TIMBER CONSTRUCTION

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BACKGROUND

Wood construction is common for many single-family houses throughout the world. In areas where timber and wood materials are easily accessible, wood construction is often considered to be the cheapest and best approach for small housing structures.

Six main types of wood construction are listed in the encyclopedia. These types use all forms of timber available from logs to sawn/shaped timbers to smaller branches and leaves. These types also utilize various types of wall coverings from plant-based coverings to timber materials to earthen materials, such as mud or stone. The first type of wood construction is thatch construction, which is generally a traditional construction type. For examples of this type, see the traditional construction section of the encyclopedia. Other types include post-and-beam frame construction, walls with bamboo/reed mesh and post (waffle and daub), wooden frames with or without infill, and stud-wall frames with plywood/gypsum board sheathing. Two final types are wood panel construction and log construction.

Only some of the main types of wood construction are discussed in detail in the encyclopedia. The first of these construction types is stud-wall frame with plywood/gypsum board sheathing (Figure 1), which is popular worldwide and is the main type used in the United States (WHE Report 90), Canada (WHE Report 82), and Japan (WHE Report 86). For this type, walls are made of vertical timber elements of rectangular cross-section covered in light plywood or composite sheathing, with roofs made of timber members or prefabricated trusses, which are sheathed similar to the walls. The building foundations are usually concrete but sometimes are made of stone. In Japan, a post-and-beam frame is also constructed. It is similar to the stud-wall frame, except that it uses diagonal members to create its shear walls instead of sheathing. Horizontal timber construction (Figure 2) is found in parts of the Russian Federation, particularly in rural forested areas (WHE Report 56, Russian Federation). For this system, walls are made of horizontal sawn timber logs of square or circular cross-section joined without mechanical fasteners at the corners. The buildings have timber roofs and stone or concrete foundations. The final system of construction reviewed in the encyclopedia is wood panel construction (WHE Report 57, Russian Federation). This is typically found in the Russian Federation where its prefabricated panels are easily constructed for government low-income housing (Figure 3). Walls and floors are made of layered wood members with timber roofs and concrete foundations.

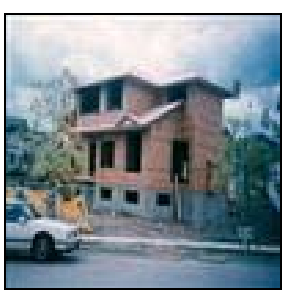

Figure 1: Typical two-story house in Canada (WHE Report 82)

Figure 2: Typical log house in the Russian Federation (WHE Report 56)

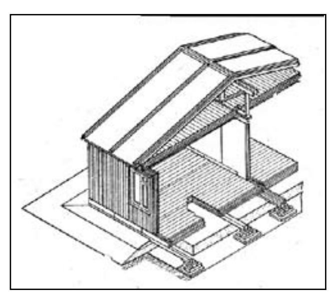

Figure 3: Typical wood panel house in the Russian Federation (WHE Report 57)

WOOD FRAME CONSTRUCTION

A typical modern wood-frame house consists of a reinforced concrete strip-footing foundation, whereupon a platform is constructed of joists covered with plywood or oriented strand board (OSB) to form the ground-floor level of the house (also known as platform wood-frame construction). This platform is connected directly to the foundation with anchor bolts. On this base, the exterior and interior walls are erected. The walls consist of a horizontal sill plate with vertical timber studs with board or panel sheathing nailed to the studs on the outside of the building (Figure 4). After the first-story walls are completed, the second-story floor is constructed, which, in turn, acts as a platform for erection of the second-story walls. This process is continued for all the stories. The roof structure typically consists of prefabricated trusses, which are covered with sheathing and roof tiles (Rainer and Karacabeyli 2000).

The standardized wood-frame structure of today is now augmented by a wide range of compatible standardized components, such as doors, windows, electrical and plumbing fixtures, and the like, which are designed to be easily installed in the wood structure. Because wood-frame walls are hollow, alternative levels of insulation can be installed enabling any climatic conditions to be accommodated. Plumbing, heating, and electrical services are easily installed within the walls, in the open spaces above ceilings, within the floor structure, and in the space between the first (ground) floor and the ground below. Wood-frame houses can be up to three stories in height, as per typical code limits.

