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# INFLUENCE OF CONNECTING ELEMENTS IN HORIZONTAL LOAD-BEARING SYSTEM OF A MASS TIMBER OFFICE BUILDING

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### *Abstract*

This paper presents an analysis of the behaviour of a wooden building and its dynamic parameters, considering different methods of modelling the connections between elements, with a focus on the structural elements that are part of the horizontal load-bearing system. The building's structural elements are made of GLT, CLT, and LVL components, with a unique horizontal load-bearing structure consisting of diagonals and a core made of CLT panels. Special attention is given to the connections of the core and the modelling of their impact on the response of the structure. A parametric analysis was conducted on four models, each employing different methods of modelling the connections between the CLT panels of the core. Based on these models, a comparison of the primary dynamic parameters, internal forces in the elements, and internal forces in the connections was made. Finally, the conclusion is drawn regarding the impact of different modelling methods on the dynamic parameters and internal forces.

*Keywords: CLT building, dynamic parameters, connection stiffness, CLT core, seismic analysis*

## 1. Introduction

New construction in seismically active regions, particularly in Croatia, typically involves reinforced concrete structures or masonry. The use of materials such as steel and wood is mainly reserved for industrial buildings or those with specific aesthetic requirements, or when construction speed dictates the choice of material. While wood was traditionally used for house construction in the interior of Croatia, building with wood requires expertise and skills that have gradually faded over time. The widespread use of reinforced concrete and masonry was also driven by greater economic efficiency. The emergence of wood-based products has expanded the potential for using wood as a construction material, simplifying construction processes, and the growing global emphasis on environmental preservation, renewable energy, and reducing energy consumption during construction has played a significant role [1].

With the development of wood-based composite materials such as Cross-Laminated Timber (CLT), Glue-Laminated Timber (GLT), and Laminated Veneer Lumber (LVL), the potential for incorporating wood into structures has greatly increased, meeting the demands of modern construction [2]. Elements made from these materials can meet nearly all structural requirements and can effectively compete with conventional materials in high-rise buildings. The load-bearing structure for vertical loads consists of traditional elements like GLT beams and columns, as well as CLT floor slabs and walls [3]. Horizontal stability is typically achieved through diagonal braces that form stabilizing ties or braced frames. The development of CLT also allows for the use of walls to ensure horizontal stability. Some manufacturers conduct tests focusing on seismic actions and highlight the importance of connection components, providing engineers with the opportunity to design entire structures using wood.

In structural engineering practice, connections between elements are generally modelled using idealized assumptions, rather than incorporating their actual stiffness, as these models are considered sufficient for satisfactory results. The specific geometry of the building in question raised the issue of how the stiffness of connections affects the structure's response and the distribution of internal forces

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within the load-bearing system under horizontal forces. This study focuses on the diagonals forming stabilizing ties in the façade planes, as well as the core composed of CLT walls.

## 2. Structural system and methodology of the analysis and structural modelling

The subject of the analysis is an office building (Fig. 1) with 3 levels (ground floor + 2 stories). The structure has a rectangular floor plan with dimensions of 30 x 10 meters. The height of the first story is 4,48 m, the height of the second story is 3,2 m and height of the third story is 4 m. Total height of the building 11.8 m.

The load-bearing structure for vertical loads is made up of slabs, beams, columns, and walls. The slabs are freely supported on beams and walls, and they bear loads only in the transverse direction of the building. Thickness of slabs is d = 18 cm. They rest on beams that extend longitudinally through the building along three axes, spaced at 5-meter intervals. The column grid is defined with a 5.0 x 5.0 meter spacing. The longitudinal beams are made of glued laminated timber (glulam) of class GL28h, b/h = 24/50 cm while two massive transverse beams, replacing columns in axes C and E, are made of laminated veneer lumber (LVL), of class GL75 b/h = 30/60 cm.

