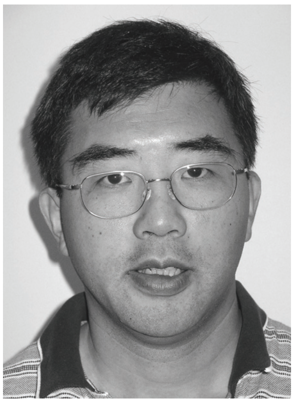

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State of earthquake research in North America and Japan

Stand der Erdbebenforschung in Nordamerika und Japan

Stadio della ricerca sismica nell'America settentrionale e in Giappone

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State of earthquake research in North America and Japan

1 Introduction

North American based light frame wood buildings and the Japanese post & beam systems are two of the most common form of timber constructions in the world. Over two million housing units are built annually in North America and Japan alone. Besides single-family housing units, these systems are also used in low-rise commercial structures and multi-family residential buildings (Figure 1).

The primary lateral resisting elements in these structures are the shear wall and horizontal diaphragm systems. The North American wood frame construction typically composed of framing members sheathed with 1.2 x 2.4 m plywood or oriented strand board panels and connected using nails (Figure 1). The framing members are 38 x 89 mm or 38 x 114 mm lumber connected using 76 mm common nails. The spacing of the vertical studs is typically 400 mm. The sheathing panels are connected to the framing members with 50 mm common or spiral nails at a spacing of 150 mm along the panel edges and 300 mm for the interior attachment of the sheathing panel to the frame members. In the US, the panels for shear walls are installed vertically; however, in Canada, horizontally installed panels (with blocking) are also used.

Figure 1: North America wood frame construction

In Japanese post and beam construction, a typical wall unit is composed of three 105 mm x 105 mm posts (Hashira) spaced at 910 mm, two 45 mm x 90 mm interior studs (Mabashira) evenly spaced between the posts, a 105 mm x 105 mm horizontal top beam (Moya), and a 105 mm x 105 mm bottom sill (Dodai). Since the late 1800's, bracing elements 27 mm x 105 mm in size, two-brace (Kata sujikai) or four-brace (Tasuki sujikai), are commonly used to form a triangulated structural system. These systems are based on fixed modules of 910 mm (2 x 455 mm) with mortise and tenon joints as the prime connection elements. More recently, it is also permitted to replace the braces by nailing OSB-sheathing to the frame to provide the post and beam walls with the lateral resistance. Metal connection hardware is required to transfer the seismic forces generated by the inertia load through the frame and to the foundation. (Figure 2)

Figure 2: Japanese post and beam construction

Well constructed wood structural systems have a good performance record against wind and seismic loading due to the high strength to weight ratio of timber as a building material, the system redundancy, and the ductility of connections (Rainer and Karacabeyli, 2000). However, the structural integrity of wood frame buildings under the action of natural hazards is not necessarily guaranteed as shown in past earthquakes and hurricanes. The structural and non-structural damages experienced from recent major earthquakes (Northridge 1994 and Kobe 1995) point out some of the inadequacies in the earthquake resistance of wood frame and post & beam constructions. Detailed review of the subject is available (Lam et al. 2002, 2004). This paper briefly reports recent research highlights to improve understanding on the seismic response of wood structures focusing on the major research initiatives in North America and Japan.

2 State of Research Activities

The Northridge Earthquake led to a major three year research initiative in the US starting in 1998: CUREE-Caltech (Consortium of Universities for Research in Earthquake Engineering – California Institute of Technology) Woodframe Project (Seible et al. 1999). It is a combined research and implementation project to improve the seismic performance of woodframe buildings. The project, funded by FEMA (Federal Emergency Management Agency), has five main elements, which together with a management element have the common objectives of advancing the engineering of woodframe buildings and improving the efficiency of their construction technology for targeted seismic performance levels. The main engineering research components of the CUREE-Caltech Woodframe Project are included in the Testing and Analysis Element managed at the University of California, San Diego.

Under this program of work significant research effort and advancement were achieved to understand the seismic behaviour of woodfame building (Figure 3). Some of the testing activities include: full scale shake table testing of two story single family houses, three story apartment building with soft story, and simplified model; racking tests of shear walls and cripple wall units; and testing of connection components from nails to anchors (Figure 4). The significant contribution of the wall finishing material was observed.