The vast majority of residences in the USA, Japan, and Canada are wood-frame construction, as described above. Canadian one-story residences are often non-engineered constructions, which differ from the USA, Japan, and the Russian Federation's government housing, where residences are engineered by an architect.

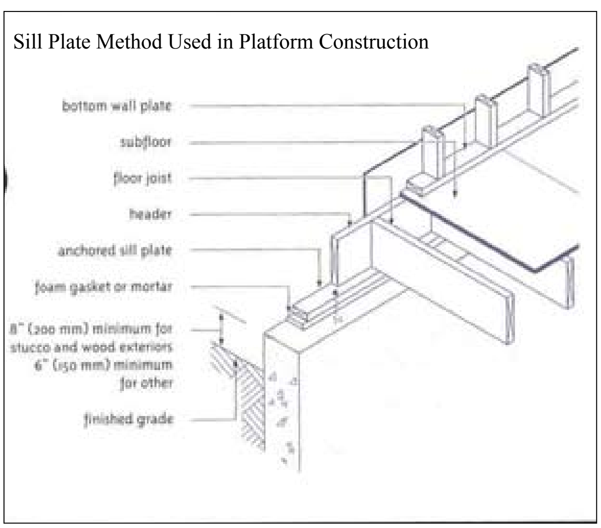

Figure 4: Platform construction detail in Canada (WHE Report 82)

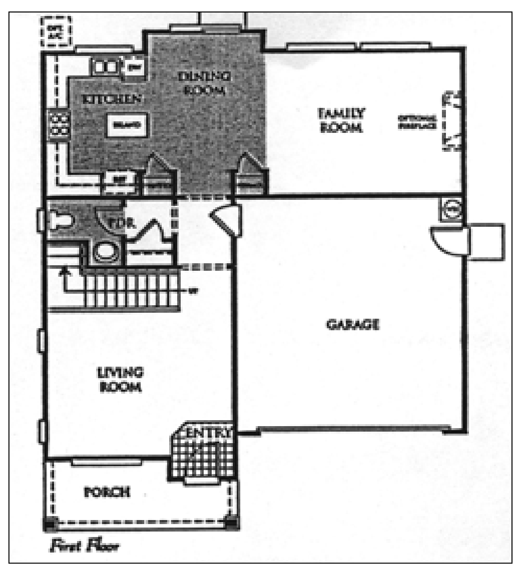

Figure 5: Typical first-floor plan for wood-frame house in California, USA (WHE Report 90)

USE AND COST

Today, wood frame is used for approximately 90% of the houses constructed in the USA, predominantly in suburban regions. Costs vary greatly by region and house design, and range from about 650 US$/$m^2$ to 2200 US$/$m^2$ (WHE Report 90, USA), excluding land cost. The cost for a single-family residential house in Japan ranges from 1100 US$/$m^2$ to 2800 US$/$m^2$ (WHE Report 86, Japan).

STRUCTURAL SYSTEM

In the typical wood frame house, gravity loads are accommodated by wood "studs," commonly placed at 16 inches (approximately 400 mm) centers. Floor and roof-framing members are commonly 2 inches (50 mm) in thickness and may be from 6 to 14 inches (150 mm to 350 mm) in depth. Lateral resistance is provided by a shear-wall system consisting of plywood or manufactured wood panels (particle board) nailed to vertical studs, creating shear walls (Figures 6 and 7). Today's wood frame construction is highly codified and regulated in the USA (WHE Report 90, USA), with a generally good standard of inspection by suburban local building departments in earthquake-prone regions. In smaller towns and rural areas, quality control may be lacking.

