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ATC-50, SEISMIC GRADING AND RETROFITTING PROJECT FOR DETACHED SINGLE-FAMILY WOOD-FRAME DWELLINGS

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SUMMARY

Prompted by high economic losses from the 1994 Northridge, California, earthquake, the City of Los Angeles has initiated a program to develop, test, and implement standardized procedures for the seismic evaluation and retrofit of single-family wood-frame dwellings (ATC-50 project). The primary products of the project include: (1) a seismic evaluation and grading system that considers damage or collapse potential in a manner that is consistent and useful to owners, purchasers, insurers, lenders, contractors, design professionals, and regulatory officials; (2) a seismic grading form that enables a certified inspector to evaluate a detached single-family wood-frame dwelling and assign a seismic grade, ranging from A through D, with each grade representing an expected range of damage (expressed as a percentage of replacement cost), should the 475-year MMI occur in the zip code containing the inspected dwelling; and (3) seismic rehabilitation guidelines comprised of prescriptive methods, simplified engineering methods, and fully engineered methods that allow for a revised resistance grade. The procedures are being tested in a pilot program involving evaluation and grading of approximately 500 detached single-family wood-frame dwellings in the Los Angeles area, and rehabilitation (or retrofit) of approximately 50 dwellings with inadequate earthquake resistance. The ATC-50 project was conceived with input from the banking and insurance industries, is being performed by the Applied Technology Council for the City of Los Angeles, and is being funded by the Federal Emergency Management Agency through a Hazard Mitigation Grant Program award from the California Office of Emergency Services.

INTRODUCTION

Societal and economic losses resulting from recent moderate-magnitude earthquakes in modern urban areas have been surprisingly high. Dollar losses due to property damage from the 1989 Loma Prieta earthquake near San Francisco, for example, exceeded $8 billion and those from the 1994 Northridge, California, earthquake exceeded $20 billion. The losses stem from existing vulnerabilities in buildings and other structures and from the fact that these earthquakes occurred within or close to major urban areas. The Loma Prieta earthquake source zone was located in an uninhabited region but severely impacted the nearby cities of Santa Cruz and Los Gatos (within 20 km) and damaged structures as far away as 100 km (in San Francisco and Oakland). The Northridge earthquake occurred in the northern portion of the Los Angeles region directly beneath the suburban communities of the San Fernando Valley, damaging hundreds of recently built buildings and other structures. Fortunately, the most severe ground shaking was beyond the north end of the valley in a relatively sparsely populated area, thus avoiding the potential for significantly greater losses in areas where the density of construction was higher. The high level of insured losses from these earthquakes, particularly to single-family wood-frame dwellings in the Los Angeles area, shocked the insurance and lending industries.

The vulnerabilities in the existing stock of dwellings and other buildings in California and elsewhere are due to many factors: (1) a significant portion were designed and constructed prior to the adoption and enforcement of seismic design provisions; (2) existing seismic design provisions are intended to provide life safety, not damage control (although some damage control is provided); (3) seismic design code requirements have been largely

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based on observations of building behavior during actual earthquakes, and gaps in this knowledge result in poorly constrained or inadequate regulations; and (4) properly designed structures are not always constructed as designed.

In the early 1990s, recognizing the potential for large losses to the existing building stock with inadequate earthquake resistance and the need to develop measures to reduce losses from future earthquakes, the mayor of the City of Los Angeles appointed a Blue Ribbon Panel for Seismic Hazard Reduction. The Financial Services Subcommittee of this Panel, which included representatives from the banking, insurance, contracting, design professional, and regulatory communities, had the special charge of recommending ways to reduce future economic losses. The damaging 1994 Northridge earthquake added impetus to this charge, particularly because of the high number of damaged wood-frame dwellings and the consequent heavy economic losses sustained by the insurance industry. The Subcommittee immediately recognized the need for standardized, inexpensive, easy-to-implement, methods for evaluating, grading and strengthening wood-frame dwellings, as well as the need to develop incentives for building owners to carry out such actions. As a result, in 1995 the Subcommittee recommended that the City of Los Angeles conduct a program to:

1. develop standardized methods for evaluating and grading the seismic vulnerability of existing detached single-family wood-frame dwellings;

2. develop a new, or adapt an existing, set of procedures and criteria for seismic rehabilitation (or retrofit) of such structures (that is, rehabilitation guidelines);

3. verify the evaluation and grading methods and the rehabilitation guidelines in a pilot test program.

