Earthquake resistance of modern wooden house design

Compiled and correlated from researched papers and technical references,
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Wooden houses are lightweight, have a high strength to weight ratio, are inherently ductile, can resist racking forces of earthquakes and provide numerous structurally redundant load paths. All these natural properties of wooden house design make it ideally suitable for high risk earthquake regions. These facts also reflect in statistics of past earthquakes, e.g. in America and Japan, where wooden houses have shown very good performance in earthquakes.[1][4]

Requirements

The following requirements have been identified with regards to earthquake resistance:

Requirement	Wood	Concrete (comments)
Lightweight Design	Lightweight	Heavy! The force imposed by earthquake is proportional to the weight of the building
Strength and Stiffness (shearwalls)	TRIANGLES add to stiffness, the combination of vertical Pillars with horizontal Walls result in strength and stiffness.	
Strength to Weight Ratio	WOOD HAS HIGH STRENGTH TO WEIGHT RATIO	Comparable concrete has about 7 times more weight (reference: Building Performance Series No. 5, page 8, by Canadian Wood Council)[1]
Anchoring	STEEL SUPPORT FEET USED WITH SCREWS	
Ductility (flexibility)	WOOD IS INHERENTLY DUCTILE, **fibrous material** bends and does not break	Concrete is NOT ductile and breaks on strong impulses that occur in earthquakes (not fibrous material)
Redundancy	MANY PILLARS / BEAMS / WALLS – distributed interconnection	Isolated Pillars, walls do not significantly add to earthquake resistance
Connectivity	MANY WELL DISTRIBUTED INTERCONNECTIONS, USING SCREWS INSTEAD OF NAILS	

Details on how modern wooden house design, especially as applied to the Nepal earthquake region, meets these individual requirements is given in the following sections.

Lightweight Design

Wood is inherently lightweight compared to other building materials as stone or concrete. Forces in an earthquake are proportianal to the weight of the structure.(1) The wooden model house of 5x5m designed for Nepal earthquake region has about 3000 kg, including the roof tiles. As a result, forces from earthquake have much less effect on wooden structures than on concrete or stone buildings.

Strength and Stiffness

To resist racking forces (walls becoming unsquare from lateral forces), triangular beams are used. Also the (internal and external) walls are horizontally arranged, such that vertical pillars together with horizontal boards of the wall form a well interconnected whole.

For good connection of structural parts (all pillars in particular), screws are used instead of nails, preventing dissociation of individual parts and keeping the structural wooden frame together.

Strength to Weight Ratio

Due to the fabric composition of wood, wood inherently holds itself together, there is no need for inclusions of e.g. rods as is the case of concrete since concrete cannot hold itself together. As a result, wooden houses have a much higher strength to weight ratio as compared to most other designs. Lower weight means less exposure to forces from earthquake (inert mass is less).

Anchoring

To resist earthquake, proper anchoring is required. Not only to hold the weight of the building but also to prevent the structure from rocking off the ground.

In the implemented wooden design, steel support feet are used(3), which have also been extended to form a T underground, which effecitvely prevents them from uplifting. These support feet can be bolted to the pillar wood, for which we use 2 heavy-duty screws in each support foot (one from each side).

This ensures both good connection to the ground and preventing the structure from rocking off the ground. Calculations have been done on the mechanical properties of the steel support foot to check adequateness for the scenario in Nepal.

Calculation of Earthquake Resistance of steel support feet for Anchoring

Based on our 5x5m, single-floor model, using 9 support feet of type Simpson Strong-Tie PPU 90/60G, with extended T rods underground, the following calculations apply. Regarding earthquake resistance, the peak ground acceleration needs to be taken into account. According to a document from University of Portland[(2)] and a report published by Weimar university (Germany)[(6)] the peak ground acceleration in the April 2015 earthquake of magnitude 7.8 (Richter scale) in Nepal was around 0.5 to 1g and up to 1.2g in the central regions of the affected area. So we need to ensure the steel support feet do not deform or break with this given force.

