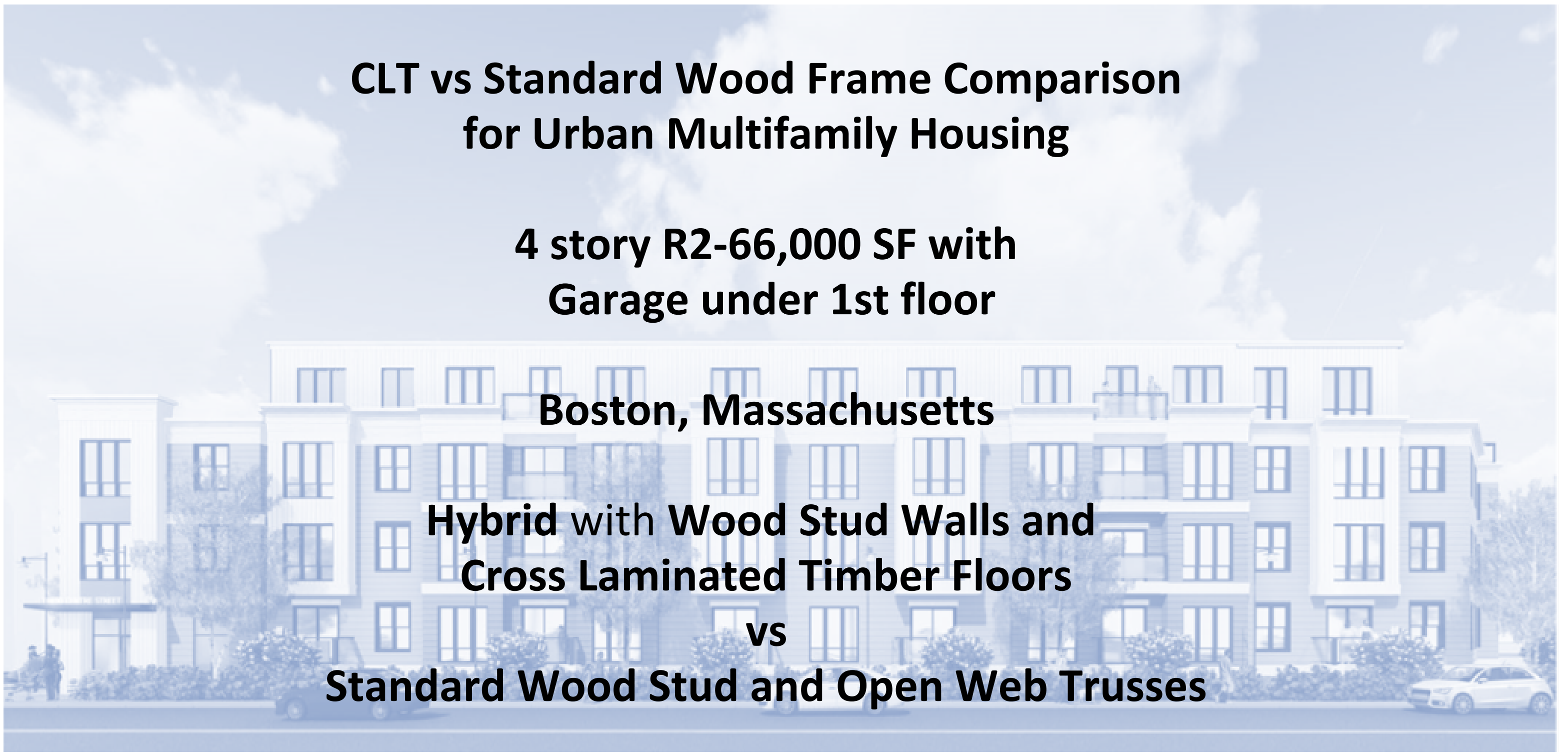
Boston Mass Timber Accelerator

SHAWMUT TOD - CLT Feasibility



CLT vs Standard Wood Frame Comparison
for Urban Multifamily Housing

4 story R2-66,000 SF with
Garage under 1st floor

Boston, Massachusetts

Hybrid with **Wood Stud Walls and**
Cross Laminated Timber Floors
vs
Standard Wood Stud and Open Web Trusses

Fast + Epp   ICON ARCHITECTURE   TRINITY FINANCIAL   MWB Construction Advisors

ICON ARCHITECTURE

Shawmut Station - Trinity

Figure 1

Figure 2.
Plan View

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I: Introduction

The overall goal of this project is to maximize the efficient use of CLT to make it cost competitive with light frame wood construction for 4 to 6 story buildings.

In the Northeast, 35% of all housing is multifamily (Urban Institute) which is higher than the National average of 31.4%(NAHB). 50% of all multifamily buildings in the Northeast are 4 stories and above (POYRY for NEFF). The share of multifamily housing that is wood stood at about 65% in 2017((POYRY for NEFF). All this points to growth and opportunity for wood construction of multifamily housing, especially for CLT in the Northeast and other parts of the United States in urban and suburban areas.

For the reasons above, we want to concentrate on CLT for 4 to 6 story multifamily housing. Shawmut TOD (transit-oriented development) will be a multifamily building; 4 stories, 66,000 SF, 74 dwelling units with a mix of studio, 1-bedroom, 2-bedroom and 3-bedroom units. There will be a parking garage below the 1st floor.

Model codes have allowed 4 story light frame wood (LFW) construction for many years. Since 2012, IBC codes allow 4 or 5 story LFW above one- or two-story non-combustible podiums. CLT has gathered recognition by governing codes since 2018 and is further expanded in the 2021 IBC to include new Type IV Mass Timber, aka Tall Wood, up to 18 stories.

While Tall Wood is a great new opportunity, the bulk of multifamily housing will be in the 4 to 6 story range as it is more suited to urban areas outside the city center as well as suburban areas. For this reason, we are looking at the use of CLT in 4 to 6 story multifamily buildings. While this building type using LFW is not unique, the purpose of our research is to explore the viability of CLT used for floors in the 4 to 6 story buildings. As such, we have designed a 4 story wood stud bearing wall/CLT floor structure (Hybrid) and compared it to a 4 story wood stud bearing wall building using open web trusses(LFW). The latter is a building type seen in construction throughout Boston and its suburbs.

The major issue controlling the use of CLT is span length. Generally, strength and deflection criteria can be met with 5 ply- 6 7/8" planks for spans up to 26'. However, vibration, even though it is not a code requirement, will govern the span length, thickness and grade of the CLT planks. Our study found that for 26' spans, 7 ply 9 5/8" planks are required to meet vibration criteria.

