MASS TIMBER FOUNDATIONS FOR HOUSING & SMALL BUILDINGS

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Foreword and Acknowledgements

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1 Executive Summary

This report research and presents the concept of using Mass Timber (MT) products in foundations. Historically, only treated wood framing (aka: Preserved Wood Foundation systems) was allowed to transfer loads from buildings to the ground and to anchor the structure against natural forces such as wind, earthquakes, and frost heave. In this report preservative-treated MT systems are proposed for foundation systems. In addition, a new MT "tanked" foundation system that utilizes untreated MT elements is introduced.

These two approaches can be summarized as follows:

1. **Wood Foundation Systems using Preservative-Treated Mass Timber using NLT, DLT, GLT and MPP.**
2. **Untreated Fully Protected (tanked) Mass Timber Foundation Systems using CLT and GLT.**

The report presents different structural foundation systems, and solutions utilizing MT elements, including Nailed Laminated Timber (NLT), Dowel Laminated Timber (DLT), Glue Laminated Timber (GLT), Mass Plywood Panels (MPP), and Cross Laminated Timber (CLT) in raft foundations, strip and pad footings, and foundation walls.

Site preparation, construction details, and the use of MT systems in different soil conditions are discussed, along with frost protection options for northern climate applications.

To support our investigation into MT foundations, two current research programs in North America and Europe were examined and design examples of recently constructed buildings are presented:

A. Tiny House Projects constructed and monitored by FPInnovations.
B. A private residence in Whitehorse, Yukon.

Based on our investigative work, the latest research available, and the demonstration projects, we conclude that wood foundations that use treated and non-treated mass timber products are practical and viable options for residential and small commercial buildings

Mass timber foundations that use preservative treated products can be easily used for any small project as the existing guidelines and regulations are already approved under the existing standard CSA-O86, the National Building Code of Canada and the Provincial Building Codes. As such, no engineer needs to be involved in the design of the foundation. In fact, Permanent Wood Foundations (PWF) have been allowed in Canada for over 40 years and are a well-established and researched approach to building foundations.

There are numerous benefits associated to constructing preservative-treated mass timber foundations including:

A) Walls and floors can be prefabricated.

B) Can be built on site by local tradespersons.

C) Can be shipped to remote and difficult to access locations.

D) Treated dimensional lumber (CCA) required for NLT systems is readily available.

E) Cost competitive when transportation over long distances is required.

F) Provides a better and healthier living environment for the occupants.

G) Suitable for all types of terrains, locations, and applications.

H) Can be easily modified and altered to suit the needs of builders.

I) MT sequesters carbon resulting in GHG reductions.

Untreated mass-timber foundations that use the tank system offer a great solution for remote locations where concrete is more expensive as they can be easily shipped in a panelized form to the construction site.

Our findings clearly demonstrate that mass timber foundations can play a vital role in Canada's and Alberta's objective to build more affordable housing in urban and rural Canada. One of the key challenges will be to encourage builders to consider MT for foundation work. This can be accomplished through education and training programs, by increasing media exposure and by communicating the benefits of using Mass Timber in foundations.

In addition, in partnership with government and industry we believe that it will be imperative to support the construction of larger-scale demonstration projects in subdivisions – where MT foundations projects will be highly visible and accessible for viewing by builders and developers - so they can be successfully replicated in all regions of Canada.

Lastly, we recommend that a detailed life-cycle cost analysis (LCCA) be done to compare mass timber versus concrete foundations. The analysis should compare the costs and environmental impact of wood and concrete in urban and rural settings including remote Canadian locations where the price of concrete is usually significantly higher. Prefabricated MT systems and on-site built systems should be investigated to define the costs of both systems and identify their key performance and financial & environmental benefits.

2 Why should Mass Timber be considered for foundations?

- The implementation of Mass Timber Foundations can effectively eliminate the need for concrete in residential and small commercial projects. The adoption of MT foundation for construction should result in a lower carbon footprint, therefore supporting the Government of Canada goals of reducing emissions by 40 to 45 percent by 2030. Another key outcome achieved through MT foundations includes limiting CO_2 emissions resulting from the use of concrete.
- Use of Mass Timber Foundations can result in greater use of local wood fibre, which in remote locations are usually processed from trees owned and/or extracted by indigenous and northern communities and as such support Canada's and Alberta's sustainable forest management strategies and policies.
- The use of MT allows a fast-track approach to construction and in some cases 100% of the components can be prefabricated on or off-site.
- For architectural and aesthetic reasons, Mass Timber basement floor can be left exposed.
- Raft slab MT foundations can be used on sites with poor soil conditions.
- MT foundations can achieve a higher level of insulation against the soil than concrete. Typically, approximately 20% of the heat transfer in a building occurs through the foundations.
- MT Foundation systems are easier to repair, reinforce, modify, and replace than concrete or block wall systems.
- MT Foundation systems perform as well as traditional concrete foundations and, in some cases, provide better living conditions to its occupants.
- MT foundations provide biophilic advantages linked to exposed wood surfaces.
- In remote and hard-to-access locations, MT Wood foundation systems are cost competitive and can in most cases use locally sourced materials.
- MT can be assembled on site and in most cases no specialized labours are required to install MT Wood foundation systems.
- MT foundation system allows the benefits of adequate insulation while accommodating soils with low allowable bearing pressure.
- When soil conditions are poor and to eliminate the need for a heated crawlspace, shallow Preserved Wood Foundations can be used.
- MT foundations can be dismantled and reused for other projects.

3 Scope of the report

The report considers only small and mid-size buildings that are allowed in Part 9 of the National Building Code of Canada that are supported by typical soils. The scope is like the one outlined in CSA S-406-16 Specification for Permanent Wood Foundations for Housing and Small Buildings.

3.1 Size and Types of Buildings

Mass Timber Foundations (MTF) can be used for all types of wood frame construction allowed under Part 9 of the National Building Code of Canada (NBC). Clauses 9.15.2.4.(1) and 9.16.5.1.(1) allow single family detached houses, townhouses, low-rise apartments, institutional and commercial buildings to utilize MTF. The height of the buildings is limited to three storeys, while the size of the structure is limited to 600 square metres in building area.

The scope of this report (building size and type) follows the requirements of CSA S406 standard: Specification of permanent wood foundations for housing and small buildings.

The buildings covered in this report can be supported by Mass Timber (MT) slabs on grade, have a crawlspace or full-height basement.

3.2 Materials used for MT foundation Systems

This report assumes that only 38 mm wide lumber (allowed in the NBC) will be used in NLT, DLT and GLT and that the CLT will be made of 19 mm and 35 mm laminations and be approved under the PRG-320 - CLT design and fabrication standard.

All species of wood currently allowed to be used in NLT, DLT and GLT are considered.

The CLT wood species are the ones approved by the CLT Standard PRG-320.

NLT and DLT should be assembled in accordance to the new manufacturing standard - CSA O125:23 (Mechanically laminated timber) and installed as per the Nailed Laminated Timber, Canadian Design & Construction Guide v1.1. published by Forest Innovation Investment. The structural design of conventional NLT is specified in the Canadian timber design standard CSA O86 (Engineering Design in Wood).

3.3 Geotechnical

All soil classes except soil class F as per NBC are considered as suitable for MT foundations in this report. Site Class F includes liquifiable soils, peat and highly organic clays, highly plastic clays, soft and medium stiff clays more than 30 m thick, as per table 4.1.8.4.-A of the BCBC 1998.

This report uses the recommendations presented in the Building Guide to Site and Foundation Drainage, Best Practices for Part 9 Buildings in British Columbia (NBC equivalent in BC), which was released by BC Housing in 2021 and is available online.

4 Environmental and Life Cycle benefits of using wood in construction.

Using wood in construction lowers the environmental impact over the life cycle of the building. Following are the main arguments for using wood in construction. The following benefits have been highlighted in the Canadian Wood Council's (CWC) technical book entitled: "Permanent Wood Foundations."

- Wood is the only renewable building material.
- Manufacturing of wood products is energy efficient.
- Wood stores carbon during the life of the project.
- Use of wood can economically reduce heat bridges resulting in superior insulation.
- Wood can be easily recycled at the end of the life of a building.
- Wood can be easily transported and available in Northern communities.
- Wood systems are easy to construct on site by local labour.

5 History of wood in foundations

5.1 First Nations Buildings in Canada

Traditional First Nations buildings used wood as foundation system in direct contact with soil. These buildings used untreated wood which resulted in the eventual decay of the wood foundation. As a result, very few buildings are currently still standing.

5.2 Preserved Wood Foundations

The first Preserved Wood Foundations (PWF) buildings were built in Alberta in 1967 and are still in good condition. For more history on PWF see the Canadian Wood Council Handbook on Permanent Wood Foundations, Chapter 1.

5.3 Modern Mass Timber Foundation Systems

One of the first modern MT Foundation Systems was built in Switzerland in the early 2020s. The system is based on raft slab foundation constructed of Cross Laminated Timber (CLT) that is edge glued and fully protected from moisture by a proprietary "tanked" foundation system. The "tanked" system is a system that uses a waterproof membrane to encapsulate and fully protect the wood from water ingress. More information on the first built European MT Foundation projects can be found in reference #3 - Timber Basement by Timbase CH.

In Canada, the first MT Foundation systems have been designed, developed, and tested by FP Innovations and Timber Engineering in Vancouver, BC. These demonstration projects are called "Tiny Houses" and are presented further in this report.

6 Preserved Wood Foundations in Canada

6.1 CSA S406-16 Specification of permanent wood foundations for housing and small buildings.

The historical Building Code acceptance of wood in foundations for housing and small buildings makes Canada a perfect location for the introduction of a new MT foundation system technology.

