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URM BEARING WALL BUILDING SEISMIC RISK MITIGATION ON THE WEST COAST OF THE UNITED STATES: A REVIEW OF POLICIES AND PRACTICES

Brandon Paxton[1], Fred Turner[2], Ken Elwood[3] and Jason M. Ingham[4]

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ABSTRACT

Unreinforced masonry (URM) buildings are the most common target for seismic risk mitigation programmes, due to their long history of poor seismic performance. While seismic risk mitigation must make use of sound engineering methodologies, good public policy is at the heart of successful programmes. Past URM seismic risk mitigation efforts on the west coast of the United States are summarized herein, as valuable insights have been gained from both successful and unsuccessful programmes. Programme details such as compliance deadlines, retrofit design techniques, and retrofit/demolition rates are provided for cities throughout California, Oregon and Washington states, and the overall observed effectiveness of mandatory versus non-mandatory seismic strengthening programmes is discussed.

INTRODUCTION

Addressing the risk posed by existing building stocks is a complex socioeconomic issue and there is no single solution that is appropriate for all communities. As such, those facing such risk should consider previously implemented solutions from many other cases and formulate an appropriate response. A succinct review of unreinforced masonry (URM) seismic risk mitigation efforts on the west coast of the United States is presented, with a focus on clay brick bearing wall buildings such that the term “URM” refers to clay brick bearing wall buildings unless otherwise noted.

The seismic performance of unreinforced masonry buildings has been of great interest to engineers, building officials, and affected public in California since seismic disasters of the early 20th century, such as the 1906 San Francisco earthquake and 1933 Long Beach earthquake. In response to the widespread damage and losses to URM buildings in the Long Beach earthquake [1], the California Legislature passed the Riley Act in 1933 [2, 3]. Among other items, the Riley Act required buildings to be designed for lateral forces. The required resistances could not practicably be achieved with URM, effectively ending new URM construction in California [4]. However, the issue of existing URM buildings was not addressed until decades later with the passage of other Acts, various municipal ordinances and, finally, state legislation in 1986, as discussed herein.

URM seismic risk mitigation has lagged further behind in Oregon and Washington States than in California, despite moderate losses in the 1949 Olympia (WA), 1965 Puget Sound (WA) and 2001 Nisqually (WA) earthquakes. However, the now well-known hazard associated with the Cascadia Subduction Zone and the potential for a ~M9 megathrust earthquake has provided further motivation for earthquake strengthening of vulnerable buildings. These regions are also now addressing URM seismic risk.

As most risk mitigation measures in California have been direct responses to losses in past earthquakes, a chronology of the 20th century earthquakes in California and details of losses associated with URM buildings are provided. Significant events are as follows (note that the figures below are not restricted to bearing wall buildings):

- **1906 San Francisco:** Nearly all URM buildings in the western portions of Northern California including San Francisco, Palo Alto and Napa were severely damaged or collapsed;
- **1925 Santa Barbara:** 40% of unstrengthened URM buildings suffered severe damage or collapsed [5];
- **1933 Long Beach:** 20% of unstrengthened URM buildings suffered severe damage or collapsed [5];
- **1971 San Fernando:** 49 deaths caused by collapse of URM buildings at Veteran’s Administration Hospital [6];
- **1983 Coalinga:** 60% of unstrengthened URM buildings suffered severe damage or collapsed [5];
- **1989 Loma Prieta:** in regions of Modified Mercalli Intensity (MMI) VIII (generally within 50 km of the epicenter), 40% of unstrengthened URM buildings were demolished; 9 deaths attributed to URM [7]; and
- **1994 Northridge:** in the Los Angeles area (which experienced mostly MMI VII shaking), approximately 600 URM buildings were unstrengthened at the time of the earthquake; no fatalities due to URM buildings were recorded [8].

Material herein focuses primarily on the mitigation policies (mandatory and non-mandatory) implemented by various communities and the resulting degree of success for each ordinance in mitigating URM seismic risk. The effectiveness of the various ordinances, as evidenced by statistics from California, are presented. Ordinances from the Cities of Portland (Oregon State), Tacoma (Washington State), and Seattle (Washington State) are also presented. Some of the design techniques commonly applied in seismic retrofits for

[1] *Design Engineer, Read Jones Christoffersen Ltd., Victoria, Canada*
[2] *Staff Structural Engineer, Alfred E. Alquist California Seismic Safety Commission, Sacramento, CA, USA*
[3] *Professor, University of Auckland, NZ (Member)*
[4] *Corresponding Author, Professor, University of Auckland, NZ, j.ingham@auckland.ac.nz (Member)*

URM buildings are also discussed. A brief background is provided on the relevant legislative requirements in California.

RETROFIT DESIGN TECHNIQUES

Some of the original ordinances for mandatory strengthening predated design techniques focusing specifically on URM and much development of URM retrofit design techniques occurred in California as a result of the mandatory strengthening programmes that were instituted. This timing, combined with the fact that individual cities were free to craft their own ordinances, means that a variety of techniques have been commonly used to design seismic retrofits (note that the word "standard" is at times used incorrectly to describe these techniques. The term "techniques" includes not only nationwide building codes and their referenced documents, but also methodologies and amendments included in state and local government ordinances). The various techniques can be grouped into two main methodologies:

1. The seismic provisions contained in building codes of the day for new construction, as applied to URM buildings;
2. URM-specific procedures that were developed in response to the need for more effective retrofitting techniques.

