluation programs provides insight into the cost of administering such programs (ATC, 1990). The administrative costs are assumed to cover expenses created by the following aspects of seismic evaluation:

- program planning;

- assignment of building evaluations to engineers and engineering consultants;
- supervision and follow-up of the evaluating personnel;
- administrative review of the evaluation reports;
- support staff, including accounting and clerical, and
- miscellaneous expenses, such as reproduction, communications, transportation, and per diem.

For the purposes of these cost estimates, the administrative expense is taken as a percentage of the funds directly expended on the seismic evaluations. The estimates assume an administrative expense of 20 percent.

Total Seismic Evaluation Cost Estimates. Based on the above described cost basis, the cost of seismic evaluation of a typical Category 1 and Category 2 building is estimated as shown in Table 7:

Based on the Total Cost per Building for structural, nonstructural and geologic hazards evaluation of Category 2 buildings, and assuming that all 7,537 Category 2 Buildings would undergo Tier 1 and Tier 2 evaluations, the total cost of evaluating Category 2 buildings is:

$$7{,}537 \times \$16{,}608 \approx \$125{,}174{,}000 \text{ (rounded off to the nearest \$1,000)}$$

If 20 percent of the Category 2 buildings that undergo Tier 1 evaluation require no further evaluation, either because they are determined to be seismically adequate or because they are clearly seismically hazardous and in need of seismic rehabilitation, then the total cost could be reduced by $11,040 x 1.2 x 7,537 x .2 ≈ $19,970,000 (rounded off to the nearest $1,000). Other strategies and outcomes are possible, as described in Chapter 5.

The total cost of conducting nonstructural evaluations only in Category 1 buildings is computed as:

$$2{,}122 \times \$3{,}360 \approx \$7{,}130{,}000 \text{ (rounded off to the nearest \$1,000)}$$

If 20 percent of the Category 1 buildings that undergo Tier 1 nonstructural evaluation require no further evaluation, then the total cost would be reduced by $2,000 x 1.2 x 2,122 x .2 ≈ $1,019,000 (rounded off to the nearest $1,000). Other strategies and outcomes are possible, as described in Chapter 5.

Table 7. Estimated Seismic Evaluation Costs by Seismic Vulnerability Category*
(Seismic-Safety Inventory of California Public Schools)**

Cost Item		Cost per Building
Category 2 Buildings: Structural, Nonstructural, and Geologic Hazards Evaluation		
Tier 1 Engineering Services:	$100/hr x 28 hours	$2,800
Tier 2 Engineering Services:	$115/hr x 96 hours	$11,040
Administrative Costs (20 percent of Tier 1 and Tier 2 engineering services):		$2,768
Total Cost Per Building		$16,608
Category 1 Buildings: Nonstructural Evaluation Only		
Tier 1 Engineering Evaluation:	$100/hr x 8 hours	$800
Tier 2 Engineering Evaluation:	$100/hr x 20 hours	2,000
Administrative Costs (20 percent of Tier 1 and Tier 2 engineering services):		560
Total Cost Per Building		$3,360

*Category 1: Buildings Expected to Perform Well in Future Earthquakes
Category 2: Buildings Requiring Detailed Seismic Evaluation
**Non-wood-frame schools designed before July 1, 1978.

4.3 Cost Estimates for Seismic Rehabilitation of School Buildings in the Seismic-Safety Inventory

Cost estimates for seismic rehabilitation of school buildings are dependent upon the type of building being evaluated, the type of seismic deficiency that exists in the building, and the seismic zone in which the building is located. As described earlier, 22 variations in structural systems have been identified in California's seismic safety inventory of non-wood-frame K-12 schools designed prior to July 1, 1978. Types of construction include concrete, steel, masonry, precast concrete, and wood.

Typical Seismic Deficiencies. Seismic deficiencies can be related to the overall configuration of the building or to the specific type of construction. An example of a deficiency related to configuration would be an "open front" condition in which a large percentage of windows or doors create a weak line along one or more walls of the building. It is termed "open front" because it usually occurs along the front elevation of a building, where doors and windows are most desirable. The side and rear elevations of most buildings are often essentially solid by comparison. An open front condition causes a weakness in one portion of the building that can concentrate damage along the weak line. It also causes the building to respond to the earthquake with a significant twisting motion (torsion) that can cause damage elsewhere in the building.

Deficiencies related to the type of construction are specific to the material and structural system used in the building. They are the result of past practices used in the construction of certain classes of structures that have proven to be vulnerable to damage in earthquakes. A prominent example of a deficiency related to construction occurs in older concrete buildings that have too few reinforcing steel bars in their concrete columns and beams. As a result, brittle concrete easily cracks and can become unstable and collapse during earthquakes.

Rehabilitation Strategies. Correction of deficiencies varies with the nature of the deficiency. Rehabilitation strategies can consist of adding overall strength and stiffness to a structure, localized addition of strength and stiffness to a specific weak location in a structure, or correction of construction-related deficiencies to prevent premature failure of connections.