A key element of the CSA S406-16 Code is the requirement that all wood in foundation systems be treated by preservatives. Clause 5.1.1 states:

"All lumber and plywood used in permanent wood foundation shall be treated with preservative in accordance with the CSA 080 Series."

This report proposes two options for the use of MT in foundations. One when wood in MT elements is treated, which is currently allowed as per the above stated code and one when untreated wood is used for the manufacturing of the MT elements in fully "tanked" water protected foundation systems.

The second option can be used under the innovation clause of CSA O86 Wood Design in the Canadian Code that is presented below.

6.2 CSA O86-24 Engineering Design in Wood

The Canadian Wood Design Code CSA O86 allows new design and construction systems under clause 4.3.2:

"New or special systems of design or construction of wood structures or structural elements not already covered by this standard may be used where such systems are based on analytical and engineering principles, reliable test data, or both, that demonstrate the safety and serviceability of the resulting structure for the purpose intended. "

The same code covers CLT and Mechanically Laminated Timber (MLT) in Clause 8. MLT clause 8.2 covers NLT and DLT. GLT is glued-laminated timber installed flat and is covered in Clause 7.

6.3 Permanent Wood Foundations CWC Handbook

The Canadian Wood Council (CWC) Handbook Permanent Wood Foundations (PWF) is available on CWC's website and is an essential source of information for anyone considering the use of wood in foundations. The MT foundation option that uses treated wood is a direct extension of the Permanent Wood Foundations' system. Therefore, many recommendations and details presented in CWC's Handbook can be directly applied when planning and building MT treated foundation systems.

The CWC Handbook covers the following information and complements this report:

- Introduction and history
- Description of system
- Materials
- Information on selecting and preparing the site
- Footings
- Exterior and interior walls
- Floors
- Moisture Barriers and Backfilling
- Interior Finishing
- Special Topics (high wind and seismic among others)

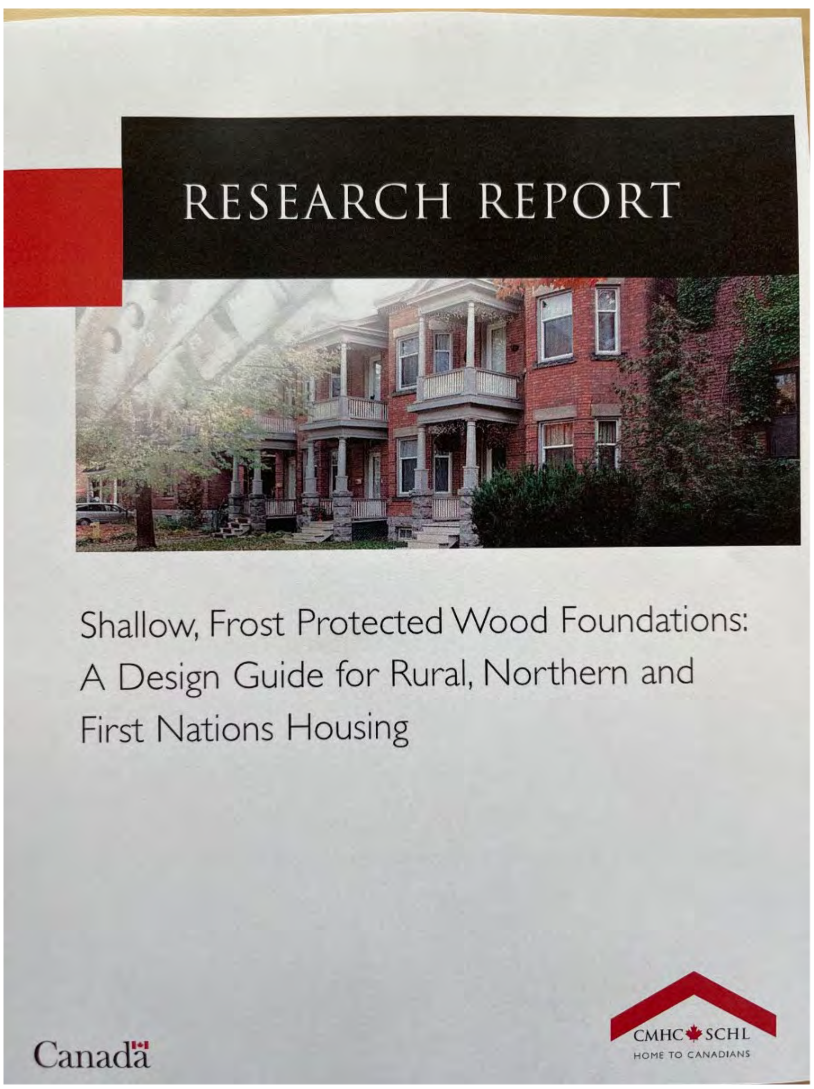
CWC's Handbook provides the design information in a prescriptive way, like Part 9 of the NBC. This report assumes that every MT foundation project will be designed by a qualified Professional Engineer and proper calculations in accordance with Part 4 of the NBC and CSA O86 will be performed.

6.4 CMHC Research Report, Shallow, Frost Protected Wood Foundations, A Design Guide for Rural, Northern and First Nations Housing.

The CMHC Research Report, “Shallow, Frost Protected Wood Foundations, A Design Guide for Rural, Northern and First Nations Housing” counters the mistaken impression that good design practices require that foundations must be constructed on footings located below the frost line. Frost protection is achieved by using rigid insulation at the perimeter of the building in foundation systems that utilize heated crawlspace.

The CMHC Report contains the design procedure to estimate the required horizontal size and thickness of the perimeter insulation and provides steps for construction procedures.

This report is building on this knowledge and proposes foundation systems that utilize heated basement living space over fully insulated MT raft slab positioned above the frost line with additional perimeter insulation to achieve superior insulation to meet the current and future building code energy requirements.



7 Water and Moisture Management

7.1 Liquid Water Management

Historically, the major cause of leaky foundations (concrete or wood), is poor site drainage. The chapter on geotechnical issues presents the requirements needed to avoid problems with water penetration.

Wood foundations can be exposed to water both during construction and during the lifetime of the building. NLT and DLT are especially vulnerable to water exposure – see NLT and DLT sections for a list of potential problems. NLT and DLT should also be protected from water and moisture exposure during construction and throughout the life of the building.

The following risks of liquid water exposure have been identified in the NLT Canadian Design & Construction Guide:

- Dimensional changes due to shrinkage and swelling.
- Checking and warping due to rapid dimensional changes.
- Corrosion of mechanical fasteners.
- Decay of NLT lamination and sheathing.

Therefore, is important to minimize NLT and DLT water exposure to and avoid substantial changes in its moisture content. This can be done by covering the slab components during construction and removal of standing water daily during the construction process.

7.2 Water Vapour Management

The gaps between the NLT laminations allow air movement and therefore a vapour barrier and air barrier system are required in the raft slab and exterior wall assembly. The type and location of these barriers differ depending on environmental conditions and interior use and need to be confirmed by the envelope consultant for each MT Foundation project.

It is important that both the vapour control layer and the air barriers do not lock moisture in the NLT assembly and that drying is possible for any moisture that gets inside the foundation system. The drying process can be done from the top or the bottom of the slab.

8 Heat Flow Management

One of the prime advantages of Mass Timber foundations is the fact that wood has lower thermal conductivity than concrete. Exposed NLT can also contribute to thermal comfort like the one experienced in CLT cladded spaces (warm wall surface).

Additional insulation required by the building code should always be placed on the cold side of the Mass Timber assembly and its thickness will depend on the local climate.

The NLT Canadian Design & Construction Guide, Section 5.1, Table 5.1 provides R Values for different NLT assemblies.
https://www.naturallywood.com/wpcontent/uploads/NLT_Canadian_Design_Construction_Guide.pdf

9 Air Flow Management

The National Building Code of Canada requires the building enclosure to manage the airflow to reduce the energy consumption, increase thermal comfort and minimize the movement of water vapour. An air barrier system and its location need to be designed by a qualified envelope consultant for each MT Foundation project.

The NLT Canadian Design and Construction Guide identifies the following requirements for the air barrier system:

- Stiffness to resist air pressure forces.
- Impermeability to airflow.
- Continuity to form a continuous boundary.
- Strength to transfer air pressure forces to the structure – NLT.
- Durability over the service life of the building.

10 Design of Treated Wood Mass Timber Foundation Members in Wet Service Conditions

10.1 Service Condition Factor Ks

Wood is generally weaker when wet. Member capacities and stiffness are higher for dry service conditions than wet service conditions. The wet service condition factors consider both the shrinkage effect and the property differences between wet and dry service conditions.

It is assumed in this report that treated wood in traditional non-tanked Permanent Wood foundations using MT systems is in wet service condition. CSA O86-24 Clause 6.4.2 and table 6.11 specify the values of Service Condition Factor Ks to be used for the design of sawn lumber.

10.2 Treatment Factor Kt

Preservative treatments appear to have negligible effect on the structural properties of wood, with the exception of incised lumber. It is assumed in this report that all lumber used in wet service conditions is properly treated as per the requirements of CSA O86-24 Clause 5.3.4.2.

Clause 6.4.3 of the same code specifies the Treatment Factor Kt and Table 6.12 provides values for Kt in wet service conditions.

Like NLT, preservative treatments are not considered to have negative effect on GLT.

11 Design of Treated Wood Mass Timber Connections in Wet Service Conditions

11.1 Service Condition Factor Ksf

Since wood is weaker when wet, wood connections used in wet service conditions have less resistance than those used in dry service conditions. In PWF's moisture content in wood members may fluctuate after storms resulting in shrinkage during drying. Since wood has low resistance in tension perpendicular to grain, splitting may occur in areas where wood is restrained against moving across the grain. The results will be lower resistance capacity of the connectors.

