Lateral Force Resisting Systems for 12 Story Timber structures – The Canadian Experience

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1. Introduction

The use of mass timber in taller buildings is an ongoing international trend.
One of the reasons amongst many is the ability to prefabricate the structural elements and reduce the construction time. But in order to really harvest the schedule savings a prefabricated structural system can offer, both the gravity and lateral system need to be prefabricated.

Ideally, lateral systems used in these projects consist of prefabricated components that align with the tolerance and sequences typical for mass timber frames.

As traditional timber engineers, we didn't typically deal with design issues that accompany taller building structures (i.e. above 6 stories). It may be a surprise to many that the typical ULS and SLS design criteria may not govern the design – even at 12 stories. So, the addition of a different set of knowledge and skills is required.

This presentation will show two examples of buildings located in the west coast of Canad:. One relying on a standard concrete core system and the other using an innovative approach to Eccentrically Braced Steel Frames.

2. Design Considerations

When designing lateral systems, several design checks need to be performed. Under Ultimate Limits States (ULS), these are as follows:

- Seismic Loads
  - Strength – does the system have enough strength to withstand the seismic loads
  - Stiffness – does the system have enough stiffness under ULS loads to not deform too much (drift)
  - Inelastic deformation capacity – can the system undergo adequate inelastic displacement to allow for energy dissipation without collapse
- Wind Loads
  - Strength – does the system have enough strength to withstand the wind loads

Under Serviceability Limits States (SLS), these are as follows:

- Wind Loads
  - Acceleration - does the system have enough stiffness to provide an appropriate level of user comfort
  - Stiffness - does the system have enough stiffness to not deform too much (drift)

Compared to heavier steel and concrete buildings, the lighter timber structures may exhibit wind accelerations that exceed the acceptable thresholds at a given building height. In other words, wind induced acceleration can become the governing consideration for buildings that are much shorter than similar steel or concrete structures.

3. Lateral Force Resisting Systems

There are multiple systems that can be considered as a lateral force resisting system. In this presentation, we'll have a look at the three most likely options.

3.1. CLT Shear Walls

CLT Shear Walls consist of one or multiple CLT panels joined together. The system resists the lateral loads through their combined bending and shear resistance. The design of such a system is heavily based on first principles as the current Canadian Design Standard *O86 – Engineering Design in Wood* provides some but not a conclusive guidance.

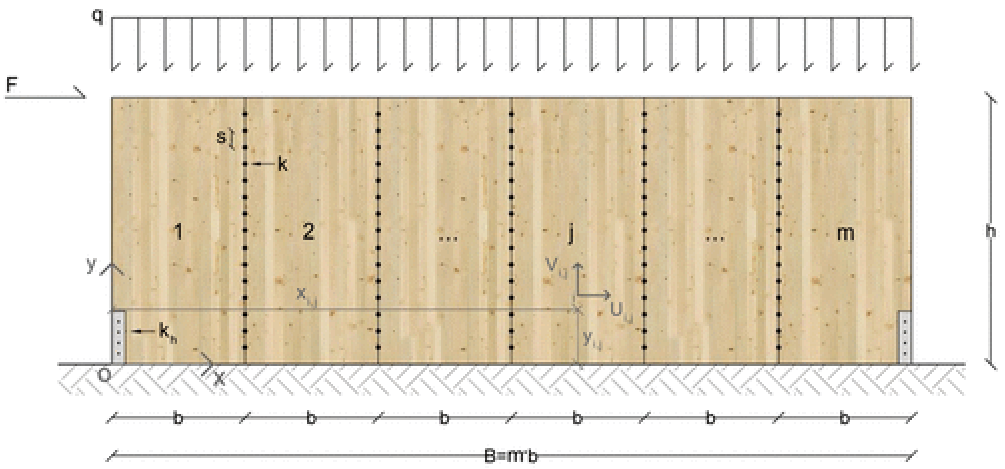


Figure 1: CLT Shear wall System[1]