For the cost comparison of framing systems alone, CLT is considerably more than LFW. However, when other cost savings for other trades are taken into account plus the savings in overall project duration, the differential narrows to between 2.5% and 5% more costly than LFW. This does not take into account possible savings in financing and other soft costs because of a shorter overall duration. This can narrow the gap even further.

We are hopeful that increased manufacturing volume and efficiency can lower the overall cost of CLT so that it is on par with the cost of LFW.

Boston Mass Timber Accelerator
Shawmut TOD

Summary Objectives:

The purposes of the project to evaluate Shawmut TOD as 4 story multifamily are:

I. Create a design that is repeatable on other projects.

II. Determine the financial viability of using CLT in hybrid construction as compared to standard light frame wood.

III. Determine Carbon Sequestration comparing standard LFW and CLT Hybrid

II. Design considerations

i. Layout of CLT planks and gravity load elements.

A primary design consideration determining the choice of span direction was flexibility of interior apartment layout. Accordingly, we chose to run the planks in a staggered layout in the transverse direction from exterior wall to corridor wall. (Fig. 5) There have been recent CLT hybrid projects that have been framed in the longitudinal direction, 90 degrees from this project's plank orientation. This direction is used to reduce the span of the planks thus obviating issues with respect to vibration and potentially using 5 ply planks. It was our view that this limits layout flexibility of unit demising walls. Interior apartment walls that would otherwise be non-bearing are needed as bearing elements. This engenders difficulty developing a consistent gravity load path as well as code required offset restrictions for lateral force resisting systems and the need to drag forces to lateral elements.

Often, as designs are developed, layout of apartments change due to architectural choices and reconfiguration of the unit mix by the owner. This can cause repeated revisions of the structural design which can be costly and cause delays. A design in which the planks clear span I the transverse direction can obviate repeated re-design. Furthermore, a less complicated and repetitive layout will lead to greater efficiency during erection which leads to cost savings.

ii. Structural.

The major thrust of the design was to maximize the long span capabilities of CLT. Most multifamily projects consist of double loaded corridors. The typical depth of a dwelling unit is between 26' and 28' from exterior wall to corridor wall. In the case of Shawmut TOD, there is a one-story garage under the 1st floor. The framing above and its load path had to accommodate parking dimensions. The team settled on a 58' dimension from outside face of exterior to the opposite exterior wall (Fig. 2). Therefore, the team chose a bearing direction of the CLT planks from exterior wall to corridor wall in the building transverse direction. This transfers at the first-floor level using steel girders and beams as the loads are too great to be carried by Glulam beams (See Figure 3). The first floor, uses CLT planks in lieu of a concrete slab on metal deck. (See Fig. 3)

ii. Design Considerations (cont.)

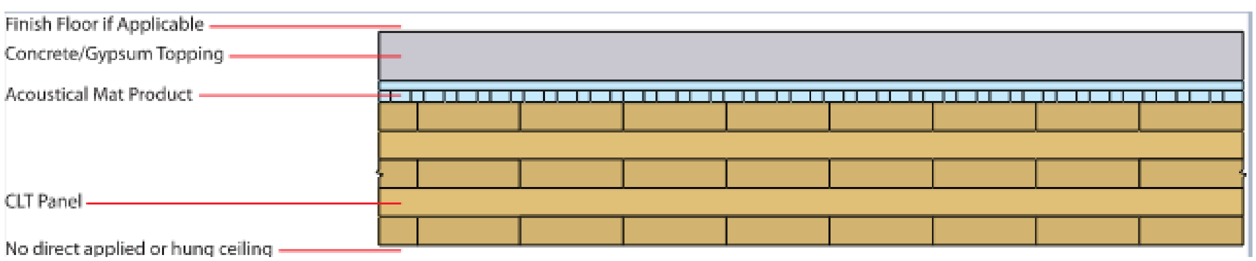
ii. Structural (cont.)

Multiple structural models were created to determine both the strength and deflection characteristics of the CLT spans (Fig. 5 and 6). Rather than use manufacturer's span tables, we calculated the expected moment and deflection for various configurations using PRG-320-2019. Given the 26' span, it is possible to use 5 ply 6 7/8" (175 mm) E1 with respect to strength and deflection.

iii. Sound transmittance

CLT floors do present challenges with respect to sound transmittance. Traditional open web trusses have the advantage of deep air space that increases resistance to sound transmission (STC). In the case of Shawmut TOD, the team chose to use a floor assembly using 1 ½ inches of gypsum concrete floor topping with a 3/8" acoustical under-mat. With respect to IIC, LVT flooring will provide the required rating.

STC ratings were taken from Reference; WoodWorks Acoustically-Tested Mass Timber Assemblies, Table 1: CLT Floor Assemblies with Concrete/Gypsum Topping, Ceiling Side Exposed. The chosen assembly shown below provides an STC of 50 which meets code.



iv. Vibration

Vibration limits are not a code required parameter. However, occupant comfort and tolerance are important considerations for design. Occupant sensitivity is subjective, but dynamic response in the form of large displacements or accelerations under a given dynamic load case may make a structure uncomfortable or even compromise strength and stability. As such, design guidelines exist that provide guidance for typical occupant sensitivity to structural vibrations. (See Woodworks U.S Mass Timber Floor Vibration Design Guide)

CLT floors are lightweight with relatively low stiffness when compared to steel or concrete. Material weight and stiffness are key factors that determine how a structure will function in a dynamic load case, such as walking. The cadence of normal walking pace is between 1 and 2 Hz, corresponding to a footfall every 1 to 2 seconds. (Fig.7) Resonant response (or resonance) occurs when the applied loading is likely to coincide with the natural frequency of the supporting structure– this is said to be the response that causes most vibration serviceability problems related to human comfort.

The CLT floor structure at Shawmut TOD is relatively light floor, approximately 22.3 psf with another 20 psf of additional mass provided by the topping. As a result the natural frequency of the system is low and is sensitive to normal footfall due to resonance (see Fig 9.).

Figure 9 shows 3 damping conditions for 2%, 3% and 5% critical damping. One of the major variables in determining the building response to footfall excitation is the amount of damping provided by building elements other than the floors. Elements such as walls, furnishings and finishes provide damping. Fast and Epp built a model of the floor to determine the maximum response using a 5% damped condition, with spring models at partition walls to include the damping effect of partitions. While 5% damping is often used as an upper bound, it is possible that these elements provide a greater amount of damping. We did not go beyond 5% as a greater amount of damping will need to be proved by full scale mockups.

