Wood Frame Design and Construction

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Executive Summary

Wood has been discovered as an important construction material since prehistoric time. As time goes, the technology of wood frame construction is developed. Today, it is widely used in many North American and European countries. Wood is a much more sustainable construction material than steel or concrete. During its production, less green house gases are produced. Wood is also a very durable material. Some old wood frame buildings are still used. History has proved the durability and strength of wood structures. In the recent days, in order to achieve stronger and more durable building structures, wooden building components production technology and wood framing technology are further developed. As a result of these developments, I-joists, metal plate connected wood trusses, structural composite lumber, platform framing and plank and beam framing are widely applied in either individual house construction or heavy industrial construction.

The purpose of this paper is to provide a detailed explanation of how wood can be a good material for building homes. This paper introduces the methods of moisture and termite protection for wood material, wood and concrete foundation construction, as well as the different types of wood frame constructions and construction processing details. This paper may help to open markets by changing the mind of people who are not used building home with wood to accept wood frame building.

List of Key Words

Wood-frame construction

Building materials

Foundation

Framing

Siding

Roofing

Moisture

Termites

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1 Introduction

1.1 Purpose

Wood as an important construction material is widely used in North American and European countries. Since there are potential fire risk problems and height limit concerns existing in wood frame buildings, people sometimes questions whether wooden buildings are as safe as concrete and steel buildings. Compared with concrete and steel, wood is a much more sustainable construction material. It causes less green house gas emission, air and water pollution and ecological resource use than concrete and steel. Additionally, wood has much lower heat conductivity – 400 times less than steel and 8.5 times less than concrete (Western Red Cedar Export Association, n.d.). Moreover, wood is a low-cost and high-value building material. It can be found all around the world in many different types. Wood frame buildings can stand up against loads from high wind and large earthquake. Historically, people around the world have started constructing buildings with wood since prehistoric time. Around 19th century or even earlier, many North American and European countries started to develop their wood frame construction technologies including balloon-frame method and platform framing techniques. As wood frame construction increased, structural strength enhancement and fire resistance techniques were developed. Wood is an extremely durable material if properly maintained. Some of the oldest wood frame buildings around the world such as the all-wood Horyu-ji temple in Japan have been used for over 1000 years. As indicate above, history has demonstrated that wood as a construction material has an extremely high durability and a high inherent strength. Today, based on the recent innovations in wood

engineering codes and standards, new wood structural products including I-joists, trusses and structural composite lumber have been developed and widely used in wood frame construction. The purpose of this paper is to provide a detailed explanation of how wood can be a good material for building homes. This may help to open markets by changing the mind of people who are not used to building home with wood to accept wood frame building.

1.2 General Scope

To achieve a strong and durable structure, methods such as prefabricated wood I-joists, metal plate connected wood trusses, structural composite lumber, and structural wood panels have been used. In addition, it is important to follow sound construction and installation and fire resistance practices for wood frame buildings in order to assure durability and trouble-free performance. Practices, such as installing sound-absorbing insulation into stud cavities and the joist, increasing the overall mass of assembly, and keeping spaces in between the two sides of walls, have been applied to reduce sound transmission and increase fire resistance as well as constructing fire-rate wall (Forintek Canada Corp., the Quebec Housing Corporation and Canada Mortgage and Housing Corporation, 2002).

1.3 Building Material Standards

1.3.1 Dimensioning

Generally, lumber has a thickness of 2 inches to 4 inches, including end-jointed lumber and solid-sawn lumber. During the installation of sill beams, floor joists, and girders, solid-sawn lumber is commonly applied. Timbers are usually about 5x5 or larger.

In the floor system construction, timbers are generally used for sill beams and girders. The dimension of lumber and timbers should follow the local material standards. For example, in the United States, the dimension of lumber and timbers should follow American Softwood Lumber Standard PS 20 (Southern Forest Products Association, 2012).

1.3.2 Grading

Wood quality refers the suitability of wood in providing specific end uses. Therefore, quality control plays an extremely important role in wooden building construction. In Canada, to assure the quality of lumber, every pieces of lumber need to be graded and stamped by the grading agency. The grading of lumber represents the size, moisture content, species and seasoning condition during the time of manufacture. All dimension lumber and timbers should be graded by following the Standard Grading Rules for Canadian Lumber which is published by the National Lumber Grades Authority (NLGA) (Canadian Wood Council, 2013).

2 Protection of Material

Protection of wood material plays an important role in the wooden building construction field. In this section, several protections including moisture protection and termite protection are introduced.