The former represents codes typically used in design of modern buildings in that they are based on lumped mass models (i.e. rigid diaphragms) and assume an inverted triangular distribution of forces over the height of the building. The most relevant example is the Uniform Building Code (UBC) [9] (and its locally-amended derivatives). 1970, 1973, and 1976 versions of the UBC were commonly specified for strengthening of URM buildings until the advent of URM-specific procedures. The latter group recognizes an important difference between URM buildings and most modern engineered buildings (eg. concrete and steel), in that the walls are relatively rigid while the flexible, timber diaphragms can dominate the dynamic response of the structure. Such methodologies were developed based upon a comprehensive testing programme in the early 1980s [10], with the purpose of minimizing the required interventions for seismic retrofits. The first design technique to incorporate this methodology was a 1987 Alternate Design Methodology [11] to the 1985 Division 88 of the Los Angeles Municipal Code [12], both of which became the basis for retrofit provisions adopted in national guidelines, codes, and standards:

- The Uniform Code for Building Conservation (UCBC): 1985, 1988, 1991, 1997 editions published by the International Conference of Building Officials [13];
- Canadian Guidelines for Seismic Evaluation of Existing Buildings: 1992 edition published by the National Research Council [14];
- The International Existing Building Code (IEBC) Chapter A1: 2003, 2006, 2009, and 2012 editions published by the International Code Conference [15]; and
- ASCE 41 – Seismic Evaluation and Retrofit of Existing Buildings: 2013 edition, Chapter 15, published by the American Society of Civil Engineers as a National Standard [16].

This list is not exhaustive, with various other versions published in documents throughout North America. It should also be noted that "performance-based" techniques such as ASCE 41 are now becoming more common in retrofit design practice in the United States. These more modern techniques bear only loose ties to the original techniques developed in the 1980's, although Chapter 15 of ASCE 41-13 contains a version of the URM-specific procedures as an acceptable alternative to compliance to meet a collapse prevention performance objective for a limited design ground motion. Other aspects such as financial aid schemes and societal issues are also noted in passing.

For buildings with flexible diaphragms, all the URM-specific methodologies noted above contain a version of what is commonly known as the "special procedure" for URM buildings. The special procedure specifies the same design seismic force (normalized relative to the storey weight) for each storey, as it is assumed that the walls transmit ground motions to the diaphragms without appreciable amplification. It is worth noting that the validity of this model has been questioned, as considerable amplification in the walls has been observed in at least one instrumented, retrofitted building [17] and a host of other items were identified during the development of the methodology [18]. However, a detailed discussion on the matter is beyond the current scope. Some versions have included rudimentary provisions to account for varying diaphragm stiffness, while others have not. The result is typically a lower design base shear than would be derived from otherwise-equivalent codes for new construction [19]. It should be noted that the special procedure places several limitations on the building form, including the need for flexible diaphragms at all levels above the base.

For normal importance buildings, the special procedure versions of Los Angeles' Division 88 and Chapter 16C of the San Francisco Building Code [20] specified allowable stress design storey forces of 10%*W (where "W" denotes the weight of the storey in question). In some cases, design forces were adjusted to account for building importance and/or reductions were afforded to buildings meeting certain restrictions. A safety factor of 3 to 5 was commonly applied to material strengths. Like Los Angeles and San Francisco, many local governments continue to publish municipal codes with outdated allowable stress provisions in their ordinances. However, more recent state laws require local governments to enforce the latest edition of the IEBC, which supersedes outdated allowable stress provisions. State laws also require local governments to maintain and periodically update their ordinances, but many have not done so [21].

With the publication of the "Guidelines for Seismic Retrofit of Existing Buildings" [22] in 2001, retrofit design techniques in the United States shifted from allowable stress design to strength design. Strength design versions of the Special Procedure were later incorporated into the IEBC and most recently into ASCE 41-13. For an example, the resulting storey force specified by the IEBC Chapter A1 for a building on Site Class C (very dense soils) in Los Angeles would be about 60%*W (although this value could be reduced by diaphragm yielding). The design shear stress for URM is correspondingly approximately 5 times greater than those commonly found in the allowable stress provisions (eg. the UCBC). While the focus herein has been on the storey force demands, there are also a number of prescriptive requirements (eg. anchor and brace spacing) that may govern a given design and many of these aspects have historically been the causes of failures in URM buildings. The foregoing discussion is intended simply to illustrate how one facet of design practice has changed over time. Quality control requirements have also evolved over time and the recent versions contain reasonably rigorous requirements for testing and inspection, including requirements addressing mortar strength, veneer ties, and wall anchors.

The "special procedure" design techniques discussed herein typically recognize partial retrofitting measures for areas of low to moderate seismicity. See, for example, Table A1-A of the 2012 IEBC Chapter A1, which is partially reproduced as Table 1. As can be seen, the scope of strengthening required varies significantly and no strengthening is required for buildings for which S_{D1} is less than 0.067g.

Table 1: 2012 IEBC seismic strengthening scope as a function of seismic hazard (modified from [15]).