Deficiencies related to configuration can be corrected by installing new lateral force resisting elements to supplement the weakness or softness in a structure. In an open front condition, for example, the installation of a new shear wall or braced frame along the weak line would prevent damage along that line, and prevent the twisting response of the building that can cause damage elsewhere.

Material or construction related deficiencies can be corrected in a variety of ways, either by locally strengthening weak connections, or by globally strengthening the structure to reduce the demands on the connections. For example, new steel “jackets” can be added to older concrete columns to keep them from collapsing.

Typical Cost Methodology. Typical structural rehabilitation costs are based on the methodology contained in the second edition of the FEMA 156 *Typical Costs for Seismic Rehabilitation of Existing Buildings*, dated December 1994. This document represents the current practice for estimating seismic rehabilitation costs for large inventories of buildings, and is based on data collected from seismic rehabilitation projects in the public and private sectors across the United States.

In developing California’s database of K-12 public schools, the inventory process did not assess the seismic vulnerability of each individual building. Based on structural system and year of construction listed in the database, none of the buildings in this study would qualify for a benchmark exemption in accordance with FEMA 310, *Handbook for the Seismic Evaluation of Existing Buildings – A Prestandard*. Therefore, for the purpose of estimating seismic strengthening costs for the entire inventory, each building was assumed to possess typical seismic deficiencies commonly observed for structures in its class.

Rehabilitation costs were estimated using option 2 of the FEMA 156 typical cost methodology. Structural costs determined using this method depend on the following factors: building group; square footage; location; year the work is to be performed; level of seismicity; performance objective; and the number of buildings in the inventory.

DSA recognizes the concern of the Department of Finance regarding the possible cost differences between national costs and seismic improvements in California. The FEMA 156 methodology includes cost adjustment factors for location in California and current costs.

- *Building group.* The building group is based on the FEMA 310 building structural classifications (adapted for the seismic safety inventory in Table 1, see Chapter 2), sorted into eight groups of similar rehabilitation strategies and similar costs of strengthening. This grouping determines the group mean cost, which is the base cost used in estimating typical costs for a class of structure in the database.
- *Square footage.* Construction costs vary with the size of the project. For most building groups costs decrease as the square footage increases due to economies of scale.
- *Location.* Construction costs can vary by location. Cities throughout California have the same location adjustment factor, meaning construction costs are assumed constant throughout the state.
- *Year of construction.* Inflation changes construction costs from year to year. Costs in this study were determined using 2002 dollars assuming an inflation rate of four percent per year.
- *Seismicity and performance.* The levels of seismicity and performance objective are closely related. Seismicity is a measure of the earthquake shaking potential at a site, and performance objectives are a statement of the intended condition of the structure following an earthquake (life safety, damage control, immediate occupancy). Higher seismicity and higher performance objectives will result in higher rehabilitation costs. All of California's school sites fall into UBC Seismic Zone 3, classified as high seismicity, or Zone 4, classified as very high seismicity. Since the CBC requires a higher performance objective for new schools (seismic importance factor of 1.15) costs have been estimated considering both the damage control and the life safety performance objectives. **Life safety allows for unrepairable damage as long as life is not jeopardized and egress routs are not blocked. Damage control is intended to provide additional protection to the occupants and to reduce damage to the building.**
- *Number of buildings.* The number of buildings in an inventory affects the confidence level of the estimated construction costs. The FEMA 156 methodology is best when applied to large inventories of buildings, such as California's K-12 public schools, and is not reliable for estimating costs on any one building in particular. As the number of buildings increases, the band of uncertainty in costs decreases. Costs in this study have been determined using a bandwidth associated with a 90 percent confidence level for upper and lower bounds, based on data contained in the FEMA 156 methodology.

Structural and Nonstructural Seismic Rehabilitation Cost Basis. Typical structural and nonstructural rehabilitation unit costs for each structural system included in the seismic safety inventory database are provided in Table 8. Unit costs are in dollars per square foot in 2002 dollars. The data represents mean costs for each system, considering the variation in building size and level of seismicity within each building classification contained in the California K-12 public school seismic-safety inventory. The structural unit costs exclude all nonstructural improvements. The nonstructural unit costs provided in Table 8 include only that work necessary to remove and replace architectural finishes and mitigation of any nonstructural elements directly affected by the structural rehabilitation as required by the CBC. The remaining nonstructural costs such as improvements to the architectural, mechanical, electrical, plumbing, or other systems of the building; damage repair costs; hazardous material costs; disabled access improvement and other fire and life safety upgrade costs; relocation costs; and management, design, testing and permitting fees are not included in the costs estimates. Unfortunately, precise values for these nonstructural costs cannot be provided as a rigorous approach for that determination is not available. Such costs depend upon a variety of factors that are not always known, especially when dealing with a large inventory of buildings. These additional costs may double or triple the costs for implementation of a seismic rehabilitation program.

