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Ensuring good seismic performance with platform-frame wood housing

By J.H. Rainer and E. Karacabeyli

This Update reviews the generally good performance of platform-frame wood housing in earthquakes, presents solutions to some problems that occur in practice, and outlines new developments in technology, standards and codes.

Residential housing in North America consists predominantly of wood-frame construction. Most is of the platform-frame type, so called because the walls are erected on top of the completed platform provided by the flooring.¹

Platform-frame wood buildings are designed in one of two ways: by rules of conventional construction or by engineered calculations. Conventional construction uses pre-engineered components and rules derived from experience. These rules are contained in Part 9 of the National Building Code (NBC) of Canada² and can generally be employed for residential housing with less than 600 m² of footprint area and three stories or less in height. All other platform-frame wood buildings must be designed by a qualified engineer according to Part 4 of the NBC. Both methods of design must take into account the possibility of seismic loading due to earthquake, based on the hazard for the building location.

Earthquake Hazard in Canada

Most earthquake activity occurs along the edges of the earth's crustal plates, which over geologic time have moved and continue to move past one another. A sudden slippage along the boundary of these plates releases energy that propagates outward from the slip in the form of waves in the ground —

an earthquake. In Canada, the North American plate and the Pacific plate meet in the ocean off Vancouver Island. The boundary between these plates extends north to Alaska and south to Mexico. Away from the edges of the crustal plates, so-called "intra-plate" earthquakes occur in areas where the crust is weak, for example, along the St. Lawrence River.

The seismic hazard in Canada is greatest on the islands off the West Coast and gradually decreases towards the Rocky Mountains. The areas adjacent to the St. Lawrence and Ottawa valleys pose a moderate hazard, as do parts of the Maritimes. The region around La Mal Baie, Quebec, in the lower St. Lawrence Valley, is one of high seismic hazard, as are small areas in the Yukon and the high Arctic. Seismic hazard maps from the Geological Survey of Canada are contained in the Structural Commentaries of the NBC.²

Significant earthquakes have occurred in Canada in the 20th century (e.g., Messina NY – Cornwall ON 1944, Courtney BC 1946, Miramichi NB 1982, Nahanny NT 1985, Saguenay QC 1988), but either they were not strong enough to cause widespread damage or the epicentre was located in a sparsely populated area. Canadian houses have thus not been "tested" at the predicted level of shaking, and we must

Table 1. Casualties in earthquakes (adapted from Ref. 4)

Earthquake	Richter Magnitude M	No. of Persons Killed		No. of Platform-frame Wood Houses Strongly Shaken (estimated)
		Total	In Platform-frame Wood Houses	
Alaska, 1964	8.4	130	< 10	
San Fernando CA, 1971	6.7	63	4	100 000
Edgecumbe NZ, 1987	6.3	0	0	7 000
Saguenay QC, 1988	5.7	0	0	10 000
Loma Prieta CA, 1989	7.1	66	0	50 000
Northridge CA, 1994	6.7	60	16 + 4*	200 000
Hyogo-ken Nambu, Kobe Japan, 1995	6.8	6 300	0**	8 000**

* Foundation failure caused collapse of buildings on hillside.

** Pertains to “2x4” houses in the affected area.

- wood’s high strength-to-weight ratio;
- structural redundancy in the design (i.e. more than the minimum number of structural components are present to resist the forces that arise from the earthquake);

learn from experience in other countries where similar platform-frame construction exists: California, New Zealand and recently Japan, where the new “2x4” house is similar to Canadian housing.

Review of Seismic Performance

The seismic design objectives for houses and other buildings have primarily been avoidance of serious injury or death to people. The more costly structural objective of minimizing property damage has recently received serious consideration, particularly in California, but in Canada human safety will likely remain paramount.

A survey of the performance of platform-frame wood construction in earthquakes has shown a remarkably low fatality level³ (Table 1). A few buildings collapsed, but many buildings survived strong shaking almost unscathed or with various degrees of superficial and structural damage.