Building Elements Included	$0.067g \le S_{D1} < 0.133g$	$0.133g \le S_{D1} < 0.20g$	$S_{D1} \ge 0.20g$
Parapets	X	X	X
Wall (out-of-plane) anchorage	X	X	X
Wall (out-of-plane) slenderness		X	X
Walls, in-plane shear		X	X
Diaphragms, shear transfer		X	X
Diaphragms, capacity			X

*S_{D1} represents a 5%-damped spectral acceleration for a period of one second and is typically (but not solely) defined as two-thirds of the site (soils) adjusted value, with a probability of exceedance of 2% in 50 years

It should also be noted that the resistance assigned to masonry walls under the "Special Procedure" is substantially more liberal than provided in typical building codes for new construction, with the expectation that (in-plane) piers and (out-of-plane) walls are permitted to crack and rock, so long as they remain dynamically stable in response to design ground motions.

In closing, it is noted that the performance expectation of these retrofit provisions is generally regarded as being lower than for equivalent codes of the day for new construction [18, 22], with the intent of the aforementioned retrofit provisions being to reduce, but not necessarily prevent, loss of life and injury, nor to prevent damage. In contrast, the intent of building codes for new construction is life safety, although provisions in both the aforementioned retrofit techniques and building codes for new construction were developed long before the advent of performance-based earthquake engineering. Nonetheless, the IEBC, and in prior decades the UCBC, (and their various locally-amended derivatives), were by far the most commonly applied design techniques for URM seismic retrofits on the west coast of the United States. In comparison, those few retrofits that were based on building codes for new construction would often result in excessive retrofit costs and disruption.

LEGISLATIVE REQUIREMENTS IN CALIFORNIA

The following is a brief review of selected legislative requirements in California on seismic safety. Details are presented in order to provide a sense of the evolution of state seismic safety policies. The California Seismic Safety Commission (CSSC, www.seismic.ca.gov) provides further details on the information presented herein.

- 1933 Riley Act: adopted in response to the Long Beach earthquake of 1933. This Act required all cities and counties to establish departments to regulate building construction [4]. It also required buildings and individual components of buildings to be designed for lateral forces. Earthquake forces of 2% of the "design load" and wind forces of 20 pounds per square foot [≈1 kPa] were specified, which effectively ended the construction of new URM buildings in California, as they could not be designed to meet these requirements [2, 4];
- 1933 Field Act: passed in response to the Long Beach earthquake of 1933. The Act ensures compliance with stringent design regulations through rigorous plan review and enhanced field inspection and testing for public school buildings for grades kindergarten through 14 (K-14), which includes primary education, secondary education, community colleges (institutions offering continuing education and up to two years of post-secondary education) and vocational schools (for example, institutions offering carpentry or cosmetology training). As noted by the CSSC, while some significant, life-threatening non-structural damage has been observed in Field Act buildings, no Field Act-compliant structural system has ever partially or wholly collapsed, and no lives have been lost in these buildings as a result of earthquakes [23, 24];
- 1939 Garrison Act: the Garrison Act required that all pre-Field Act public K-14 school buildings receive a seismic evaluation and be retrofitted to meet the requirements of the Field Act. However, there was reportedly little action initially as a result of this act [25];
- 1967/1968/1974 Greene Acts: the Greene Acts effectively reaffirmed the requirements for public school districts to comply with the Garrison Act. Issues of personal liability of School Board members who own the buildings were clarified, and the deadline for retrofits was eventually extended to 1977 [25]. The end result was that by 1977 the vast majority of pre-Field Act buildings were replaced or retrofitted; and
- Senate Bill 547: Enacted in 1986, California's "URM Law" [26] required the 365 local governments in California's highest seismic zone (Zone 4) to: complete an inventory of URM buildings within their jurisdictions, establish loss reduction programmes by 1990, and report on progress to the California Seismic Safety Commission. Local governments in low and moderate seismic zones were exempt. The law recommends (but does not require) that the loss reduction programmes include mandatory strengthening ordinances. Non-mandatory programmes also meet the requirements of the URM Law. Approximately 26,000 URM buildings were inventoried as a result of the law [27]. Note that this law applies equally to non-bearing wall URM buildings, but the focus herein is primarily on bearing wall buildings.

This list of California legislation is not exhaustive, but is intended to provide a sense of the level of political attention that seismic safety has received in California. For example, the Alfred E. Alquist Seismic Safety Act, passed in 1973, was aimed at improving the design of new hospitals [28]. In 1994 the Senate Bill 1953 was passed, which requires all hospitals to resist earthquakes without posing a threat of loss of life, and to receive seismic upgrading by 2030 so as to be operational after earthquakes, insofar as practical [28].

MUNICIPAL ORDINANCES IN CALIFORNIA

The regulatory framework for building construction in the United States provides local government with significant discretion and authority. As such, retrofit ordinances were ultimately crafted by individual cities and counties and, thus, they are reviewed on this basis. Many communities have adopted mandatory strengthening ordinances, but this review is limited to some of the more significant examples, including: Long Beach, Los Angeles, and San Francisco. These three cities provide a good sampling, as their enactment essentially covers the chronological range over which URM retrofit ordinances were adopted in California, with Long Beach enacting the first ever mandatory retrofit ordinance in 1971, followed by Los Angeles in 1981, and San Francisco in 1992. The ordinance adopted by the City of Palo Alto is also reviewed, as this was the first notable "voluntary" programme, as well as that of the City of Napa, as the latter is highly topical following the recent South Napa earthquake that occurred on 24 August, 2014. Note that some cities (such as Long Beach) included non-bearing wall URM buildings in their mandatory strengthening ordinances, while other cities (such as Los Angeles and San Francisco) did not.