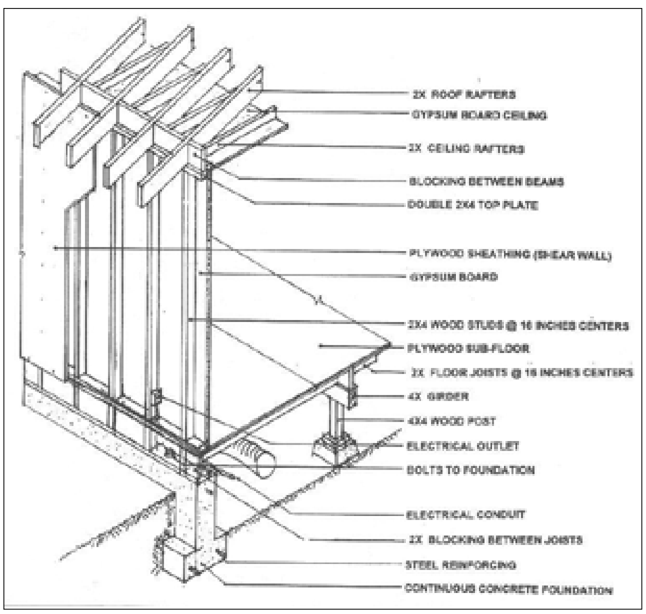

Figure 6: Installation of prebuilt stud wall on reinforced concrete floor slab (WHE Report 90)

Figure 7: Typical one-story wood-frame construction (WHE Report 90)

Japanese wooden housing is built using "post-and-beam" construction (WHE Report 86, Japan), similar to the construction in the USA and Canada. Wooden posts, with cross-sectional dimensions ranging from 105 mm to 150 mm, carry gravity loads. The roof structure is made out of wood and is covered by roof tile or slate. The roof load is transferred to the wood frame. The roof-supporting system in Japan is different from that of western countries and is based only on vertical and horizontal members. No diagonal members or trusses are used, as is common for similar construction in Western countries.

For most timber structures in Japan, Canada, and the USA, the lateral load resistance is provided by wooden shear walls with plywood or manufactured wood panels ("particle board") nailed to the vertical wooden members. The building code generally regulates the number and dimensions of shear walls. In Japan (WHE Report 86), another common approach to shear-wall construction is a wooden wall with interior diagonal brace members (Figure 8). However, the traditional Japanese house did not have a diagonal brace. A thin lumber running through posts, called "Nageshi," and a thick wood post provided lateral resistance. Japanese construction also often uses metal joints, and in recent wooden housing, plates are used to stiffen the wood frame.

Alternate approaches to the post-and-beam construction are the Russian Federation's timber panel construction and horizontal timber log construction (WHE Report 56, WHE Report 57, Russian Federation). The panel buildings use load-bearing panel walls to carry gravity loads. The layered paneling acts as a shear wall to resist lateral loads. These layered timber panels also serve as floor and roof diaphragms. The horizontal timber system uses stacked logs as vertical and lateral load-resisting elements (Figure 9). The horizontal logs are joined by hand-sawn connections without mechanical fasteners (Figure 10).

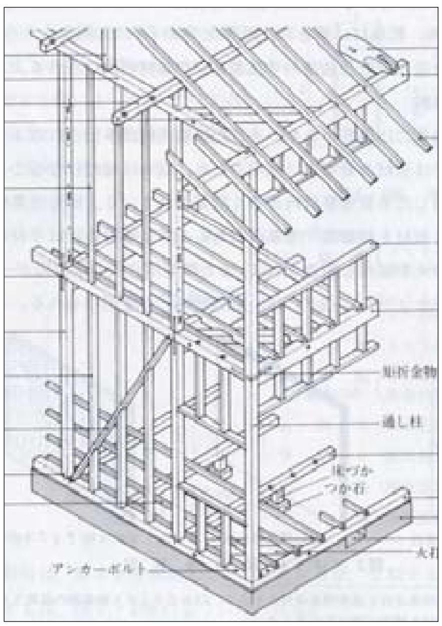

Figure 8: Post-and-beam construction in Japan with diagonal bracing (WHE Report 86)