Horizontal load-bearing system consists of diagonals that form bracing in the facade planes, as well as a core made of CLT panels. The core of the structure is made of CLT (Cross-Laminated Timber) and consists of three walls positioned next to one facade plane of the building as shown in Fig. 1. Two walls are placed in the shorter direction of the building, each with a length of 3.7 meters, and they do not have openings. A wall extends along the longitudinal direction, with a length of 5 meters, and has openings for doors. Thickness of walls at ground level is d = 22 cm, and d = 14 cm on the first and second floor. The longitudinal wall should cover width of 5 meters, but since the panels are made of CLT, they are limited by one shorter side, which most manufacturers produce up to 3.5 meters Therefore, it was decided that the wall in the longitudinal direction would be made of two panels, which are connected by connectors that ensure that panels act as a one part. The braces (diagonals) are made of glued laminated timber (glulam) of class GL28h, with cross-section dimensions of b/h = 24/24 cm.

First, a model with rigid connections (Model 1) was created and presented, and then flexible connections will be modelled using links in the critical parts of the structure (Model 2). A model was also created that uses links to connect elements, but the links are rigid (Model 3). A comparison was made between models with rigid connections and those with flexible connections. This paper presents but also expands authors' master thesis and contributes to it. New improvements were made in terms of modelling flexibility of bracing connections to columns and beams.

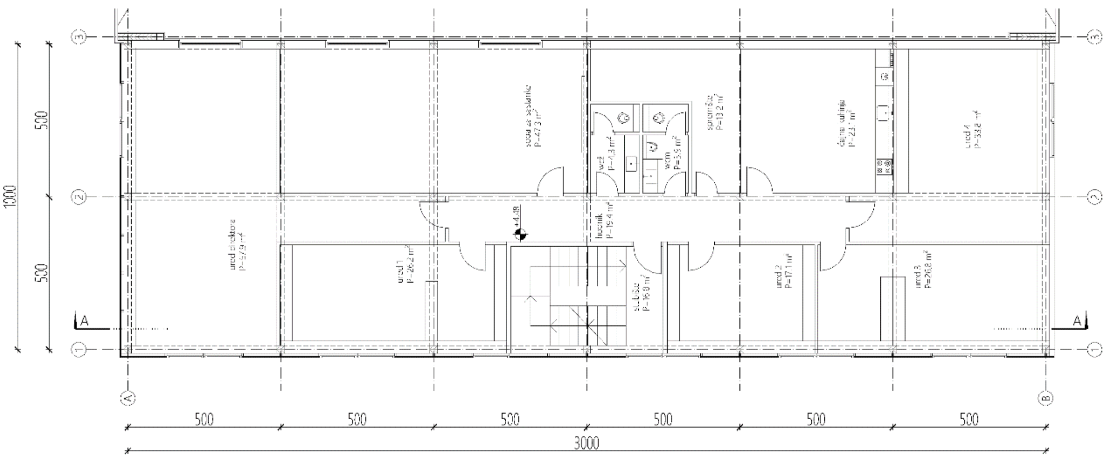


Figure 1. Characteristic floor plan of the building

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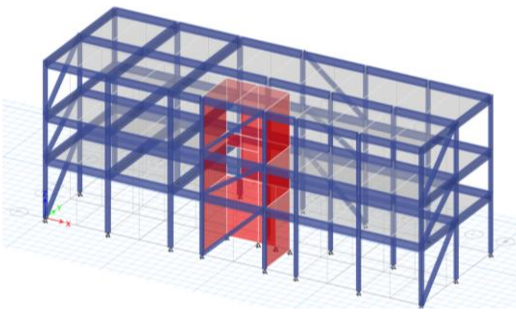
## 2.1 Numerical model with rigid joints (Model 1)

In this chapter modelling of an idealised numerical model with rigid joints will be presented. This model (Model 1) was used for design of structural elements and its results will be compared to and verified with a more complex model that includes flexibility of joints. End releases for bending moment were used to model correct behaviour of the core and slabs. Moment release was also applied on ends of bracing elements.

