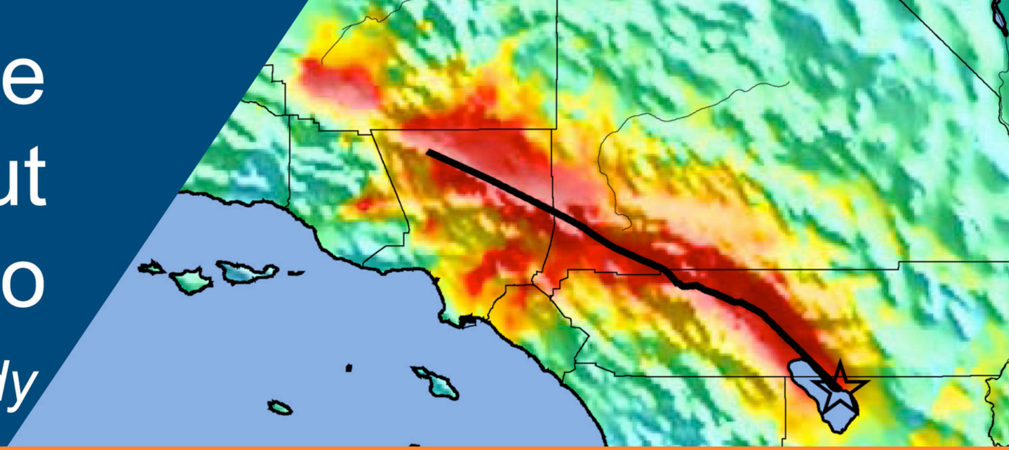
The ShakeOut Scenario

Supplemental Study



Unreinforced Masonry (URM) Buildings

Prepared for
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Note: over the course of the ShakeOut Scenario, the project name evolved. Where a study mentions *the SoSAFE Scenario* or *San Andreas Fault Scenario,* it refers to what is now named the ShakeOut Scenario.

Impacts of a M7.8 Southern San Andreas Earthquake on Unreinforced Masonry (URM) Buildings

Richard L. Hess, S.E.

I Past Performance of URM Buildings:[1]

Unreinforced masonry (URM) bearing wall buildings have shown poor performance in past earthquakes: 1868 Hayward, 1906 San Francisco, 1925 Santa Barbara, 1933 Long Beach, 1952 Kern County, 1971 San Fernando, 1983 Coalinga, 1987 Whittier, 1989 Loma Prieta, and 1994 Northridge. The reasons for this poor performance are the inherent brittleness, lack of

Figure 1
Most photographed commercial URM building in town, the Continental Baking Company, Long Beach, California 1933 – complete collapse
(Historical Society of Long Beach, PO Box 1869, Long Beach, CA 90801 (562) 424-2220)

tensile strength, and lack of ductility; that is, a lack of the properties given to reinforced masonry by the steel reinforcing. Earthquake forces oscillate, and after a crack occurs in a brittle material, subsequent pulses cause uncontrolled displacement and collapse.

(1) From the *Commentary on Appendix Chapter 1 of the Uniform Code for Building Conservation* prepared by the Structural Engineers Association of California, December 1999.

Masonry is one of the oldest building materials and has been considered the most durable. However, it depends on a static, unyielding base. California happens to be a region of high seismicity because it straddles the boundary between the Pacific and North American Plates. However, not many large earthquakes occurred during the first part of the twentieth century when southern California was experiencing a high growth rate, and it was during that period that many URM buildings were constructed.

After the 1933 Long Beach earthquake, building codes changed prohibiting unreinforced masonry buildings, and few have been built in California since then; however, there are URM buildings that remain, which fall into three categories: 1) fully retrofitted; 2) partially retrofitted; and 3) not retrofitted. Following the lead of the cities of Long Beach in the 1970's and Los Angeles in the 1980's, the State of California declared, through Senate Bill 547 (Section 8875 et seq. of the Government Code), that the hazard posed by this class of building is unacceptable and that communities must identify them. The Senate bill does not specify the level of performance required or expected, but leaves it up to each community.

Figure 2

Morrison Apartments, 915 E. Ocean, Long Beach, California 1933 – Front wall only fell away from floors and roof onto street below due to directional properties of earthquake

(Historical Society of Long Beach, PO Box 1869, Long Beach, CA 90801 (562) 424-2220)

It is generally accepted that the intensity of earthquakes which could be reasonably expected to occur in California would be sufficient to cause buildings with minimal seismic resistance characteristics to be seriously damaged or, perhaps, to collapse, causing serious injury or death to the occupants or passers-by. Figures 1 and 2 show the collapse of URM buildings from the 1933 earthquake.