Based on the dynamic analysis model provided by Fast+Epp, a 5 ply 175 mm (6 7/8") E1 plank will meet strength and deflection requirements, however given the 2 span condition, 5 ply planks were found to be beyond the guidelines for vibration comfort. Modeling found that given the 26' span, we would need a 7 ply CLT E1. This could be either 7 ½ " (191mm) or 9 5/8" (245mm). It was determined from feedback from manufacturers that 191mm was not a product that they were setup to produce readily and therefore would be more expensive.

It was found that given the 2 span 7 ply E1 layout that vibration excitation in one dwelling unit did not carry into adjacent units or from the corridor into dwelling units. (Fig.10). Therefore pricing was done using 7 ply CLT planks on floors 2,3 and 4 (see Scheme 1 below) . An alternate for 5 ply CLT was also priced. (See Scheme 2 below)

III. Cost

An estimate of the cost of the project was calculated comparing LFW and CLT Hybrid using 3 models:

- CLT Hybrid *Scheme 1* with:
  - 2x6 bearing walls at the exterior with ½" OSB sheathing
  - 2x6 bearing walls at the corridor
  - 2x4 shear walls sheathed with ½" OSB
  - 7 ply - 245mm EI CLT at 2nd, 3rd,4th floors
  - 5 ply -175mm V2 at the 1st floor over the garage
  - 5 ply – 175mm E1 at the roof.
- CLT Hybrid *Scheme 2* with:
  - 2x6 bearing walls at the exterior and corridor
  - 2x4 shear walls
  - 5 ply - 175mm EI CLT at 2nd, 3rd,4th floors
  - 5 ply -175mm V2 at the 1st floor over the garage
  - 5 ply – 175mm E1 at the roof.
- LFW:
  - 2x6 bearing walls at the exterior with ½" OSB sheathing
  - 2x6 bearing walls as the corridor
  - 2x4 shear walls sheathed with ½" OSB
  - 2x4 open web floor trussed with ¾ T&G Advantech sheathing.

The cost of the project was estimated using a full quantity take-off based on conceptual plans and unit layouts. Current pricing for the following trade items were provided by regional subcontractors:

- Concrete
- Wood Framing
- Steel
- Cementitious floor topping
- Roofing
- Metal Stud and Gypsum Board Assemblies
- Finish Carpentry
- Doors and Windows
- Plumbing
- HVAC
- Electrical
- Other items were priced based on unit price allowances based on recent data.

III. Cost (cont.)

Cost Parameters and Basis of the Estimate.

- All structural walls including shear walls are 2x6 wood stud walls.
- All non-bearing walls are 25ga metal studs.
- All demising walls are double stud walls for sound transmittance purposes.
- Floor Framing spans from exterior wall to corridor wall.
- Earthwork assumes spoils are typical urban fill. (RCS-1)
- Earthwork contractor employs union labor.
- Structural Carpentry Labor Rates are Boston Union Residential Rate.
- Trades allied with Carpenters' Union such as drywall, flooring and glazing use a blended commercial/residential rate.
- All other trades are open shop.
- Finishes are mid-priced.
    - Galley Kitchens/Laminate Counters
    - Ceramic tile bath floors and tub surrounds
    - LVT flooring in apartments
- 5% Contingency of Total Construction Cost included.

Pricing was done with full quantity take-offs for all trades with quotes or unit prices from subcontractors in all trades

The CLT was priced by Element 5. This included design assist, shop drawings, hardware allowance and transportation.

It should be noted that prices in the current market are volatile and this is a snapshot of current conditions.

III. Cost (cont.)

Savings line items for Shawmut TOD using CLT vs LFW (For a full tabulated cost comparison for items affected by using CLT in lieu of LFW see Table 1 and Table 2)

- **Concrete on metal deck over the garage eliminated.**
- **CMU Elevator and Stair shafts eliminated.**
- **Reduction in Structural Steel at the 1st floor over the garage due to lower weight o CLT.**
- **Reduced steel requires less fireproofing.**
- **Shorter building allowing:**
  - **Reduction of insulation and air barrier.**
  - **Reduced area of exterior cladding.**
- **Elimination of spray foam insulation under deck in garage.**
- **Elimination of acoustical ceiling in the garage. CLT remains exposed.**
- **Reduction in ceiling gypsum board and painting of same.**
- **Elimination of sprinkler head in interstitial spaces of open web floor trusses.**
- **Reduction in General Conditions due to faster erection of structure.**
- **Reduction in project finance cost due to shorter duration. (not included in pricing)**
- **Reduction of weather-related delays for concrete and CMU not used with CLT (not included in pricing)**

Increased cost items for Shawmut TOD using CLT vs LFW

- **Structural frame. Primarily due to large volume of wood for CLT. This is offset partially by the decrease in labor cost.**
- **Increase thickness of gypsum underlayment to achieve required STC 50.**

Highlights of the pricing comparison are:

1. Use of CLT for 1st floor framing over the garage in lieu of concrete reduced cost by $200,000. It also displaced a significant volume of a carbon intensive material. One other advantage is that CLT is not as weather sensitive as concrete. Concrete slabs in particular are vulnerable to freezing in cold weather. The cost of freeze protection and increased duration due to cold weather delays for concrete pours was not included in the pricing but is an important consideration and should always be kept in mind.
2. Steel framing of the garage floor was reduced by 35% from 55 tons to 35 tons by using CLT at the 1ST floor. This also allowed reduction in spray fireproofing.
3. Ceilings in Living/Dining and Bedrooms are exposed using CLT thus eliminating gypsum board on ceilings. There are additional savings eliminating paint on the LR/DR and BR ceilings.

III. Cost (cont.)

4. CLT on the 1st floor exposed in the garage eliminated the use of an acoustical ceiling and insulation under the floor.
5. CLT stair and elevator shafts eliminate CMU shafts which decreases cost and project duration. CLT shafts can be erected in 2-3 days whereas CMU shafts require 10 -12 days and are weather sensitive which can increase cost and duration.
6. Trucking costs for CLT are currently a significant portion of cost. For CLT it currently constitutes 25% of the cost of the material.
7. The overall height of the building using CLT is reduced by 4' plus. This results in a savings in framing and cladding. It may also be an advantage for municipal and community approvals.
8. For Light Frame wood vs. CLT Hybrid, the cost of CLT on a structural system only basis is 115% greater for Scheme 1 CLT and 80% greater for Scheme 2 CLT. However, when reductions in other line items are included, the difference in cost between LFW and CLT Hybrid is approximately 2.5 -5 %.