The Service Condition Factor for connection design is defined in CSA O86-24 Clause 12.21.7.2 and the values are provided in 12.1.

11.2 Treatment Factor Kt

Preservative treatments appear to have negligible effect on the structural properties of wood connections, except for incised lumber, which is typically not used in Preserved Wood Foundations.

Treatment Factor Kt for connection design is defined in 12.2.1.7.3. in CSA O86-24.

12 Treated Mass Timber Foundation Systems

12.1 Materials

The most suitable material for Mass Timber treated foundation systems is Nailed Laminated Timber. Dowel laminated timber is also a possibility and all the recommendations for NLT can also be used for DLT. DLT requires specialized machines to insert the hard wood dowels connecting the laminations and is therefore less popular than NLT.

Glue laminated timber is a possibility in the future. Timber Engineering is exploring this opportunity with Wood Preservation Canada. Currently untreated GLT is only allowed in dry service conditions.

Another potential material is Mass Plywood (MPP). Mass Plywood Panels are currently fabricated by a limited number of companies and it's not currently available as a treated product.

12.2 Nailed Laminated Timber - NLT

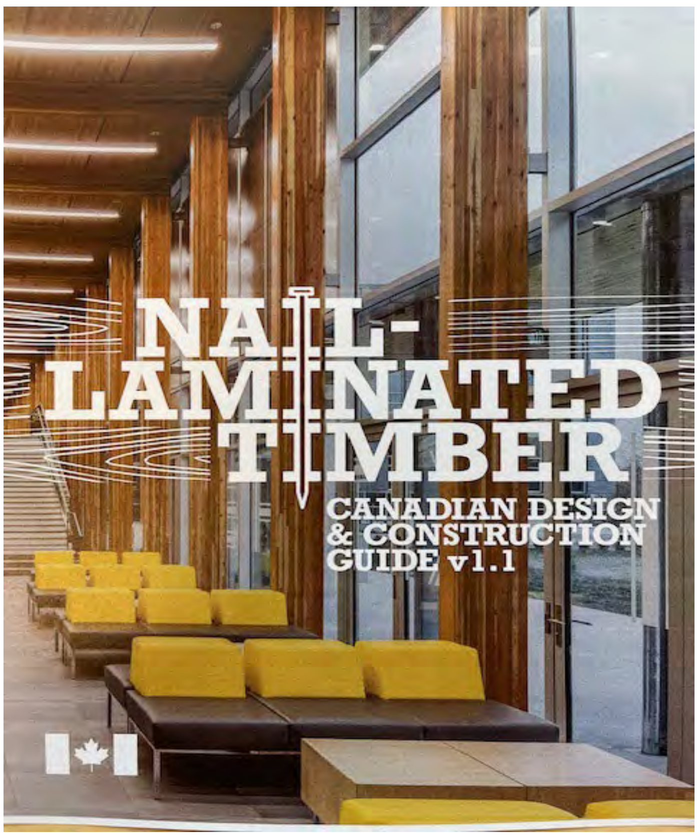
The most readily available MT system using treated lumber is made of Nailed Laminated Timber (NLT).

NLT is created by nailing dimensional lumber on edge to create a solid and continuous element. The recently released CSA O125:23 provides more information on the manufacturing of NLT. This report assumes that only 38 mm wide lumber with depths from 89 mm to 235 mm (standard 2”x4” to 2”x10”) will be economically used in MT foundations. Historically NLT has been used for floors, roofs, and walls. Recently several local fabricators have used it in combination with glulam post and beam systems for modern MT buildings.

The main advantage of NLT is its ease of fabrication and availability of the materials. In most cases no manufacturing facility is required, and readily available treated lumber can be used by local labour to assemble the panels.

Structural design of NLT panels can be conceptualized as wood joists with spacing equal to the width of the material: 38 mm.

All NLT assembly types as identified in Table 4.2 of the NLT Canadian Design and Construction Guide and CSA O125:23 can be used in MT foundation systems.



The NLT Canadian Design and Construction Guide and the new edition of CSA O86 allow untreated NLT to be used in dry service conditions only. The NLT Guide identifies problems with durability, impact on strength properties and long-term deflections learned from the first NLT projects.

This report proposes to allow treated lumber NLT to be used in wet service conditions as encountered in MT foundation systems with all the precautions outlined in the Permanent Wood Foundation Handbook and the PWF CSA S406 standard.

Durability is addressed by using treated lumber as allowed in CSA S406 (see section 12.6 for treatment regulations in Canada) while the possible reduction of strength and stiffness is proposed to be addressed by the application of appropriate reduction factors for wet service conditions as per the current CSA O860 standard.

12.2.1 NLT Swelling due to Wet Conditions.

NLT slabs require allowances for swelling due to changing moisture content that occurs often during construction. The NLT Design Guide recommends leaving a 38 mm gap every 6 metres of the width of the slab.

Large stresses and deformations are known to be induced on the structure without the gaps described above. Another way to address this phenomenon is to allocate service line gaps in the foundation slab when the direction of the span is parallel with the direction of the service line. The maximum width of the slab should not exceed 6 metres as per the above recommendation.

12.2.2 Other NLT Water Management Issues

NLT exposed to water experience significant dimensional changes due to shrinkage and swelling and the situation needs to be addressed as per the paragraph above. In addition to shrinkage and swelling, major checking and warping often appears as well when NLT is exposed to water.

The water trapped in the NLT system was historically a result of plywood installation on top of wet NLT members. The resulting decay has a major impact on serviceability and long-time behaviour of both plywood and the NLT.

It is therefore critical to minimize NLT's exposure to moisture during construction and during the service life of the building and to provide proper venting if wetting occurs during both construction and the life of the building. This is most often achieved using temporary tarping to protect the wood from rain.

12.3 Glued Laminated Timber Panels - GLT

Glued-Laminated Timber (GLT) is manufactured by glueing together lumber laminations with an adhesive. It is similar to traditional glulam (GL) which has been in use for over a hundred years mostly as posts and beams.

Unlike NLT, Glue Laminated Timber Panels are prefabricated in a glulam plant and shipped to site as ready to install panels. The depths of the GLT vary from 80 mm to 365 mm. The width can reach over 2 metres. GLT is typically manufactured from standard 38 mm thick laminations.

In Canada, most fabricators offer Douglas Fir-Larch or Spruce-Pine GLT. Hemlock GLT is available in some regions.

CSA O86 addresses the design of GLT in Clause 7.5.3. The basic design assumption is that it is a built-up system consisting of No. 2 grade lumbers and the specified strengths are multiplied by the system factor Kh for built up beams.

For factored bending moment and shear resistance, system factor Kh is equal to 1.1. CWC's Wood Design manual provides Mr, Vr, and EI values for typical GLT thicknesses per metre width. The NBC Structural Commentary D provides guidance for GLT floor vibration limits.

Glue laminated timber is typically fabricated in widths of less than 1.2 m. This enables it to be treated similarly to lumber or plywood. Treated GLT can be then used similarly to NLT in treated mass timber foundation systems as currently allowed by the CSA S406 code.

12.4 Mass Plywood Panels - MPP

Mass Plywood Panels (MPP) are currently fabricated by Freres Engineered Wood in Oregon, USA. Historically, MPP's have been treated with the following methods: Penta, Copper Naphthenate and Permapost HI Clear. According to the treatment fabricator, the best option is HI-clear as it is odourless and provides the same protection as Copper Naphthenate. Freres has successfully used Hi Clear for permanent outdoor deck installation.

Note: In Canada only CCA treated MPP systems are presently allowed.

12.5 MT Slab on Grade Foundation Systems

MT Slab on Grade Foundation system is similar to the one allowed by CSA S406. Horizontal NLT, DLT or MPP is placed in the same location as the treated joists to form a raft slab, while the vertical MT element is in the same plane as the treated stud wall. For more information, see Figure 1.

12.6 Insulation

Since the bearing surface is above the frost depth, it is recommended (like the CMHC Report described above) to extend the horizontal insulation beyond the perimeter of the building. The extent and thickness of XPS insulation depends on the climatic zone, and the exact requirements should be established by the geotechnical and envelope engineers.

The size of the treated plate needs to be checked against the vertical load in the exterior wall together with the compressive resistance of the XPS insulation. We recommend that the insulation used in MT foundation systems has a minimum compressive strength of 150 kPa. The geotechnical engineer should confirm the allowable load-bearing strength of soil.

12.7 Treatment Regulations in Canada

The CAN/CSA 080 Series of Wood Preservation standards are the governing standards for wood preservation in Canada and are referenced in the National Building Code of Canada (NBC) where preserved wood is required.

The CAN/CSA 080 Wood Preservation standard, developed by the CSA Group, specifies requirements related to the treatment of wood with a wood preservative (e.g. pesticides). Regulations pertaining to the use of pesticides (such as CCA) is done through the Pest Control Products Act (PCPA), administered by Health Canada's Pest Management Regulatory Agency (PMRA). Wood preservative product conditions of use are listed on pesticide labels, which are legal documents. The use of wood preservatives in a manner inconsistent with label directions is prohibited by the PCPA.

As per CSA 080 Series 21, Clause 8.2.2.1.1 General: Lumber shall be manufactured in accordance with CSA 0141 and air seasoned, kiln dried, and/or steam conditioned to a moisture content of not more than 25% before treatment. Lumber shall also comply with the grade requirements specified in tables 1, 5 and 10 of the CSA S406.