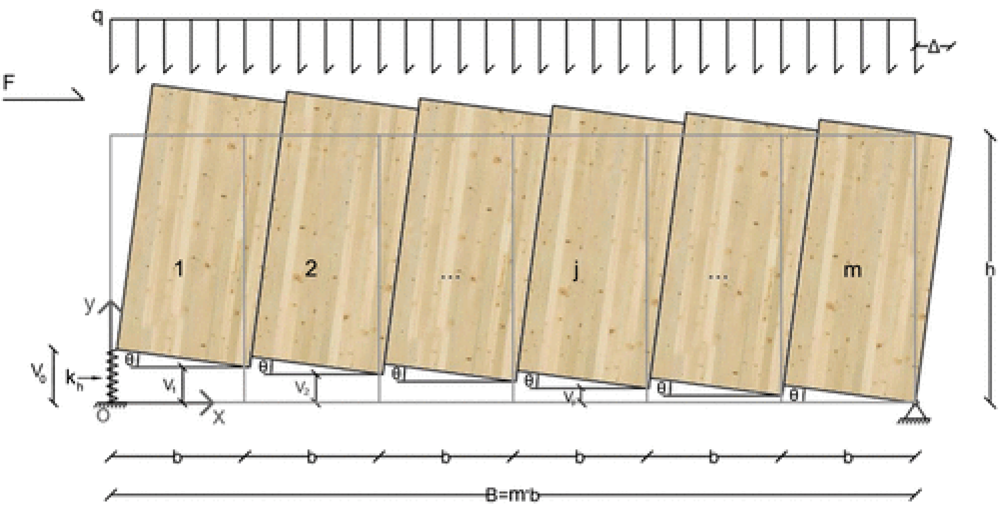


Figure 2: CLT Shear wall Deformation

In Canada the use of CLT as lateral force resisting system is currently limited by the building code to six stories only. Therefore, any use of the system in buildings taller than six stored would require special approvals.

[1] Analytical Approach to Establishing the Elastic Behavior of Multipanel CLT Shear Walls Subjected to Lateral Loads; Daniele Casagrande, Ph.D.; Ghasan Doudak, Ph.D., M.ASCE; Luigi Mauro; and Andrea Polastri, Ph.D

3.2. Concrete Shear Walls / Cores

Concrete shear walls and cores are very common and consist of individual concrete walls or walls forming to a square or rectangle in plan. The system resists the lateral loads through its bending and shear resistance. Given their shape and monolithic behavior, the system will typically act more like a tube rather than a single wall. The behavior and design of such systems is well understood and documented.

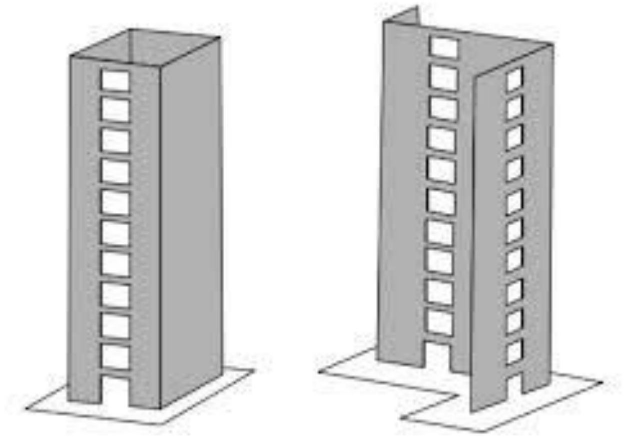


Figure 3: Concrete Shear Wall Configurations[2]

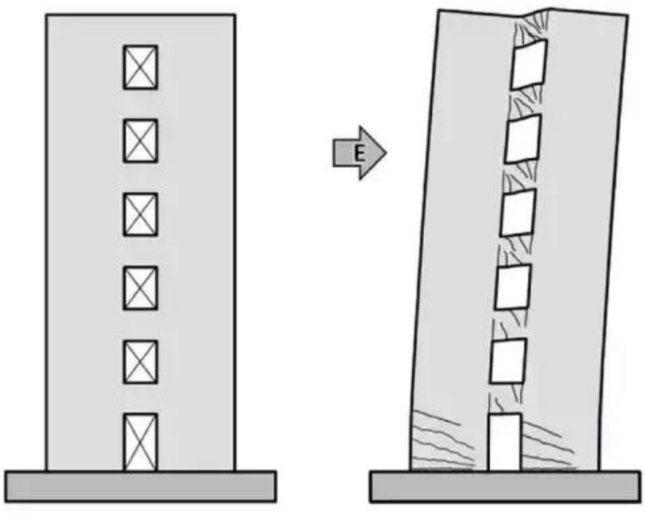


Figure 4: Concrete Shear Walls Deformation

In Canada, concrete walls have no code based height limitation (for most shear wall systems).