Note that this review focuses primarily on "active" seismic risk mitigation programmes, where active programmes require action by owners to mitigate the hazards posed by their buildings. In passive programmes, strengthening requirements are typically triggered by other events such as changes of occupancy or significant renovations such that owners can avoid strengthening their buildings. Passive programmes typically exist in all the regions discussed, including for three decades in the City of Napa prior to 2006.

Long Beach

The City of Long Beach is considered a pioneer of URM seismic risk mitigation in the United States. In 1959, local amendments to the building code gave the building official authority to abate parapets and other appendages that posed falling hazards [29] and most parapets were reportedly abated by the 1960s [30]. In 1971 the city passed the first ordinance in the United States for mandatory comprehensive strengthening of buildings. The ordinance applied to all non-wood frame pre-1934 buildings [30], including buildings with non-load bearing masonry walls and concrete buildings. As of 1992, 68% of 936 identified URM buildings had been mitigated (335 retrofitted, 304 demolished) [29], with almost 300 more having received building permits or submitted plans. By 1995, 94% of buildings had been mitigated (523 retrofitted, 361 demolished) [31]. Thus, it appears that the original ordinance was reasonably successful, but that a significant portion of the work occurred as a result of the 1986 "URM Law" (and the requirement to report on progress to the state). The latest statistics, are shown in Table 2.

Table 2: Long Beach URM compliance rates [27].

Total URMs	Historic URMs	Retrofitted	Demo'd	Non-compliant
936	49	60%	40%	0%

The data in Table 2 include a small, but unknown quantity of non-bearing wall buildings although this issue is of minor significance to the overall purpose of the reported study. The City of Long Beach programme has obviously been successful at mitigating risks, although the demolition rate is relatively high, compared to the average demolition rate in the high seismic regions of the state. From a preservation perspective this outcome is unfortunate, while from a public safety point of view demolitions obviously offer an even greater level of risk reduction than do seismic retrofits.

The design of seismic retrofits for URM buildings in Long Beach have reportedly been in accordance with either the 1970 UBC or the URM-specific retrofit ordinance in Los Angeles, Division 88 [30]. Because Division 88 was not in place until 1981, URM retrofits between 1971 and 1981 were presumably undertaken in accordance with the UBC.

Los Angeles

The City of Los Angeles was the first local government in the United States to pass a retroactive URM seismic ordinance, in the form of its 1949 parapet correction ordinance [32]. Essentially all buildings were in compliance by the 1960s [30].

In 1981 the City of Los Angeles adopted an ordinance for comprehensive seismic strengthening, which is now known as Division 88 (of the Los Angeles Municipal Code). This ordinance covered all URM bearing wall buildings (i.e. infill, non-bearing wall buildings were not included), except one and two family dwellings and apartments with four or less units [12].

Varying timelines for compliance were established based on a "rating classification" that prioritized buildings based on function and occupant load. As expected, higher priority buildings had shorter timelines for compliance: essential buildings were to be strengthened within three years of their owners being served notice from the City that the building fell within the scope of the ordinance. The owners of lower priority buildings had the option of extending the deadline for full compliance by performing partial retrofits as shown in Table 3. Partial retrofits included parapet bracing and the installation of tension anchors.

Table 3: Division 88 compliance timelines.

Rating Class	Definition	Full compliance (no partial retrofit)	Full compliance (w/ partial retrofit)
Essential	Medical/Emergency Services	3 Years	3 Years
High-Risk	> 100 occupants	3 Years	3.25 Years
Med. Risk	All Others	3 Years	4-6 Years
Low Risk	< 20 Occupants	3 Years	7 Years

The City of Los Angeles did not provide any significant incentives for the general building stock, but the city's Community Development Department (CDD) provided low-interest loans to cover project costs for residential and mixed-use buildings. Statistics on the total number of buildings covered were not available, but there were over 1500 residential or mixed-use URM buildings affected by Division 88. It should be noted that in order to be eligible for the financing, buildings also had to receive basic fire safety upgrades such as sprinklers and egress equipment. Additionally, the City's Rent Stabilization Division controlled rent increases [33].

While low-interest financing is a useful option, Comerio [33] notes a few pitfalls that were encountered:

- The funds were intended only for seismic upgrading and the minimally required architectural and fire safety work. However, several building owners took advantage of the loans to complete other work, and thus a strict control system is needed;
- Changes in the work during construction were reviewed by the Building and Safety Department, which tended to slow construction. It was recommended that measures be put in place to expedite this process;
- By 1989, 8% of the 1500+ residential/mixed-use buildings had been demolished and another 9% were in

danger of demolition due to non-compliance with the ordinance. It was recommended that the city implement some type of demolition control, including requirements that an owner at least obtain and submit cost estimates and that the owner meet with the city to discuss funding options; and

- Many of the buildings housed low-income tenants, who already spent an above average portion of their income on rent. It was recommended that rent increases be limited to $100/month or less (existing rental rates were $400-500/month). Typical rent increases varied between $69/month and $144/month. Note: values are in 1989 US Dollars.

The latest compliance statistics are shown in Table 4:

Table 4: Los Angeles URM compliance rates (from [27, 34]).