Chromated Copper Arsenate (CCA) is presently the only wood preservative approved for permanent wood foundations (PWFs) in the CAN/CSA 080. It is also the primary wood preservative used in industrial and agricultural treated wood applications. CCA contains inorganic arsenic, chromium and copper and is a pesticide registered for use in Canada under the Pest Control Products Act.

Wood Preservation Canada's Permanent Wood Foundation Guide lists the approved manufacturers of PWF treated products in Canada:

https://woodpreservation.ca/wp-content/uploads/2024/07/Permanent-Wood-Foundations.pdf

A Life Cycle Assessment (LCA) evaluates the potential environmental impacts of a product throughout its entire life cycle, from cradle to grave. An environmental LCA for CCA utility poles has been completed to compare the impact of galvanized steel, concrete and fibre-reinforced composites. The Conclusions and Summary Environmental Life Cycle Assessment Report can be found at www.preservedwood.org. The same results would be expected from CCA treated Mass Timber products and construction systems.

Another important document is the Label Guidance for CCA (Health Canada's Pest Management Regulatory Agency): Re-evaluation Note REV2006-07 (publications.gc.ca).

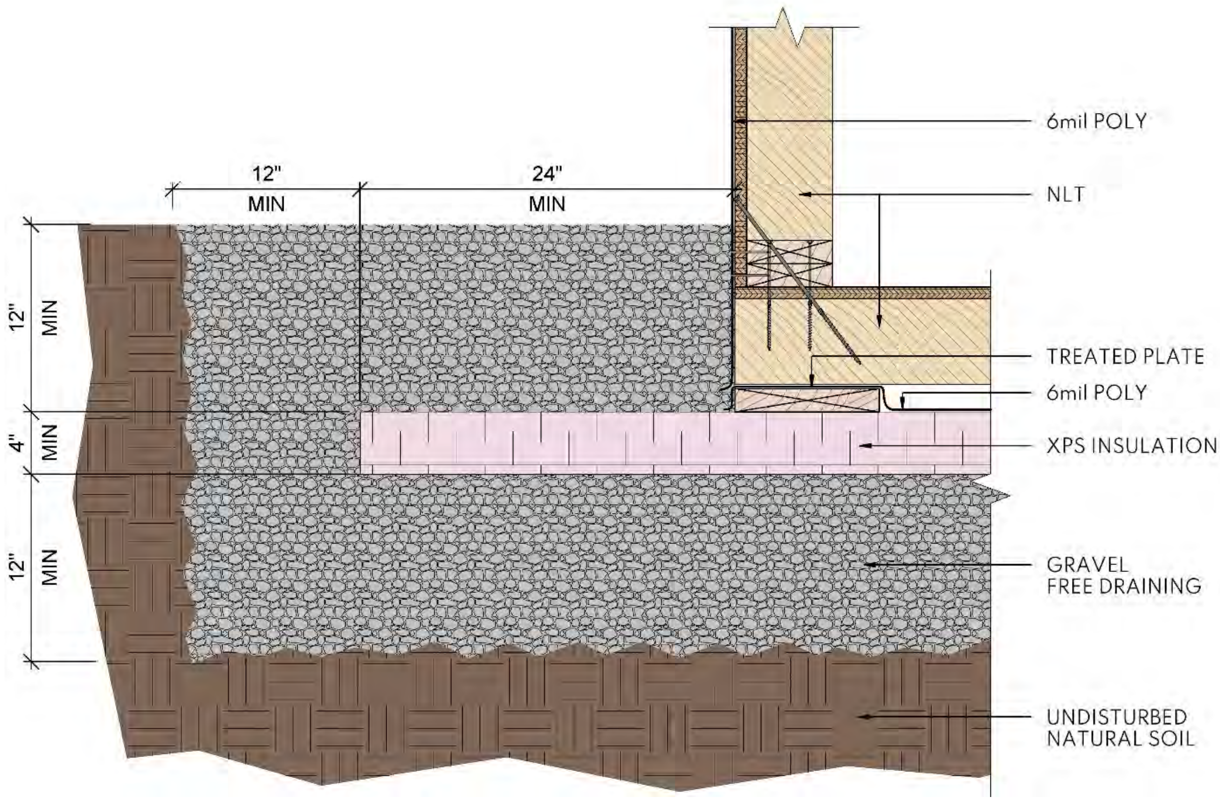


Figure 1 - MT NLT Slab and wall edge of building detail for Slab on Grade (SOG) Buildings.

Notes:

1. Spacing of the treated plates located under the NLT floor can be established by structural calculations and using design tables from CWC's Wood Design Manual.
2. See Chapter 15 for Geotechnical Issues and special soil conditions.
3. All plywood 200 mm above grade and below to be treated.
4. ALL NLT to be used with at least one layer of plywood – see sketch above.
5. MPP and DLT can be used instead of NLT - when treated.

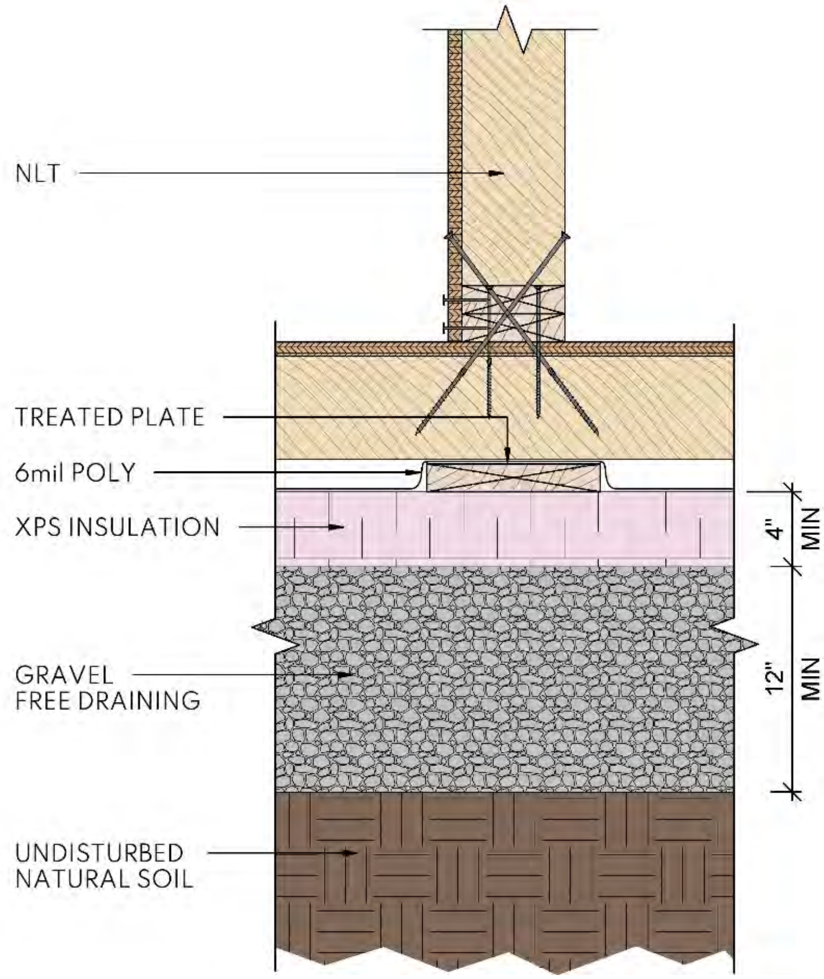


Figure 2 - MT NLT Slab and wall interior load-bearing wall detail for Slab on Grade (SOG) Buildings.

12.7.1 Air Barrier

The 6-mil polyethylene air barrier needs to be installed on both the vertical face of the exterior wall and at the top of the horizontal XPS insulation. Please note that these two layers should not overlap, and the installer needs to ensure the gap between the vertical and horizontal polyethylene as shown on Figures 1, 3 and 4. This allows moisture when present to vent out of the foundation system. Other code allowed barrier systems can be used instead of typical 6-mil poly to increase the durability of the system.

Figure 2 shows the load-bearing wall resting on the structural slab for slab on grade buildings. Similar detail can be used for crawlspace and full basement structures.

12.8 MT Crawlspace Systems

The crawlspace is assumed to be heated in the MT Crawl Space System. To achieve this with minimum heat loss a layer of vertical insulation is installed on the outside of the NLT structural wall. The thickness and type of the insulation needs to be determined by an envelope engineer to address the requirements of the geographical location of the project.

The crawlspace can be positioned above the frost level with a properly extended horizontal insulation – see Figure 1. or it can extend to or below the frost level – as per Figure 3.