The low fatality level with platform-frame wood construction can be attributed to several factors:

- high energy absorption capacity from frictional losses at nailed connections; and
- ductile behaviour of the various wood components.

From a seismic perspective, the key elements in this type of building are the shear walls. A shear wall is formed by the combination of the vertical studs and the top and bottom plates, with bracing on one or both sides provided by attached sheets of plywood, oriented strand board (OSB) or gypsum board. Depending on the seismic loading requirements, hold-down devices may need to be employed to prevent the wall from lifting at corners or at wall openings (see Figure 1).

Potential Problems

There are several factors that are detrimental to satisfactory seismic performance, which have led to serious damage, collapse and danger to occupants. These include a weak first storey, unstable foundation soils, and unrestrained furnishings, components or appliances.

A Weak First Storey

Large openings in the shear walls — such as windows, doors and garage doors — can leave too little wall area. Because the shear wall is so important in resisting seismic shaking, this lack of wall resistance capacity leads to large distortions and eventual collapse, particularly serious in multi-storey buildings (see Figure 2). Large wall openings can also result in an unsymmetrical building layout, which induces additional seismic torsional or twisting forces in the building, aggravating the weak-storey effect (see Figure 3). To compensate for large openings, additional structural resistance may be needed.

A special case of a weak storey is the collapsing knee wall, also called “cripple

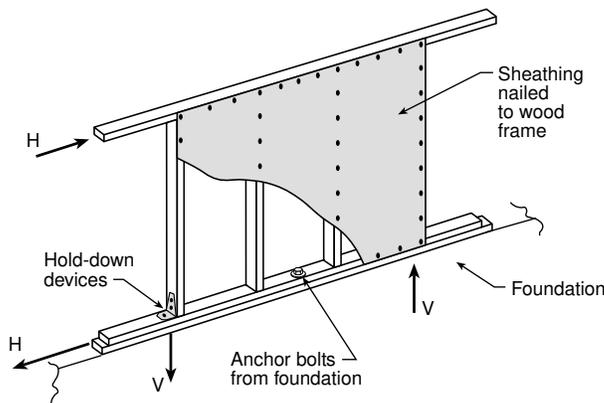


Figure 1. Simplified diagram of main seismic forces acting on a shear wall



Figure 2. Excessive deformation of a weak first storey in an apartment building, Northridge earthquake 1994. In another part of the building the ground floor collapsed completely.

wall” or “pony wall.” The knee wall is the short stub wall in some buildings between the top of the concrete or masonry foundation and the ground floor joists. Its collapse threatens the integrity of the entire structure. The deficiency is often a lack of bracing rather than large openings in the knee wall.

Unstable Foundation Soils

These can cause partial or total collapse of a building. Chief among these problems are liquefaction of the ground, the formation of soil slides and

fissures, and the loosening of rock or soils on slopes above the building. As a result of the shaking, the soil literally turns to a liquid and loses strength, causing uniform or differential settlement and possible distress to the structure. On sloping terrain, soil slides and ground fissures can cause dislocation of the entire structure. Loosening rock and soil on slopes above a building can result in slides engulfing and endangering the building.

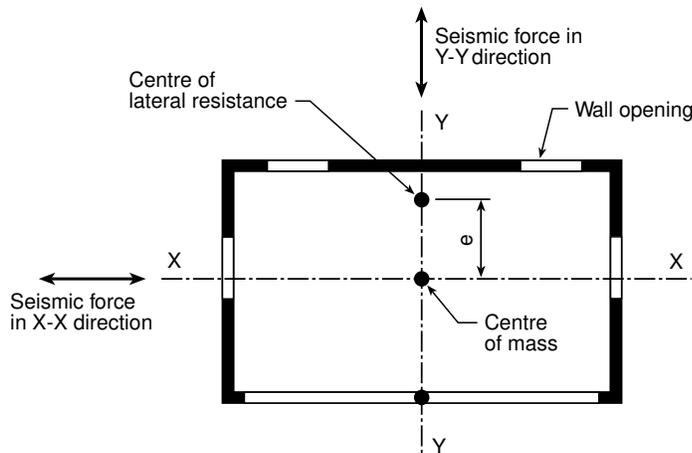


Figure 3. Schematic of an unsymmetrical building layout. Seismic forces in X-X direction cause twisting action in horizontal plane due to eccentricity “e,” the distance between the centre of storey mass and the centre of storey shear wall resistance.