Total URMs	Historic URMs	Retrofitted	Demo'd	Non-compliant
8080	255	77%	23%	<1%

Note that an additional 1132 non-bearing wall URM buildings have been identified and reported to the CSSC (in conformance with the URM law), which are not subject to Division 88. As of 2006 only 11 of these buildings had reportedly been retrofitted [27]. While ultimately quite effective, the ordinance was fiercely contested and was debated in political arenas for more than eight years (1973-1981). Detractors argued (rightfully so to at least some extent) that the ordinance would place pressure on poor, marginalized citizens through displacement and increased rent. Alesch and Petak [35] provide a detailed discussion of the political and economic issues.

The vast majority of the retrofits were designed in accordance with Division 88, because this ordinance was also responsible for mandating the strengthening. With regards to the seismic performance of the retrofits, the 1994 Northridge earthquake provided a significant test. Shaking in Los Angeles was mostly of MMI VII. Bruneau [8] noted that for unstrengthened buildings, out-of-plane failures were numerous, but that no lives were lost because the earthquake occurred at 4:30 am, when the streets were effectively empty. The majority of strengthened buildings survived undamaged, but approximately 200 of the more than 5800 [31] previously-retrofitted buildings suffered moderate to severe damage. As noted by Bruneau [8], this performance actually exceeded prior expectations (judgmentally) established by a panel of experts [36].

Palo Alto

After a failed attempt to establish a mandatory programme in 1982 – and the Coalinga earthquake of 1983 – the City of Palo Alto formed a "Seismic Hazard Committee" that represented a variety of stakeholders and was tasked with developing an acceptable risk mitigation programme. In 1986 the city passed an ordinance that entailed the following [2, 37]:

- Three building types were included:
  - 46 unreinforced masonry buildings (of which only one was a non-bearing wall building)
  - 28 Pre-1935 non-URM buildings with 100+ occupants
  - 21 Pre-1976 non-URM buildings with 300+ occupants
- Building owners were required to engage a structural engineer to conduct a seismic evaluation of the building, specifying the necessary seismic upgrades;
- Seismic evaluations were submitted to the city and owners were required to inform building occupants that the reports were available for their review; and
- Within one year of filing the report, owners were required to submit a letter to the city indicating their intentions to address the building.

The deliberations that led up to the adoption of this ordinance, along with its incentives, are described in "Earthquake Hazard Identification and Voluntary Mitigation: Palo Alto's City Ordinance" [38]. Strengthening remained voluntary and incentives were made available. However, the incentives were not widely used [37]. The primary driving factor was the public/occupant awareness created by the publicly available engineering assessments. Seismic improvements were marketed by building owners. Additionally, some tenants agreed to help finance upgrade costs and others voluntarily agreed to vacate the space during construction (and return upon completion). Table 5 provides the latest compliance statistics. Strengthening of URM buildings was reportedly to the UCBC provisions for all buildings [27].

Table 5: Palo Alto URM compliance rates [27].

Total URMs	Historic URMs	Retrofitted	Demo'd	Non-compliant
46	4	46%	30%	24%

The compliance rate (76% strengthened or demolished) is much higher than for other voluntary programmes, which (as of 2006) averaged 24% [27]. However, there are a number of factors which likely contributed to the success:

- The relatively small size of the community (1990 population of 55,000), which facilitated community involvement and generation of support for the programme;
- The relatively small size of the URM building stock, leading to smaller overall costs; and
- The fact that the community is relatively affluent compared to the rest of California [2].

This programme is an example of policy-making that was carefully crafted to generate public support rather than opposition, making it successful from both an engineering and political view. In general, however, mitigation rates for other voluntary strengthening programmes tend to be well below average mitigation rates elsewhere in the high seismicity regions of California.

San Francisco

In 1976 the City/County of San Francisco enacted its Parapet Safety Programme, which required owners to retain a structural engineer to provide a seismic assessment of parapets, with the programme applying to all pre-1949 URM buildings posing fall hazards to public sidewalks or occupied spaces [39]. Based on field observations after the 1989 Loma Prieta earthquake, Bonneville and Cocke [39] concluded that the parapet safety programme had been effective: of 66 red-tagged buildings that were reviewed, 50 were reportedly in compliance with the ordinance. None of these 50 buildings suffered collapse of the parapets, although some of these buildings suffered damage to unretrofitted portions. Of the remaining 16 buildings (that were not in compliance with the ordinance), 3 suffered parapet collapse. However, it was also noted that this apparent effectiveness was likely due to the relatively modest intensity (mostly VI and VII in San Francisco on the Modified Mercalli Scale) and short duration of shaking.

As aforementioned, Senate Bill 547 was passed in 1986, which required local governments to establish loss reduction programmes for URM buildings. Like many communities, San Francisco opted to employ a mandatory strengthening programme. In 1992 the city passed ordinance 225-92 [40], which mandated strengthening/abatement of approximately 2000 identified URM buildings. Similar to Los Angeles, non-bearing wall buildings were not subject to the mandatory strengthening ordinance and various timelines for compliance were established based on levels of risk. Table 6 shows the compliance deadlines.

Table 6: Ordinance 225-92 compliance timelines.