Program Administrative Cost Basis. The non-construction costs of seismic rehabilitation are termed Program Administrative Costs. These include such things as:

- professional fees, which will run on the order of 15 percent of construction costs;
- construction management fees, which is assumed to run on the order of 10 percent of construction costs; and
- project contingency costs equal to four percent of construction costs plus professional fees plus construction management.

Excluded from the administrative cost basis are other costs, such as demolition and restoration costs; damage repair costs; hazardous material costs; disabled access improvement and other fire and life safety upgrade costs; testing and permitting fees.

Total Seismic Rehabilitation Cost Estimates. The total structural and nonstructural seismic rehabilitation costs determined using the FEMA 156 typical cost methodology are summarized in Table 9 (for Seismic Zone 3), Table 10 (for Seismic Zone 4), and Table 11 (total for both seismic zones). The total structural and nonstructural seismic rehabilitation costs to achieve the life safety performance objective, and for the damage control performance objective for seismic vulnerability Category 2 buildings are estimated at $3,242,302,000 and $3,630,305,000, respectively. Total seismic rehabilitation costs for the life-safety performance objective, including Program Administrative Costs, are summarized in Table 12. Total seismic rehabilitation costs for the damage control performance objective, including Program Administrative Costs, are summarized in Table 13. Strategies for reducing these costs and ranking buildings for seismic rehabilitation are discussed in Chapter 5.

It must be emphasized that costs at this stage are very preliminary. They are not based on site visits or detailed analysis of individual buildings and also do not take into consideration any recent alterations made through bond measures.

Table 8. Mean Seismic Rehabilitation Costs by Building Type and Seismic Zone (Seismic Safety Inventory of California Public Schools*)

Structural System	Seismic Zone 3		Seismic Zone 4		Nonstructural Unit Costs: ($ per sq. foot)
	Structural Unit Costs: Life Safety ($ per sq. foot)	Structural Unit Costs: Damage Control ($ per sq. foot)	Structural Unit Costs: Life Safety ($ per sq. foot)	Structural Unit Costs: Damage Control ($ per sq. foot)	
C1	$30.30	$37.20	$40.20	$48.70	$22.30
C1B	30.70	37.60	40.70	49.40	22.30
C2	26.90	32.90	35.20	42.70	22.30
C2A	22.00	26.90	28.90	35.00	22.30
C3	**	**	40.40	49.00	22.30
C3A	21.20	26.00	29.40	35.60	22.30
M	22.10	27.00	29.00	35.10	22.30
PC1	21.90	26.90	28.80	34.80	22.30
PC1A	22.00	27.00	29.10	35.30	22.30
PC2	**	**	35.70	43.30	22.30
PC2A	**	**	35.80	43.40	22.30
RM1	22.20	27.10	29.40	35.60	22.30
RM2	27.10	33.10	35.60	43.10	22.30
S1	30.20	37.00	40.20	48.80	22.30
S1A	30.90	37.80	40.80	49.50	22.30
S1B	30.90	37.90	40.90	49.60	22.30
S2	12.10	14.80	14.60	17.80	22.30
S2A	11.90	14.60	15.80	19.10	22.30
S3	12.10	14.80	15.90	19.30	22.30
S4	26.50	32.40	35.10	42.50	22.30
S5	35.30	43.30	46.60	56.50	22.30
S5A	22.30	27.30	29.10	35.20	22.30

*Non-wood-frame schools designed before July 1, 1978.
**No structures of this type in Seismic Zone 3.

Table 9. Total Seismic Rehabilitation Estimated Costs for Category* 2 Buildings in Seismic Zone 3 (Seismic Safety Inventory of California Public Schools)**

Structural System	Total Structural Costs: Life Safety	Total Structural Costs: Damage Control	Total Non-Structural Costs	Total Structural Plus Non-Structural Costs: Life Safety	Total Structural Plus Non-Structural Costs: Damage Control
C1	$10,961,000	$13,424,000	$8,127,000	$19,088,000	$21,551,000
C1B	$7,843,000	$9,606,000	$5,735,000	$13,578,000	$15,341,000
C2A	$62,842,000	$76,964,000	$68,121,000	$130,963,000	$145,085,000
C3A	$346,000	$424,000	$363,000	$709,000	$787,000
M	$20,916,000	$25,616,000	$21,566,000	$42,481,000	$47,181,000
PC1	$5,695,000	$6,975,000	$5,859,000	$11,554,000	$12,834,000
PC1A	$46,202,000	$56,585,000	$48,004,000	$94,206,000	$104,589,000
PC2	$0	$0	$0	$0	$0
PC2A	$0	$0	$0	$0	$0
RM1	$65,971,000	$80,796,000	$68,725,000	$134,696,000	$149,521,000
S1B	$32,423,000	$39,709,000	$23,420,000	$55,843,000	$63,129,000
S3	$2,969,000	$3,636,000	$5,490,000	$7,981,000	$9,126,000
Total	$256,168,000	$313,735,000	$255,410,000	$511,099,000	$569,144,000

* Category 2: Buildings Requiring Detailed Seismic Evaluation.
**Non-wood-frame schools designed before July 1, 1978.