4. develop a manual for administering and managing the grading and rehabilitation program;

5. develop a set of examinations to certify seismic rehabilitation designers, contractors, and inspectors; and

6. develop incentives for homeowners to evaluate voluntarily and upgrade, if necessary, the seismic resistance of their dwellings.

In recommending this project, which focuses on detached single-family dwellings, the Subcommittee envisioned that the results could later be adapted and expanded to include one-to-four-family wood-frame dwellings, condominiums, and apartments. Eventually the methods could be expanded to include all types of building structural systems in all seismically active regions of the country.

In 1998 the Applied Technology Council (ATC), whose mission is to develop state-of-the-art, user-friendly engineering resources and applications for use in mitigating the effects of natural and other hazards on the built environment, was awarded a contract by the City of Los Angeles to develop seismic evaluation and grading procedures, rehabilitation procedures, an administration manual, certification examinations, and incentive concepts (ATC-50 project). Funding for the project was provided by the Federal Emergency Management Agency through a Hazard Mitigation Grant Program award from the California Governor's Office of Emergency Services.

At the time of this writing, preliminary concepts and inspection forms have been developed for the seismic evaluation and grading system, and initial developmental work has been completed on the seismic rehabilitation procedures. Following is an overview of technical development on the project to date.

SEISMIC EVALUATION AND GRADING SYSTEM

The initial specification for the seismic evaluation and grading system dictated (1) that the methodology be based, to the extent possible, on existing technologies and information, and that it consider typical attributes of representative wood-frame dwellings (see Figure 1) that affect seismic performance, including foundations, framing systems, nonstructural components, and local site conditions that influence the seismic hazards affecting the building; (2) that application of the methodology would enable an inspector to assign a grade that would represent the approximate level of damage expected when a specified severity of ground shaking occurs; and (3) that the methodology include a simple form for recording the results of an inspection and that the form could easily be revised subsequent to seismic rehabilitation and re-evaluation. It was assumed that evaluations of individual dwellings would be carried out by certified inspectors.

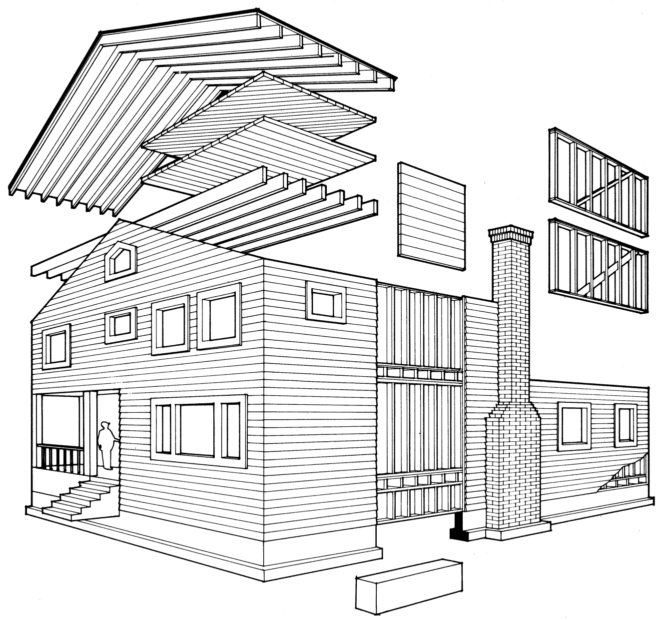

Figure 1: Exploded view of typical pre-1940 California single-family wood-frame dwelling showing typical structural systems. Floor and roof systems typically consist of wood joists and rafters and diagonal or straight sheathing; wall systems consist of stud walls and horizontal siding; and foundation systems consist of unbraced cripple walls, unbolted sill plates, and concrete or masonry foundations. Masonry chimneys are typically unreinforced and water heaters are typically not braced [from Lagorio, Freedman and Wong, 1986].