2.1 Moisture Protection

Moisture has been considered as the biggest enemy of all wooden construction components for a long time. Increasing the moisture content in timber will cause some serious damages, including mildew, fungus, crowning, cupping, buckling, mold and dry rot. As a result of these water damages, the strength of timber will decrease. Moreover, construction failure could occur. Therefore, it is extremely important to protect timber from water, especially in the wooden building construction field. In following paragraphs, several commonly used moisture protection methods are introduced, including protection of moisture damage at the construction site caused by rain and absorbing water from ground and the protection provided by water repellents.

2.1.1 Rain protection

In order to protect wooden materials from cold and wet weather condition such as rain and snow, most building contractors usually arrange required wood materials to be delivered right before each installation begins during the construction period. For example, during a normal construction procedure, after the foundation is complete, the first load including all required wooden materials for the floor system will be delivered. Then several days later, after the floor system has been completed, the second load including all materials for framing and sheathing of the walls will be delivered. After all, the third load providing all materials for roof construction will arrive (Anderson, 2002).

In this manner, building contractors will not have to pay too much attention on the storage and protection of wooden materials, since they use these wooden materials right after each delivery. However, situations such as a single house construction, contractors are not able to require the material delivery separately. All construction materials will be delivered once only at the same time. Therefore, in this situation, material protection and storage under a cold or wet weather are very important. Lumber should not be just piled together tightly without applying any moisture protections. The pile of lumber must be covered with a waterproof paper, polyethylene, or canvas to shed the water from rain or snow (Anderson, 2002).

2.1.2 Ground moisture protection

Wood can absorb water from the ground because it is hygroscopic. Therefore, it is also important to consider how to prevent wood from absorbing water from the ground. If lumber is not going to be used for a week or longer, it should be remained on the skids after the delivery in order to have a 6 inch clearance above the ground (Anderson, 2002). It is important to keep a clear distance above the ground, since this helps to shed the water from ground. Additionally, if the lumber is going to be piled on the ground from skids, a water proof cover such as polyethylene must be applied over the ground before the lumber is piled (Anderson, 2002). This can also reduce the moisture rise of the lumber.

2.1.3 Water repellents protection

Water repellents (WRs) are simple treatments for wood to prevent it from soaking water and keep it dry. Water repellents are usually chemical solvent that contains about 10% to 20% varnish resin or drying oil, a substance that is able to repel water such as a

wax, and organic liquids including turpentine and mineral spirits (Williams & Feist, 1999). The varnish resin or drying oil can be absorbed by the wood surface and seal the wood surface to shed the water. Different WRs have different concentration of water repellent. High concentration of water repellents is usually used as stand-alone finishes. On the other hand, low concentration of water repellents is usually used as pretreatments of other finishes (Williams & Feist, 1999).

2.2 Termite Protection

Termite damage for wooden buildings is a serious problem in North American countries, especially at the United States. Termites can cause strength reduction and the durability decrease of timber. However, termite damage can be controlled by preventative measures and proper building practices at the construction site. Termite protections must be applied at both site preparation period and construction period.

2.2.1 Site preparation

Termites protection of wooden buildings usually start with a proper jobsite clean-up and a careful preparation. During the clean-up, buried wood including tree roots must be completely excavated and removed, because termites can be attracted by the presence of buried wood and cause construction failure. Additionally, all other lumber scraps, logs, limbs and stumps must be removed before the construction of wood or concrete floor starts. By doing these, termites damage can be controlled effectively.

2.2.2 On construction

Usually the best method to protect wooden building from termites is to stop them outside of the building. In order to do so, Permanent Wood Foundation (PWF) with

poured concrete may be required. Poured concrete can seal the wood foundation and prevent termites gaining access to the building from the underground (American Forest & Paper Association, 2006). For preventing winged termites, attic vents and crawl space must be screened. In addition, any untreated wood elements such as floor joists, studs, girders, and columns must be raised with a minimum clearance above the ground level to prevent any termites attack. For example, the minimum height above ground of floor joists is 18 inches and minimum height of studs is 8 inches. Minimum height requirement of other untreated wood elements can be found from U.S. model building codes and American Forest & Paper Association recommendations (Canadian Wood Council, 2001).

3 Foundation

In general, a foundation is designed to bear the load and hold together the building structure above it. It is one of the most important parts of the building structure and it must be built to support the building adequately. If the foundation cannot support building adequately, cracks will occur and get larger over time and finally cause structure collapse. The foundation system has two main functions. The first function is to support the building structure above it, prevent the uplift forces of expansive soils or frost, and protect the building from nature horizontal forces such as earthquake and wind. The second function is to hold the wooden structure above the ground and keep the wooden structure away from moisture and organisms to prevent terminate attacks and wood decay which could cause structural failure.