[2] https://www.quora.com/What-is-boundary-element-in-Shear-Wall-or-Column

3.3. Eccentrically Braced Steel Frames (EBF)

EBFs have a history of use in mid-rise and high-rise steel frame buildings in North America, including high seismic zones. EBFs possess high ductility and moderate stiffness. They are designed to dissipate energy by yielding links which form part of the beam in a braced frame. All elements of the braced frame, other than the yielding link, are designed to remain elastic. The figures below show the system and its behavior.

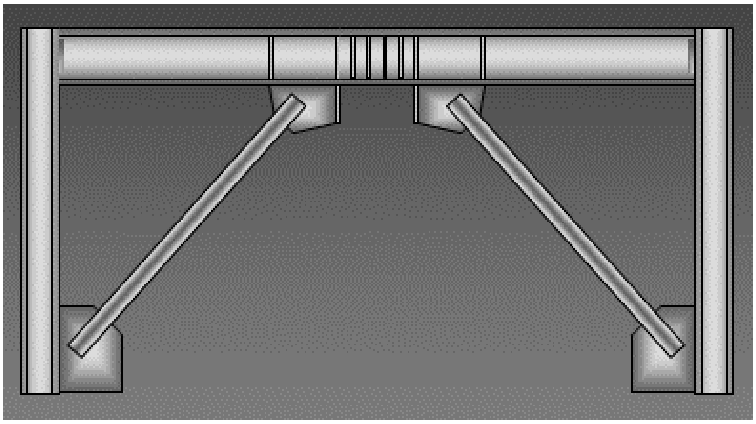


Figure 5: EBF System[3]

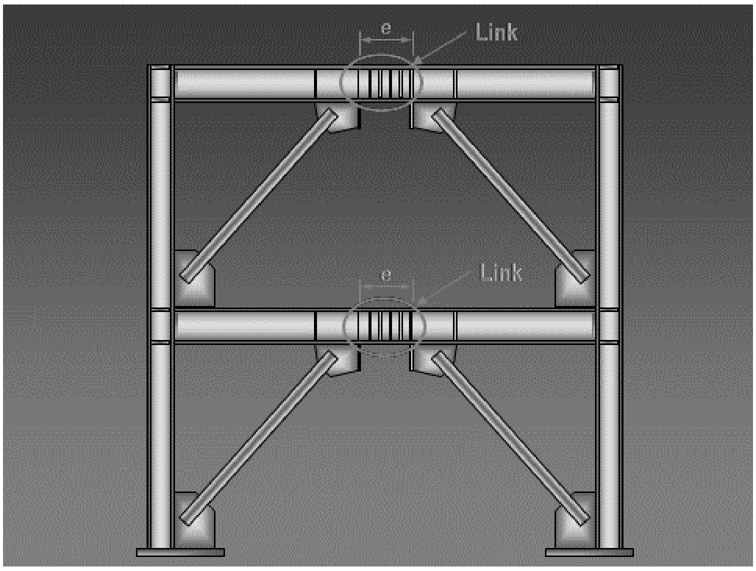


Figure 6: EBF Links

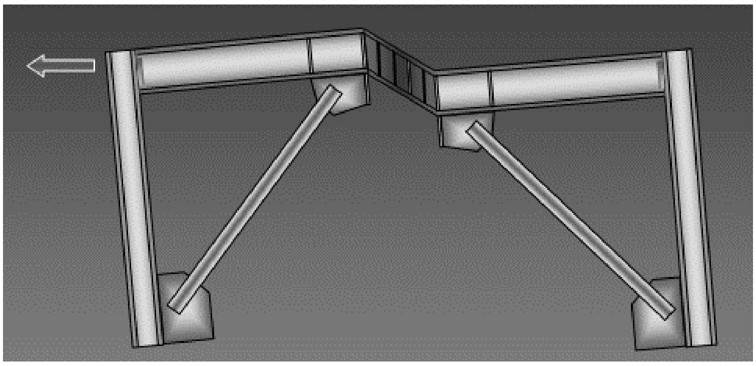


Figure 7: EBF Deformation

In Canada, EBF's have no code based height limitation.