### 2.1.1 Geometric and material properties of model with rigid joints

The plan view of the characteristic floor and 3D model of the structure are shown in Fig. 2 In the next models this won't be shown, because general layout of the model is the same. Emphasis will be put on modelling of connections.

a)



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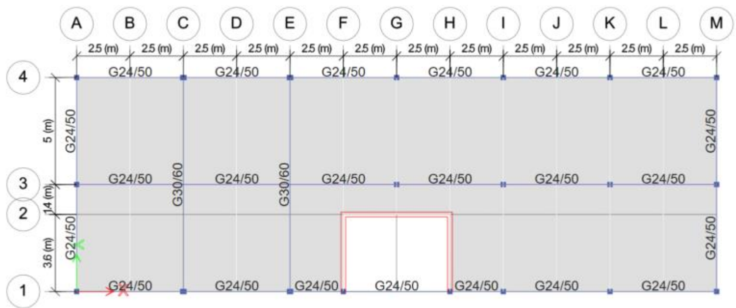


Figure 2. a) Numerical model; b) Ground floor plan with cross sections

CLT panels have properties that are defined by the arrangement of the laminations, depending on the layers. Since CLT is a composite (laminate), the mechanical properties were calculated using composite theory [10]. The modulus of elasticity differs in two orthogonal directions in the plane of the panel. The panel is made of wood of quality grade C24, and the manufacturer offers CLT panels with three, five, or seven layers [6]. For the walls on the upper floor and slabs, CLT elements with five layers were chosen, while for the ground floor walls, elements with seven layers were selected. Characteristics of materials and cross sections are given in Tables 1, 2 and 3.

Table 1. – Characteristics of materials [4] [5] [6]

| **Material** | **E1** [Mpa] | **E2** [Mpa] | **E3** [Mpa] | **G12** [Mpa] | **G13** [Mpa] | **G23** [Mpa] | **ν** | **γ** [kN/m$^3$] |
|---|---|---|---|---|---|---|---|---|
| GL28H | 10200 | 420 | 420 | 780 | 780 | 780 | 0,2 | 4,1 |
| GL75 | 15300 | 470 | 470 | 850 | 850 | 850 | 0,2 | 8,9 |
| CLT, d = 14 cm | 7972 | 3411 | 311 | 690 | 690 | 690 | 0,2 | 5 |
| CLT, d = 18 cm | 7465 | 3367 | 3367 | 690 | 690 | 690 | 0,2 | 5 |
| CLT, d = 22 cm | 8160 | 3367 | 3367 | 690 | 690 | 690 | 0,2 | 5 |

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Table 2. – Characteristics of beam and column cross sections

| **Cross section** | **Material** | **Height [ mm]** | **Width [mm]** | **I22** | **I33** |
|---|---|---|---|---|---|
| G24/50 | GL28H | 500 | 240 | 0.5 | 0.5 |
| G30/60 | GL75 | 600 | 300 | 0.5 | 0.5 |
| S24/24 | GL28H | 240 | 240 | 0.5 | 0.5 |
| S24/30 | GL75 | 300 | 240 | 0.5 | 0.5 |

Table 3. – Characteristics of CLT panel cross sections

| **Cross section** | **Modelling** | **Material** | **Thickness [mm]** | **m11** | **m22** | **m12** |
|---|---|---|---|---|---|---|
| d = 18 cm | Shell thin | CLT, d = 18 cm | 180 | 0.5 | 0.000001 | 0.5 |
| d = 14 cm | Shell thin | CLT, d = 14 cm | 140 | 0.5 | 0.5 | 0.5 |
| d = 22 cm | Shell thin | CLT, d = 22 cm | 220 | 0.5 | 0.5 | 0.5 |

Bending stiffness of all cross sections were reduced in according to Eurocode 8 [7]. The design of structural elements and connections was carried out according to Eurocode 5 [8] and CLT Engineer Manual [9].

### 2.1.2 Load Analysis

In this chapter analysis for vertical and horizontal loads is given with summary of load cases and load combinations. Only load cases and combinations that are needed for dynamic and seismic analysis of the structure will be considered because design of structural elements was carried out in master's thesis [10]. Wind load is not considered because dominant horizontal load is seismic load. This load analysis applies to all models that will later be presented.

