SEISMIC PERFORMANCE OF LOW-RISE WOOD BUILDINGS

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Abstract. [1] ***This article updates a previous literature review paper on the performance of wood-frame buildings during earthquakes and summarizes recent research related to understanding seismic behavior of low-rise wood buildings.***

Low-rise, light-framed wood buildings have performed adequately in earthquakes provided they acted as a unit, had adequate shear walls, and were reasonably symmetric in plan and elevation.

This paper is the third literature review related to the performance of wood structures in earthquakes. The first [1] reviewed literature through 1984; it was based mainly on observations from the 1964 Alaska earthquake (8.6 Richter) and the 1971 San Fernando earthquake (6.6 Richter). The second [2] reviewed literature through 1988; it had observations from two additional earthquakes -- the 1983 Coalinga (6.2 Richter) and the 1984 Halls Valley (6.5 Richter). There has been much more interest in research on wood buildings in recent years as a result of observations from these earthquakes. Additionally, the 1989 Loma Prieta earthquake (on national TV, 7.0 Richter) has increased interest and support for seismic research. This report summarizes recent observations and research on component and building response and discusses current design philosophy.

PAST PERFORMANCE

Damage to wood buildings resulting from earthquakes prior to 1988 has been documented in the previous literature surveys [1,2]. In summary, the primary cause of overall residential damage was inadequate lateral support, particularly near large openings such as garage or patio doors. The 1964 Alaska earthquake did limited damage to houses with simple rectangular configurations, continuous floors, and small door and window openings. These types of buildings had symmetric box-like lateral resisting systems. On the other hand. the San Fernando residences that were two-story and split level homes with large garage openings at ground level were particularly susceptible to damage. Their nonsymmetry made them vulnerable to torsional as well as lateral motion. Residences subjected to the Coalinga and Halls Valley earthquakes failed due to inadequate lateral support provided by short wood stud walls in the substructure (cripple walls). There are limited observations of commercial and industrial buildings during these earthquakes; most literature describes residential construction.

The American Plywood Association [3-5] and National Institute of Standards Technology [6] reported on damage from the 1989 Loma Prieta earthquake. This earthquake resulted in 64 deaths, more than 3,700 injuries and $10 billion in economic losses. Canadian literature [7,8] also reported on the Loma Prieta in relation to what the implications are for Vancouver, British Columbia and for the Canadian building codes.

COMPONENT AND BUILDING RESPONSE

Floor and roof diaphragms and vertical shear walls constitute the lateral load-resisting elements of timber structures. Research prior to 1988 has been reported [1,2] which related to the strength and stiffness of horizontal and vertical diaphragms and their connections.

Past research on shear wall strength and stiffness was mainly experimental studies of plywood-sheathed walls subject to a static load. Recent research has included other types of sheathing, dynamically loaded walls, and analytical methods. Recent research on plywood-sheathed shear walls includes input of the El Centro and Taft earthquakes into both the analysis and experimental verification of the walls' performance [9]. Dynamic testing was also performed to determine the hysteretic damping and period of vibration of a plywood shear wall [10]. The load-deflection characteristics of a nailed and glued plywood wall with openings were determined in Japan [11].

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Experimental load-deflection characteristics were also determined for gypsum- [12]. plasterboard- [13], particleboard- [14], and waferboard-sheathed walls [15].

The conclusions reached from the aforementioned studies indicate any panel material will function for shear walls provided the nail heads don't pull through the sheathing; however, the shear capacity of gypsum and plasterboard is lower than plywood or particleboard for the same nail spacing. Further, the strength and stiffness of the shear wall is more strongly related to the nail spacing than to the sheathingmaterial.

Several studies developed analysis techniques to predict the dynamic characteristics of shear walls [9,16]. Modeling recommendations are summarized [17].

Less research has been conducted on horizontal diaphragms than on shear walls. A finite element analysis was used to predict displacements for a 16 foot by 48 foot modeled diaphragm [18]. Both finite element analysis and experimental verification were done on three roof systems with gypsum as the diaphragm material [19]. An overview paper discusses horizontal diaphragms and gives guidance on analysis, design, and details [20].

The characteristics of a whole building differ from that of its components. There have been a number of attempts to model an entire wood building subjected to lateral loads. The nonlinear behavior of connections and racking walls requires a nonlinear analysis. Moody [21] presented a nonlinear structural analysis model and compared it to experimental results from Japan.

The Japanese have been especially active in both analytical modeling and experimental verification. Traditional Japanese post and beam buildings have been analyzed to determine lateral displacements using nonlinear finite element models [22] and experimental studies [23]. Glulam frame structures [24] and historic structures [25] have also been analyzed and tested. The traditional post and beam structures have included both diagonal bracing and gypsum shear walls to increase racking resistance [26].

US-type, light-framed buildings are also being adopted in Japanese construction. One study determined the increase in racking resistance to a sheathed house by including the sheathing applied to wall spaces above or below window and door openings [27].

The Japanese are also studying multistory buildings. One study was to load a two-story timber building experimentally to understand the ductility of the connection system combining tension bolts and steel plates [28]; this system was compared also to a nailed gusset system. Another study found experimentally the distribution of shear forces from a full-scale test of a three-story sheathed building [29].

Dynamic characteristics have also been determined experimentally from full-scale buildings. The natural frequency and displacements were found for a two-story post and beam building with diagonal bracing [30]; the damping values and displacements were found for a three-story glulam timber building with shear walls of light-weight concrete and cemented wooden chipboard [31].

Some research is also underway in Yugoslavia. A general seismic response analysis was done using the second order differential equations of motion [32]. A full-scale, one-story truss frame house was tested and the results for lateral displacements were compared to a nonlinear finite element analysis [33].

DESIGN ASPECTS

Low-rise wood buildings are designed based on experience, empirical methods, and theory for idealized materials. Examples of buildings are given based on the experience of 35 centuries from ancient Greece [34]. A review of design requirements are summarized for the Eurocode, and codes of Canada, Yugoslavia, and Japan [35].

Several researchers have performed structural analysis of wood buildings subjected to different earthquake accelerograms of ground motions. One study determined the response analysis of one-, two-, and three-story dwellings subject to five earthquake ground motions [36]. The results are plotted in diagrams of maximum deflection vs strength for the dwellings. Another study analyzed the effect of different earthquake accelerograms on the nonlinear loaddisplacement response for a single-story portal frame building [37]. The effects of differing moment-rotation in the joints were also studied.

Energy dissipation and ductility in wood structures have been studied by several researchers. One study describes structural wood systems that can develop ductility and gives recommendations for details with nailplates, toothplates, or bolted connections [38]. A seismic design procedure is recommended to ensure that inelastic deformation is confined to those components having ductile capacity. Another study presents an example of how to dissipate energy in connections of shear walls constructed of screwed laminated veneer lumber [39].

Post-earthquake repair requirements are outlined in a Japanese manual to restore wood buildings [40].

SUMMARY

This paper reviews literature since 1988 related to the performance of wood structures in earthquakes. The Loma Prieta earthquake, 1989, has been the most significant and visual seismic occurrence in the last several years.

Most recent research has focused on two areas. The first relates to the strength and stiffness of shear walls. Earlier research concentrated on plywood-sheathed shear walls. Recent research has studied other sheathing materials. The major result is that most materials perform adequately in shear walls; the strength and stiffness are more strongly related to the nail spacing than to the sheathing material. The second area relates to analyzing and testing entire buildings. A number of these studies have been completed; however, there is not yet enough generality of results to impact code design requirements.

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