APPROXIMATELY 80% TO 90% OF ALL STRUCTURES IN ALL REGIONS OF THE U.S. ARE WOODFRAME CONSTRUCTION.

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[Front cover] Collapsed Northridge Meadows apartment complex | [shown above] Damage to a typical suburban woodframe house as a result of the 1994 Northridge Earthquake.

Photos provided by the National Information Service for Earthquake Engineering (NISEE), Pacific Earthquake Engineering Center (PEER-U.C. Berkeley)—Steinbrugge Collection.
The Project took sizable steps toward understanding and communicating the important issues. Many high quality laboratory experiments significantly augmented the existing data set on the cyclic behavior of components and even complete buildings. These data have been incorporated into recommendations for building code improvements, and they will prove invaluable as codes move beyond life safety to damage control. Realistic computer calculations were made of the benefits and costs of retrofitting wood buildings, such as bracing of cripple walls. Such calculations are rarely done, even for other, simpler types of structural systems. Worthwhile collaborations between university researchers and practicing engineers have been established, with much knowledge transferred and many students trained. Previously, seismic researchers from universities mostly kept their distance from wood engineering, preferring instead the more “glamorous” materials of steel and reinforced concrete. That has now changed.

Perhaps the most interesting of the laboratory experiments undertaken in the Woodframe Project were the shaking table tests on a two-story house and on unretrofitted and retrofitted versions of a three-story apartment building with tuck-under parking. An unexpected result in both cases was a significant improvement in performance attributed to the presence of stucco and drywall. Heretofore, based on actual experience, these finishes had been viewed as major contributors to damage; being stiff and brittle, they attract earthquake loads intended for the more flexible wood frame and then crack or detach. In fact, such construction cannot be viewed as rational from the point of view of damage control. However, our experiments showed that if stucco and drywall are properly installed, the strength increment provided is substantial and can keep a structure essentially elastic under quite strong shaking. This was especially evident from the difficulty of damaging the unretrofitted version of the apartment building and was actually a little embarrassing at the time since the experiment was designed, in part, to demonstrate the benefits of retrofit in preventing life-threatening collapse.

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Enhancement of stucco and drywall with reliable attachment mechanisms and increased ductility is an excellent candidate for future research, with a potentially large payoff. Engineered versions of these or other finishing materials could strengthen wood structures to the point where their damage threshold would be exceeded only in rare earthquakes. This would mean significantly reduced damage costs. Even in events like Northridge, at a nominal investment. Funding is needed so this worthwhile project can get underway.

Another priority is to reduce the risk of collapse and life loss presented by the hundreds if not thousands of apartment buildings with tuck-under parking. Not all such structures are vulnerable, as demonstrated by the better-than-expected performance of the controled specimen tested in the Woodframe Project. This result just emphasizes the need to develop classification procedures to identify the most hazardous structural types. Work initiated by the Project should continue until proof-tested retrofit schemes are routinely installed on buildings similar to the Northridge Meadows Apartments where 16 people died during the 1994 earthquake.

Many other worthy topics for investigation can be suggested. Analysis procedures, even with considerable progress made under the Woodframe Project, lag behind what is available for other construction materials. More field characterization of actual wood structures is needed, including field tests of buildings slated for demolition. Additional laboratory experiments on components and complete building systems can also be justified. The shaking tests on the house and apartment building had to use greatly reduced plan areas of these structures because of limits on the size of available shaking tables. Such reductions distort three-dimensional effects and may lead to erroneous conclusions.

However, a large new table coming on line in 2004 at the University of California San Diego, funded by the National Science Foundation's NEES program, will be ideally suited to testing complete wood buildings. Of tremendous value would be a series of tests on representative building types and configurations to help us understand and improve designs of the complex interactions among components. Finally, wood school buildings contain some unique construction features whose seismic performance is uncertain, and a targeted investigation is needed to resolve any safety concerns for these important facilities.