[3] https://civilhelper.com/Design-Parameters-of-Dual-Braced-Frame-System

3.4. Practical Comparison

Table 1 provides a practical comparison of the three systems. The cost and time are through the lens of the Vancouver marketplace.

Table 1: Practical Comparison of the systems

	CLT Shear Walls	Central Concrete Core and Shear Walls	Eccentrically Braced Steel Frames
Cost	$$	$$$	$$
Time	Quick	Slow	Quickest
Quality/Prefab	High	Low (Medium if slip forming is adopted)	Highest
Availability	Low	High	Medium
Weight	Light	Heavy	Medium
Geometric flexibility	Average	Good	Poor
Other	Does not meet the current building codes at this height and will require alternative solution. Challenging connection details	Efficient use of space	Inflexible in plan, additional fire protection, acoustics

4. 1001 Kingsway

4.1. Project Description

Location: Vancouver, Canada
Architect: ZGF
Owner: Vancouver Affordable Housing Agency's

As part of the Vancouver Affordable Housing Agency's seven-site program, the design of a new mixed-use tower at 1001 Kingsway, Vancouver, Canada is underway. The current proposal is for a seven-story tower which sits on top of a wider five-story base, with all but one of the twelve stories above ground designed for residential accommodation. The main floor level will house two commercial retail units (CRU) in addition to back of house operation space.

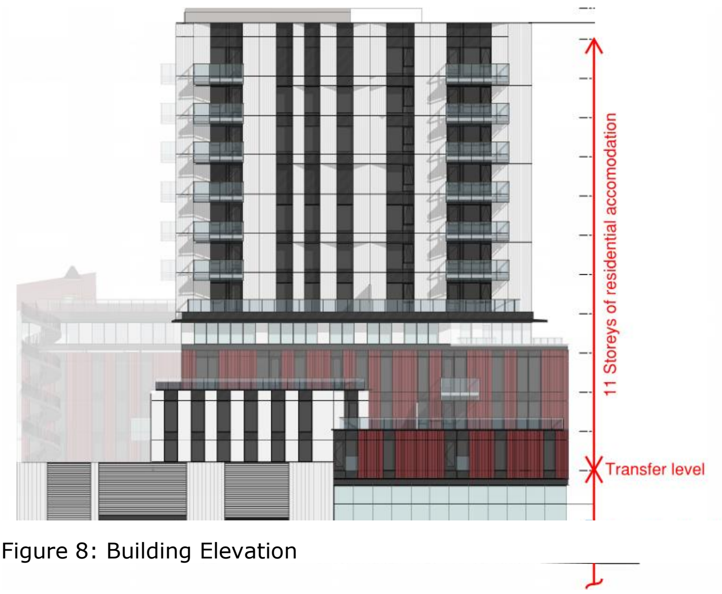


Figure 8: Building Elevation

The combined twelve-story building will have three stories below ground to accommodate parking and ancillary spaces for mechanical and electrical services. The building will require a significant transfer structure which is currently assumed to be at level two (above the CRU level). Positioning the transfer structure at this level will allow for fewer, albeit larger, columns to be positioned within the CRU spaces which will be more accommodating to large structural members. The building will be designed to meet the Passive House requirements.

4.1. Lateral Force Resisting System

The irregular shape of the building naturally lends itself to the use of a centralized core, as this closed shape is better suited to handle the torsional forces due to the geometric irregularities of the building. Figure 9 shows the extent the core on a typical floor plate