Table 10. Total Seismic Rehabilitation Estimated Costs for Category* 2 Buildings in Seismic Zone 4 (Seismic Safety Inventory of California Public Schools)**

Structural System	Total Structural Costs: Life Safety	Total Structural Costs: Damage Control	Total Non-Structural Costs	Total Structural Plus Non-Structural Costs: Life Safety	Total Structural Plus Non-Structural Costs: Damage Control
C1	$113,351,000	$137,366,000	$64,734,000	$178,084,000	$202,099,000
C1B	$49,599,000	$60,108,000	$27,346,000	$76,946,000	$87,454,000
C2A	$157,541,000	$190,919,000	$124,555,000	$282,096,000	$315,474,000
C3A	$1,296,000	$1,571,000	$996,000	$2,292,000	$2,567,000
M	$82,590,000	$100,088,000	$66,156,000	$148,746,000	$166,244,000
PC1	$87,073,000	$105,521,000	$70,626,000	$157,699,000	$176,147,000
PC1A	$244,373,000	$296,147,000	$191,332,000	$435,706,000	$487,480,000
PC2	$20,593,000	$24,956,000	$12,982,000	$33,576,000	$37,939,000
PC2A	$4,107,000	$4,977,000	$2,570,000	$6,677,000	$7,548,000
RM1	$730,933,000	$885,791,000	$566,493,000	$1,297,426,000	$1,452,284,000
S1B	$55,238,000	$66,942,000	$30,827,000	$86,066,000	$97,769,000
S3	$10,702,000	$12,970,000	$15,186,000	$25,889,000	$28,156,000
Total	$1,557,396,000	$1,887,356,000	$1,173,803,000	$2,731,203,000	$3,061,161,000

* Category 2: Buildings Requiring Detailed Seismic Evaluation.
**Non-wood-frame schools designed before July 1, 1978.

Table 11. Total Estimated Seismic Rehabilitation Costs for Category* 2 Buildings (Seismic Safety Inventory of California Public Schools)**

Seismic Zone	Total Structural Costs: Life Safety	Total Structural Costs: Damage Control	Total Non-Structural Costs	Total Structural Plus Non-Structural Costs: Life Safety	Total Structural Plus Non-Structural Costs: Damage Control
Zone 3	256,168,000	313,735,000	255,410,000	511,099,000	569,144,000
Zone 4	1,557,396,000	1,887,356,000	1,173,803,000	2,731,203,000	3,061,161,000
Total	1,813,564,000	2,201,091,000	1,429,213,000	3,242,302,000	3,630,305,000

* Category 2: Buildings Requiring Detailed Seismic Evaluation.
**Non-wood-frame schools designed before July 1, 1978.

Table 12. Seismic Rehabilitation Estimated Cost Summary for Category 2 Buildings for the Life-Safety Performance Objective (Seismic-Safety Inventory of California Public Schools*)

Structural Rehabilitation Costs Nonstructural Rehabilitation Costs				$1,813,564,000 $1,429,213,000 $3,242,777,000
Professional Fees Construction Management	15% 10%	x x	$3,242,777,000	$486,417,000 $324,278,000 $810,695,000
Project Contingency	4%	x	$810,695,000	$32,427,000 Total $4,085,899,000

*Non-wood-frame schools designed before July 1, 1978.

Table 13. Seismic Rehabilitation Estimated Cost Summary for Category 2 Buildings for the Damage-Control Performance Objective (Seismic-Safety Inventory of California Public Schools*)

Structural Rehabilitation Costs Nonstructural Rehabilitation Costs				$2,201,091,000 $1,429,213,000 $3,630,304,000
Professional Fees Construction Management	15% 10%	x x	$3,630,305,000	$544,546,000 $363,031,000 $907,577,000
Project Contingency	4%	x	$907,577,000	$36,303,000 Total $4,574,184,000

*Non-wood-frame schools designed before July 1, 1978.

Chapter 5. RECOMMENDED IMPLEMENTATION STRATEGIES AND POLICIES

This inventory shows that the preliminary estimated cost for seismic rehabilitation of all Category 2 buildings approaches $4.7 billion when evaluation costs are included (see Table 14). Through the use of ranking strategies and staged rehabilitation starting with the most hazardous buildings, the estimated costs can be spread over several years. Concurrently, the risk to the safety of teachers and pupils drops quickly.

5.1 Rehabilitation Priority Ranking Strategies

Historically ranking strategies have been used successfully for practical mitigation of seismic hazards of vulnerable buildings that are part of large inventories. Several factors have been used to best determine the order in which the most vulnerable buildings should be rehabilitated. Those factors include, but are not limited to the following: structural system of the building, calculated strength, building deterioration, soil conditions, ground motion intensity, earthquake probability, location relative to a fault, cost of retrofit, relocation costs, availability of funds, building age, size and occupancy, and the performance objective. Given the number of factors that influence a ranking and the variability within each factor, many options are available.