Risk Level	Definition	Apply for Permit	Complete Construction
Level 1	Group A occupancies 300+ persons, OR Group E Occupancies, OR 4+ storeys on poor soil	2 Years	3.5 Years
Level 2	Non-Level 1 on poor soil in high-density areas	2.5 Years	5 Years
Level 3	Non-Level 1 on poor soil in other areas	8 Years	11 Years
Level 4	All others	10 Years	13 Years

In terms of incentives, low-interest loans were made available through a $350 million general obligation bond, approved by a public vote. $150 million of this fund was devoted for affordable housing, while the remainder was available for the entire building stock. However, as of 2014, San Francisco had disbursed only $60 million to retrofits because it stipulated restrictions on the use and eligibility of the bond funds [41].

The latest compliance statistics, from 2006, are shown in Table 7.

Table 7: San Francisco URM compliance (from [27]).

Total URMs	Historic URMs	Retrofitted	Demo'd	Non-compliant
1985	516	78%	8%	14%

These figures include only bearing wall buildings. When comparing these figures to those of Los Angeles, it can be seen that San Francisco has achieved a similar compliance rate, but appears to have experienced less demolitions. This outcome is likely due to a number of factors, including the following:

- Economic, construction costs, and real estate conditions were different between the two regions;
- Design and construction practices were more refined (after 10-20 years of implementation elsewhere in California);
- San Francisco's timelines for compliance were longer than those in Los Angeles;
- A much higher fraction of San Francisco's buildings (26%) were considered historic than those of Los Angeles (3%);
- Los Angeles experienced demolitions of previously-retrofitted URM buildings in the aftermath of the Northridge Earthquake; and
- The San Francisco ordinance allowed a "Bolts Plus" relaxation for a few eligible buildings (as subsequently discussed).

Essentially two retrofit alternatives were specified by San Francisco. Chapter 16C of the San Francisco Building Code was created as part of the ordinance, which contained essentially all of the provisions of the 1991 UCBC. This chapter was the default requirement for the seismic retrofits, although a lesser degree of retrofitting was permitted for buildings meeting certain requirements. This alternative, commonly known as a "bolts-plus" retrofit, included wall anchorages for tension and shear, as well as out-of-plane bracing of URM walls not meeting the height-to-thickness limitations of Chapter 16C (again equal to those from the UCBC). In order to qualify for the bolts-plus procedure, buildings were required to meet a number of criteria including:

- The buildings did not contain occupancies of group A (assembly) with > 300 persons, Group E (education), Group H (hazardous), or Group I (industrial);
- Mortar shear strength (from in place shear tests) ≥ 30 psi (≈ 0.20 MPa);
- Timber diaphragms at all levels above the base of the building;
- Maximum of 6 storeys;
- The buildings did not have various irregularities, listed below:
    - Soft/weak storey
    - In-plane discontinuity (of walls)
    - Diaphragm discontinuity
    - Out-of-plane offsets
- Minimum of two lines of lateral force resisting elements in each direction (i.e. open front buildings do not qualify); solid walls must comprise at least 40% of the wall length to be considered a line of resistance; and
- The buildings have or will be provided with crosswalls at spacings not exceeding 40 feet (≈ 12 m) on centre.

Owners could either correct deficiencies and rehabilitate to bolts-plus or implement a UCBC-compliant retrofit scheme. These requirements are relatively restrictive: in a review of the aforementioned 66 red-tagged San Francisco buildings after the Loma Prieta earthquake, Bonneville and Cocke [39] estimated that only 35 buildings would have qualified for a bolts-plus retrofit. The City and County of San Francisco chose not to keep track of which URM building retrofits were fully-compliant with the UCBC and which were to the bolts-plus level, but the percentage of buildings that were eligible for "bolts-plus" is thought to be quite small.

In highlighting these reduced retrofit requirements, it is important to acknowledge the trade-off between safety and retrofit cost. The use of "bolts-plus" retrofits was opposed by structural engineering organizations and many engineers at the time, who pointed out that the UCBC provisions were developed to reduce the level of required intervention to a minimum acceptable level of safety. The performance of the retrofits in San Francisco has essentially remained untested, with no significant, damaging earthquakes in the region since the ordinance was implemented. No other major local government adopted "Bolts Plus" in California. The vast majority of cities and counties with mandatory strengthening ordinances adopted requirements consistent with the Seismic Safety Commission's Model Ordinance [31], developed with statewide consensus from the California Building Officials and the Structural Engineers Association of California. The model ordinance was referenced in the Uniform Code for Building Conservation [13] and later the International Existing Building Code Appendix Chapter A1 [15] and included recommended compliance timelines and time extensions for partial retrofits.

Napa

Like all of the previously noted cities/counties, the City of Napa was subject to the 1986 URM Law. Findings since the Napa earthquake on 24 August, 2014 indicate that Napa has 54 URM buildings in its jurisdiction [42], but that some of these buildings with early retrofits dating back to the 1970s had been removed from the inventory. By 1992 the city had established an inventory of its URM buildings (45 buildings identified) and reported this to the CSSC, although it had not yet established a qualifying loss reduction programme [29] and, thus, was not in full compliance with the URM law.

Based on 1993 interview responses (by a Napa building official) reported by Hoover [30], it appears that Napa was fairly aggressive in requiring seismic upgrades when owners voluntarily proposed changes of occupancy or renovations. By 2003 the CSSC indicated that Napa had notified owners whose buildings appeared to be of URM construction and, thus, complied with the URM law. The city also reportedly encouraged strengthening with reimbursement grants for design fees. At this time, 11 of 46 identified buildings had reportedly been strengthened [43].