Parameters:

Rod **diameter** of support foot: **16mm**

Material: S235JR[(3)]

Allowable **lateral force** according to datasheet(3) (worst case) = **6000 N**

Calculated weight of typical 5x5m, single story wood house (for Nepal earthquake region): 3000 kg

Adding a load of 1000kg (people, rice, …), results in a **total weight** of around **4000 kg**.

Number of support feet used (5x5m model): **9**

Calculation:

Approximate Structural Weight resting on one steel support foot = 4000 kg / 9 = **444 kg**

Since F = m x a (Newton), the allowed **acceleration** a = F/m = 6000N / 444kg = **13.5 m/s^2**

Since g (gravity) = 9,81 m/s^2, the allowed **acceleration expressed in g** = 13.5/9,81 = **1.38 g**

Since the peak ground acceleration of the Nepal 2015 earthquake was mostly below 1g in central affected areas, and adding the fact that the wooden framing is flexible (ductile), meaning the actual load on the steel support feet is less than the weight, the used configuration of steel support feet provides adequate anchoring to ground.

To summarize: implemented anchoring both holds down the structure to the foundations and provides adequate resistance to lateral forces.

Ductility (Flexibility)

Wood, being a fibrous material, is naturally flexible and can thereby dissipate energy of sudden impacts imposed by earthquakes, smoothing them out. In contrast, concrete is not ductile and requires good design to ensure seismic perforamce.[(1)]

Redundancy

Wood frame design is composed of many smaller pillars instead of few large pillars. Thereby impact force can be distributed among redundant paths and weaker paths can be compensated by neighbouring connections.

Connectivity

In Nepal earthquake region, screws are used instead of nails, to hold together the structural components (pillars, beams, …), as such, the entire framing is strongly interconnected and does not tend to fall apart from shaking.

Earthquakes experienced by wooden houses built in Nepal/Nuwakot

According to the National Seismological Centre[(7)], the following earthquakes (Nuwakot/Rasuwa region only) have already been experienced by the wooden houses built in early 2016:

Date	Local Time	Latitude	Longitude	Magnitude(ML)	Epicentre	
2016/04/24	2:16	28.08	85.13	4.2	Nuwakot	
2016/04/26	15:18	28.05	85.38	4.3	Rasuwa	
2016/06/21	11:34	27.93	85.21	4.4	Nuwakot	
2016/10/15	18:22	28.04	85.17	4.1	Rasuwa	NSC
2016/10/17	10:03	27.87	85.30	4.0	Nuwakot	

Note that according to calculations, the actual April 2015 earthquake would have been resisted by the wood houses built so far.

References

(1) Canadian Wood Council, Wood-Frame Construction – Meeting the Challenges of Earthquakes,
http://cwc.ca/wp-content/uploads/publications-BP5_WoodFramesAndEarthquakes.pdf

(2) University of Portland, Magnitude 7.8 NEPAL
https://www.iris.edu/hq/files/programs/education_and_outreach/retm/tm_150425_nepal/150425_Nepal.pdf

(3) SIMPSON Strong-Tie Steel support feet, including horizontal load specification
http://pim.simpson.fr/public/download/de/de/product/112

(4) Wood-frame construction advantageous in areas prone to seismic activity
http://csengineermag.com/article/wood-frame-construction-advantageous-in-areas-prone-to-seismic-activity/

(5) S235JR steel, Biegewechselfestigkeit (fatigue behaviour) = 180 N / mm²
http://www.schweizer-fn.de/festigkeit/festigkeitswerte/stahl/stahl_start.php

(6) maximum PGA (peak ground acceleration) was 1.2 g, but mostly around 0.8 g in central region
http://www.edac.biz/en/news/earthquake-reports-mostly-german/earthquake-of-gorkha-nepal/

(7) List of recent Earthquakes in Nepal
http://www.seismonepal.gov.np/index.php?action=earthquakes&show=recent