The probability of building performance falling short of meeting the performance objective is dependent on several of the factors listed above. These can be merged into two basic groups: 1) building strength (structural system, calculated strength, and building deterioration) and 2) earthquake force (soil conditions, ground motion intensity, earthquake probability, location relative to a fault). The building strength is estimated using the detailed evaluation procedures described in Chapter 4. The earthquake force is estimated through site specific studies or by calculations allowed in the current UBC, which requires increases in the earthquake force for those buildings near active fault. When the earthquake forces exceed the strength of the building, the life-safety of the occupants is threatened and rehabilitation or demolition of the building is warranted. Buildings with the highest ratio of earthquake force to building strength should be rehabilitated first.

5.2 Future Actions

In order to provide the greatest benefit for the estimated cost, a ranking strategy is needed prior to an expenditure of funds. Development of this strategy by a panel of experts familiar with all of the following is recommended: ranking strategies, earthquake performance of buildings constructed to out-of-date codes, earthquake performance of rehabilitated buildings, estimating rehabilitation costs and determining the earthquake forces on buildings. Once a ranking strategy is determined and the performance objective is established, a timeline for addressing the problem is possible.

For illustration purposes, a possible step-by-step strategy to spread the estimated cost of rehabilitation over a period of time and to capture the most vulnerable buildings early in the process may follow this chronology (estimated costs indicated in each step are based on a damage control performance objective):

- Perform detailed evaluations of Category 2 buildings located within 2 km of an active fault ($18,435,000).

- Rank the buildings according to previously established criteria, based on the results of the building specific evaluations.

- Begin the funding of these rehabilitation projects in the order of ranking ($873,147,000).

- When the evaluations of the Category 2 buildings located within 2 kilometers have been finished, begin evaluations of those between 2 and 5 kilometers ($24,030,000).

- Rank these buildings.

- Begin funding these projects in the order of ranking as funds become available ($1,136,159,000).

- Repeat this process of evaluation, ranking and rehabilitation of all Category 2 buildings located between five and ten kilometers from an active fault ($1,201,506,000) and those located over 10 kilometers from an active fault ($1,805,502,000).

Table 14 shows the relative costs for each step in the strategy shown above.

5.3 Conclusions

Public school buildings have had an excellent history of performance when subjected to moderately large earthquakes, such as the 1989 Loma Prieta and 1994 Northridge earthquakes, in that there have been no collapses or partial collapses of the structures. However, performance of the older more vulnerable types of school buildings when subjected to major earthquakes may not meet the minimum life-safety performance. The inventory shows that there are thousands of public school buildings that need a detailed evaluation to determine the actual threat these buildings pose to students and teachers. Use of a ranking strategy to determine the order in which buildings are to be rehabilitated will ensure timely, cost-effective improvement in the seismic safety of California public schools.

This report on the seismic safety inventory of public school buildings provides the scope of the problem for policymakers to make informed cost-effective decisions to address the problem.

Bond financing of public school construction has in part contributed to seismic upgrade of California's public schools. The passage of Proposition 47 on November 5, 2002, a 13 billion dollar measure for school construction will provide much needed funds for continuing to make California schools the safest in the nation.

A number of school districts throughout California have independently undertaken reviews of the seismic condition of their facilities built prior 1978 and of these some have implemented seismic retrofit programs. Among these are Fremont, San Mateo, Santa Clara, Beverly Hills, Charter Oaks, Glendale and Newport Mesa. Some of the buildings identified in this inventory may be included in current work underway or recently completed. The State Architect and the Department of General Services have always and will continue to work in partnership with local school districts to assure the protection of California's children.

Table 14. Estimated Costs for Rehabilitation of Category 2* Buildings within 2, 5, 10 and More Than 10 km of an active Fault for Life-Safety and Damage-Control Performance Objectives (Seismic-Safety Inventory of California Public Schools)**

Performance Objective	Distance from an Active Fault	Number of Buildings	Cost of Evaluations	Cost of Rehabilitation	Total Cost
Life Safety	0 - 2 km	1,229	$20,411,000	$718,869,000	$739,280,000
	2 - 5 km	1,602	$26,606,000	$935,409,000	$962,015,000
	5 – 10 km	1,896	$31,489,000	$979,841,000	$1,011,330,000
	10+ km	2,810	$46,668,000	$1,451,780,000	$1,498,448,000
	Total all Buildings	**7,537**	**$125,174,000**	**$4,085899,000**	**$4,211,073,000**
Damage Control	0 - 2 km	1,229	$20,411,000	$787,185,000	$807,596,000
	2 - 5 km	1,602	$26,606,000	$1,024,303,000	$1,050,909,000
	5 - 10 km	1,896	$31,489,000	$1,172,949,000	$1,204,438,000
	10+ km	2,810	$46,668,000	$1,589,748,000	$1,636,416,000
	Total all Buildings	**7,537**	**$125,174,000**	**$4,574,185,000**	**$4,699,359,000**

*Category 2: Buildings Requiring Detailed Seismic Evaluation
**Non-wood-frame schools designed before July 1, 1978.

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Appendix A. Assembly Bill No. 300 (Corbett, Chapter 622, Statutes of 1999)

An act to add Section 17317 to the Education Code, relating to School facilities.