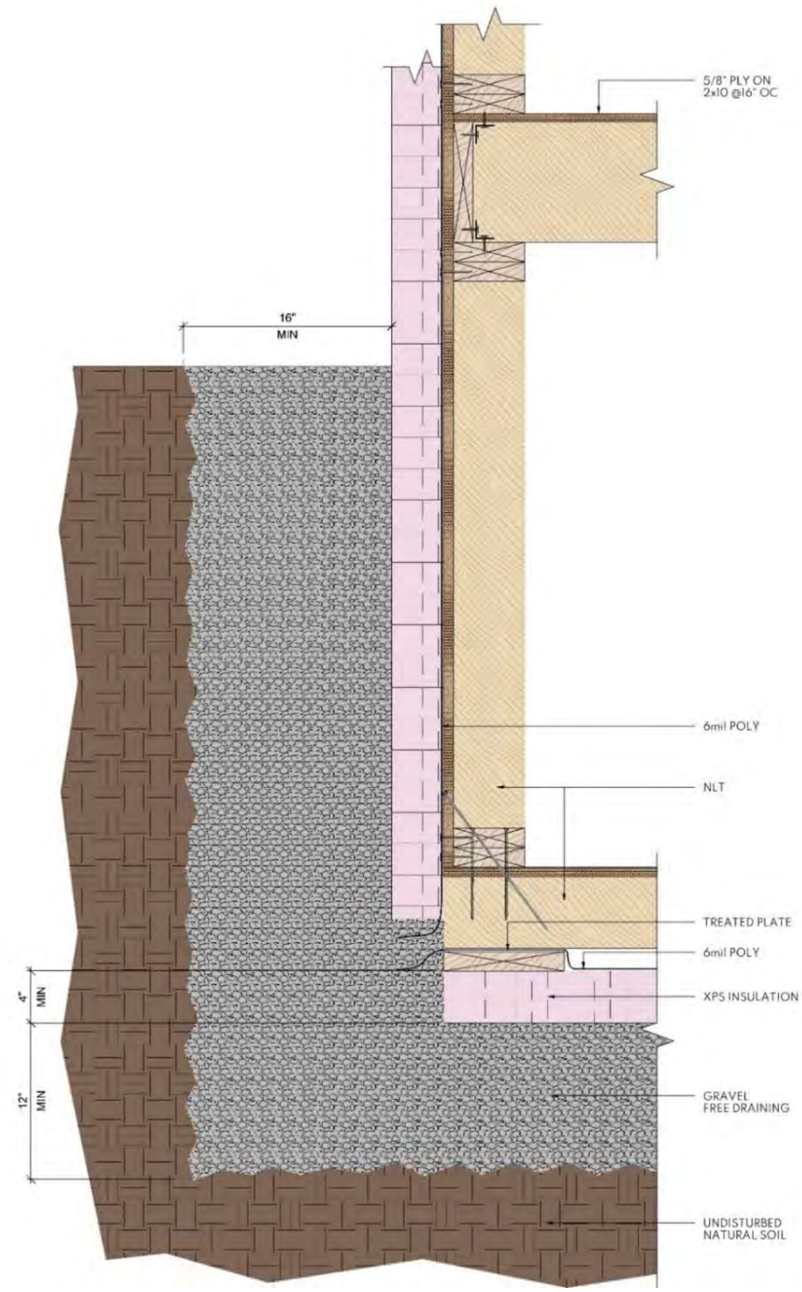


Figure - 3 MT NLT Slab and wall interior load-bearing wall detail for Crawlspace Buildings.

12.9 Mass Timber Full Basement Systems

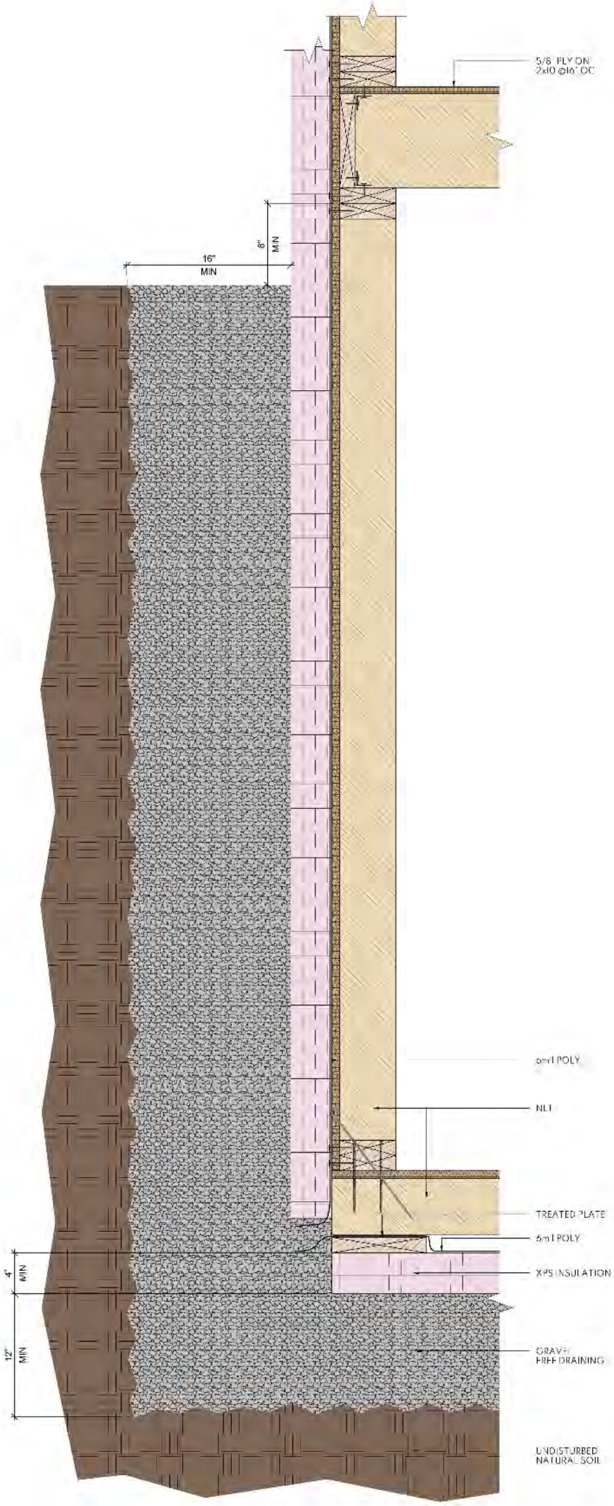


Figure 4 - MT NLT Slab and wall interior load-bearing walls detail for buildings with a full basement.

13 Untreated “tanked” Mass Timber Foundation Systems

The new MT tank foundation system works with a number of innovative ideas that address many of the historical criticisms of the existing preserved wooden foundations that use treated wood with 6-mil polyethylene as water proofing. The new foundations and external walls of the basement can be constructed entirely of untreated MT, including CLT.

The structure is fully waterproofed and encapsulated with a continuous waterproofing layer that has been used for many years in landfills and flat roofs construction. No gaps in the waterproofing layer are allowed to avoid potential water ingress or unnecessary thermal bridging.

Thermal insulation is also used to place the dew point of the external wall and floor slab outside the structure. The aim is to ensure that the MT elements remain open to inward diffusion, allowing the relative humidity of the interior of the building to be equalized during use.

In Europe, wood is treated as a precious material that needs to be protected from the impact of moisture from wet soil, rain, or snow. In older structures, two approaches apply: large overhangs protect as much as possible the wood of the exterior walls of buildings or of covered wooden bridges, and if it gets wet, the wood elements are allowed to dry, therefore no persistent or accumulating damp spots are permitted. The durability of untreated timber using this adequate structural protection has been widely demonstrated.

One of the first “tanked” projects, 100% constructed with wood and no concrete is a multi-unit residential building in Thun, Switzerland. An interesting feature of this building is the fully exposed top surface of the CLT floor in the basement – see figure 6 below. Both the raft slab foundation and the basement retaining walls are constructed with CLT – see Figures 5, 6 and 7.

The building is equipped with a moisture measuring layer (acting as a part of a monitoring system) on the soil face of the CLT that constantly checks the moisture content to provide in time information for any possible water penetrations.

During the first year of operation, a failure of the washing machine resulted in a water leak on the top surface of the CLT raft slab. The reading of the moisture content at the base of the slab indicated higher moisture content for few weeks after the leak. After a couple of weeks, the moisture content returned to its original low level as the wood was able to dry due to the top surface being exposed and allowed to aerate.

Figure 5 - Front Elevation of an All-Wood Residential Project in Thun, Switzerland.

Figure 6 - Exposed Top Surface of the Raft Slab, Residential Project in Thun, Switzerland.

Figure 7 - Exposed Interior Surface of the CLT Foundation Wall, Residential Project in Thun, Switzerland.

13.1 MT Slab on Grade Foundation System

Both the CLT raft slab and the CLT foundations wall are fully protected by the waterproofing layer in this system. CLT raft slab rests on XPS insulation that sits on the free-draining gravel layer - see Figure 8.

CLT is currently only allowed in dry service conditions. No treated CLT is currently available on the market.

Moisture monitoring sensors are an optional part of the water-proofing layer. This monitoring system has been successfully installed in the first Swiss residential project in Thun. The system uses equally spaced electrical wires that detect changes in moisture content and report it to the monitoring software available to the building owner.