A firm footing, as a part of the foundation, plays an extreme important role in the foundation construction. It transfers dead and live loads of the building to the soil. Dead load is the total load of the building itself, including weight of all the building materials and the surrounding soil of the foundation. Live load contains the weight of people, wind, rain, snow, and furniture. Due to frost reason, in some areas, footings must be set below the frost line in order to prevent the frost damage to structures and foundations.

Two major types of foundations are commonly used in wood frame constructions. These two types of foundations which are made of pressure treated wood and concrete will be introduced in the following paragraphs.

3.1 Concrete Foundation

Two principal types of concrete footings including reinforced concrete footings and unreinforced concrete footings are commonly used. Unreinforced concrete footings are usually used in stable soil conditions. However, in some cases the soil is not stable, then reinforced concrete footings are applied. Decision making is based on the engineering analysis of the footings. Foundation walls of concrete footings are usually poured concrete or masonry blocks. Thicknesses and types of concrete foundation walls are controlled by local building codes. In general, based on the length of unsupported walls and the height of each story, the thickness of the poured concrete basement wall varies from 8 inches to 10 inches (Sherwood & Stroh, 1989). The forming of the poured concrete wall must be well-braced, tight, and tied to bear the forces from the fluid concrete and the pouring operation. Poured concrete walls can be sealed by a tar or asphalt coat to shed water and damp from ordinary seepage such as rainstorm. When set, a dried concrete surface must be obtained before the coating is applied to the outside of the footing. The thickness of the masonry blocks wall varies from 8 inches to 12 inches. However, the most commonly used thicknesses of masonry blocks walls are 8 inches, 10 inches and 12 inches (Sherwood & Stroh, 1989). The masonry block wall can be reinforced by installing reinforcing rods vertically in the block cores with concrete filled. This will help the masonry wall to obtain additional strength. To prevent the seepage, the masonry block wall can be damp proofed with a coating of asphalt over the dried mortar parging (Sherwood & Stroh, 1989).

3.2 Wood Foundation

Compared with concrete foundations, wood foundations are significantly lighter. Since wood foundations do not require casting and curing as concrete foundations, it is easier and costs less time to construct. Therefore, permanent wood foundations are widely used in North American countries in house construction. All lumbers and plywood must be pressure treated with a high concentration of preservative to prevent wood decay and termites attack. With pressure preservative treatment and prefabrication, the permanent wood foundation gains the suitability of construction in all weather conditions including the cold weather condition. It has been applied in both basement and crawl space foundations constructions.

During construction, after the excavation, to prevent local frost condition in some areas, a trench with an appropriate width is required around the perimeter to provide a greater depth. Then, a layer of gravel or crushed stone which has a minimum 4 inches thickness is placed to the bottom of the trench carefully. Wall panels should be placed and installed on the gravel over the footers. After the installation, a cover of 6-mil polyethylene is applied to seal the exterior of the wall below grade. Exterior plywood joints are caulked. Basement floors can be finished with concrete slabs or wood flooring installed on the wood joists. Compacted gravel with a depth of 4 inches should be installed as the base of concrete slabs or wood floors. The top of the gravel base should also be covered with a film of 6-mil polyethylene in order to protect basements from moisture attack (Sherwood & Stroh, 1989).

Permanent wood foundations do not require drain tiles. The permanent wood foundation can drain the ground water through the gravel slab base and the gravel footing

to the outside of the building structure. Such basements have a great advantage on keeping dry interior conditions. Additional information of permanent wood foundations can be found from the Southern Pine Council and American Forest & Paper Association (AF&PA) (American Forest & Paper Association, 2001).

4 Frame Construction Types

As the frame construction technologies develop, four types of frame construction are commonly used. They are platform frame construction, balloon frame construction, plank and beam construction and truss frame construction.

4.1 Balloon Frame Construction

Balloon framing was a very popular frame construction method until the mid of 19th century in Canada and United States. Balloon framing utilized studs that run continuously from the sill plate to the rafter plate. In the balloon frame construction, the exterior wall studs rest on the sill plate in the interior side and the floor joist. The exterior wall studs extend continuously from the sill plate of the first floor to the top plate of the second floor. At the second level floor connection, joists rest on the inside of edges and are then face nailed to the exterior wall studs (American Forest & Paper Association, 2001).