IV. Carbon Calculation

Carbon calculations were run using the WoodWorks Carbon Calculator. Volumes of wood material were taken directly from the Bill of Materials report from the structural model. The Calculator does not take into account the CO_2 emitted by the production of concrete used on the 1st floor slab on metal deck in the LFW model. Concrete production emits 400 lbs of CO_2 per cubic yard of concrete. Given a 5 ½" slab on 3" metal deck, the 1st floor slab at Shawmut TOD uses 215 cy of concrete. This represents 86,000 lbs of CO_2 emitted which equals 39,100 Kg-CO_2. Accordingly, the amount of carbon stored in wood in the LFW model has been reduced by that amount.

CLT Quantities

							Scheme 1			Scheme 2		
		m^2	mm	m^3		ft^2/m^2	ft^2	in	ft^3		in	ft^3
Flr 2-4	7 ply	4,352	0.245	1066.2		10.76	46,844	9.63	37,573	As 5 ply	6.875	26,838
Roof	7 ply	1,689	0.245	413.81		10.76	18,180	9.63	14,582	As 5 ply	6.875	10,416
Stair Shaft	5 ply	175	0.175	30.625		10.76	1,884	6.88	1,079	5 ply	6.875	1,079
Elev/Stair Shaft	5 ply	337	0.175	58.975		10.76	3,627	6.88	2,078	5 ply	6.875	2,078
Subtotal							**70,536**		**55,313**			40,411

Garage	ft3	wt-lbs
5 ply CLT	9,689	
Glulam	772	
Steel		71000

Walls	ft3	
Interior bearing-258 cf/floor	1,187	From VA- 258CF per floor plus 15% waste etc
Ext Walls 2x6	1,710	10' high x 750 lf of wall at 1 stud/lf x .057 cf/lf x 4 floors
Shear walls 2x6	1,029	12' high x 376lf of wall at 1 stud/lf x .057 cf/lf x 4 floors
Wall sheathing	1,313	1/2"

Floors	ft3
Wood Truss floor	

Wood Truss floor	12,250	305 cf per 1480 sf= .2 cf/sf
2 x 8 at corridor	331	8 cf/1480 sf = .0054 cf/sf
Floor Sheating	3,828	3/4 " Advantech
CLT Floor Scheme 1	55,313	
CLT Floor Scheme 2	40,411	

Carbon calculations were run for all three cost models, LFW, CLT -Hybrid 7 ply (Scheme 1), CLT-Hybrid 5 ply (Scheme 2):

	Unit	LFW	CLT/Hybrid Scheme 1	CLT/Hybrid Scheme 2
Volume of wood products used:	m^3	613	1715	1293
U.S. and Canadian forests grow this much wood in:	minutes	2	5	4
Carbon stored in the wood: *	Kg-CO_2	468,900	1,388,000	1,047,000
Avoided greenhouse gas emissions:	Kg-CO_2	1,079,000	2,950,000	2,226,000
Total potential carbon benefit:	Kg-CO_2	1,587,000	4,338,000	3,273,000
Cars off the road per year	Cars	335	917	692
Equivalent Homes operated per year	Homes	168	458	346

*Stored carbon reduced by 39,100 Kg-CO_2 for concrete slab at 1^{st} floor.

Stored carbon is 296% greater than LFW for 7 ply Scheme 1

Stored carbon is 224% greater than LFW for 5 ply Scheme 2.

V. Conclusion

The next step is to build Shawmut TOD. It is clear that at this point that CLT for midrise structures is more expensive than standard LFW. However, when the advantages of CLT that accrue to the project beyond the structure itself are included, the price differential is within a reasonable range of 2.5% to 5% greater than LFW.

There are also less tangible cost items such as avoidance of weather delays and reduction of time sensitive soft cost and finance costs that can only be realized once CLT/Mass Timber becomes more widely adopted. It is the authors' opinion that additional savings can be realized in MEPFP systems as CLT flat slabs will make installation of these systems faster once those trades have experience with CLT/Mass Timber.

Further study and introduction of prefabrication of exterior walls with elements such as windows, weatherproofing and cladding, could reduce costs and project duration even further.

The report shows significant reduction in cost if 5 ply 175 mm planks can be used. At present, calculations for vibration show that 5 ply planks are beyond accepted limits for vibration. Since manufacturing and transportation limitations preclude the use of 3 span planks, a method of end joining the planks is a possible solution to provide a 3 span condition. There is a current technology called TS3 https://www.ts3.biz/en/technologien/ that could enable the 3 span condition thus saving considerable cost. It is currently under approval for use in the U.S.

Vibration comfort is a subjective criterion. The use of 5ply CLT would make the CLT Hybrid model in the transverse configuration more cost competitive with LFW. Calculations show that the 3-span condition 5 ply system remains above published vibration limits. However, residential use has aspects that can reduce vibrations. It is possible that partitions and other items such as furniture and fixtures in residential construction may add more damping than currently accounted for. A full-scale mockup with 3 floors of a typical apartment layout is suggested as a next step to prove this system.

CLT has clear advantages in terms of carbon sequestration and speed of construction over LFW. It is our hope that the CLT Hybrid system using the layout and design suggested for Shawmut TOD can serve as a template for other projects in New England and beyond.