#### 2.1.2.1 Vertical loads

Permanent loads are taken as follows according to norms: HRN EN 1991-1-1:2012 [11] and national annex HRN EN 1991-1-1:2012/NA:2012 [12] :

- Dead load of all structural elements is taken into account automatically in ETABS (*Dead*)
- Additional dead load is taken into account (*DS*) ; shown in Table 4

Service loads are taken for each floor according to norms: HRN EN 1991-1-1:2012 [11] and national annex HRN EN 1991-1-1:2012/NA:2012 [12]. Their intensities are shown in Table 4.

Snow load is taken for the roof according to norms: HRN EN 1991-1-3:2012 [13]; national annex HRN EN 1991-1-3:2012/NA:2012 [14]. Intensity are shown in Table 4.

Table 4. – Load intensity for vertical loads

| **Level** | **Δg (kN/m$^2$)** | **q (kN/m$^2$)** | **s (kN/m$^2$)** |
|---|---|---|---|
| Roof | 0,80 | 0,60 | 1,00 |
| 2nd floor | 2,00 | 3,00 | / |
| 1st floor | 2,50 | 2,00 | / |

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#### 2.1.2.2 Horizontal load

Horizontal loads acting on this structure are wind and seismic load. Wind load will not be considered in this paper because seismic load is governing horizontal load as it is proven in the thesis [10] [15] [16].

Data needed for spectral analysis:

- Ground type: C
- Behaviour factor: q = 2,5
- Peak ground acceleration for $T_p = 95$ years: $a_g = 0{,}133$ g [17]
- Peak ground acceleration for $T_p = 475$ years: $a_g = 0{,}266$ g [17]

### 2.1.3. Load cases and combinations

Load cases for vertical and horizontal loads were made:

- Vertical loads: Dead, Additional dead, Live and Snow
- Horizontal loads – load cases for 95-year and 475-year return period were made, also for both return periods response spectrum 1 and response spectrum 2 were considered

Load combinations that are of importance in this paper are seismic load combinations because we are observing behaviour of the structure under horizontal loading. Seismic load combination according to Eurocode 8[7] is: 1,0 x Dead + 1,0 x Additional dead + 0,3 x Live + 1,0 x Seismic load case

## 2.2 Numerical model with flexible joints (Model 2)

After selection of connections between structural elements, Model 2 was made. Flexibility of the joints was added in elements that make horizontal load bearing system, which includes bracing and CLT core. In this chapter nature of modelled connections and modelling of flexible joints is explained, with calculations of their stiffness and the way it was considered in structural analysis.

### 2.2.1 Slip modulus and stiffness of connections

For connecting CLT core panels Rothoblaas connectors were used [18]. There are three basic connectors that are analysed in this paper and are shown in Fig. 3 and Fig. 4:

1. Tension angle brackets (THT) → WHTPT 720 and WHT 740
2. Shear angle brackets (TITAN S) → TCS 240 and TTS 240 (Fig.4)
3. Connectors for structural panels → SLOT (Fig.4)

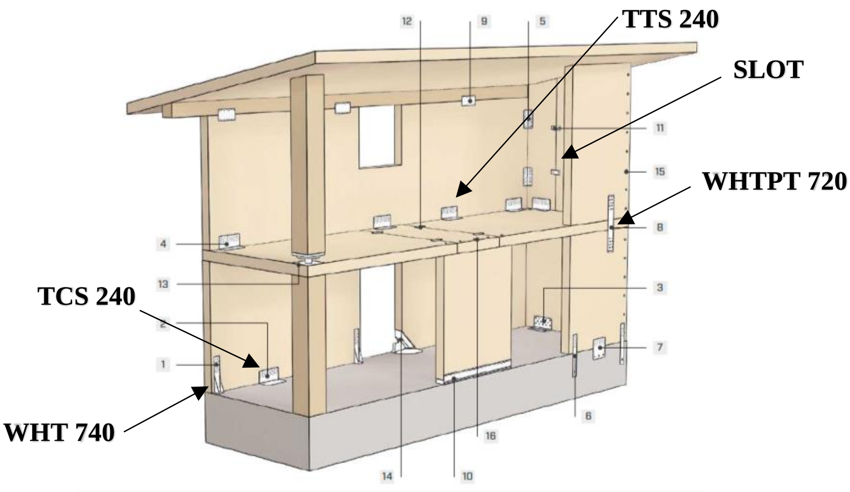


Figure 3. Illustrative representation of CLT wall connectors in a building [18]