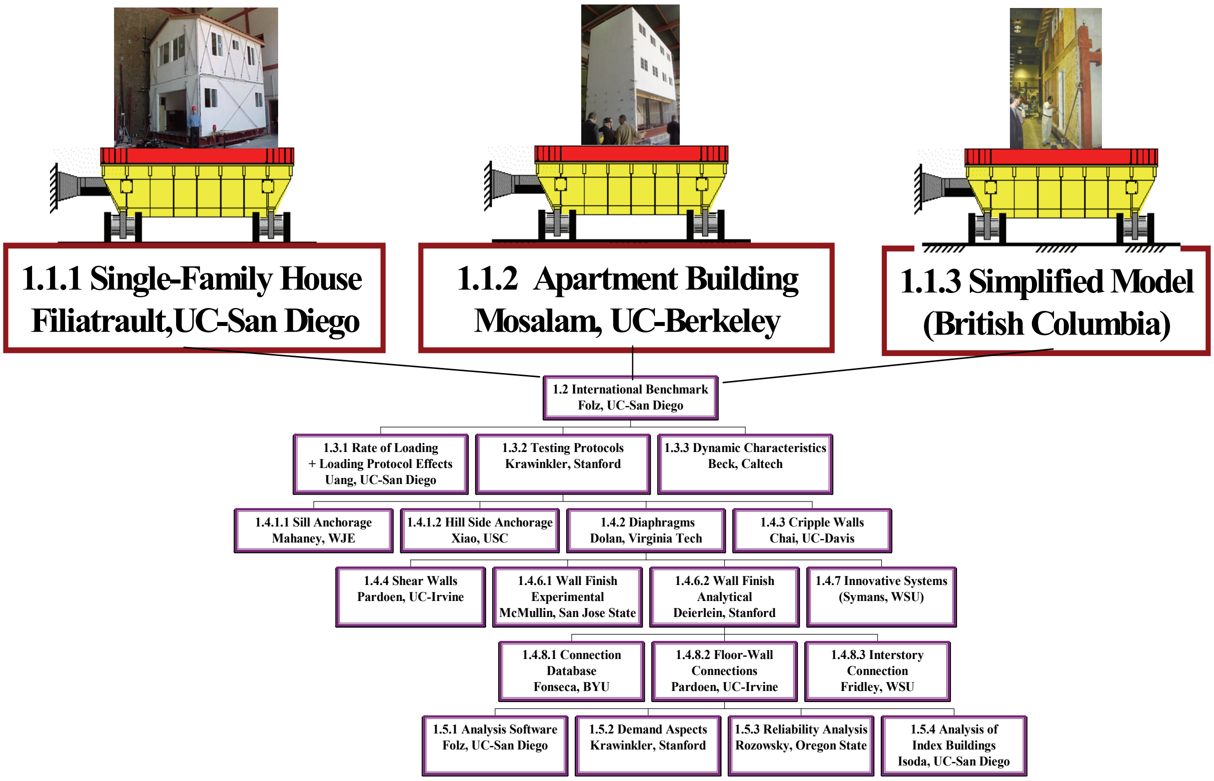

Figure 3: Research Strategy of the CUREE-Caltech Woodframe Project

Figure 4: Shake table test structures of the CUREE-Caltech Woodframe Project (after Fischer et al. 2000 ad Mosalam et al. 2002).

Significant advancement was also achieved in the computer modeling area where hysteretic rules of individual nails were implemented in computer structural analysis programs to perform cyclic and time series analysis of woodframe structures: CASHEW (Cyclic Analysis of SHEar Walls), performs the cyclic analysis of wood shear walls (Folz and Filiatrault 2001a) and SAWS (Seismic Analysis of Wood Structures), performs nonlinear static pushover or nonlinear time-history dynamic analyses of complete three-dimensional wood buildings (Folz and Filiatrault 2001b). These programs have been validated against the results of the shake table tests described by Lam et al (2002).