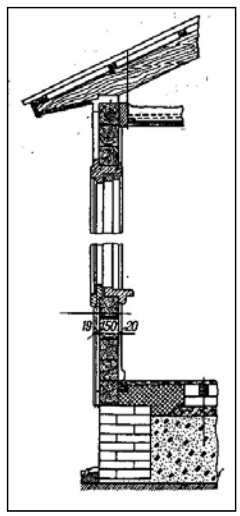

Figure 9: Section of horizontal log house wall construction in the Russian Federation (WHE Report 56)

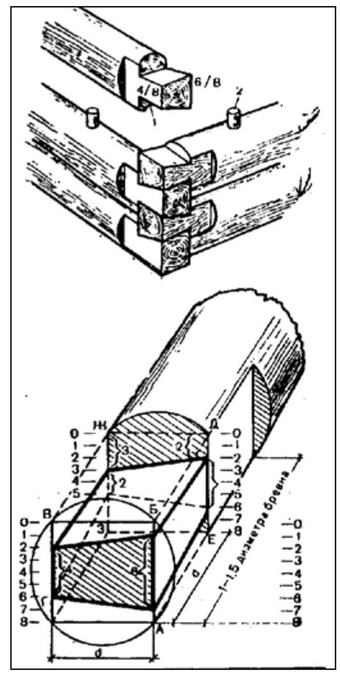

Figure 10: Detail of wood connections in log house construction (WHE Report 56)

SEISMIC PERFORMANCE

The seismic resistance of wood-frame structures is relatively high, provided the quality of materials and the construction are satisfactory. The buildings generally tend to be lightweight, especially when compared to brick or stone, which helps reduce earthquake forces on the structures. In addition, because of the relatively large number of walls and the use of numerous nailed connections, wood-frame houses have traditionally performed well in earthquakes so that deaths and serious injuries are rare.

The seismic performance of wood-frame construction is greatly enhanced by its non-structural components (WHE Report 82, Canada). The architectural finishes and numerous non-load-bearing walls increase the amount of energy the building can dissipate during an earthquake because these additional systems absorb energy as they are damaged. Finishes, such as stucco that are used in the USA, Canada, and Japan, crack and spall, which adds additional earthquake resistance to buildings; therefore, a typical wood frame house is usually considered to have medium-to-low vulnerability to earthquakes.

Horizontal timber buildings in the Russian Federation have performed moderately well in past earthquakes (Figure 11).

Panel buildings in the Russian Federation have yet to experience large earthquakes.

SEISMIC DEFICIENCIES

Inadequate connection of the building to its foundation is a critical issue for all types of wood structures. During a seismic event, buildings that are not properly bolted to their foundation may move off the foundation, causing structural damage and possible severance of water, gas or electrical lines. All countries under discussion highlight this as a major seismic deficiency.

The most common deficiency for buildings in the USA is unbraced cripple walls (WHE Report 90, USA). A cripple wall is a low stud wall sometimes used between the top of the foundation and the underside of the first floor. The collapse of a cripple wall or damage to it from an earthquake are generally not life-threatening but expensive to repair (Figure 12).

Figure 11: A photograph illustrating typical earthquake damage from the1958 Kamchatka earthquake (WHE Report 56)

Figure 12: Damage caused by unbraced cripple walls. Note that the house has shifted about 1 foot (30 cm) off its foundation (WHE Report 90, USA)

Inadequate shear resistance may also be a problem for older structures in both the USA and Japan that are deficient in sheathing or bracing. In Canada, the use of horizontal board shearing,which is commonly constructed, may also have inadequate shear resistance. The results of a Canadian experimental study clearly indicate that measures to address this high-risk construction practice will substantially reduce earthquake damage (WHE Report 82, Canada).

In older buildings in the US, Canada, and Japan, deficiencies may exist in the joints especially where studs are joined by finger joints without any mechanical fasteners. This is the same problem found in the horizontal timber construction type of the Russian Federation (WHE Report 56), which relies solely on hand-sawn connections (Figure 13) These horizontal timber structures are also weak in their connections at openings due the lack of a frame to support the members.