Based on this specification, the ATC-50 consulting team has developed a preliminary seismic evaluation and grading system that incorporates weighted numeric penalties for observed seismic deficiencies in five categories, as shown in Table 1. The seismic deficiencies of interest, which all relate to damage potential, include: horizontal discontinuities or irregularities (e.g., split levels), vertical discontinuities or irregularities (e.g., non-stacking exterior walls); in-plane discontinuities (e.g., one section of a wall is a glass wall); non-parallel seismic resisting systems, which induce torsional motion; foundation weaknesses (e.g., discontinuous or unreinforced masonry foundations, unbolted sill plates); soft or weak stories (e.g., upper stories over garages); material deficiencies (e.g., deteriorated or rotted wood); mass irregularities (e.g., heavy roofs); and certain nonstructural components (e.g., unreinforced masonry chimneys, unbraced water heaters, and inadequately attached veneer). The possible seismic deficiencies are uncovered by questions with corresponding penalties. The penalties relate to the degree of the deficiency and are based on a consensus of the research development team. A sample set of questions is provided in Table 2.

The seismic hazard is specified for each postal zip code by the maximum value, within that zip code, of the Modified Mercalli Intensity (MMI) [Wood and Neumann, 1931] having a 10% probability of being exceeded in the next 50 years (or having a recurrence interval of 475 years). The Structural Score for a given dwelling is calculated by summing the penalties and subtracting from 100. The Seismic Grade is then assigned by combining the Structural Score with the seismic hazard using the matrix in Table 3. Seismic Grades range from A to D, with each grade representing an expected range of damage (expressed as a percentage of replacement cost), should the 475-year MMI occur in the zip code containing the given dwelling. While the damage ranges for a given grade have not yet been defined, A (the best grade) corresponds to the lowest expected range of damage, and D the highest expected range, with B and C representing intermediate ranges.

A preliminary 4-page seismic evaluation and grading form has been developed for rapid use in the field. The form is self-contained (no additional explanation is necessary), concise, and can easily be updated. A example portion of the form is provided in Figure 2.

Preliminary versions of the seismic evaluation and grading procedures and form will be field tested on approximately 500 single-family dwellings in the Los Angeles area. Based on information developed during this pilot test program, the procedures and form will be finalized and published by the Applied Technology Council.

Table 1: Preliminary Categories and Relative Contributions of Seismic Deficiencies

	Damageability Category	**Category Definition**	**% Contribution**
A.	FOUNDATION	The structure between the ground and the wood framing, including continuous footings, isolated piers, pads and connectors.	19
B.	FRAMING CONFIGURATION OF SUPERSTRUCTURE (including under-floor system)	The structure and the shape of the structure above the foundation. The shape is determined by the site topography and framing members.	34
C.	NON-STRUCTURAL/ MISCELLANEOUS	All components that make up dwellings and are not part of the structure, but may have the potential for damage and loss. Miscellaneous refers to contributors to potential loss not included in another category.	10
D.	LOCAL SITE CONDITIONS	Topography, soil conditions, neighboring properties.	14
E.	CONDITION OF STRUCTURAL ELEMENTS	The condition of all structural components and their connections, foundations, all metal connectors, and secondary structural members.	23

Note: Percent contribution of seismic deficiencies based on consensus of research development team.

Table 2: Sample Preliminary Seismic Deficiency Questions and Corresponding Penalties

	Sample Questions		**Penalties**
A-6	For a raised foundation system		
	a. is the mudsill of the exterior wall bolted to the foundation with bolts spaced at 72 inches or less, or retrofitted?		[0]
	bolted with >72-inch spacing?		[1.5]
	c. are there no foundation bolts?		[4.2]
C-2	Does the water heater have approved anchor straps and flexible connections for water or gas or both?	Yes	[0]
		No	[1.3]
D-2	For a cut-and-fill “transition” lot, was the lot developed		
	a. before 1963?		[2.6]
	b. 1964 or later?		[1.3]
	c. Not applicable. Lot is not from cut-and-fill		[0]

Note: Penalties based on consensus of research development team.