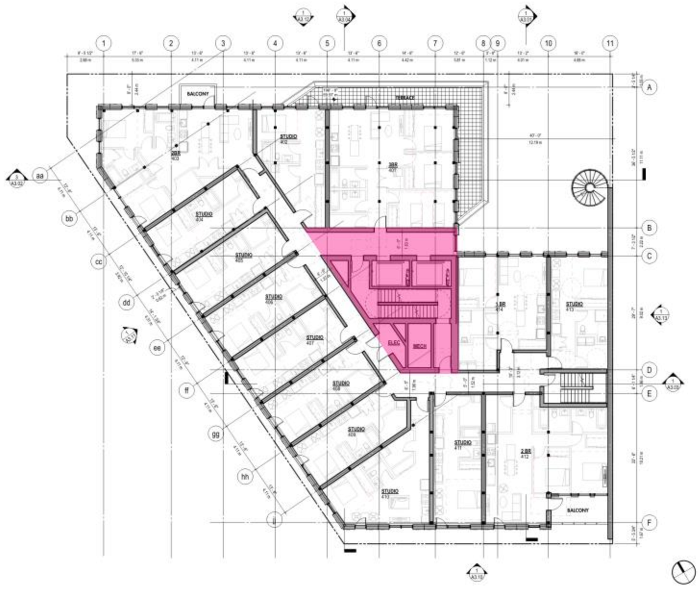


Figure 9: Typical Floorplan

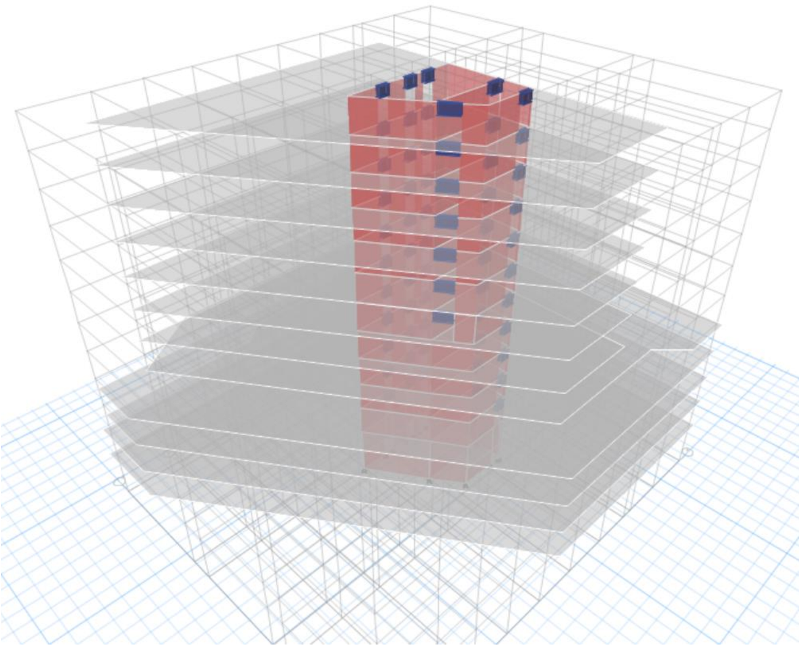


Figure 10: Lateral Model View (ETABS)

Furthermore, the use of a central concrete core results in design that has minimal impact on the usable floor area throughout all the levels of the building and especially at the CRU's on the lower level. Eccentrically Braced Steel Frames (EBF'S) would need to be concentric throughout the height of the building which would impact the architectural layout.

Although the construction of an eleven-story concrete core (above level 2) is slower in comparison to a braced steel frame, a concrete core is the more suitable system for this project. Given the heavy and stiff concrete core system, the design for this lateral forcing system is governed by seismic loads.

5. Langford TallWood

5.1. Project Description:

Location: Langford, Canada
Architect: DB Services
Owner: DB Services

TallWood 12 story mixed-use building with 11 stories of residential space, one level of commercial retail units at ground level, and two levels of underground parking. The residential levels will consist of point supported CLT floors on steel columns within partition walls. All structure below L2, including the L2 transfer slab, will consist of cast-in-place reinforced concrete.

One of the objectives of this project was to adjust the architectural massing and unit layout to suit the product supply and trade sequencing in order to reduce overall project cost.

Figure 11 & Figure 12: Architectural Renderings

5.2. Lateral Force Resisting System

In order to maximize the speed of construction of the structural system, the client and design team were looking for a solution that can keep pace with the installation of the gravity system. A cast-in-place concrete core system was therefore not desired. Prefabricated Eccentrically Braced Steel Frames located throughout the building were chosen. A good alternative would be the use of timber concentrically braced frames (CBF). But given the high ductility of the Steel EBF's compared to the Timber CBF's, Steel EBF's are more economical in this case.

In addition, this system allows for replacement of the ductile shear links after a major seismic event, increasing the likelihood of a relatively quick refurbishment of the structure. The figures below show the proposed layout of the lateral force resisting system.