Finally, I wish to thank those who have been involved in the Woodframe Project: Project Director Robert Reitherman; element leaders Andre Filatov, Gootzi Schiere, Kelly Cobeen, L. Thomas Tobin and Jill Andrews; major contributors James Russell, J. Daniel Dolan and Chia-Ming Uang; all the university researchers and students, and the numerous practicing engineers and industry representatives. Many of these people donated significant amounts of their time, worked at reduced rates, or otherwise helped the Project meet its cost-sharing requirement. Within this group as well as outside, interest in improving the seismic performance of wood buildings remains strong. The momentum generated by the Woodframe Project should continue far into the future.

Testing of a three-story woodframe apartment performed at the University of California, Berkeley (Richmond Field Station). Photo Credit: D. B. Wong (CUREE)
Field Investigations

As 24 of 25 fatalities caused by building damage in the Northridge Earthquake were in woodframe structures, and because 99% of residential buildings in California (89% in Los Angeles county) are wood structures. The investigators focused on residential woodframe buildings as multifamily dwellings built between 1977-1993 performed worse than older buildings, contrary to what is commonly assumed.

The Statistical Analysis report (CUREE publication W-09), authored by University of Southern California Prof. G. G. Schierle, indicates this may be because new dwellings with larger and often two-story-high spaces are more vulnerable to seismic forces. Poor performance may also have been partly due to less construction observation by design professionals since the increase of lawsuits in the mid 1970s, resulting in reduced quality control. Damage patterns in this study appear to be defined by seismic severity, rather than existing housing density patterns. Researchers identified large discrepancies between post-earthquake safety inspection estimates of repair costs and the damage ranges vs. repair costs recorded on building permits. Two possible reasons for this may be under-reported repair costs due to financial concerns, and possible errors in damage cost estimates by volunteer inspectors.

To complement the macro or statistical scale of analysis, the Field Investigations Element also produced an investigation at the micro level: a compilation of Case Studies (W-04) by consulting engineers on the performance of specific buildings in the Northridge Earthquake. This provided detailed data, drawings, photos, and other documentation on a set of approximately twenty buildings. In addition to purely objective performance data, such as descriptions of the damage state of a particular portion of the structure, the authors also provided their engineering judgments as to the causes of damage.

Testing and Analysis

The CUREE-Caltech Woodframe Project consisted of 23 different investigations carried out by 16 different organizations (13 universities, three consulting engineering firms). Approximately half the total $5.9 million budget of the CUREE-Caltech Woodframe Project was devoted to its Testing and Analysis tasks, which was the primary source of new knowledge developed in the Project. Within the context of the Woodframe Project, the Testing and Analysis Program clearly addressed two common objectives: one, to advance the engineering of woodframe buildings, and two, to improve the efficiency of their construction technology for targeted seismic performance levels. Investigators also conducted an Invitational Workshop on Seismic Testing, Analysis and Design of Woodframe Construction (CUREE publication #W-01), which underscored the general lack of understanding of the seismic behavior of woodframe structural systems. At the onset of the program, very few numerical models capable of analyzing the seismic behavior of three-dimensional woodframe structures existed, and only limited experimental data had been generated at the system level.

Recognizing these deficiencies, investigators emphasized testing and analysis at both the component and system levels. The research strategy centered on the shake table tests of large-scale woodframe systems.
Economic Aspects: Loss Estimation

While building code applications are a key result of the Project, a distinct topic concerns the potential for using the information developed in this project to refine insurance, mortgage lending, loss estimation, and disaster relief policies and procedures. The goal of the Economic Aspects task was to outline the risk reduction benefits that accrue if various combinations of risk reduction construction measures are implemented.

Researchers and experts examined key issues in separate tasks, which included loss estimation, analysis of index buildings, and cost and performance. The main objective of the loss estimation task was to produce a set of probabilistic damage-estimation relationships based on detailed modeling and field data, suitable for incorporation into HAZUS software and other applications.

The loss estimations report (W-18) presents a methodology for creating probabilistic relationships between seismic shaking severity and physical damage and loss for buildings in general, and for woodframe buildings in particular. The methodology, called assembly-based vulnerability (ABV), is illustrated in the report for 10 specific woodframe buildings of varying ages, sizes, configuration, quality of construction, and retrofit and redesign conditions.