II Overview and Historical Background of Seismic Strengthening Codes and Regulations for URM Bearing Wall Buildings in California:[(1)]

The goal of URM retrofit codes and ordinances has been to reduce life-safety hazards as best possible with the available resources. The efforts are directed to insuring a coherent load path for lateral loads, reduction of out-of-plane wall failures, reduction of loss of support for floors and roofs, and reduction of falling parapets or ornamentation. Application of these Provisions will decrease the probability of loss of life, but loss of life cannot be prevented. Many retrofitted URM buildings will sustain substantial damage, which may make future repair rather than replacement uneconomical.

Figure 3
Partial collapse of a retrofitted URM with walls that exceed h/t limitations.
(Earthquake Spectra, January 1996 Supplement C to Volume 11)

Since the early 1950's, the city of Long Beach, California, has adopted a series of ordinances that addressed the earthquake hazard of URM buildings. The current ordinance, adopted in 1976, has been used as a model by some other communities.

The City of Los Angeles adopted an earthquake safety ordinance in January, 1981. The ordinance, originally designated Division 68, has become a model for other communities and for the State model ordinance; it is commonly referred to as "Division 88" from its chapter number in the code. The ordinance requires evaluation and upgrading of buildings that have bearing walls of unreinforced masonry. In these provisions, the prescribed force levels are only applicable for seismic zone 4 and are reduced for buildings with an occupant load of less than 100 (and if they have crosswalls in all stories), and increased for essential buildings. The comparable section of the Los Angeles County Building Code is Chapter 96.

In December, 1987, the Seismic Safety Commission, in response to Senate Bill 547 ("the URM Law"), published a two-volume report (SSC, 1987) consisting of (1) *Guidebook*, which offers assistance to local government in meeting the requirements of the URM Law, and (2) *Appendix*, which repeats several pertinent codes and a model ordinance called Rehabilitation of Hazardous Masonry Buildings: A Draft Model Ordinance (SSC, 1985). The SSC model ordinance is based on Division 88 and has been recommended to local governments in zone 4 as a mitigation program that complies with the URM Law. A version of Division 88 appears in Appendix Chapter 1 of the 1985 and 1988 Editions of the Uniform Code for Building Conservation (UCBC).

Figure 4
Out-of-plane damage to a retrofitted URM building with a clipped corner
(Earthquake Spectra, January 1996 Supplement C to Volume 11)

III Relevance of Past Experience for Future Performance:[1]

Experience with URM buildings in the 1987 Whittier, 1989 Loma Prieto, and 1994 Northridge earthquakes is relevant to future expectations insofar as the magnitude of shaking is concerned. However, we do not have experience with the higher magnitude and longer duration that will occur near (within 30-50 km of) the San Andreas Fault. The Northridge and Loma Prieta durations were seven seconds, while the 1906 San Francisco duration was 110 seconds. After the Northridge event, some buildings that had not collapsed showed displaced supports that appeared ready to collapse after one or two more ground oscillations.

The minimum required procedure of earthquake hazard reduction has been described by the following descriptive items.

- Remove parapets and ornamentation above the roofline or brace these items to the roof.
- Anchor the Exterior and interior URM walls to the roof and floor framing.
- Check the height/thickness ratios of the URM walls to verify their out-of-plane stability. Brace wall if required.
- Develop horizontal diaphragms at each wall-bracing level. Verify adequacy of these diaphragms to control the relative dynamic displacement of the center of the diaphragm span.
- Develop adequate in-plane strength of URM walls and other elements that control interstory displacements.