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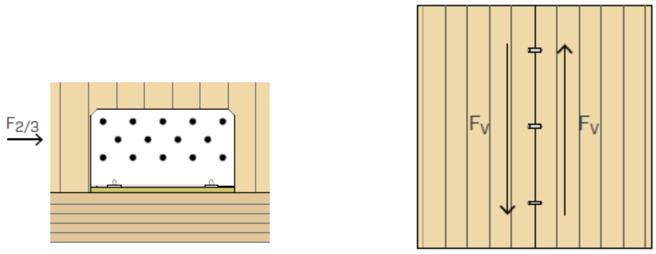


Figure 4. a) Scheme of TTS 240/TCS 240 [11]; b) Scheme of SLOT connector [18]

For calculation of joint stiffness Eurocode 5 is used. According to Eurocode slip modulus $K_{ser}$ is a numerical value that defines stiffness of a connection. It can be used to define the translational stiffness of each joint. [7]

$$K_{ser} = n \cdot \frac{{\rho_m}^{1,5} d^{0,8}}{30} \left[\frac{N}{mm}\right]$$

Rotational stiffness is something that shouldn't be neglected, especially when discussing the connections between the wall and the foundation, as they are directly connected to the fixed restraint. Rotational stiffness for connections used in this model wasn't given, but will instead be taken from the scientific paper (work) [20].

Axial stiffness of a connection between bracing and columns/beams is also considered as bracing is important part of horizontal load bearing system. It is crucial that all elements that take part in transfer of horizontal loads are modelled with flexible joints. Rigid joint in axial direction of the bracing would make it too stiff, and realistic distribution of internal forces wouldn't be achieved. Translational stiffness of all connections is given in Rothoblass catalogue [11] but will not be used in this paper, it's given only for informative purposes. With their use Stiffness of all joints in Model 2 is calculated according to Eurocode 5 [7] and Eq. (1). In Table 5 stiffness of used connections is given.

Table 5. - Slip modulus and rotational stiffness of observed connections

| **Connection type** | **$K_{ser}$ (EC5)** | **$K_{ser}$ (Rothoblaas)** | **Rotational stiffness** |
|---|---|---|---|
| | kN/m | kN/m | kNm/rad |
| TCS 240 – wall to foundation (shear) | 37072 | 8200 | 390 |
| TTS 240 – floor to wall (shear) | 37072 | 5600 | 390 |
| WHTPT 720 – wall to wall (tension) | 74144 | - | - |
| WHT 740 – wall to foundation (tension) | 130462 | - | - |
| SLOT – wall to wall (in plane shear) | 25000 | - | - |
| Bracing – column/beam connection | 49718 | - | - |

### 2.2.2 Flexible joints in structural model and analysis

Flexible joints in Model 2 were modelled as link elements. Link element is an element that joins two nodes. Each link element can be modelled with six degrees of freedom that are represented with six flexible springs [21]. Stiffness of each spring can be defined as linear or non-linear. In this model all springs were given linear properties. Parameter that is used to define linear properties of links is effective stiffness. Effective stiffness that is attributed to specific links is slip modulus of a connection that is presented in Table 5.

Stiffness modelled with slip modulus is taken account in specific direction for each link. In Table 6 propertied of each link element are given.

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Table 6. - Effective stiffness of joints in CLT core

| Link element | U1 [kN/m] | U2 [kN/m] | U3 [kN/m] | R3 [kNm/rad] |
|---|---|---|---|---|
| Link 1 | 100000000 | - | 100000000 | - |
| Link 2 (TTS 240) | 100000000 | 37072 | 100000000 | 390 |
| Link 3 | 100000000 | - | 100000000 | - |
| Link 4 (TCS 240) | 100000000 | 74144 | 100000000 | 780 |
| Link 5 (SLOT) | - | 25000 | fixed | - |
| Link 5.2 (SLOT) | - | 50000 | fixed | - |
| Link 6 (TTS 240) | 37072 | 37072 | 37072 | 390 |

Axial stiffness of bracing end joints that is presented in Table 5 is modelled as flexible end release. In Fig.5 isometric view of modelled links and mesh is shown. Link elements are modelled with length of 10 cm, and mesh is created so that it represents realistic spacing between connectors.