Section 1. The Legislature finds and declares the following:

(a) California's "lucky streak" of not having an earthquake during school hours is still enjoyed today, but that good fortune cannot be relied on forever. It is likely that a damaging earthquake will strike the state during school hours in the future, and if it does, pupils are likely to be harmed due to partial or full structural collapse, as well as due to nonstructural failures of some older buildings that have been approved pursuant to the Field Act.

(b) Fifty percent of the State's 60,000 school buildings housing pupils in kindergarten and grades 1 to 12, inclusive, that have been approved pursuant to the Field Act, were built prior to 1976 when significant seismic requirements were added to the regulations for the Field Act. As a result, a major earthquake may cause significant loss of school functions, property damage, and injuries to pupils and teachers. A small but significant number of schools approved pursuant to the Field Act are prone to collapse because they were built in accordance with older regulations that are now considered obsolete.

(c) Before any meaningful solution may be developed, the scope of the problem needs to be quantified. This measure would do just that, which in turn will enable policymakers to make informed, cost-effective decisions to address the problem.

(d) Studies have been completed for hospitals, bridges, state and local governments, and community colleges. It is reasonable to do the same using the same methodology for schools that house pupils enrolled in kindergarten and grades 1 to 12, inclusive.

SEC. 2. Section 17317 is added to the Education Code, to read:

17317. The Department of General Services shall, in consultation with the Seismic Safety Commission, conduct an inventory of public school buildings that are concrete tilt-up school buildings and school buildings with nonwood frame walls that do not meet the minimum requirements of the 1976 Uniform Building Code. Priority shall be given to the school buildings identified in the act that added this section that are in the highest seismic risk zones in accordance with the seismic hazard maps of the Division of Mines and Geology of the Department of Conservation.

(b) The Department of General Services shall submit a report by December 31, 2001, to the Legislature and the Governor that summarizes the findings of the seismic safety inventory and makes recommendations about future actions that should be taken to address the problems found by the seismic safety inventory. The report shall not identify individual school sites on which inventoried school buildings are located.

SEC. 3. It is the intent of the Legislature that the Department of General Services shall pursue nonstate funding of up to five hundred thousand dollars ($500,000) for the purposes of conducting a seismic safety inventory pursuant to Section 17317 of the Education Code to identify the most vulnerable school buildings in the state. If the Department of General Services is not able to secure sufficient nonstate funding, it shall seek funding from the Legislature through future Budget Acts or other legislation.

Appendix B. Structural Systems

This appendix contains descriptions of each of the building lateral force resisting systems common in the seismic safety inventory of California public schools, kindergarten through grades 12, inclusive (excluding wood-frame buildings). In some instances, drawings are provided showing the structural components in each system.

S1 Steel Moment Frame With Rigid Diaphragm

These buildings consist of a frame assembly of steel beams and steel columns. Floor and roof framing consists of cast-in-place concrete slabs or metal deck with concrete fill supported on steel beams, open web joists or steel trusses. Lateral forces are resisted by steel moment frames that develop their stiffness through rigid or semi-rigid beam-column connections. When all connections are moment resisting connections, the entire frame participates in lateral force resistance. When only selected connections are moment resisting connections, resistance is provided along discrete frame lines. Columns are oriented so that each principal direction of the building has columns resisting forces in strong axis bending. Diaphragms consist of concrete slab or metal deck with concrete fill and are stiff relative to the moment frames. When the exterior of the structure is concealed, walls consist of metal panel curtain walls, plaster on gage-metal stud walls, glazing, brick masonry, or precast concrete panels. When the interior of the structure is finished, frames are concealed by ceilings, partition walls and architectural column furring. Foundations consist of concrete spread footings or deep pile foundations.

S1A Steel Moment Frame With Flexible Diaphragm

These buildings are similar to S1 buildings, except that diaphragms consist of wood framing or untopped metal deck, and are flexible relative to the moment frames.

S1B Steel Cantilever Columns with Wood Roof Diaphragm

These buildings consist of a frame assembly of wood or steel beams, steel columns, and a wood frame roof. The wood roof assembly typically consists of wood or steel primary members, wood secondary members, and plywood or wood roof sheathing.

The seismic load-resisting system utilizes steel columns that transfer seismic forces between the foundation and roof-level diaphragm. These columns are typically fixed at (rigidly connected to) a concrete grade beam at the foundation. These columns act as an “inverted pendulum”, and are subject to special design requirements only incorporated in the most recent building code.

S2 Steel Braced Frame With Rigid Diaphragm

These buildings consist of a frame assembly of steel beams and steel columns. Floor and roof framing consists of cast-in-place concrete slabs or metal deck with concrete fill supported on steel beams, open web joists or steel trusses. Lateral forces are resisted by tension and compression forces in diagonal steel members. When diagonal brace connections are concentric to beam column joints, all member stresses are primarily axial. When diagonal brace connections are eccentric to the joints, members are subjected to bending and axial stresses. Diaphragms consist of concrete or metal deck with concrete fill and are stiff relative to the braced frames.