Table 3: Seismic Grade as a Function of Structural Score and Seismic Hazard (Preliminary)

<table>
<tr><th rowspan="2">Structural Score</th><th colspan="14">Regional Seismic Hazard (Maximum value of the 475-year MMI for all points within a specified postal zip code)</th></tr>
<tr><th>8.2</th><th>8.3</th><th>8.4</th><th>8.5</th><th>8.6</th><th>8.7</th><th>8.8</th><th>8.9</th><th>9.0</th><th>9.1</th><th>9.2</th><th>9.3</th><th>9.4</th><th>9.5</th></tr>
<tr><td>1-20</td><td colspan="2">C</td><td colspan="12">D</td></tr>
<tr><td>21-40</td><td>B</td><td colspan="7">C</td><td colspan="6">D</td></tr>
<tr><td>41-60</td><td colspan="6">B</td><td colspan="8">C</td></tr>
<tr><td>61-80</td><td colspan="5">A</td><td colspan="9">B</td></tr>
<tr><td>81-100</td><td colspan="11">A</td><td colspan="3">B</td></tr>
</table>

B. Superstructure/Framing/Configuration : (Every accessible area such as the attic and underfloor area that reveals structural elements must be inspected.)

Grade

B-1 Does the dwelling have any one of these:
- a. unsymmetric wall strength (torsion problems) yes [1.6] no [0]
- b. reentrant corners yes [0.3] no [0]
- c. diaphragm discontinuity (split level) yes [2.0] no [0]
- d. out-of-plane offsets more than 4' yes [0.4] no [0]
- e. non-parallel systems yes [0.6] no [0]

B-2 For the first floor exterior wall, is the total length of wall between openings less than:
- a. 20% the length of the wall for single story yes [3.1] no [0]
- b. 25% the length of the wall with one level above the wall yes [3.1] no [0]
- c. 40% the length of the wall and has two levels above yes [3.1] no [0]

B-3 The roofing is heavy (clay tile) and the dwelling is:
- a. single story? [1.6]
- b. multi story? [3.5]
- c. none of the above? [0]

B-4 For an attached garage with a second floor directly above, do the narrow walls on either side of the garage door openings have:
- a. plywood on both walls? [0.5]
- b. steel frames on either side of the door? [0]
- c. none of the above? [2.8]

Grade

B-5 The exterior wall(s) of the dwelling is primarily
- a. siding [2.5]
- b. stucco [0]
- c. brick veneer [3.1]

B-6 Are the interior partitions full-height
- a. to the framing above? yes [0] no [1.0]
- b. to the roof? yes [0] no [0.9]

B-7 Is the dwelling located on a 3:1 slope or steeper with wood frame braces or tension only braces below the lower level diaphragm yes? [2.5] no? [0]

B-8 Are the number of stories
- a. one (1)? [0]
- b. two (2)? [1.8]
- c. 3 or more? [3.6]

B-9 The main level floor is supported on a
- a. cripple stud wall with no visible retrofit? [8.8]
- b. retrofitted cripple wall? [1.0]
- c. no cripple wall? [0]

Total [ ]

Figure 2: Sample portion of preliminary ATC-50 Seismic Evaluation and Grading Form.

SEISMIC REHABILITATION GUIDELINES

The intent of the of the Seismic Rehabilitation Guidelines is to promote public safety and welfare by reducing the risk of earthquake-induced damage in existing wood-frame residential buildings. The Guidelines document is based on existing available standards of practice, including the *Uniform Code for Building Conservation*, (ICBO, 1997), the *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (ATC, 1997) and several references, uniquely applicable to the Los Angeles area, that have been developed considering the past seismic behavior of wood-frame buildings. The local documents, collectively called *the LA Cripple Wall Provisions*, consist of:

- *How You Can Strengthen Your Home for the Next Big Earthquake in the Los Angeles Area* (a 10-page pamphlet);

- *Earthquake Hazard Reduction in Existing Wood-Frame Residential Buildings with Weak Cripple Wall and Unbolted Sill Plates,* Standard Plan Number One, a 30” x 42” drawing with standard details and general notes (hereinafter called the *LA Cripple Wall Standard Plan*); and