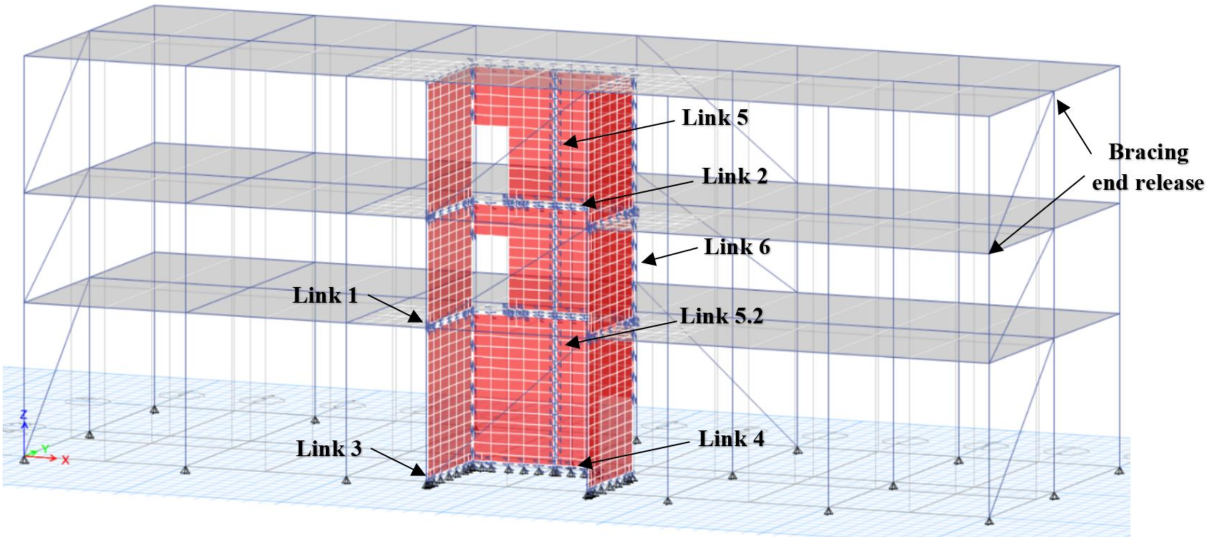


Figure 5. Isometric view of Model 2 with emphasis on CLT core and link elements

## Dynamic and seismic analysis results and comparison

### 3.1 Comparison of dynamic parameters

In this chapter results of modal analysis are given trough comparison of Model 1 and Model 2. Table 7 shows comparison of mode shapes with corresponding vibration periods and Fig.6 and Fig.7 comparison of mass activation by mode shapes in different directions. It is expected that the structural model with flexible joints will be softer than the one with rigid joints. That should show trough higher numerical values of vibration periods. Mode shapes and mass activation are expected to stay similar.

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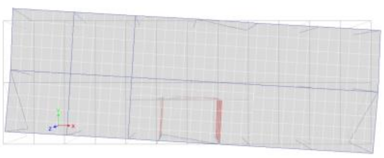
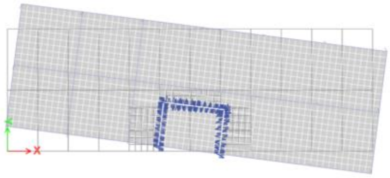
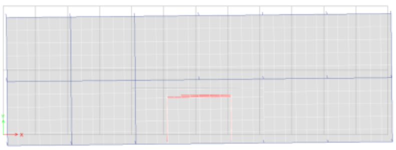
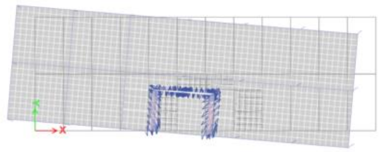
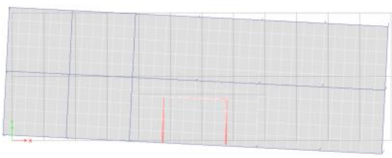
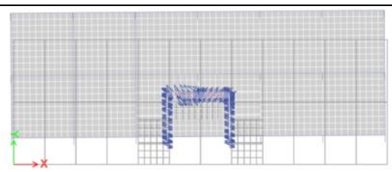
Table 7. - Graphical display of mode shapes and corresponding vibration periods