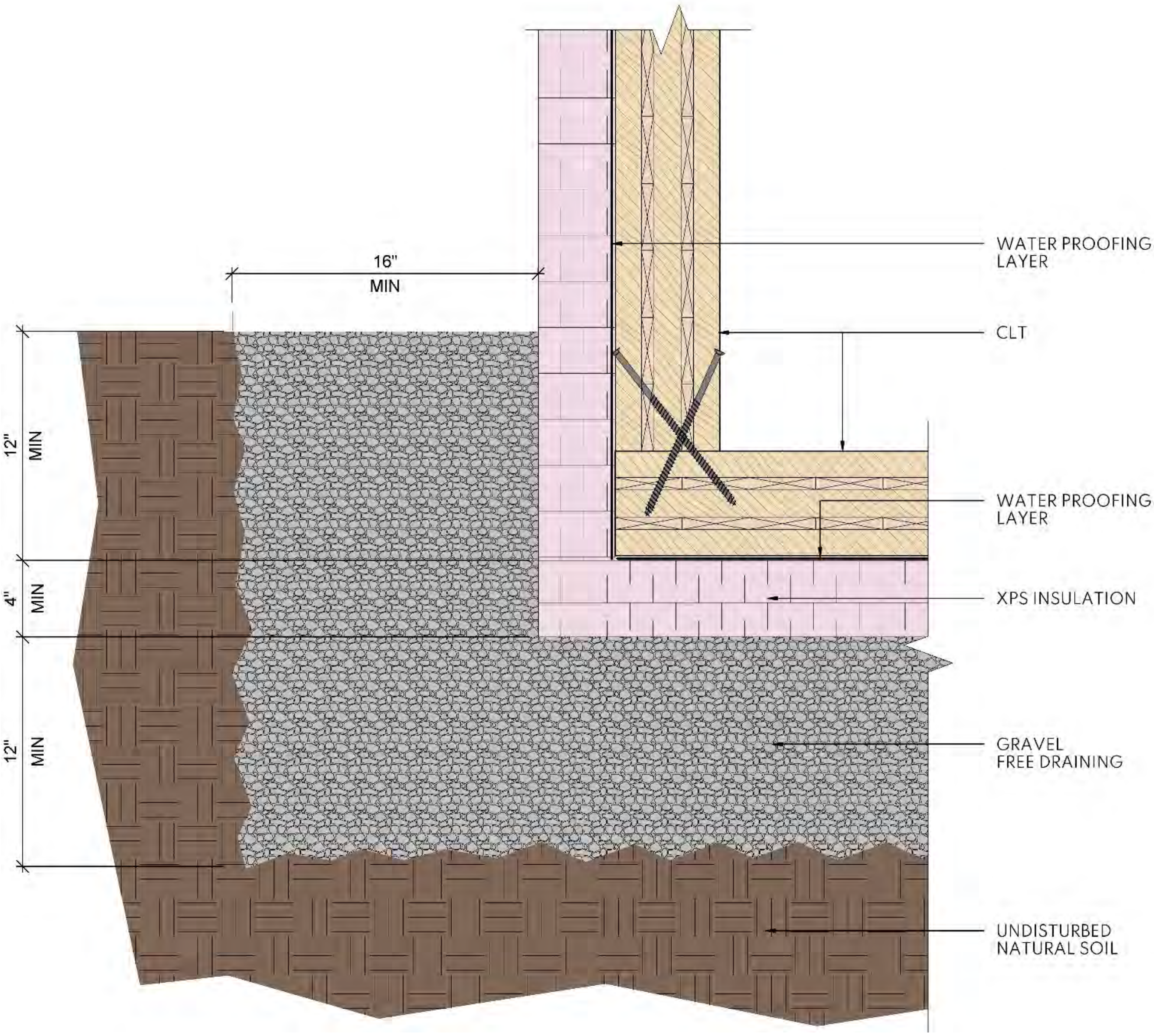


Figure 8 - MT CLT slab and exterior wall of building detail for Slab on Grade (SOG) Buildings.

Notes:

1. Water proofing layer in a tanked system is continuous at the corner of the foundation system, unlike the 6-mil poly used in the traditional Preserved Wood Foundation System that has gaps – see Figures 1, 3 and 4.
2. Water proofing layer should be extended at least 8” above grade level.

13.2 MT Full Basement Systems

Figure 9 shows the full basement option with a “tanked” system. The water-proofing system is installed up the vertical wall and should extend at least 8” above grade.

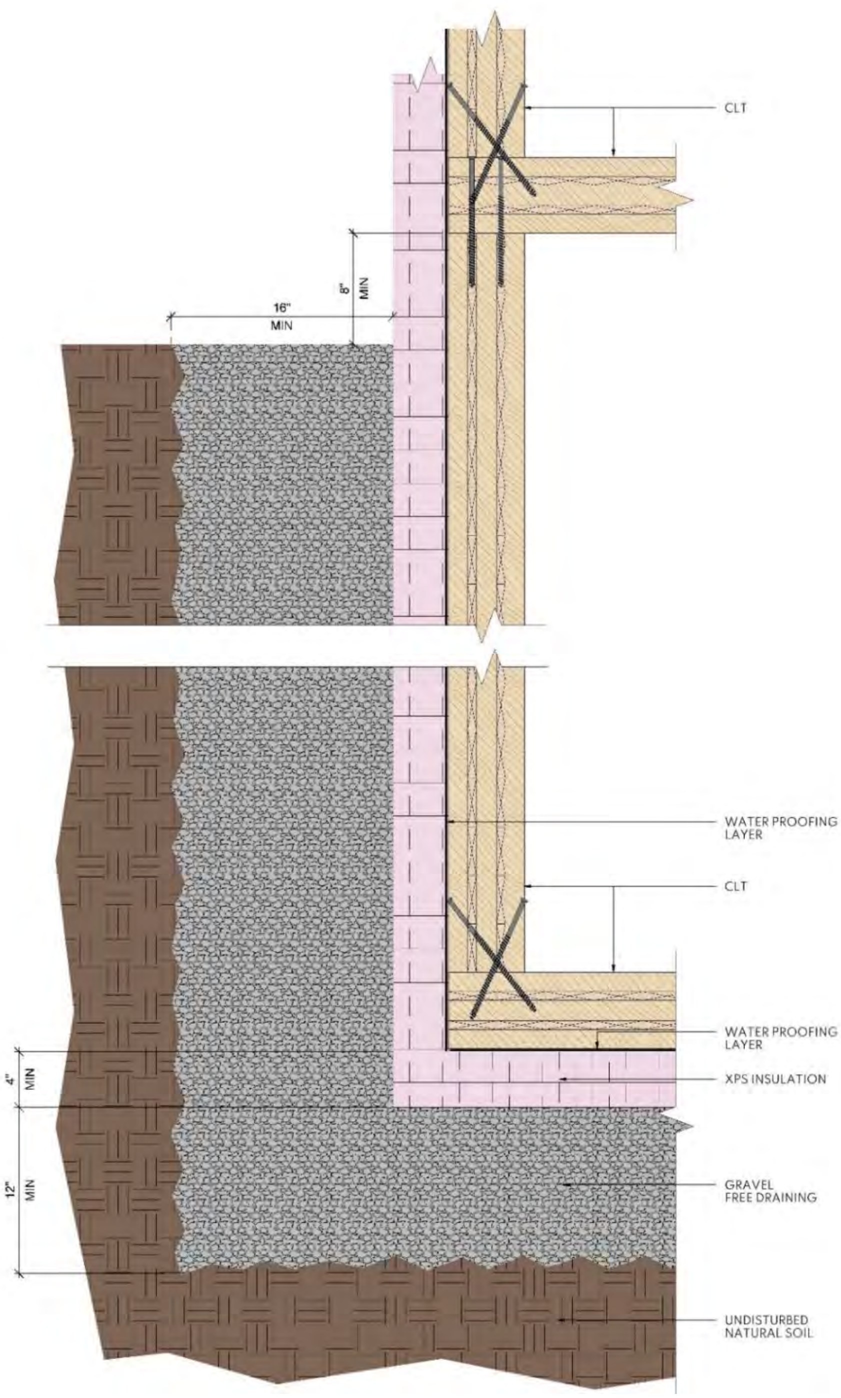


Figure 9 - MT CLT slab and exterior load-bearing wall detail for buildings with a full basement.

14 MT Structural Foundation Systems

14.1 MT Raft Foundations

The most common application for Mass Timber in foundations is the raft slab system. For most residential and small commercial buildings, the structural raft can safely spread the point and line loads of the building to the soils as one big raft. Typically, a 5-ply CLT would be used with a thickness from 139 mm to 175 mm for smaller buildings and 7-ply 245 mm thick slab required for larger spans.

The water protection of a large flat surface is easiest to achieve on a constant depth layer of insulation resting on a horizontal level free draining gravel fill.

It is important to ensure possible drying of the slab by either venting it to the bottom like in PWF systems, or exposing its top surface (as done in the first European projects)

14.2 MT Foundation Walls

MT Foundation walls work in the same way as treated framing foundation walls in traditional PWF systems. The walls are supported at the bottom by the raft slab and by the crawlspace floor or the main floor framing at the top.

Walls are typically anchored to the slabs with self-tapping screws or standard CLT angle connectors.

14.3 MT Strip Footings

Although MT Strip Footings can easily be achieved structurally, it is more economical to use MT Raft Slab Systems due to other factors like water protection and ease of construction.

14.4 MT Pad Footings

Although MT Pad Footings are doable structural options, it is more cost-effective to use MT Raft Slab Systems due to other factors like water protection and ease of construction.

15 Geotechnical Issues

15.1 BC Housing Builder Guide to Site and Foundation Drainage

Due to its wet and diverse climate, British Columbia developed the widely used geotechnical guidelines for the construction industry. Its findings can be used in all regions of Canada including Alberta.

The "Building Guide to Site and Foundation Drainage, Best Practices for Part 9 Buildings in British Columbia" was released by BC Housing in 2021 and is available online. Two BC experts: Karen Savage of Horizon Engineering and Graham Finch of RDH building science, prepared the publication The authors of this report collaborated with both individuals and were always impressed by their practical approach and a thorough knowledge of site and foundation drainage.

Below is a quick summary of the material that is most relevant to MT foundations. We recommend that all the applications found in the guide be implemented in MT foundation systems and the entire BC report be thoroughly examined and applied by designers of future MT foundation systems.

Below are the key issues presented in the Guide:

Site Drainage

The purpose of site drainage is to direct surface water away from the building.

Foundation Drainage

Foundation drainage is about managing moisture below the slab on grade and removing any water that accumulates against the foundation walls.

Building Enclosure

The building enclosure is the last line of defence against groundwater.

The authors identified two basic approaches to achieving water protection for MT Foundations:

1. Minimize contact with water and use treated wood.
2. "Tank" the raft slab (fully waterproof) and use untreated wood.

Both approaches were presented in earlier parts of this report.

In locations with high groundwater table, basements need to be fully tanked, so they are fully waterproofed and designed not to "float away" when submerged in water. Historically, this was an expensive solution for small buildings. With the recent introduction of new rubberized waterproofing membranes this option is slowly becoming more cost and performance competitive.