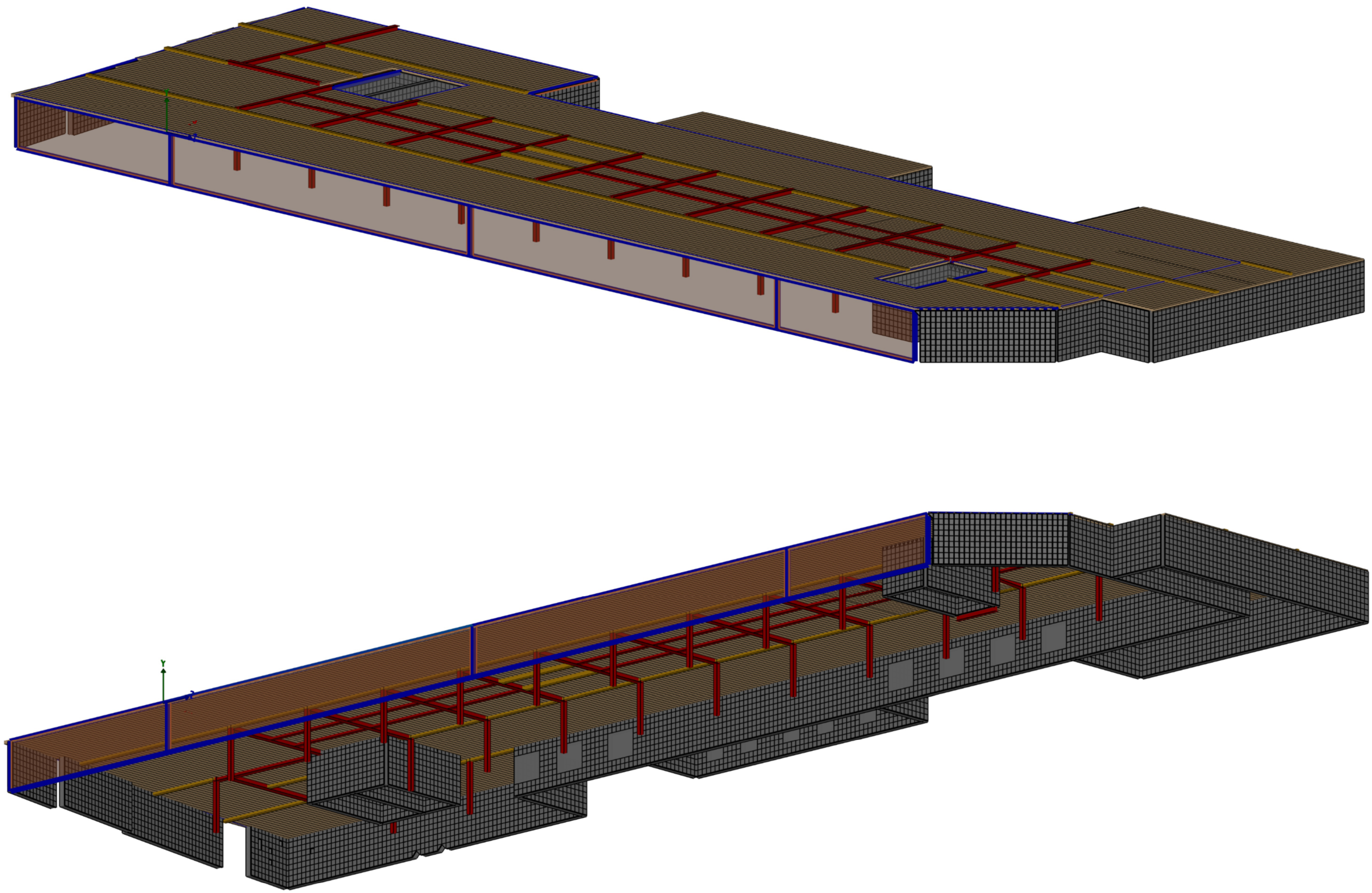


Figure 3
Garage Framing

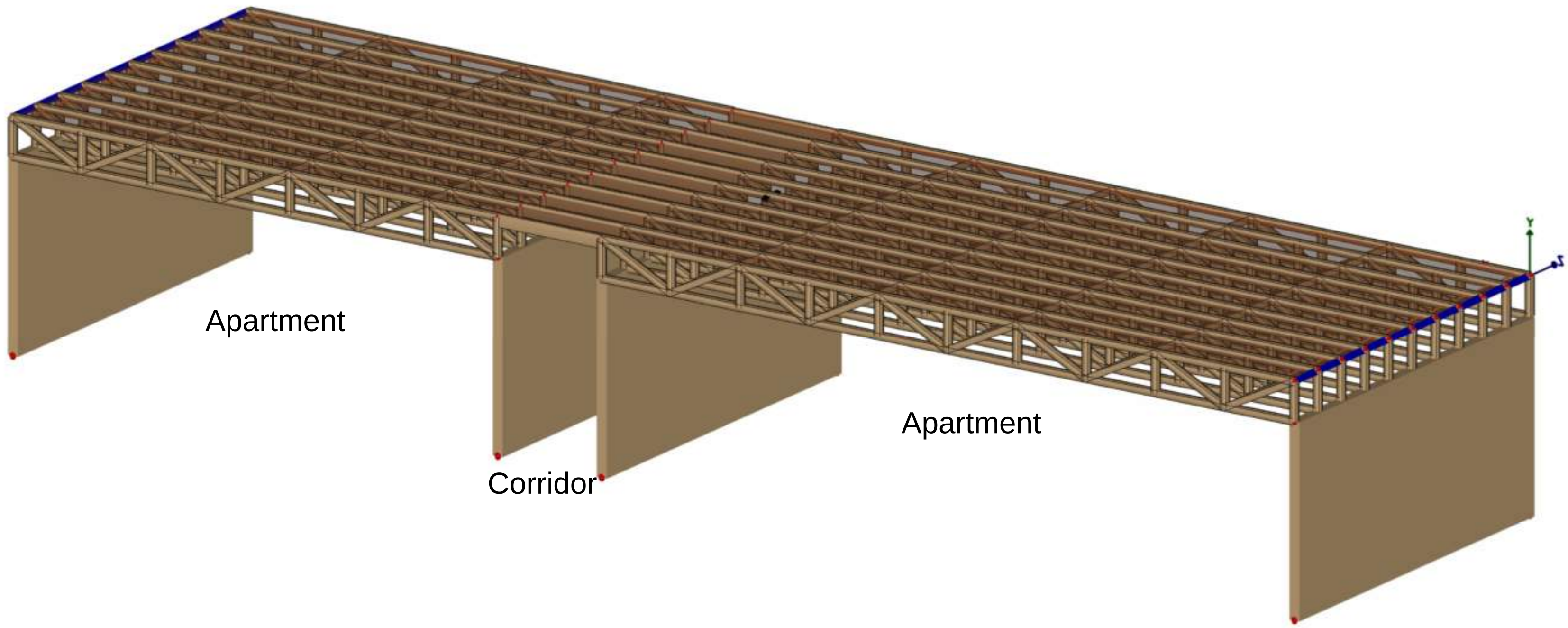