The study employs variations on four basic floor plans or "index buildings" (a small house, a large house, a town house and an apartment building). An Index Building is similar to but more detailed than a "Model Building." The Woodframe Project Index Buildings were designed with almost a complete set of working drawings, along with associated detailed cost estimator's breakdowns, weights of materials, etc. 400 inelastic time history analyses were conducted for each Index Building, providing a statistical profile of probable earthquake performance. The report "Design Documentation of Woodframe Project Index Buildings" (W-29) includes complete AutoCad drawings, cost estimation spreadsheets, and 3D illustrations.
Education and Outreach

Education and Outreach tasks managed by Jill Andrews, drew from the other Woodframe Project components with the goal of broadly disseminating the research results. Since 1998, it has been the primary vehicle for communication and delivery of products for the Project.

Project managers supported one of the most important keys to mitigation: educate owners and residents so that they initiate actions to reduce the risks to life and property posed by hazardous types of existing wood buildings. Specific targets included older houses on cripplewall foundations and multi-story apartment or condominium buildings with "tuck-under" parking. For new construction, engineers will be taught the techniques forthcoming from the Building Codes and Standards Element's effort. Contractors will be instructed in the basics of the components of lateral load resisting systems and why each component is important. Vehicles to meet these goals include a comprehensive array of eye-catching publications that hold the reader's attention, traveling exhibits at home-care shows and county fairs, and seminars accompanied by carefully prepared notes and videos. This issue provides information on each of these products.

Resolution of discrepancies among the messages being given to the public was a key objective. For example, a common perception is that if one merely retrofits a house with anchor bolts, it follows that it will then have above average seismic performance, that more extensive measures are not necessary, and that it may not be worth it to purchase insurance. These quick conclusions, or misconceptions, are in conflict with both expert engineering opinion and the Northridge data.

Through a series of products including newsletters, publications, video footage, web-based instructional materials, and "ShakeZone," a permanent museum exhibit and traveling exhibit for the general public, Element 5 addressed all the topics covered in the other four Elements. Those who benefit from these products include government officials concerned with public safety, property owners and renters, media reporters and writers, and educators and students.

Detailed model of the collapsed two-story Northridge Meadows apartment building created by Graphic Blade Studios.

Young visitors to the ShakeZone museum exhibit interact with the various small woodframe hands-on models on display.
Building Codes and Standards

While the body of information produced by the CUREE-Caltech Woodframe Project has greatly advanced the state of knowledge and understanding of seismic response of woodframe construction, its implementation is a process that will continue for many years into the future. The Codes, Standards and Guidelines Element took steps to begin utilization of that knowledge via the publication of a report wherein conclusions have been drawn from all of the other Project reports and data. The three principal authors of “Recommendations for Earthquake Resistance in the Design and Construction of Woodframe Buildings: Codes, Standards, and Guidelines Design and Analysis Procedures and Construction Practice,” (W-30) were Kelly Cobeen, James E. Russell, and J. Daniel Dolan. A specific advisory group called the Codes and Standards Committee provided most of the review comments through a series of meetings. A wider group known as Corresponding Members of the Codes and Standards Committee also provided comments on a partial draft presented at a workshop held in September 2000. The discussions, recommendations and findings presented in the report are primarily based on interpretation of the content of other Woodframe Project reports by the three authors and the guidance provided by members of the Codes and Standards Committee.

The Recommendations report was formatted with care to increase its usefulness. Part I: Recommendations succinctly presents the actual recommendations for changes in codes or practice, or verification statements concerning existing provisions. Relevance to specific code or standard documents and their sections (e.g., period of vibration formulas) are called out. Cross-references lead the reader to brief research synopses, then more deeply in the accompanying second volume Part II: Topics/ Discussion to further the original research report(s). This report is available for download at: www.curee.org

Credits

Professor John F. Hall
California Institute of Technology

Robert Reitherman, Project Coordinator

TESTING AND ANALYSIS
Professor Andre Filatoff, Manager
University at Buffalo, SUNY (formerly with UC San Diego)

FIELD INVESTIGATIONS AND STATISTICAL ANALYSIS
Professor G.G. Shierle, Manager
University of Southern California

ECONOMIC ASPECTS
L. Thomas Tobin, Manager
Tobin and Associates

EDUCATION AND OUTREACH
Jill Andrews, Manager
(formerly with the University of Southern California)

Research reports from this project available for download at:
www.curee.org

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