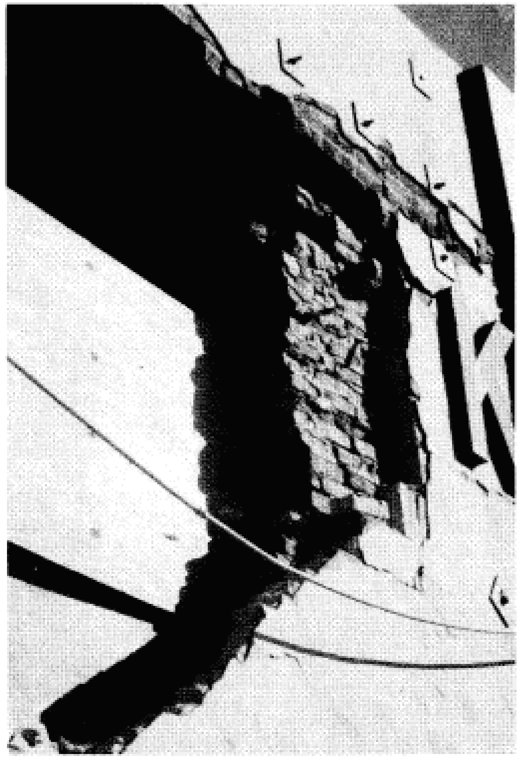

Figure 5
Typical failure of a 9-inch masonry wall with an unbonded veneer course. Note successful performance of the wall anchors.
(Earthquake Spectra, January 1996 Supplement C to Volume 11)

Past risk reduction procedures have applied to the overall average performance of rehabilitated unreinforced masonry (URM) buildings, and especially to life safety. An individual building may have damage levels above or below the average depending on its structural characteristics and the local ground motion. If it has features other than being rectangular with continuous floor and roof diaphragms, additional damage will occur unless the retrofit engineer and contractor correctly deal with these irregularities. Please refer to Figures 3-6 for damage to retrofitted URM buildings during the Northridge earthquake.

Past experience is relevant in proving that retrofitting URM buildings reduces damage and loss of life, but also that building configuration and the quality of the evaluation, design and construction makes a substantial difference in the degree of improvement.

Figure 6
Collapse of a retrofitted URM tower onto the second floor and the street below.
(Earthquake Spectra, January 1996 Supplement C to Volume 11)

IV Regional Damage Scenarios:

Figure 7 shows the number of URM buildings in Los Angeles City after the Northridge earthquake of 1994, in a report for the City of Los Angeles Task Force on Building Damage. This tabulation shows that 2.5% of retrofitted buildings were damaged over 10%, and 0.3% were damaged over 50%. For non-retrofitted buildings, 10.5% were damaged over 10%, and 7% had damage over 50%. This demonstrates the value of the retrofit program.

				URM Status				Unstrengthened			Strengthened		
Council District	Location (approx.)	MMI	Total URM Buildings	Prior Demolition	Exempt	Divison 88 Strengthened	Non-Division 88 Unstrengthened	< 10% Damage	< 50% Damage	> 50% Damage	< 10% Damage	< 50% Damage	> 50% Damage
1	[25,-15]	VII	906	151	15	654	86	10	5	2	94	9	0
2	[20,5]	VII	31	3	1	23	4	0	0	0	2	0	0
3	[-5,0]	VIII	54	7	1	45	1	0	0	0	8	7	2
4	[20,-10]	VII	644	81	7	490	66	15	9	2	73	8	2
5	[10,-10]	VII-IX	220	20	9	183	8	1	2	1	7	3	1
6	[10,-25]	VI-VII	265	34	12	178	41	2	2	1	9	1	0
7	[10,10]	VII-VIII	23	5	0	11	7	5	0	1	1	2	2
8	[20,-25]	V-VII	613	105	20	383	105	4	1	3	22	7	0
9	[25,-20]	VII	3013	735	41	1935	302	23	11	6	74	27	1
10	[15,-20]	VII-VIII	607	51	11	466	79	12	11	3	80	15	0
11	[5,-10]	VII	125	18	0	94	13	1	4	2	13	3	2
12	[0,10]	VIII-IX	3	1	0	2	0	0	0	0	0	1	0
13	[25,-10]	VII	858	101	14	654	89	17	7	5	90	9	8
14	[30,-15]	VI-VII	560	78	12	378	92	15	12	5	18	6	0
15	[25,-45]	V	320	60	4	213	43	5	2	1	0	0	0
			8242	1450	147	5709	936	110	66	32	491	128	18

Figure 7

URM Data for City of Los Angeles Arranged by City Council District and MMI

(Earthquake Spectra, January 1996 Supplement C to Volume 11)

As a measure of the effectiveness of the URM Law and these retrofit ordinances, Report SSC 2006-04 prepared by the California Seismic Safety Commission for the Legislature details the current status of California's URM Building Law. It states that approximately 25,900 URM buildings with an average size of 10,000 square feet have been inventoried in Zone 4's 365 jurisdictions. The average mitigation rate is 70% statewide, and Los Angeles and Orange Counties have 87% and 89% rates respectively. Appendix A of that report, Figure 8, shows the percent of buildings that have been mitigated in each of the affected counties.