In parallel a four-year research project entitled "Reliability and design of innovative wood structures under earthquake and extreme wind conditions" was conducted at the University of British Columbia (UBC) between August 1997-July 2001. The principal investigators in this project were Professors R. Foschi, F. Lam, H. Prion and C. Ventura. The overall objective of the study aimed to develop fundamental understanding of the static and dynamic structural behavior of two- and three-dimensional frame or panel assemblies made with wood products and subjected to earthquake shaking or wind pressures. The different phases in the project included: the development of structural analysis models and computer programs of wood frame systems; the validation of the models using the UBC Earthquake Engineering Laboratory facilities; and the development of framework and tools needed for reliability studies of wood frame systems under earthquake loading.

Another study of wood light-frame buildings under earthquake loading conditions at UBC is the Earthquake 99 Project. The project was led by Professors Ventura and Prion (UBC), TBG Seismic Consultants, and Simpson Strong-Tie in which the seismic performance of narrow Simpson Strong-Walls, conventional shear walls complying with the 1997 Uniform Building Code of the United States, non engineered shear walls were tested in a series of one- and two-storey buildings (Pryor et al. 2000, Ventura et al. 2002). A specially designed unidirectional shake table was constructed to accommodate the test specimens with plan dimensions of 6.1 x 7.6 m and a inertial weight of 200 kN (Figure 5). Significant database has been developed to guide the design and construction of light-frame wood structures. Some the major findings include the significant contribution of exterior stucco to the seismic resistant in wood frame construction, the documentation of damage levels in the various tested buildings, and the higher damage in non-engineered buildings sheathed with wall boards.

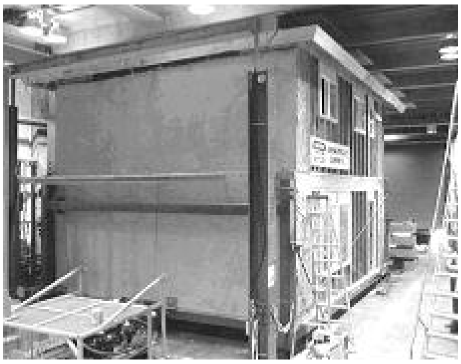

Figure 5: Shake table tests of Earthquake 99 project

More recently in UBC, research efforts also focus on the behaviour of Japanese post and beam buildings including significant modeling and full scale testing activities to develop basic understanding and quantify the behaviour of Canadian species in this method of construction.

In Japan, there exists some of the most sophisticated large scale shake table testing facilities in the world. Wood structure, being relatively light and low, is ideally suited to be tested on a shake table without the much need to scale the test structure. The drawback is of course the high cost of shake table tests and therefore may limit the number replications and variations. Nevertheless much valuable shake table test data on timber structures have been reported from Japan (Ohashi et al. 1998, Tanaka et al. 1998, Watanbe et al. 1998, Yamaguchi and Minowa 1998, Yamaguchi et al. 2000). Japanese researchers also follow parallel approach to develop sophisticated models to predict the structural response and use the shake test results to verify the model so that the verified model can be used in code implementations (Kawai 1999 & 2000, Sakamoto et al. 1984, Sakamoto and Ohashi 1988, Sakamoto 2001).

More recent shake table tests of wood structures in Japan included studying the collapse behaviour of multistory post and beam structures; comparing the response of retrofitted and non-retrofitted single family residential unit (the specimens were an actual in-service buildings relocated to the shake table from buildings lots); and studying the behaviour of 3 story light frame wood structure. These studies clearly point out that well designed and constructed woodframe and post and beam structures can withstand significant seismic demand without collapse. Models can be built to accurately predict the failure sequence of these timber structures.

3 Conclusions

Within the past decade, large volume of research effort in the area of seismic response of timber structures has been conducted in N. America and Japan. The data and models developed in these studies are invaluable to improve our understanding of how timber structures behave in earthquake. With this information safer and more economical buildings can be built in the future. However, much work is still needed to study new forms of structures and construction methods including tall/irregular buildings, hybrid buildings and massif wood structures. Furthermore, heavy timber construction, built with solid sawn timber, glulam and structural composite lumber, needs to be studied to ensure safe behaviour under cyclic loading. This is particular important for moment connections if shrinkage induced perpendicular to grain stress occurs during service life of the structure. Finally seismic events and the structural properties of wood are both random. Reliability studies are needed to define and quantify the performance of wood structure under earthquake. The definition of limit states must be studied in relation to the damage experienced by structures.

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