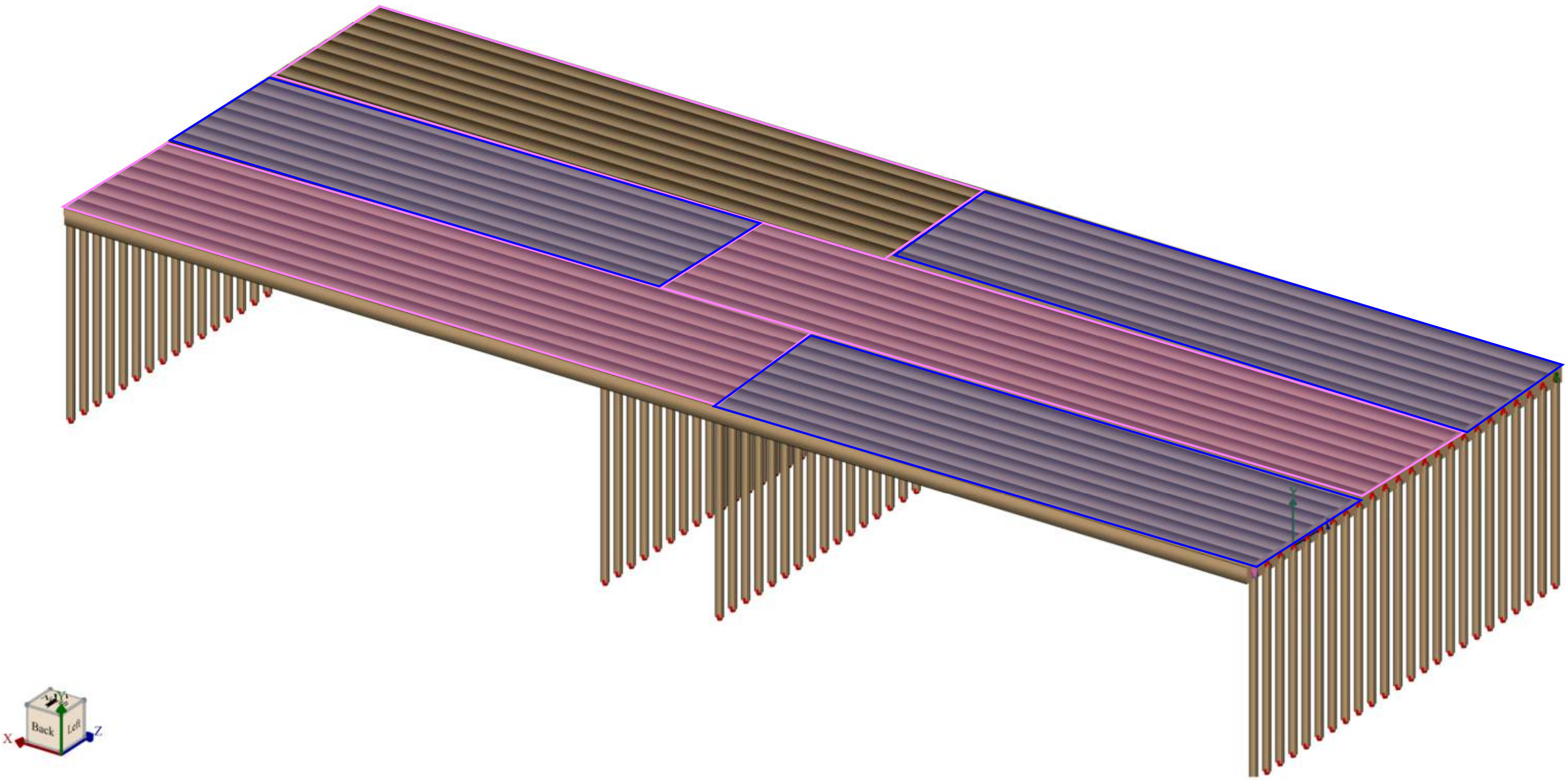
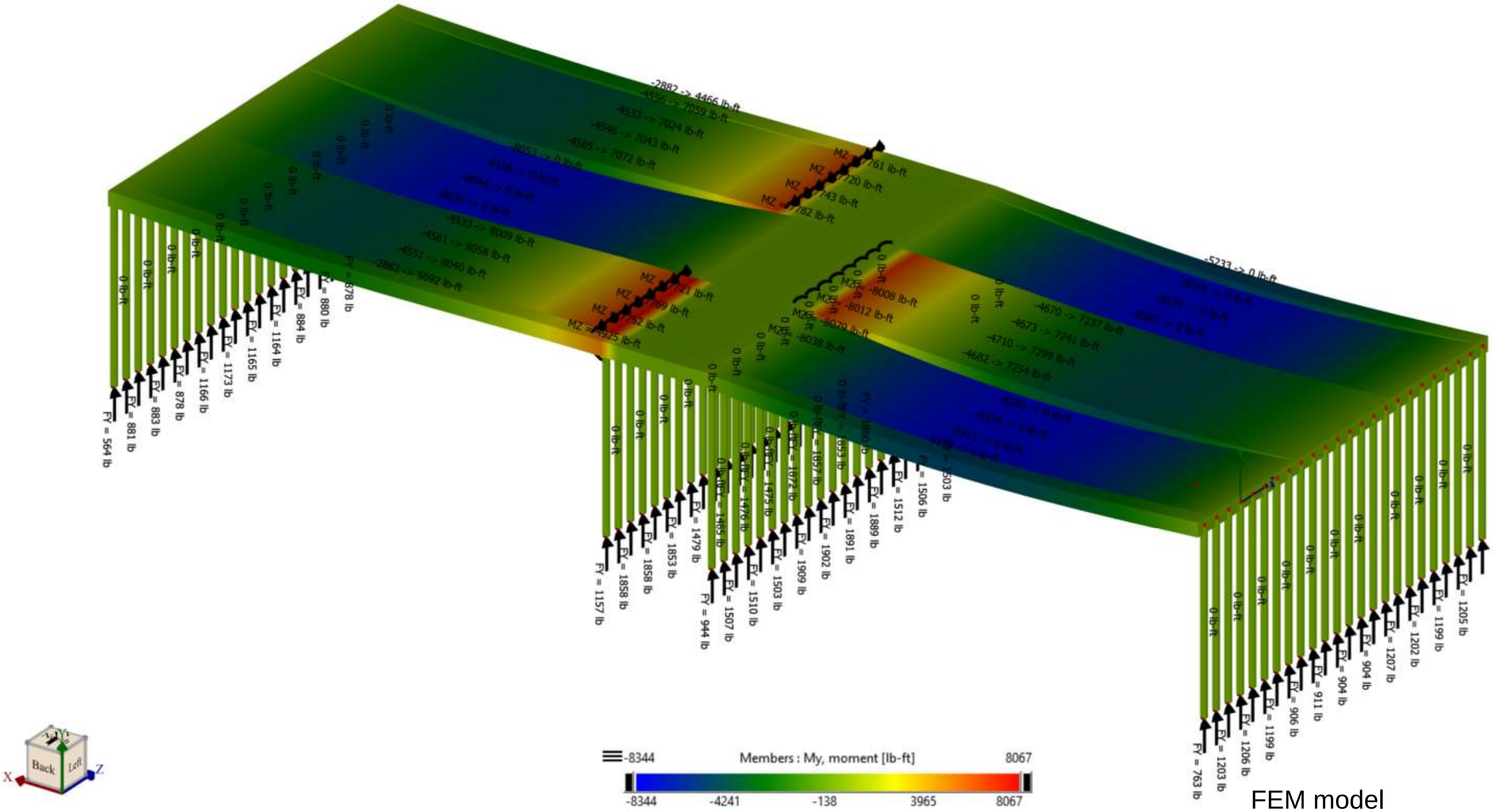