Appendix A

2006 Survey of City and County Mitigation Efforts in Seismic Zone 4

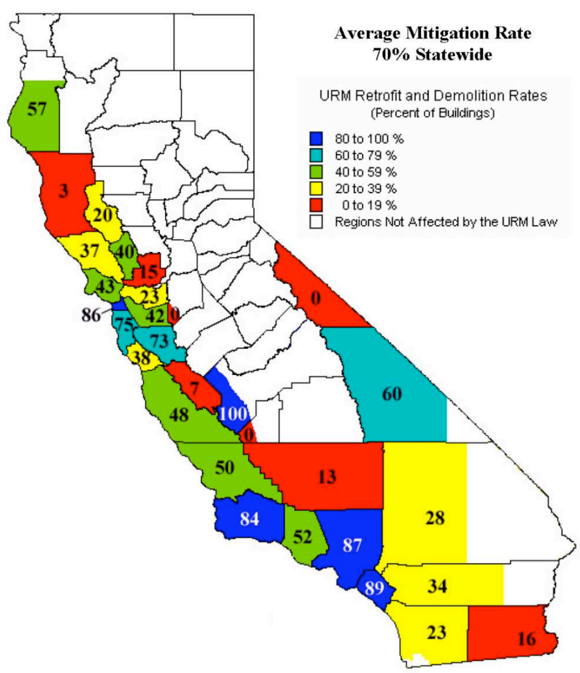

Figure 8

We would expect a higher rate of damage near the southern San Andreas Fault; however, there is no reason to think that the difference between retrofitted and non-retrofitted would not be the same as in Los Angeles. This fault does not pass through any large densely populated areas; however, its magnitude and duration will be larger and will affect areas at greater distance than faults in the Los Angeles Basin.

The magnitude and duration of shaking on the San Andreas will be greater than the Northridge earthquake. Therefore, although quantitative data is not available, I expect that essentially all (90%) URM buildings within 30 km to 60 km will be destroyed beyond economical repair, and lives will be lost, especially in multistory, non-retrofitted buildings.

The critical part of the southern San Andreas Fault originates in Imperial County near Salton City and proceeds in a northwest direction near Palm Springs, Yucaipa, San Bernardino, Palmdale and Taft on the boundary between Kern and San Luis Obispo Counties.

The following table summarizes the number of retrofitted and non-retrofitted URM buildings in cities near the southern San Andreas Fault:

City	Miles north from origin of event	Distance from fault	No. of URM	% Mitigation	No. Mitigated
Indio	40 m	5 km	48	0%	0
Palm Desert	46 m	13 km	3	100%	3
Palm Springs	60 m	10 km	26	96%	25
Banning	80 m	8 km	49	92%	45
Beaumont	85 m	12 km	37	46%	17
Yucaipa	90 m	5 km	14	0%	0
Redlands	100 m	9 km	77	0%	0
Highland	104 m	4 km	12	25%	3
Riverside	108 m	33 km	200	22%	44
San Bernardino	110 m	8 km	170	41%	70
Colton	112 m	17 km	20	0%	0
Rialto	114 m	13 km	19	21%	4
Fontana	120 m	20 km	85	20%	17
Palmdale	165 m	2 km	0	N.A.	
Maricopa	238 m	12 km	14	7%	1
Taft	245 m	11 km	40	0%	0
(totals:)			814	28%	229

V Cost and Down Time:

The 2006 Progress Report (SSC 2006-04) on URM building retrofit by the Seismic Safety Commission has inventoried approximately 25,900 URM buildings with an average size of 10,000 square feet in seismic zone 4 of California. This includes apartments, offices, stores and industrial with a probable average building value of $100.00 to $80.00 per square foot, respectively. Because of the era in which they were built, a high percentage of the commercial and industrial buildings contain residential areas on upper floors. Using a rough estimate of 250 square feet per occupant, this equates to an average of 40 people per building.

Our tabulation along the San Andreas Fault totaled 814 units and the City of Los Angeles inventoried 8,242. Therefore, a reasonable estimate of buildings significantly affected by this seismic event would be in the range of 10,000 to 12,000. In 2006, it was estimated that 70% of these URM buildings were retrofitted.

Using the Los Angeles City 1994 URM data, 10.5% of unstrengthened buildings and 2.5% of strengthened buildings had over 10% damage. This would, in most cases, require relocation of the users of those buildings.