When the exterior of the structure is concealed, walls consist of metal panel curtain walls, plaster on gage-metal stud walls, glazing, brick masonry, or precast concrete panels. When the interior of the structure is finished, frames are concealed by ceilings, partition walls and architectural furring. Foundations consist of concrete spread footings or deep pile foundations.

S2A Steel Braced Frame With Flexible Diaphragm

These buildings are similar to S2 buildings, except that diaphragms consist of wood framing or untopped metal deck, and are flexible relative to the braced frames.

S3 Steel Light Frame Metal Siding and/or Rod Bracing

These buildings are pre-engineered and prefabricated with transverse rigid steel frames. They are usually one-story in height. The roof and walls consist of lightweight metal, fiberglass or cementitious panels. The frames are designed for maximum efficiency and the beams and columns consist of tapered, built-up sections with thin plates. The frames are built in segments and assembled in the field with bolted or welded joints. Lateral forces in the direction parallel to the frames are resisted by the rigid frames. Lateral forces in the direction perpendicular to the frames are resisted by wall panel shear elements or rod bracing. Diaphragm forces are resisted by untopped metal deck, roof panel shear elements, or a system of tension-only rod bracing.

S4 Steel Frames with Concrete Shear Walls and Diaphragms

These buildings consist of a frame assembly of steel beams and steel columns. The floors and roof consist of cast-in-place concrete slabs or metal deck with or without concrete fill. Framing consists of steel beams, open web joists or steel trusses. Lateral forces are resisted by precast or cast-in-place concrete shear walls. These walls are bearing walls when the steel frame does not provide a complete vertical support system. In older construction the steel frame is designed for vertical loads only. In modern dual systems, the steel moment frames are designed to work together with the concrete shear walls in proportion to their relative rigidity. In the case of dual system, the walls shall be evaluated under this building type and the frames shall be evaluated under S1 or S1A, Steel Moment Frames. Diaphragms consist of concrete slab or metal deck with or without concrete fill. The steel frame may provide a secondary lateral-force-resisting system depending on the stiffness of the frame and the moment capacity of the beam-column connections.

S5 Steel Frames with Infill Masonry Shear Wall/Concrete Diaphragms

This is an older type of building construction that consists of a frame assembly of steel beams and steel columns. The floors and roof consist of cast-in-place concrete slabs or metal deck with concrete fill. Framing consists of steel beams, open web joists or steel trusses. The framing is often encased in concrete for fire protection. Walls consist of infill panels constructed of solid clay brick, concrete block, or hollow clay tile masonry. Infill walls may completely encase the frame members, and present a smooth masonry exterior with no indication of the frame. The seismic performance of this type of construction depends on the interaction between the frame and infill panels. The combined behavior is more like a shear wall structure than a frame structure. Solidly infilled masonry panels form diagonal compression struts between the intersections of the frame members. If the walls are offset from the frame and do not fully engage the frame members, the diagonal compression struts will not develop. The strength of the infill panel is limited by the shear capacity of the masonry bed joint or the compression capacity of the strut. The post-cracking strength is determined by an analysis of a moment frame that is partially restrained by the cracked infill. The diaphragms consist of concrete slabs and are stiff relative to the walls.

S5A Steel Frame With Infill Masonry Shear Wall/Wood Diaphragms

These buildings are similar to S5 buildings, except that diaphragms consist of wood sheathing or untopped metal deck, or have large aspect ratios and are flexible relative to the walls.

C1 Concrete Moment Frames

These buildings consist of a frame assembly of cast-in-place concrete beams and columns. Floor and roof framing consists of cast-in-place concrete slabs, concrete beams, one-way joists, two-way waffle joists, or flat slabs. Lateral forces are resisted by concrete moment frames that develop their stiffness through monolithic beam-column connections. In older construction, or in regions of low seismicity, the moment frames may consist of the column strips of two-way flat slab systems. Modern frames in regions of high seismicity have joint reinforcing, closely spaced ties, and special detailing to provide ductile performance. This detailing is not present in older construction. Foundations consist of concrete spread footings or deep pile foundations.

C1B Reinforced Concrete Cantilever Columns with Wood Roof Diaphragm

These buildings consist of a frame assembly of wood or steel beams, reinforced concrete columns, and a wood-frame roof. The wood roof assembly typically consists of wood or steel primary framing members, wood secondary framing members, and plywood or wood roof sheathing.

One typical seismic load-resisting system utilizes infill concrete walls between adjacent columns. The infill concrete walls transfer seismic forces between the top of the wall and the foundation. The concrete columns may extend vertically above the top of the infill concrete walls, to accommodate clerestory windows. These columns transfer seismic forces between the roof and the top of the infill concrete walls, which imposes concentrated stresses in the columns.

The other typical seismic load-resisting system utilizes concrete columns that transfer seismic forces between the foundation and the roof-level diaphragm. These columns are typically fixed at (rigidly connected to) a concrete grade beam at the foundation. These columns act as an “inverted pendulum”, and are subject to special design requirements only incorporated in the most recent building code.