- City of Los Angeles *Ordinance No. 171259, An Ordinance to Amend Article 1, Chapter IX of the Los Angeles Municipal Code with Respect to Voluntary Earthquake Hazard Reduction Standards for Existing Wood-Frame Residential Buildings with Weak Cripple Walls and Unbolted Sill Plates.*

The Guidelines consider four predominant configurations for supporting a wood-frame house on a foundation: (1) cripple wall (with a crawl space); (2) basement; (3) slab-on-grade; and (4) post-and-pier. A fifth common house configuration, the split-level house, is usually a combination of a slab-on-grade and a cripple wall.

Three approaches are provided in the Guidelines

1. *Prescriptive Method*. In this method, the prescriptive measures of the *LA Cripple Wall Provisions* are to be used for retrofitting 1-to-3-story cripple-wall houses meeting certain criteria. This method requires that a prescribed percentage of the wall length be calculated and measured for retrofit plywood sheathing. A plan of the house is drawn and certain other information is noted on the *LA Cripple Wall Standard Plan*. Prescriptive measures for the retrofit of certain house elements are also provided.

2. *Simplified Engineering Method*. The *Simplified Engineering Method* can be used for 1-to-3-story cripple-wall houses with heavy sheathing and roofing or with tapered elevation cripple walls, for certain other houses, and optionally for houses in near-fault areas. This method requires that the house plan area be determined and that other basic seismic force demand and retrofit sheathing capacity calculations be made. This method can also be used by engineers or architects.

3. *Fully Engineered Method*. Guidance for designing houses by a fully engineered method is intended for use by engineers and architects experienced in house seismic retrofit. Fully engineered retrofit designs are required by the LA Building Department for certain house configurations, including hillside homes, 3-story cripple wall houses with tall cripple walls, and certain slab-on-grade houses.

The *Prescriptive Method* does not meet the requirements for new buildings. Both the *Prescriptive Method* and the *Simplified Engineering Method* only strengthen the lowest-level walls. The *Fully Engineered Method* can be used to ensure that vulnerable walls at all levels have been identified and retrofitted. The *Simplified Engineering Method* and the *Fully Engineered Method* do not necessarily meet the requirements for new buildings or address all of the building’s seismic vulnerabilities. These measures are intended to improve the seismic performance of existing buildings significantly but will not necessarily prevent damage in an earthquake.

The Seismic Rehabilitation Guidelines provide guidance on how to interpret the seismic deficiency penalties and overall seismic grade assigned during the inspection of a given building using the ATC-50 Seismic Evaluation and Grading Form. As previously indicated, the overall grade will provide a measure of the degree of damage to be expected in a major earthquake. A house receiving a grade of C or D should be seriously considered for retrofit strengthening in accordance with the Seismic Rehabilitation Guidelines. However, it is possible for a house to receive an A or B grade and still have critical vulnerable elements. Any element penalty larger than 2 indicates a potentially significant structural or nonstructural deficiency. For such deficiencies, specific guidance is provided on how to conduct a pre-retrofit inspection of the element to determine all existing conditions, dimensions, and other considerations significant to the retrofit construction.

The Guidelines also provide guidance on how to choose one of the three recommended retrofit methods (*Prescriptive Method, Simplified Engineering Method*, or *Fully Engineered Method*) and guidance for implementing a retrofit design. A preliminary version of the contents of the Seismic Rehabilitation Guidelines is provided in Figure 3.

Preliminary versions of the seismic rehabilitation guidelines will be field tested on approximately 50 single-family dwellings in the Los Angeles area found to have inadequate earthquake resistance (as part of the seismic evaluation and grading pilot test program). Based on information developed during this pilot test program, the guidelines will be finalized and published by the Applied Technology Council.

ATC-50 Seismic Rehabilitation Guidelines for Single-Family Wood-Frame Dwellings
Preliminary Table of Contents

Figure 3: ATC-50 Seismic Rehabilitation Guidelines Preliminary Table of Contents

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