If it is assumed that 11,000 buildings will be affected, 90% of 1000 relatively near the fault will have total damage, and 2.5% of 7000 strengthened buildings and 10.5% of 3000 unstrengthened buildings will have over 10% damage.

The total number of buildings that will have personnel relocated will be:

90% of 1000 =	900
2.5% of 7000 =	175
10.5% of 3000 =	315
	1,390 buildings
1,390 x 40 =	55,600 people

Unlike buildings made of other material, it is probable that virtually all URM buildings with over 10% damage will be replaced rather than repaired after an earthquake. Therefore, the loss in value would be in the neighborhood of:

1,390 units x 10,000 sf/unit x $90/sf = $1.25 billion

If the 3,000 unstrengthened URM buildings were retrofitted, according to these statistics, 240 fewer buildings would be damaged at a savings of approximately $216 million, and almost 10,000 fewer people would be displaced, i.e., 46,000 instead of 55,600. In addition, the incidence of injuries and deaths would also decrease proportionately. This easily justifies the cost of retrofitting these remaining buildings.

VI Recommendation for Mitigation of Injury and Loss of Life Danger:

Past efforts to require retrofit of URM buildings have been successful, and lives have been saved. For example, there was no loss of life due to URM building collapse in the 1994 Northridge earthquake, although some buildings were damaged beyond economical repair. Another justification of the rationale to limit required retrofit to the life safety level is that, in many cases, the building is commercially obsolete due to parking or mechanical-electrical-plumbing requirements or under utilization of the property on which it stands, and many damaged buildings were removed after the earthquake and new buildings built in their place.

Partially and non-retrofitted buildings, in general, pose a greater risk to people both inside and out, and jurisdictions which have not undertaken an active mandatory retrofit program should assess the condition of their inventory of URM buildings, first by initial screening and then making a structural evaluation of those that could pose a significant risk.

All URM buildings have been identified by each jurisdiction in accordance with SB 547. Initial screening will eliminate buildings that do not have URM walls supporting floors, roofs or upper story walls weighing at least 100 pounds per linear foot. On buildings that have been retrofitted, there should be record of the design by an appropriately registered Civil or Structural engineer.

Retrofitted URM buildings may have structural deficiencies that are not unique to that material, but which pose a known threat of collapse. The most common of these is the weak or soft story. This condition is identified by a lack of shear wall on one side in a multi-story building; a common condition in commercial buildings with storefront glass at street level. These buildings, depending on the geometry of their floor plan, may rotate to such an extent that the side walls lean over and are no longer able to support the floor above.

Another deficiency sometimes found in a retrofitted URM building is that the exterior wythe may not be connected by headers and therefore should be considered veneer and not be counted in the width of the wall. Most codes require that not less than 4% of the area of each wall face be composed of headers. In an earthquake, the veneer may fall away, leaving a height-to-thickness ratio of the remaining structural wall inadequate to support the imposed loads. This falling veneer can be a major threat to life on the surrounding streets.

ASCE Standard 31-03, *Seismic Evaluation of Existing Buildings*, contains checklists in Section 3.7.15 and 3.7.15A for Tier 1 screening of URM buildings with flexible and stiff diaphragms, respectively. This document should be used to determine the need for further analysis and retrofit. ATC 20 and ATC 20-2, *Procedure for Postearthquake Safety Evaluation of Buildings* and the *Addendum*, respectively, are also sources of information for the evaluation of possible failure scenarios.

Because of limited effectiveness of voluntary retrofit programs, the California Seismic Safety Commission has made the following recommendation to the Legislature in its 2006 Progress Report:

- Mandate the strengthening of all unreinforced masonry bearing buildings including state-owned buildings in accordance with the State's model building code.
- Recommend that local governments with little or no retrofit progress provide incentives to encourage owners to retrofit.
- Adopt the International Existing Building Code as the State's model building code so that future alterations to existing buildings trigger seismic retrofits to the latest standards.
- Establish retrofit standards and mitigation programs for other types of collapse-risk buildings such as soft-story apartments, tilt-ups and older concrete buildings.
- Chapter 308 of the Statutes of 2004 prohibits local governments from imposing additional building or site conditions such as parking spaces, or other onsite or offsite requirements or fees on or before the issuance of a building permit for seismic retrofits. The Commission does not recommend the extension of its sunset date of January 1, 2009.

Following these recommendations will save lives and reduce the cost of dealing with the aftermath of a M7.8 southern San Andreas earthquake.

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