| **Mode shape** | **Model 1** | | **Model 2** | |
|---|---|---|---|---|
| | **Period [s]** | **3D view** | **Period [s]** | **3D view** |
| 1 | 0,371 |  | 0,623 |  |
| 2 | 0,342 |  | 0,545 |  |
| 3 | 0,327 |  | 0,495 |  |

a) b)

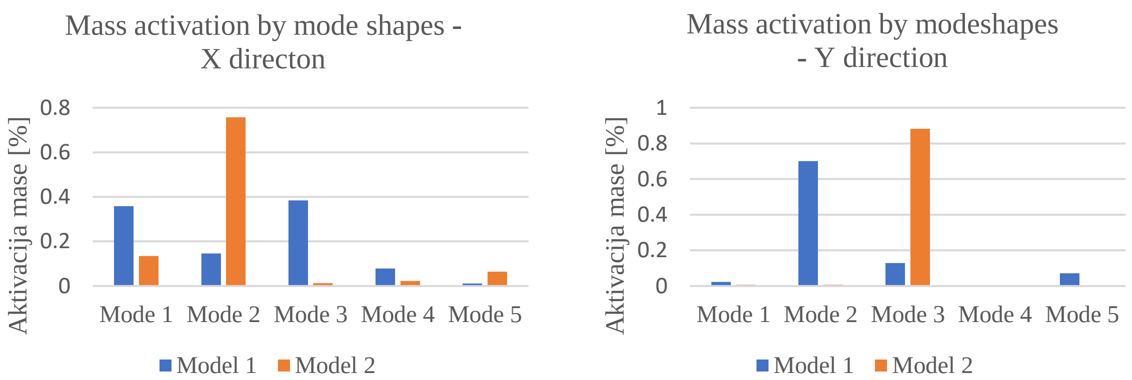



Figure 6. a) Translation in X direction by modes; b) Translation in Y direction by modes

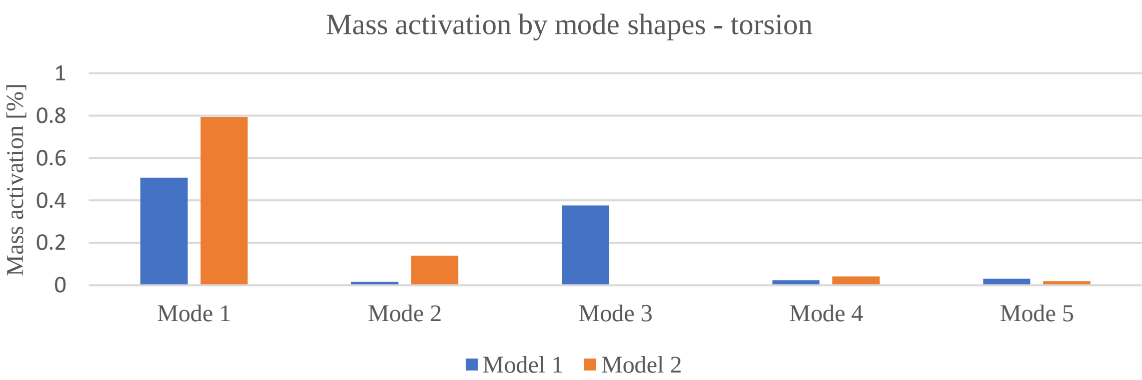



Figure 7. Graphic display of mass activation by modal shapes - torsion

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It is visible from the results that first mode stayed in torsion but with significantly higher vibration period and mass activation. Second mode shape changed, in Model 1 building translates in Y direction and in Model 2 structure translates in X direction. Accordingly, the third mode change too, Model 1 translates in X direction and Model 2 in Y direction. Overall, it is visible that the vibration periods are higher.