Figure 13: Floor Plan with Brace Locations

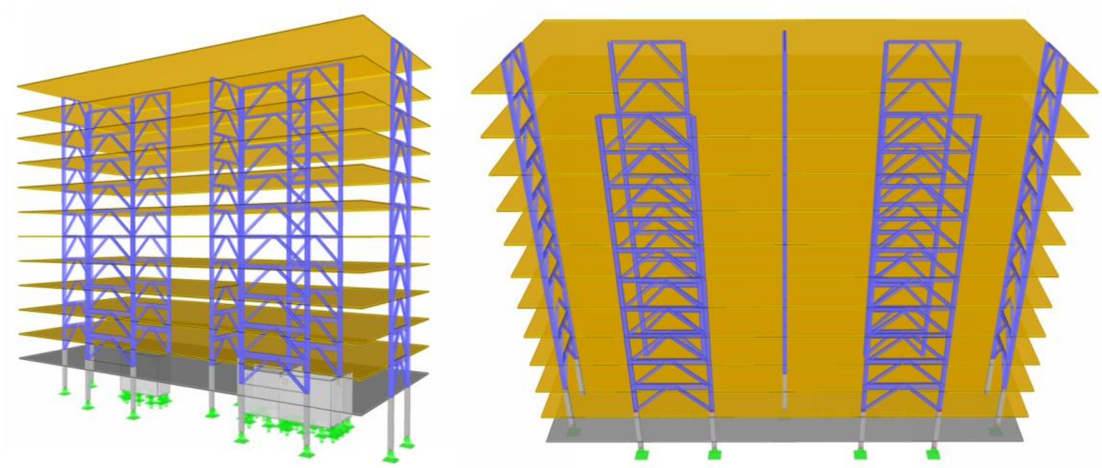
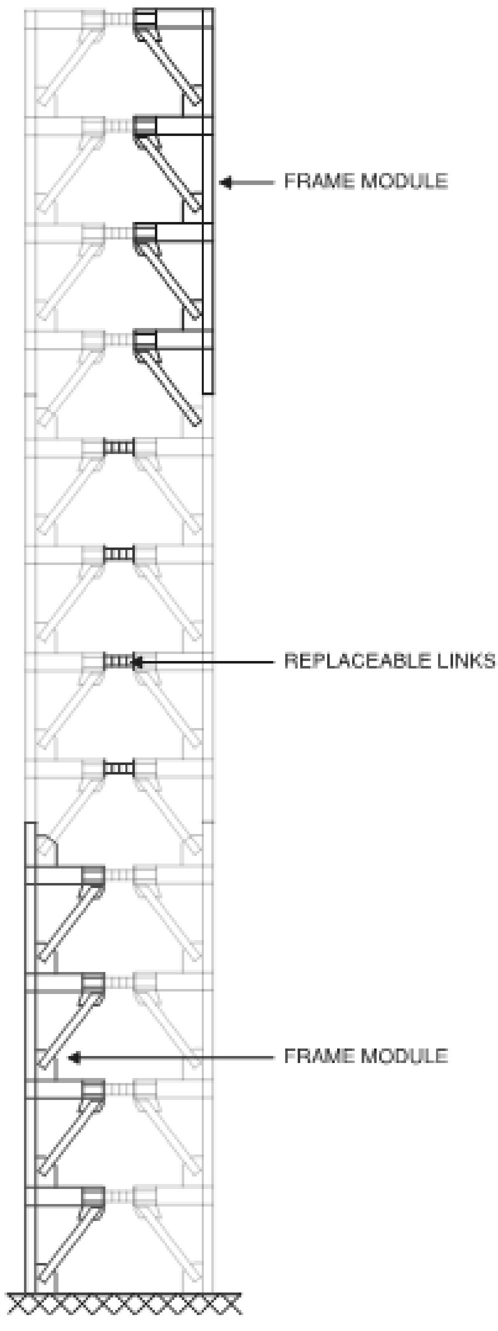


Figure 14 & Figure 15: 3-D Model Views

The design of the link beams is governed by web shear demand due to seismic loading. Design of the braces and columns is governed by limiting inelastic inter-story drifts to 2.5% under seismic loading. Braces, columns, beams outside the link, and the concrete structure below are capacity protected to ensure yielding occurs in the link beams.