Inadequate blocking in walls and between joists in the roof and floor diaphragms for frame structures, especially at stress concentrations, can be a significant building weakness.

A deficiency likely to be found in Japanese structures is that of very heavy roofing materials (Figure 14). The traditional heavy tiles often lead to the collapse of buildings as seen in the 1995 Kobe earthquake (WHE Report 86, Japan).

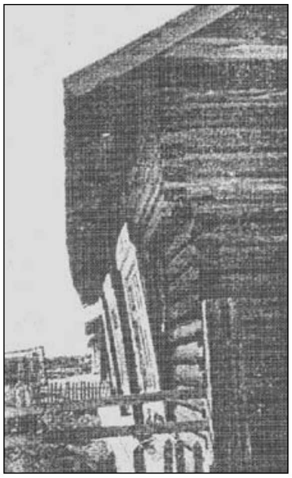

Figure 14: Damage caused by heavy roof construction in Japan from 1995 Kobe earthquake (WHE Report 86)

Figure 13: Wall damage in the 1958 Kamchatka earthquake (WHE Report 56)

For the wood panel structures common in the Russian Federation, the most problematic area is the panel connections (WHE Report 57, Russian Federation). The joints between the panels and the attachment of panels to the roof framing members or to the foundation are particularly susceptible to earthquake damage.

Lack of proper building maintenance is another issue for all timber buildings.

TYPICAL SEISMIC-STRENGTHENING TECHNIQUES

Cripple wall bracing is the most common and cost-effective strengthening measure for timber frame structures in the USA and Canada. These retrofits are simple and can be done at very low cost by a homeowner who has moderate carpentry skills (Figure 15). It is not necessary to brace the entire wall as long as all corners are braced and some intermediate portions of wall are also braced, depending on the length of the walls (WHE Report 90, USA).

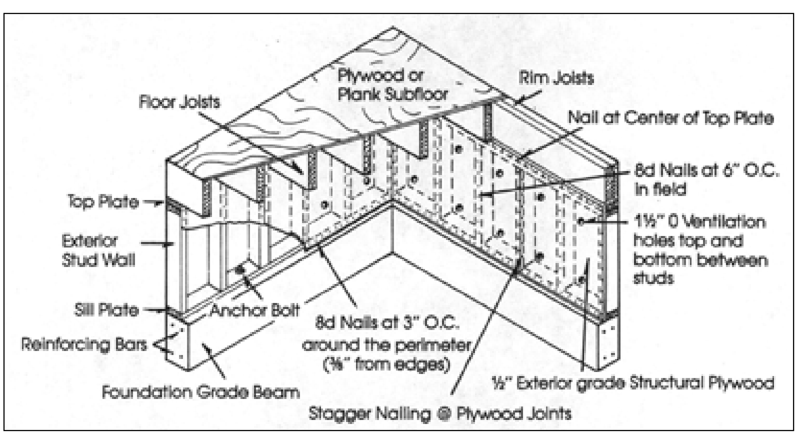

Figure 15: Cripple wall retrofit and foundation anchorage (WHE Report 90)

Basic anchoring and connection of the wood building to the foundation is also commonplace in the USA and Canada.

Four main areas are commonly strengthened in Japan (WHE Report 86, Japan). Inadequate framing-member connections are retrofitted with additional metal connectors as are the wall-to-foundation connections. For buildings with inadequate lateral systems, additional timber diagonal braces are installed, or plywood sheathing is added to the existing walls. Heavy tile roofs are often changed to lighter weight materials. Rather than institute these strategies, however, many owners of damaged buildings choose to demolish existing buildings and construct new structures. Retrofit of existing structures is not popular and is not required by the current code in Japan though it is encouraged.

For the horizontal timber houses in the Russian Federation, several retrofit measures can be done but very rarely are actually instituted (WHE Report 56, Russian Federation). The installation of vertical clenching members in the walls for two-story buildings, the connection of wood logs using vertical steel bars, and the installation of frames around the openings should all prevent the failures seen in previous earthquakes.