In 2006, out of concern over the performance of URM buildings in the 2000 Yountville earthquake, the city passed an ordinance (#020061) requiring all URM buildings to be strengthened within 3 years [27]. The administrative and technical requirements are contained in Section 15.110 of the Napa Municipal Code [44]. The latest compliance statistics are shown in Table 8.

Table 8: Napa URM compliance statistics (from [27, 40]).

Total URMs	Historic URMs	Retrofitted	Demolished	Non-compliant
54	10	87%	6%	7%

The City of Napa has no non-bearing wall buildings. By 2011 the City had required owners of 10 non-compliant buildings to post warning placards (inside the main entrance) stating the following [44, 45]:

> *"This is an unreinforced masonry building which constitutes a severe threat to life safety in the event of an earthquake of moderate to high magnitude."*

When the South Napa earthquake struck on 24 August 2014, there were reportedly four URM buildings that had yet to be strengthened [42]. All four were red tagged and two of those partially collapsed. However the performance of retrofitted URM buildings was also mixed [46]. Retrofit practices have evolved considerably since the earliest retrofits in the 1970's, so efforts are underway to learn from the performance of these early retrofits.

Section 15.110 of the Napa Municipal Code specifies two candidate design provisions: the UCBC [13] or a city-specific procedure. The city-specific procedure is not consistent with current (or recent historical) design practices for URM buildings. Despite the allowances in the Municipal Code, Napa reported to the CSSC [27] that 28 retrofits complied with the requirements of the UCBC.

MUNICIPAL ORDINANCES IN OREGON

URM seismic risk mitigation appears to be much less advanced in the State of Oregon. A state-wide seismic needs assessment for public buildings was completed in 2007 [47], which identified 1800 URM buildings. However, there is no state legislation similar to California's URM Law.

The City of Portland (the largest city in Oregon, with a regional population of over 2.6 million) has some limited requirements addressing URM buildings, included in Chapter 24 of the Portland City Code [48]:

1. When 50% or more of the roof of a URM building is replaced, parapet bracing (complete with roof anchors) are to be provided.
2. A variety of specific triggers are specified for renovations, including the need for seismic strengthening if the cost per square foot of the proposed renovation exceeds US\$30/sq.ft. (≈ US\$323/m^2). This value was increased to US\$40/sq.ft. (≈ US\$430/m^2) for single storey buildings.

Without an active URM seismic risk mitigation programme, the retrofit rate for Portland is relatively low, and is thought to be similar to that of Seattle, where about 5% of all URM buildings were comprehensively upgraded (as triggered by changes of occupancy or renovations) between 1990 and 2007 and another 7% were demolished [49].

MUNICIPAL ORDINANCES IN WASHINGTON

Having experienced damaging earthquakes in 1949, 1965, and 2001, awareness of seismic risk in Washington is considerable, especially among building officials and design professionals. Despite this awareness, public policy-making has not evolved commensurately. Two communities with appreciable accomplishments are reviewed: Tacoma and Seattle.

Tacoma

In 1965, just months after the Olympia earthquake, the City of Tacoma adopted an ordinance addressing URM seismic strengthening [50, 51]. This ordinance specifically identifies parapets and exterior walls as potentially hazardous building appendages that must be able to withstand seismic forces, making it possible for the city to require abatement. However, despite the strong wording the provision has been enforced only when a building undergoes renovations [52].

More recently, with the adoption of the International Building Code [53] and International Existing Building Code [15], parapet bracing is mandatory when more than 25% of the roof area is re-roofed. However, re-roofing typically does not require a building permit, so the enforcement mechanism is not necessarily always effective.

Seattle

Recognizing the risks associated with unretrofitted URM buildings, in 1973 the City of Seattle passed ordinances requiring retrofit of all URM buildings, although the ordinances were quickly repealed due to the public opposition and administrative difficulties [2].

Currently, comprehensive seismic upgrading is only triggered by changes of use or occupancy. However, Section 3401.8 ("Unsafe Building Appendages") of the Seattle Building Code states that:

> *"Parapet walls, cornices...that are in a deteriorated condition or are otherwise unable to sustain the design loads...are hereby designated as unsafe building appendages"* and *"shall be abated in accordance with Section 102"* [54].

This requirement is essentially a narrowing of focus of the general "unsafe condition" clause (in this case Section 102) that is present in most building codes. Unfortunately enforcement of this clause has reportedly been limited [51].

More recently, development of URM risk mitigation policies have again become of interest in Seattle, with draft documents indicating that comprehensive mandatory upgrading is being considered, including relaxations to partial upgrading requirements for certain buildings, similar to San Francisco [55]. Table 9 shows proposed compliance deadlines. Other timelines were set for permit application and approval.

Table 9: Proposed Seattle compliance timelines.

Rating Classif.	Definition	Engineering Assessment	Complete Construction
Critical Risk	Emergency Services, Schools	1 Year	7 Years
High Risk	4+ storeys on poor soil, OR 100+ occupants	2 Years	10 Years
Medium Risk	All others	3 Years	13 Years

Sanctions for non-compliance may include: quarterly fines (US$500 at assessment stage, US$1000 at permit stage, US$45,000 for full compliance deadline); public posting of non-compliance (online or on site); freezes on new permits for the building; denial of incentives; and abatement of the property by the city.