The authors of the BC Housing Guide have identified site selection as the first key step in achieving a long-term safety and proper performance of the foundation system. Below are the major points to be considered when selecting a proper site:

1. Gravity drained systems are preferred over pumped foundation drainage systems.
2. Swelling and shrinking clay should be avoided due to substantial changes in water present in these soils.
3. Organic soils like peat are weak and deform excessively, especially when groundwater table is lowered, and methane gas can also be produced during soil decomposition.
4. Frost-susceptible soils can produce frost heave by formation of ice lenses. In cold climates raft slab bases should be insulated from freezing.
5. Collapsable soils are deposited by natural events like wind, water, gravity, or floods.
6. Sensitive clays can become very weak when disturbed.
7. High groundwater sites should be avoided.
8. Geotechnical consultant should be contacted during site location.

The next step in soil preparation should include:

1. Ground surface to be graded to follow the natural terrain slopes. Surface water to be directed to disposal locations if available.
2. Excavated surface to be graded towards the storm sump and utility tranches should be used to drain water away from excavation.
3. Site grading is the best way to minimize possibility of water ingress.

The next issue to be addressed is the subsurface drainage. Permeability of soil is the ability of water to flow through soil. It is based on particle size, soil composition and compaction. Soils with low permeability include clays, silt, and glacial till (hard pan). Soils with high permeability include clean sand (free of silt or clay), and gravel and are considered free draining. Water flows along the path of least resistance: down the slope, through pipes, through free draining materials, poorly compacted fills, etc.

BC's Building Code requires that excavations be drained by a granular fill, and it is graded to the drainage discharge to promote natural drainage. Swales, ditches, lawn basins and French drains can be used but they require maintenance during the life of the building.

For the under-slab drainage (under MT raft foundations), the authors of the guide recommend an angular (more compactible) gravel with a range in granular size from 19 mm to 25 mm and free of fines. The recommended thickness of this layer is 150 mm. Timber Engineering participated in projects where this thickness increased to 400 mm on sites with a history of water accumulation. The required thickness of gravel bed should be established by the geotechnical engineer of the project.

The NBC additionally requires the following:

- The topsoil and all organic materials shall be removed from the site below the construction project location.

- The base of the excavated site area shall be graded from the centre to the outside, or from side to side and filled with gravel or other suitable granular inorganic material to a level above the surrounding finished grade.

16 Design Examples – Case Studies

The section presents two design examples of recently constructed wood foundations. The two projects are residential in nature and use two different mass timber products for the foundation. To describe and design the foundations, the following method was used. First, wind and seismic loads calculations are done to determine the governing load for the lateral design of the building and especially for the wood foundation. Then the resisting capacity of the building was calculated to determine the requirements needed for the wood foundations.

16.1 FPInnovations Tiny House

The first project is a collaboration between FPInnovations and Timber Engineering to design a Tiny House for the Yunesit'in community. The Yunesit'in community is one of six communities within the Tsilhqot'in Nation and is located in British Columbia, close to Williams Lake. The building shape consists of two 10.9 m by 3.7 m rectangular boxes installed staggered that create the tiny house shown in Figure 10.

Figure 10 - Tiny House at FP Innovations

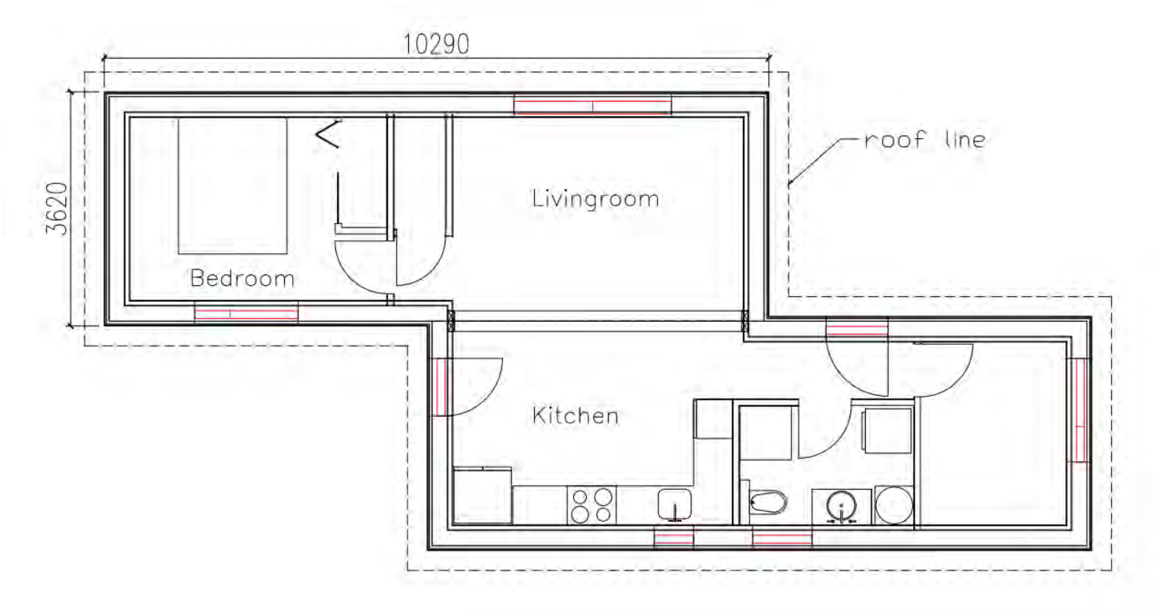


Figure 11 - Plan view of the Tiny House Project

The house is composed of a CLT floor and a light wood frame. A post and a beam were added between the living room and the kitchen to assure the stability of the structure. The roof is composed of OSB panels installed on wood rafters. The lateral force resisting system (LFRS) is composed of shear walls distributed all around the house. The shear walls consist of OSB panels connected by nails to the wood studs.

The following example presents the lateral design only. It illustrates the resistance load path for the shallow foundation system.

Lateral Design

Climatic data (from NBCC 2020 Appendix C)

$w_{1.50} := 0.35\ \text{kPa}$ Hourly Wind Pressure 1/50

$Sa_{0.2} := 0.159$ Spectral acceleration for a period of 0.2 seconds

- <u>Seismic loads</u>

To calculate the seismic loads, the size of the building is needed, so dimensions are presented below:

$h := 3.3\ \text{m}$ Height of the building

$A_{roof} := 76\ \text{m}^2$ Area of the roof

$A_{wall} := 73.8\ \text{m}^2$ Area of the wall

To calculate the lateral force due to the seismic loads, it is first needed to determine the seismic weight of the building, which is presented below:

$SID_{roof} := 1\ kPa$ Super Imposed Dead Load on the roof

$SW_{roof} := 0.5\ kPa$ Self weight roof

$SW_{wall} := 0.5\ kPa$ Self weight wall

$SL := 2.1\ kPa$ Snow load

The Seismic Frame Resisting System (SRFS) uses nailed OSB clad shear walls. Therefore, to describe the ductility of the building, it is necessary to define two coefficients: the coefficient R_d, Ductility factor, and R_0, overstrength factor, which are respectively equals to 3.0 and 1.7 (refer to Table 4.1.8.9 of NBCC 2020).

$R_0 := 1.7$ Overstrength factor

$R_d := 3.0$ Ductility factor

$I_E := 1.0$ Importance factor

$Sa_{0.2} := 0.159$ Spectral acceleration for a period of 0.2 seconds

$Fa_{0.2} := 1.24$ Site coefficient

$$Reduction_{seismic\_weigth} := \frac{Sa_{0.2} \cdot Fa_{0.2} \cdot I_E}{R_0 \cdot R_d} = 0.039$$

$$Base_{shear} := Reduction_{seismic\_weigth} \cdot Seismic_{weigth} = 7.4\ kN$$

The final base shear of the building is **7.4kN.**

- <u>Wind Loads</u>

The building is symmetrical, and the north face and south face are identical. The same applies for the west and the east face.

$w_{1.50} := 0.35\ \text{kPa}$ Wind information of the location

$Design_{wind} := 1\ \text{kPa}$ Design value of the wind (4.1.7.3 NBCC 2020)

$A_{North\_face} := 39\ \text{m}^2$ Area of the north face exposed to wind

$A_{West\_face} := 14\ \text{m}^2$ Area of the west face exposed to wind

Base Shear calculation

$Wind_{NS} := Design_{wind} \cdot A_{North\_face} = 39\ \text{kN}$ Base shear due to wind in N-S direction

$Wind_{WE} := Design_{wind} \cdot A_{West\_face} = 14\ \text{kN}$ Base shear due to wind in W-E direction

The wind governs the design in both directions and is equal 39 kN and 14 kN, respectively for the north south direction and the west-east direction.

Wood Foundation Design

Once the lateral design is confirmed, it is necessary to design the requirement of the wood foundation. First, the friction between the building and the soil is calculated to determine the behaviour of the building when a lateral load is applied.

$$Total_{weight} := \left(A_{roof} \cdot \left(SW_{roof} + SID_{roof}\right) + A_{wall} \cdot SW_{wall}\right) \cdot 0.85 = 128.3\ \text{kN}$$

$$Friction := 0.3$$

$$R_{friction} := Friction \cdot Total_{weight} = 38.5\ \text{kN}$$

Since the resistance of the building due to its own weight is not sufficient, the passive bearing pressure should be included in calculating the resistance of the lateral forces.

To determine the minimum depth of the foundation, the calculation of the passive bearing pressure on the short and long side of the building is presented below.