C2 Concrete Shear Wall Rigid Diaphragm

These buildings have floor and roof framing that consists of cast-in-place concrete slabs, concrete beams, one-way joists, two-way waffle joists, or flat slabs. Floors are supported on concrete columns or bearing walls. Lateral forces are resisted by cast-in-place concrete shear walls. In older construction, shear walls are lightly reinforced, but often extend throughout the building. In more recent construction, shear walls occur in isolated locations and are more heavily reinforced with boundary elements and closely spaced ties to provide ductile performance. The diaphragms consist of concrete slabs and are stiff relative to the walls. Foundations consist of concrete spread footings or deep pile foundations.

C2A Concrete Shear Wall Flexible Diaphragm

These buildings are similar to C2 buildings, except that diaphragms consist of wood sheathing, or have large aspect ratios, and are flexible relative to the walls.

C3 Concrete Frame With Infill Masonry Shear Walls/Concrete Diaphragm

This is an older type of building construction that consists of a frame assembly of cast-in-place concrete beams and columns. The floors and roof consist of cast-in-place concrete slabs. Walls consist of infill panels constructed of solid clay brick, concrete block, or hollow clay tile masonry. The seismic performance of this type of construction depends on the interaction between the frame and infill panels. The combined behavior is more like a shear wall structure than a frame structure. Solidly infilled masonry panels form diagonal compression struts between the intersections of the frame members. If the walls are offset from the frame and do not fully engage the frame members, the diagonal compression struts will not develop. The strength of the infill panel is limited by the shear capacity of the masonry bed joint or the compression capacity of the strut. The post-cracking strength is determined by an analysis of a moment frame that is partially restrained by the cracked infill. The shear strength of the concrete columns, after cracking of the infill, may limit the semiductile behavior of the system. The diaphragms consist of concrete floors and are stiff relative to the walls.

C3A Concrete Frame With Infill Masonry Shear Walls/Flexible Diaphragm

These buildings are similar to C3 buildings, except that diaphragms consist of wood sheathing, or have large aspect ratios, and are flexible relative to the walls.

PC1 Precast/Tilt-up Concrete Shear Wall with Concrete Diaphragm

These buildings are one or more stories in height and have precast concrete perimeter wall panels that are cast on site and tilted into place. Framing is supported on interior steel columns and perimeter concrete bearing walls. The floor and roof diaphragms consist of precast elements, cast-in-place concrete, or metal deck with concrete fill and are stiff relative to the walls. Lateral forces are resisted by the precast concrete perimeter wall panels. Wall panels may be solid, or have large window and door openings which cause the panels to behave more as frames than as shear walls. Foundations consist of concrete spread footings or deep pile foundations.

PC1A Precast/tilt-up Concrete Shear Wall with Flexible Diaphragm

These buildings are similar to PC1 buildings, except that diaphragms consist of wood sheathing or untopped metal deck with concrete fill, and are flexible relative to the walls.

PC2 Precast Concrete Frame & Concrete Shear Walls/Rigid Diaphragm

These buildings consist of a frame assembly of precast concrete girders and columns with the presence of shear walls. Floor and roof framing consists of precast concrete planks, tees or double-tees supported on precast concrete girders and columns. Lateral forces are resisted by precast or cast-in-place concrete shear walls. Diaphragms consist of precast elements interconnected with welded inserts, cast-in-place closure strips, or reinforced concrete topping slabs.

PC2A Precast Concrete Frame No Concrete Shear Walls-Rigid Diaphragm

These buildings are similar to PC2 buildings, except that concrete shear walls are not present. Lateral forces are resisted by precast concrete moment frames that develop their stiffness through beam-column joints rigidly connected by welded inserts or cast-in-place concrete closures. Diaphragms consist of precast elements interconnected with welded inserts, cast-in-place closure strips, or reinforced concrete topping slabs. Current code allows this type of construction in California for new construction if detailed as required for special moment resisting frames.

RM1 Reinforced Masonry Bearing Wall-Flexible Diaphragms

These buildings have bearing walls that consist of reinforced brick or concrete block masonry. Wood floor and roof framing consists of wood joists, glulam beams and wood posts or small steel columns. Steel floor and roof framing consists of steel beams or open web joists, steel girders and steel columns. Lateral forces are resisted by the reinforced brick or concrete block masonry shear walls. Diaphragms consist of straight or diagonal wood sheathing, plywood, or untopped metal deck, and are flexible relative to the walls. Foundations consist of brick or concrete spread footings.

RM2 Reinforced Masonry Bearing Wall-Stiff Diaphragms

These buildings are similar to RM1 buildings, except the diaphragms consist of metal deck with concrete fill, precast concrete planks, tees, or double-tees, with or without a cast-in-place concrete topping slab, and are stiff relative to the walls. The floor and roof framing is supported on interior steel or concrete frames or interior reinforced masonry walls.

M Mixed

These buildings consist of two or more of the above systems.