For two stories wooden building that constructed with stone veneer or brick, balloon framing controls and minimizes variations in settlement of the masonry veneer and framing. Due to the solid masonry exterior walls, distortions between door and closet openings can also be reduced. Since balloon framing requires longer studs and has potential fire risk problems, the popularity of balloon framing has reduced (American Forest & Paper Association, 2001).

4.2 Platform Frame Construction

Platform framing is a widely used method of constructing wood frame buildings in the recent days. Platform framing and balloon frame are very similar to each other.

Both platform framing and balloon framing requires the similar basic layout. However, a platform frame uses shorter lengths of lumber because each story of the building is built individually and placed on top of the one below. The walls are positioned on the sub flooring. In the platform frame construction, floor joists will rest on a sill plate or on top of a stud wall. The wall framing of the next level will then sit on the top of the fully sheathed floor joists (Arnold, 2011). The roof and attic are installed upon last set of walls.

There are several major advantages of this method over balloon framing. First, the materials required are shorter, so the materials are easier to handle. Second, fire stops occur at each floor in order to reduce the fire risk. Third, it is faster. Since each story is constructed on top of the previous story floor, the next floor could be used by workers to build the second story walls. This results a much faster and easier construction.

4.3 Plank and Beam Construction

The plank and beam framing construction method has been generally applied in the floor and roof construction of heavy timber buildings. In the plank and beam framing, plank roofs and subfloors that have a nominal thickness of 2 inches are used to support beams. Each beam is positioned up to 8 feet apart from each other. At the end of each beam, piers or posts are used to provide the support. Doors and windows should be installed between posts in exterior walls. By doing this, the need of header due to openings is not necessary (American Forest & Paper Association, 2003).

The plank and beam framing system has many advantages, such as saving in cost and labor. For example, in many houses, the ceiling can serve as roof planks to provide extra height to living areas without paying additional costs. Moreover, while using planks

for appearance, there will not be any further ceiling treatment required (American Forest & Paper Association, 2003). As a result, it saves cost.

4.4 Truss-framed Construction

The truss-framed construction is a light-frame wood construction, including wall studs, floor trusses, and roof trusses. In the truss-framed construction, connectors, such as plywood gusset plates or metal truss plates, are used to develop the strength and increase the capability of bearing bending moment, axial and shear forces (NAHB Research Foundation, 2010).

In many truss-framed system designs, 2x4 and 2x3 members are commonly used. However, some situations may require a special spacing or spans. At this point, larger lumber members may be used. For example, in some high velocity wind areas, 2x6 studs may be required in truss-frames to replace the normal 2x4 stud materials, since in this situation, 2x4 studs at the typical spacing may not be strong enough to against the heavy wind load. Similarly, stronger framing connections and heavier members may be applied for bearing heavy snow loads and seismic loads. The truss-framed construction can be also used to build advanced energy-conserving structures, including box stud, envelop designs and double wall (NAHB Research Foundation, 2010).

5 Construction Processing

5.1 Floor Framing

Floor framing contains all fasteners and structural components that are used in floor constructions, including joists, girders, sills or sub-flooring and floor trusses. It supports floor loads and exterior walls. Masonry anchors or series of bolts are used to anchor wooden sill plates into the concrete. 2x4 or 2x6 lumber sills are commonly used on the continuous masonry foundation walls (American Forest & Paper Association, 2001). Then, the rows of wooden beams are located over the surface. The end of each beam is positioned on the sill. Nails or screws are used to fastening. The exact spacing and size of the beams should follow the local building code. After floor framing is complete, subfloor is formed by covering with the plywood sheathing. Walls are constructed upon the subfloor. Nails or screws are used to connect the floor framing (Turner, 2013). The floor framing provides the support to the walls vertically and horizontally.

5.2 Fire Safety Design

To ensure the safety of the constructed building, a number of methods have been applied in the building codes to provide the fire protections in case of any emergency situations. There are many elements combined together to provide fire protection in a building, including firewalls, fire separations, fire stops, and concealed space barriers (Building Regulations Division, 2003).

- Firewalls are generally used to separate a building into number of smaller buildings to prevent to the fire extension.

- A fire separation is constructed as during a wall or floor construction. It provides a fire-resistance rating for a particular period of time and stops the fire flame by separating the passage of flame.
- Fire stops are using fire stop systems or cast-in-place construction to seal openings to stop the spread of fire.
- Concealed space barriers are constructed to prevent the spread of fire. When the fire emergency situation occurs, large concealed spaces can be broken into smaller spaces to stop the spread of fire.