$\gamma_{soil} := 15 \frac{kN}{m^3}$ Assumption of a soil class D

$K_{MH} := 3$ Passive pressure coefficient

$l := 3.7\ m$ Length of the bearing pressure - short side

$P_{pressure} := \gamma_{soil} \cdot K_{MH} = 45 \frac{kN}{m^2}$ Passive bearing pressure

$Wind_{design} := \max\left(\left[\, Wind_{NS} \ \ Wind_{WE} \,\right]\right) = 39\ kN$ Design value for the lateral load

$h_{min} := \frac{Wind_{design}}{P_{pressure} \cdot l} = 234\ mm$ minimum height of the foundation

On the short side of the house, the depth needed for the foundation is <u>235 mm</u>.

$K_{MH} := 3$ Passive pressure coefficient

$l := 10.9\ m$ Length of the bearing pressure - long side

$P_{pressure} := \gamma_{soil} \cdot K_{MH} = 45 \frac{kN}{m^2}$ Passive bearing pressure

$Wind_{design} := \max\left(\left[\, Wind_{NS} \ \ Wind_{WE} \,\right]\right) = 39\ kN$ Design value for the lateral load

$h_{min} := \frac{Wind_{design}}{P_{pressure} \cdot l} = 80\ mm$ minimum height of the foundation

On the long side of the house, the depth needed for the foundation is <u>80 mm</u>.

The short side of the house governs the dimensions of the foundation. The minimum depth of the wood foundation is at least **235 mm**.

16.2 Whitehorse A-Frame Building

The second project is in Whitehorse, Yukon. It is an A-frame residential structure constructed with mass timber products. Dowel Laminated Timber (DLT) is used for the roof and floor of the house. The geometry of the house is 7.2 m by 6.2 m as shown in Figure 15.2.

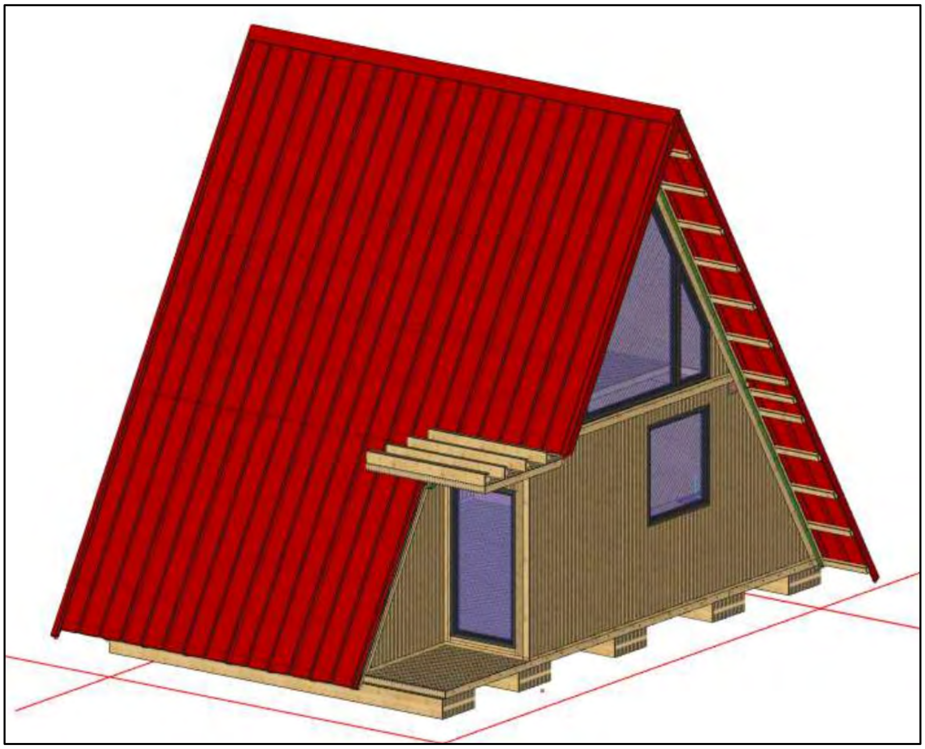


Figure 12 - A-Frame House

The lateral force resisting system (LFRS) consists of DLT in the north-south direction and with plywood on the west-east direction.

The same procedure is used to determine the base shear associated to the seismic load and the base shear due to wind load.

Lateral Design

Climatic data (from NBCC 2020 Appendix C)

$w_{1.50} := 0.38\ \mathrm{kPa}$ Hourly Wind Pressure 1/50

$Sa_{0.2} := 0.334$ Spectral acceleration for a period of 0.2 seconds

- <u>Seismic Loads</u>

To calculate the seismic loads, the dimensions of the building are needed. The calculations are presented below:

$h := 6.45\ \text{m}$ — Height of the building

$h_{mezz} := 2.75\ \text{m}$ — Height of the mezzanine

$A_{roof} := 45.9\ \text{m}^2 \cdot 2 = 91.8\ \text{m}^2$ — Area of the roof

$A_{wall} := 23.5\ \text{m}^2 \cdot 2 = 47\ \text{m}^2$ — Area of the wall

$A_{mezz} := 19\ \text{m}^2$ — Area of the mezzanine level

To calculate the lateral force emanating from the seismic loads, you need to calculate the seismic weight of the building - which is presented below:

$SID_{roof} := 1\ \text{kPa}$ — Super Imposed Dead Load on the roof

$SW_{roof} := 0.5\ \text{kPa}$ — Self weight roof

$SW_{wall} := 0.5\ \text{kPa}$ — Self weight wall

$SL := 1.11\ \text{kPa}$ — Snow load

$LL := 1.9\ \text{kPa}$ — Live load

$$Seismic_{weigth} := A_{roof} \cdot \left(SID_{roof} + SW_{roof}\right) + A_{wall} \cdot SW_{wall} + 0.25 \cdot A_{roof} \cdot SL + A_{mezz} \cdot LL = 222.8\ \text{kN}$$

The Seismic Frame Resisting System (SRFS) consists of nailed shearwalls. Therefore, to describe the ductility of the building, it is necessary to define two coefficients: the coefficient R_d, Ductility factor, and R_0, overstrength factor, which are respectively equals to 3.0 and 1.7 (refer Table 4.1.8.9 NBCC 2020).

$R_0 := 1.7$ — Overstrength factor

$R_d := 3.0$ — Ductility factor

$I_E := 1.0$ — Importance factor

$Sa_{0.2} := 0.334$ — Spectral acceleration for a period of 0.2 seconds

$Fa_{0.2} := 1.16$ — Site coefficient

$$Reduction_{seismic\_weigth} := \frac{Sa_{0.2} \cdot Fa_{0.2} \cdot I_E}{R_0 \cdot R_d} = 0.076$$

$$Base_{shear} := Reduction_{seismic\_weigth} \cdot Seismic_{weigth} = 16.9\ \text{kN}$$

The final base shear due to seismic load is **16.9 kN.**

- <u>Wind Loads</u>

  The building is symmetrical and the north and south faces are identical. The same conditions apply for the west and the east faces.

$w_{1.50} := 0.38\ \text{kPa}$ Wind information of the location

$Design_{wind} := 1.5\ \text{kPa}$ Design value of the wind (4.1.7.3 NBCC 2020)

$A_{North\_face} := 23.25\ \text{m}^2$ Area of the north face exposed to wind

$A_{West\_face} := 45.9\ \text{m}^2$ Area of the west face exposed to wind

<u>Base Shear calculation</u>

$Wind_{NS} := Design_{wind} \cdot A_{North\_face} = 34.9\ \text{kN}$ Base shear due to wind in N-S direction

$Wind_{WE} := Design_{wind} \cdot A_{West\_face} = 68.8\ \text{kN}$ Base shear due to wind in W-E direction

The wind governs the design in both directions and is equal 34.9 kN and 68.8 kN, respectively for the north-south and the east-west directions.

$\gamma_{soil} := 15\ \dfrac{\text{kN}}{\text{m}^3}$

$K_{MH} := 3$ Passive pressure coefficient

$length := 6.2\ \text{m}$ Length of the bearing pressure - long side

$P_{pressure} := \gamma_{soil} \cdot K_{MH} = 45\ \dfrac{\text{kN}}{\text{m}^2}$ Passive bearing pressure

$Wind_{design} := \max\left(\left[\ Wind_{NS}\ \ Wind_{WE}\ \right]\right) = 68.8\ \text{kN}$ Design value for the lateral load

$$h_{min} := \frac{Wind_{design}}{P_{pressure} \cdot length} = 247\ \text{mm}$$ minimum height of the foundation

The minimum depth of the wood foundation must be at least **250 mm**.

17 Current Research on Timber Foundation Systems

17.1 University of Alberta

The University of Alberta (U of A) is currently conducting a study of Preserved Wood Foundations on a small-scale building experiment built on U of A campus. Professor Y.H. Chui, his team and postgraduate students are currently conducting research in the following fields:

1. Structural Analysis and Design of Sustainable Cross Laminated Timber Foundation Walls
2. Field Research on Soil-Structure Interaction of Sustainable Basement Using Mass Timber Panels
3. Moisture and mould growth risk of cross-laminated timber basement walls: laboratory and field investigation.

See references 11, 12 and 13 to get more information about the research reports, which are available from U of A.

17.2 FPInnovations Vancouver, BC

FPInnovations is currently conducting a series of durability tests on untreated small-scale CLT samples exposed to soil and weather at its facility in Vancouver. See Reference 8, Accelerating Mass Timber Systems from Niche to Mainstream, CLT Foundation Slab, for more information. The final report is due in the fall in 2024.

17.3 Bern Technical University

The Bern University of Applied Sciences in Switzerland has been working in close cooperation with Timbase Schweiz AG on MT Foundation system. In Europe, Timbase Schweiz AG offers consulting and construction services in the field of solid wood foundations.

See company website: www.timbase.com for more information.

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