Identifying and alleviating the dangers of unstable soils generally require the services of experienced geotechnical professionals.

Unrestrained Furnishings, Components and Appliances

Tall objects such as bookcases can topple, and sliding or rolling objects can become projectiles. Heavy, unbraced interior partition walls can fall over, and improperly attached canopies and curtain walls (e.g., brick cladding) can fall on passers-by. Domestic gas water heaters, unless properly braced and secured, can easily tip over or displace, causing a possible leakage of gas and the risk of explosion.

Special Preventive Measures

Where architectural or functional requirements limit the construction of sufficient solid wall for adequate seismic resistance, the following patented or proprietary systems are among several special measures that can be employed in engineered wood-frame buildings, for both new construction and retrofit strengthening:

- ZWALL: a metal vertical truss installed within and parallel to a wall, and fastened to both the foundation and ceiling structures
- MIDPLY: a wall consisting of three layers of sheathing rather than the conventional one or two
- Strong-wall: a pre-fabricated wall element reinforced on the periphery with metal strapping

Other costly special devices, such as friction dampers and base isolation mounts, have so far been used in platform-frame wood construction only in exceptional circumstances.

Alleviating Seismic Deficiencies in Existing Buildings

Some older wood-frame buildings — and some not so old — contain deficiencies that can have serious consequences when a major earthquake strikes. For housing built by conventional rules, Canada Mortgage and Housing Corporation has published a guide for recognizing potential structural deficiencies that suggests ways of alleviating them.⁵ For engineered construction, a set of three publications is available from IRC, presenting guidelines for rapid screening, detailed structural evaluation and upgrading of buildings.⁶ The U.S. Federal Emergency Measures Agency also produces useful documentation.

New Developments in Seismic Resistance

Advances in seismic risk evaluation methods, construction materials and techniques, and design and analysis tools, along with changes in economic and social conditions and in consumer preferences provide an ongoing impetus to improve seismic resistance of buildings. Results from research on the seismic behaviour of such components as shear walls and diaphragms, connections made with nails, bolts and other materials, as well as full-scale tests of houses on shake tables, now permit a better quantitative assessment of the seismic resistance of platform-frame wood construction than before. New information is being incorporated into various design guides and standards, some of which are listed below:

- The Canadian Wood Council is preparing a new wood frame construction guide for Part 9 of the NBC.
- The wood design standard CSA O86 from CSA will soon include provision for shear walls with openings, contribution of gypsum board, shear walls without blocking, power-driven nails, hold-downs and anchorages, and Force Reduction Factors R as employed in Part 4 of the NBC.
- CSA S832, a new guideline on reducing the seismic risk from non-structural components of buildings, is nearing completion.
- NBC seismic design requirements are being revised based on a seismic risk of 2% chance of exceedance in 50 years, rather than the current 10%.
- Seismic provisions in building codes elsewhere have been newly published or are being revised, for example, the International Building Code (IBC) 2000 in the United States, the 2001 Eurocode in the European Union, and the revised seismic regulations in New Zealand.

Summary

When reasonable care is taken in design and construction, platform-frame wood housing performs well in earthquakes from the human-safety perspective and in some cases from a damage-prevention point of view. Special techniques and materials can be used to achieve adequate seismic performance and to deal with serious potential problems, such as the weak storey effect and foundation deficiencies. Design guides, material standards and building codes, in Canada and elsewhere, are being changed to reflect new developments in seismic research.

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