Several incentives (all of which were also employed in California to regionally varying degrees) have been identified by city personnel for consideration, including the following [56]:

- Federal grants: available for public/non-profit owned buildings from the Federal Emergency Management Agency;
- General obligation bonds: voter-approved municipal bonds for a city-administered retrofit funding programme;
- Levies: a voter-approved increase in money collected from each property owner for a city-administered retrofit funding programme;
- Transfer of development rights: allows owner of buildings in a designated area to sell developable air space above the building to other developers, who could then increase the density of their developments; and
- Federal tax credits: tax credits of 10% (of the retrofit construction cost) for pre-1936 non-residential, non-historic buildings and 20% for national historic buildings are available [57], pursuant to the 1986 Tax Reform Act.

In closing it is noted that the URM risk mitigation measures are still in flux in Seattle and that much information is available online through the City of Seattle Website, at: *http://seattle.gov/dpd/codesrules/changestocode/unreinforcedmasonrybuildings/whatwhy/.*

CONCLUSIONS

Mandatory versus Non-Mandatory Strengthening Ordinances

Having reviewed several programmes in detail, the relative effectiveness of mandatory versus voluntary strengthening for URM buildings (as it was experienced in the State of California) is examined. As aforementioned, the URM Law required local governments in California to inventory their URM buildings, establish loss reduction programmes, and report on progress to the California Seismic Safety Commission. The law recommends, but does not require, that local governments include mandatory strengthening in their loss reduction programmes. “Voluntary strengthening” and “notification-only” programmes also meet the requirements of the law.

Mandatory strengthening programmes generally required comprehensive upgrading for in-plane and out-of-plane seismic demands. Some jurisdictions, such as San Francisco, implemented relaxations in the required scope. As aforementioned, there is clearly a trade-off between retrofit cost and the safety achieved and the difference in safety achieved has yet to be fully tested under significant, damaging earthquakes. Moreover, some have pointed out that the UCBC provisions were originally intended only as a significant reduction in risk to life (performance below that expected from new buildings).

Voluntary strengthening programmes typically require seismic evaluations and encourage comprehensive upgrading, with retrofit scopes being similar to the mandatory requirements noted above. Notification-only programmes typically included only a letter from the local authority having jurisdiction to building owners, stating that their building appears to be of URM construction and is potentially a seismic risk [27].

Of the 365 affected local governments in California, 283 were found to have URM buildings in their jurisdiction. The majority of these local governments adopted mandatory strengthening programmes, as shown in Table 10. As of 2006, approximately 55% of the affected URM buildings had been retrofitted and 15% had been demolished, for an overall mitigation rate of 70%. A breakdown of the results by programme type is also provided in Table 10. Note that these figures also include non-bearing wall buildings, but again this detail is of minor significance as they constitute less than 10 percent of the buildings inventoried [31].

The statistics show that mandatory programmes are much more effective at mitigating seismic risks than are non-mandatory programmes. Additionally, the demolition rate can be highly variable for mandatory programmes, with the earlier programmes (eg. those of Long Beach and Los Angeles) experiencing higher demolition rates.

Certain voluntary programmes, such as that of Palo Alto, are counterexamples to the trend of disappointing results for non-mandatory programmes. An important conclusion from this example (and the “URM Law” in general) is that monitoring and reporting progress, and making expected performance of buildings publicly available is an important factor in implementing successful risk mitigation programmes. Another important factor is likely the process by which the ordinance is crafted. As was seen herein, ordinances that were crafted without due consultation with all stakeholders have often been defeated, or at least ineffective. Proper enforcement and quality assurance provisions are also essential.

Table 10: California URM mitigation statistics by programme type (from [27]).

Programme Type	# (%) Jurisdictions	# (%) URMs	% URMs Retrofitted	% URMs Demolished	%URMs Mitigated
Mandatory Strengthening	134 (47%)	19,043 (73%)	70%	17%	87%
Voluntary Strengthening	39 (14%)	1,269 (5%)	16%	8%	24%
Notification-only	46 (16%)	1,487 (6%)	7%	6%	13%
Other	41 (14%)	3,737 (14%)	15%	11%	26%
No Programme	23 (8%)	409 (2%)	4%	27%	31%
Total	**283**	**25,945**	**55%**	**15%**	**70%**

Retrofit Design Techniques

Although a detailed review was not completed herein, it was shown that a variety of design techniques (and force levels) have been used in conjunction with hazard mitigation of URM buildings. Most programmes throughout the west coast of the United States have specified a version of the "Special Procedure". This design technique attempts to recognize the dynamic behavior of URM buildings with flexible floors and roofs. A few newer retrofits have applied the masonry provisions of ASCE 41 Chapter 15 [15]. Although such methodologies are regarded as targeting lesser performance than codes for new construction, buildings retrofitted to these provisions have generally reduced risks to life compared to nearby unretrofitted URM buildings when tested by moderate to strong earthquakes with short durations, such as the 1994 Northridge (Los Angeles) earthquake and the 2014 South Napa earthquake [46]. Of course, such retrofits have not been subjected to highly intense and repeated shaking, such as occurred in New Zealand during the 2010/2011 Canterbury earthquakes. Performance can be expected to be much worse in major, long-duration earthquakes or in multiple earthquakes. Considering the brittle nature of archaic materials, the uncertainty in the performance of URM retrofits in varying ground motions must be recognized when mitigating life safety risks in URM buildings.

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