5.3 Exterior Wall Framing

An adequate strength and size of exterior wall framing is required during the construction. Exterior wall framing is constructed to support the roof and floor loads. Walls should also be able to bear lateral loads including earthquake forces and wind loads. Doubled top plates are located at the intersections of bearing partitions and at comers to hold the entire building together in order to enhance the strength. During exterior walls construction required for one and two-story buildings, the minimum size requirement of wall studs are nominal 2x4 inches in order to form the basic wall thickness (American Forest & Paper Association, 2001). A spacing of 16 inches among each stud is commonly used in exterior wall framing. A header is required to be sized adequately for door and window openings. This allows it to support loads vertically across the opening. Adequately nailed wall sheathing is required at the outside edges of plates, headers and exterior wall studs to provide a high resistance to nature forces, such as hurricanes and earthquakes (American Forest & Paper Association, 2001).

5.4 Interior Partition Framing

Two types of interior partitions, including non-bearing partitions and bearing partitions, are generally used. Bearing partitions carry the loads from ceilings, floors or roofs. Minimum sizes of 2x4 inches studs are required in bearing partitions. Studs spaced 24 inches on center are required to support the floor. Plates are positioned and lapped into intersection of the exterior walls (American Forest & Paper Association, 2001). Non-bearing partitions support the weight of the materials in the partition, such as attachments in finished building. Studs that have sizes of 2x3 or 2x4 inches are required in the non-bearing partitions. Studs are installed parallel or perpendicular to the wall surface. Single top plates are usually applied in the non-bearing partitions. Studs are spaced 16 or 24 inches on center (American Forest & Paper Association, 2001).

5.5 Roof and Ceiling Framing

Roof construction must be built adequately in order to carry anticipate wind and snow loads. It is important to fasten framing members securely to exterior walls and wall sheathing. This will help to hold the entire roof system as one structural unit to enhance the strength. Maximum allowable spans of rafters and ceiling joists are provided in the local building code. Ceiling joists must be adequately nailed. 1x6 or 2x4 lumbers are used as collar beams and are installed in the attic space (American Forest & Paper Association, 2001). Light trusses may be used as roof framing and should be installed as one complete structural unit. Fasteners including nails, glue, metal plates, bolts or other framing devices are used to hold all truss members together. The spacing of roof trusses is generally 24 inches on center (American Forest & Paper Association, 2001).

5.6 Insulation and Vapor Retarders

Adequate insulations are required in wood frame construction to make the entire construction efficient to the cold and hot condition. Insulations are applied in stud spaces of exterior walls, between ceiling joists and floor and on the inside of masonry foundations. Other benefits of insulations are absorbing noise from outside and increasing occupant comfort (American Forest & Paper Association, 2001).

Vapor retarders are used to prevent moisture vapor from passing through the insulated wall. It can also protect the wooden structure from the condensation of moisture vapor on the back side of siding and sheathing. The condensation of moisture vapor can significant reduces the performance of insulations. Failures in exterior finishes and paints may also occur because of such condensation (American Forest & Paper Association, 2001).

5.7 Exterior Siding

Siding can be manufactured in many kinds of materials such as metal, vinyl, stucco, fiber-cement, composites, wood and masonry. Wood siding is the most popular one, including plywood, shakes, solid wood, shingles, particleboard and hardboard (Greiner, 2005). During construction, wooden skeletons of exterior walls are framed with a sheathing of plywood installed on the exterior side of the framed walls. Before siding is applied, house wrap should be installed first. The installation of the house wrap should be applied on the exterior plywood. It prevents the wooden structure from absorbing moisture from outside and removes the interior moisture by allowing it passing through to the outside (Anacan, 2013). Then, siding is installed to protect the exterior sheathing of a home from water and elements. Moisture content should be controlled to match the

general level during the installation of the siding. Generally, acceptable moisture content for most places is approximately 10 to 12 percent (Sherwood & Stroh, 1989). Details of siding installation should follow the local building codes.

6 Conclusion

All in all, wood is a natural, versatile, durable, and cost-effective construction material. It is also strong, lightweight, and flexible. Therefore, it provides structural safety and has a high resistance to earthquakes and hurricanes. Due to its thermal, acoustic, electrical, mechanical, aesthetic properties, it is very suitable for building a comfortable house. Wood framed construction can be used in many types of buildings, including single-family houses, low rise apartments, retail and office buildings, and structures for education and government. This paper can help building inspector and students to consider wood as a construction material to build homes.

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