The building is located adjacent to Rough Terrain, as defined by the British Columbia Building Code. If the same building were located adjacent to Open Terrain (fields, water, etc.) wind induced accelerations would be one of the main design drivers for brace and column sizes.

In order to maximize the efficiency of the EBFs in regard to construction sequencing, ASPECT developed a concept that would maximize the prefabrication of the system. The figures below show a conceptual elevation of an EBF frame, the conceptual link detail and field splices for the column and brace . One vertical section would consist of two prefabricated frames and links at each level.



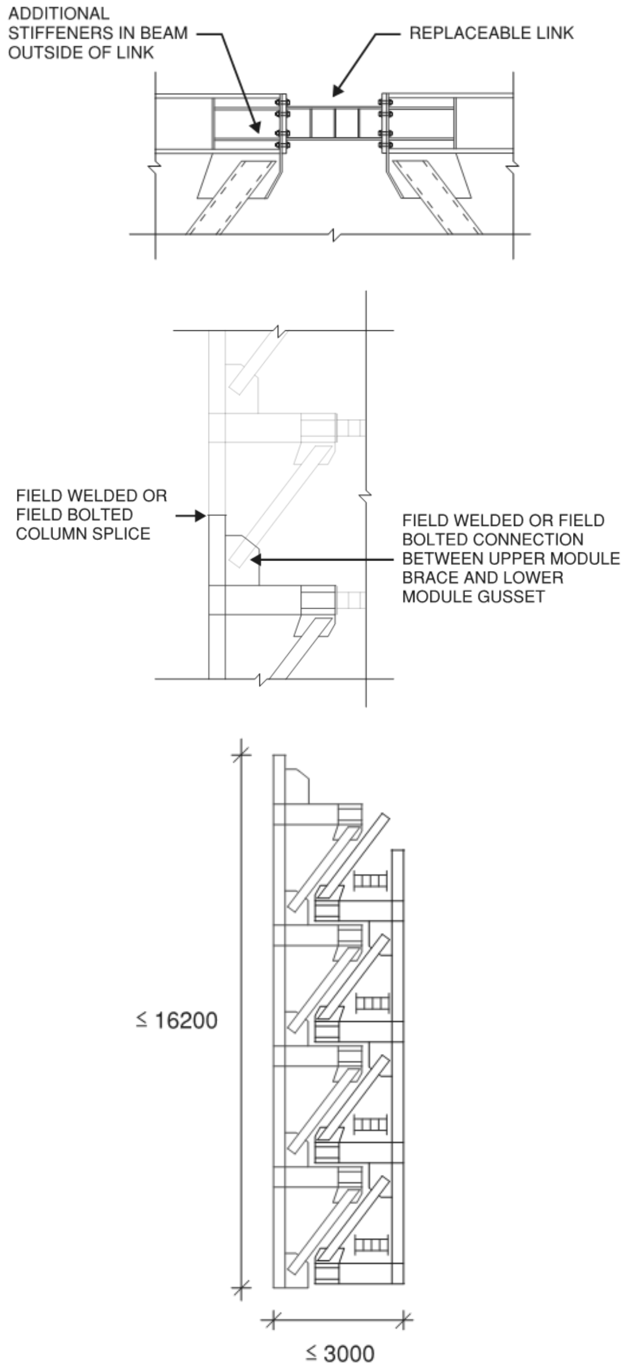


Figure 16: System

Figure 17, Figure 18 & Figure 19: Individual Components

6. Conclusion

Our experience based on these two projects and other tall wood projects shows, that a steel eccentrically braced frame is a very suitable lateral force resisting system to be integrated into a mass timber structure. This system provides the strength, ductility and stiffness needed and allows for a high degree of prefabrication while having similar construction tolerances.

Concrete shear walls & cores are very common and exhibit the necessary the strength, ductility and stiffness, but falls short on the construction sequencing as it's a field installed system and therefore much slower than EBF's. Concrete systems also have much larger construction tolerances than prefabricated steel or mass timber structures.

CLT shear walls are not well suited for taller buildings that need to rely on a minimized amount of shear walls. If a residential building would make use of all interior walls as shear walls, the necessary strength, ductility and stiffness could be achieved. But our experience shows that such structures are not cost effective – at least not on the Canadian westcoast.