Figure 4
Typical Open
Web Truss
Layout



Shawmut TOD
FEM model
7 ply CLT/ Hybrid bay study

Figure 5
Typical Plank
Framing



FEM model
7 ply E1 CLT/ Hybrid bay
study

Figure 6
Moment Diagram

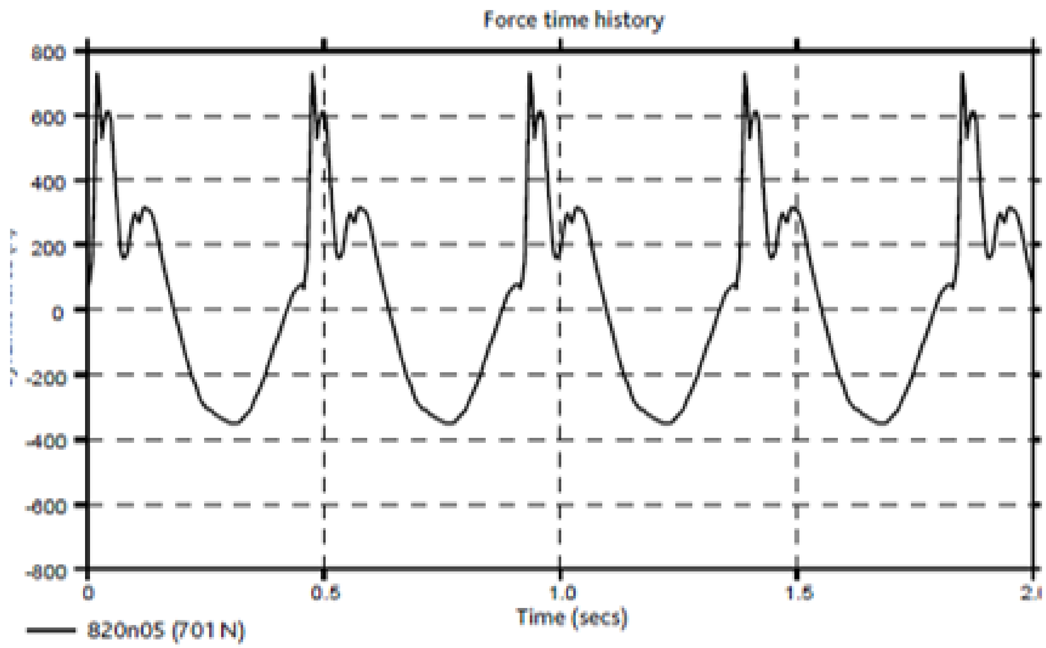


Figure 7
Walking Frequency

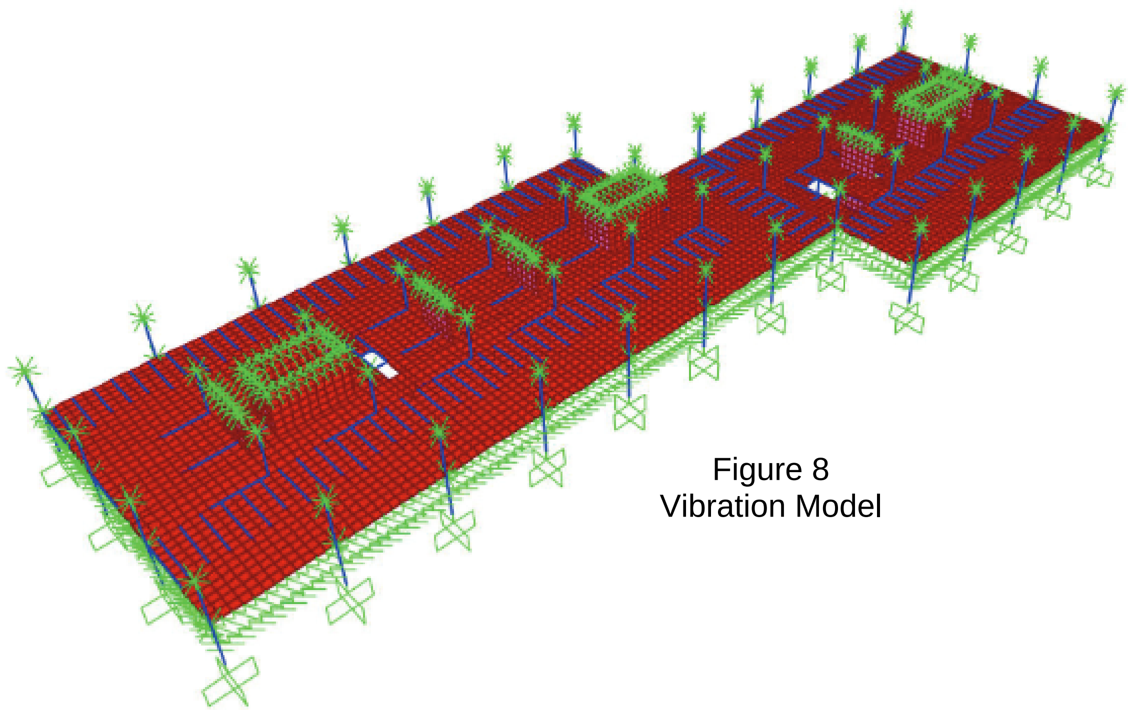


Figure 8
Vibration Model

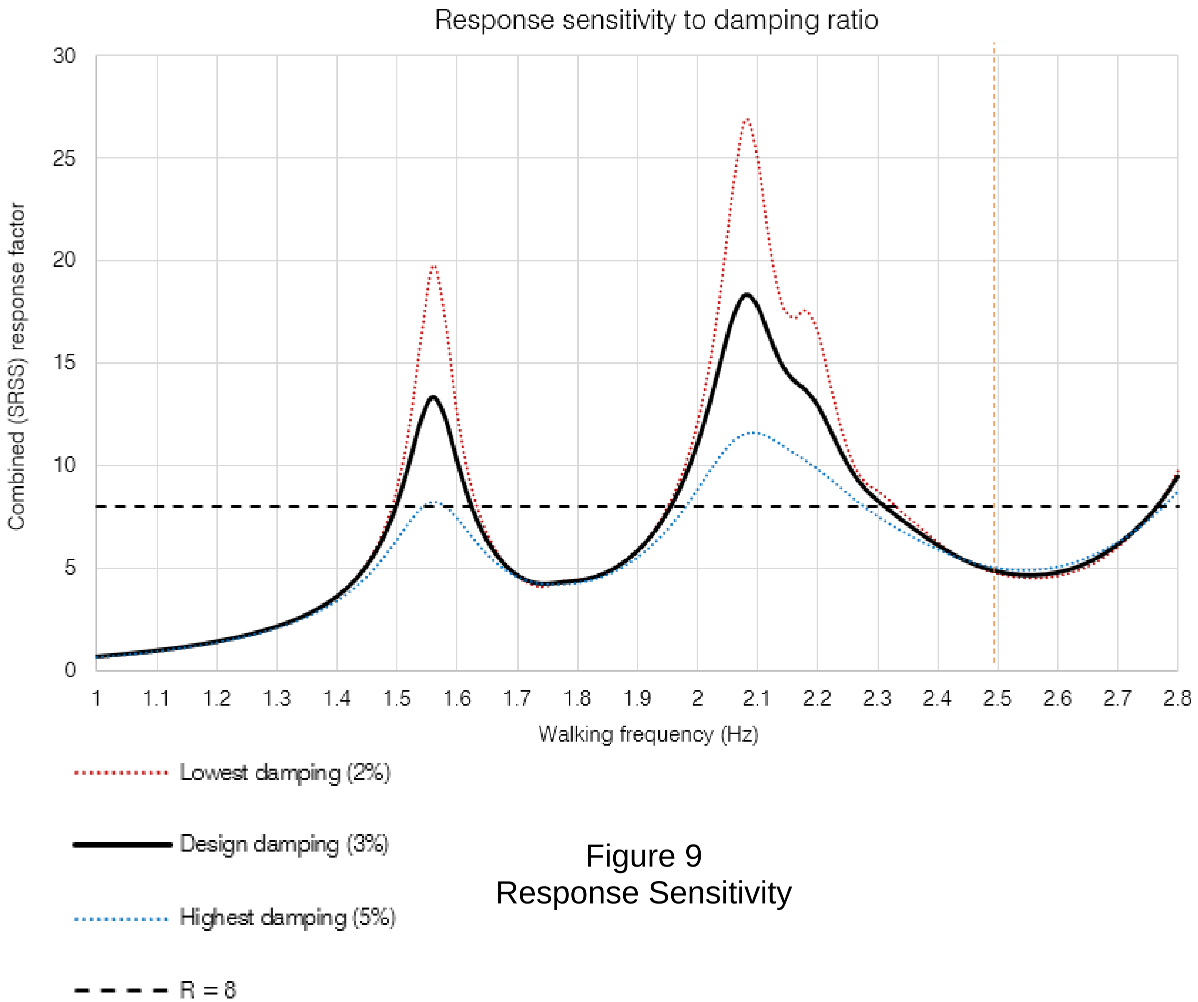


Figure 9
Response Sensitivity

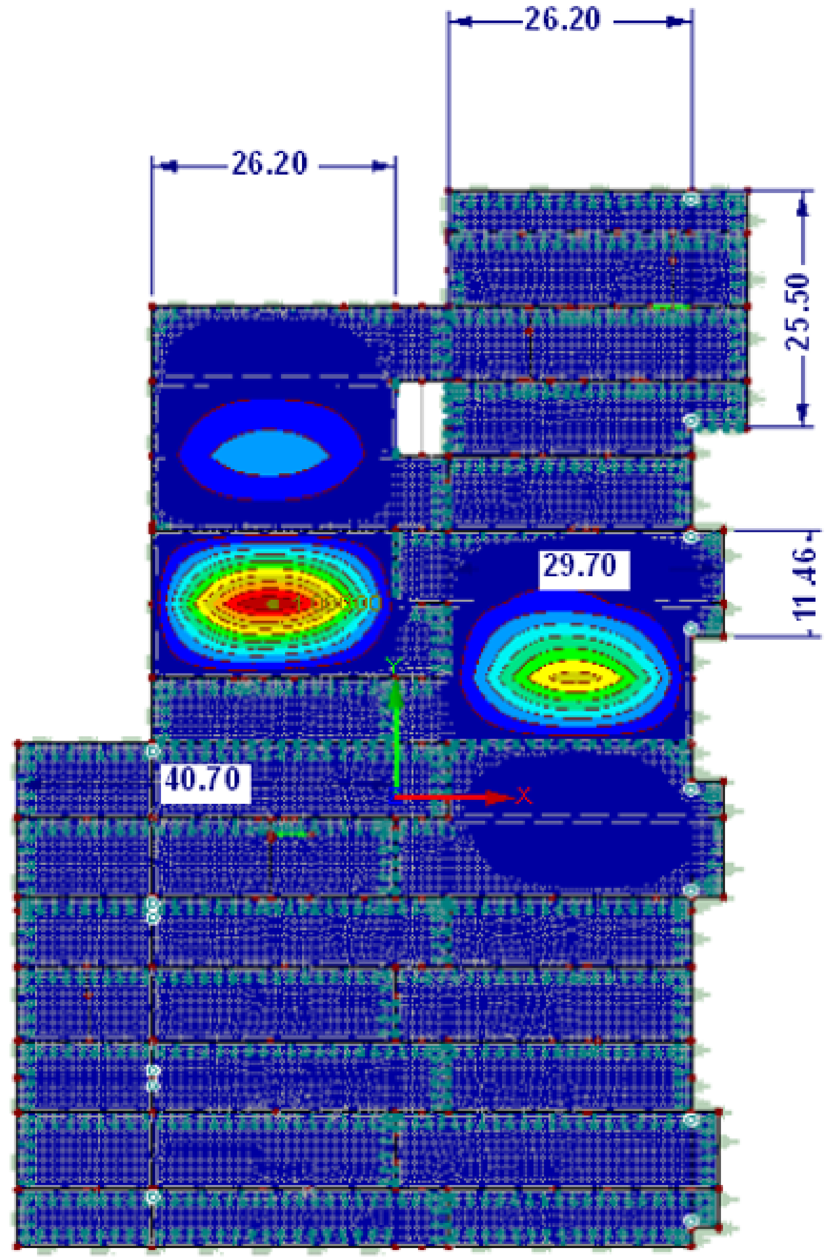


Figure10
Response Sensitivity