### 3.2 Displacements and deformation

In Fig.8 and Fig.9 maximum story displacement and in story drift are shown for both models. Fig.10 and Fig.11 display shear force distribution in all stories for both response spectrums. In Fig.12 maximum displacement of chosen elements that are representative is shown, one corner column and CLT core wall in axis 2.

a) b)

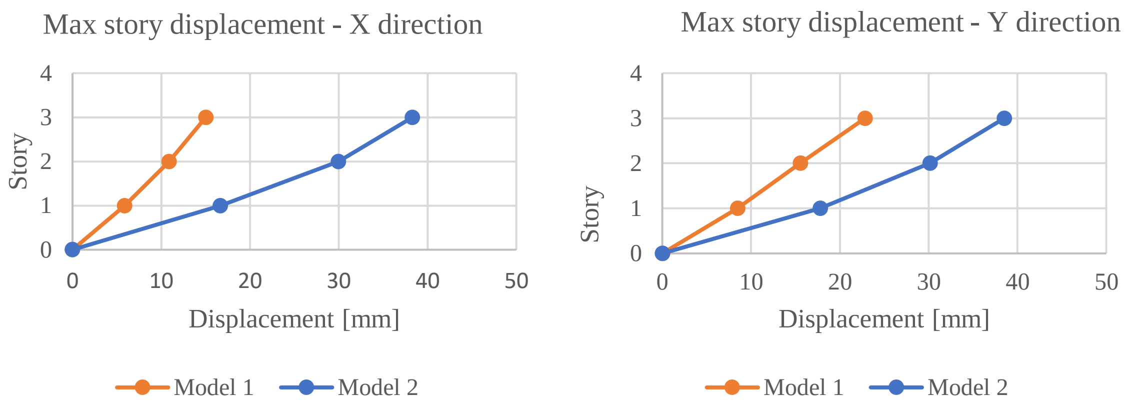


Figure 8. a) Graphic display of maximal story displacement in X direction; b) Graphic display of maximal story displacement in y direction

a) b)

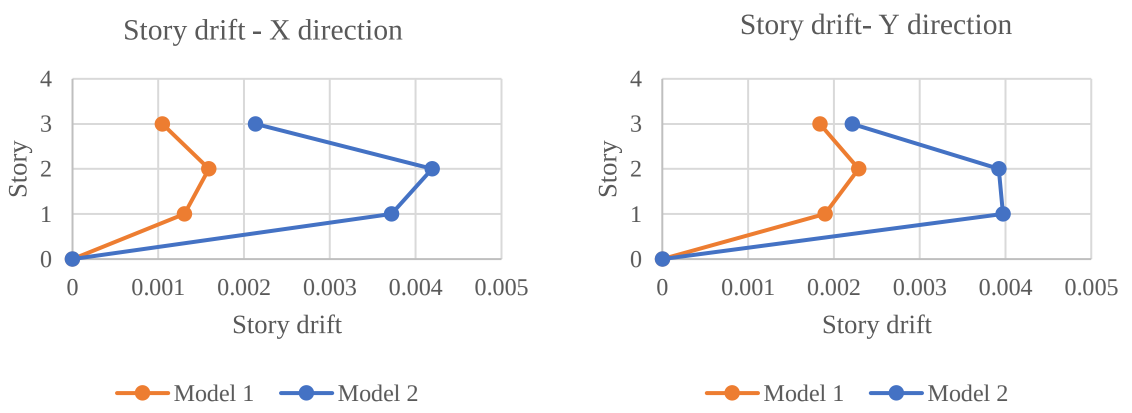


Figure 9. a) Graphic display of story drift in X direction; b) Graphic display of story drift in Y direction

As expected, both maximum story displacement and story drift are higher in Model 2. Less stiffness leads to bigger displacements and deformation. One information is interesting and that's shift in maximum story drift from story 2 to story 1 in Y direction when we compare Model 2 to Model 1.

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a) b)

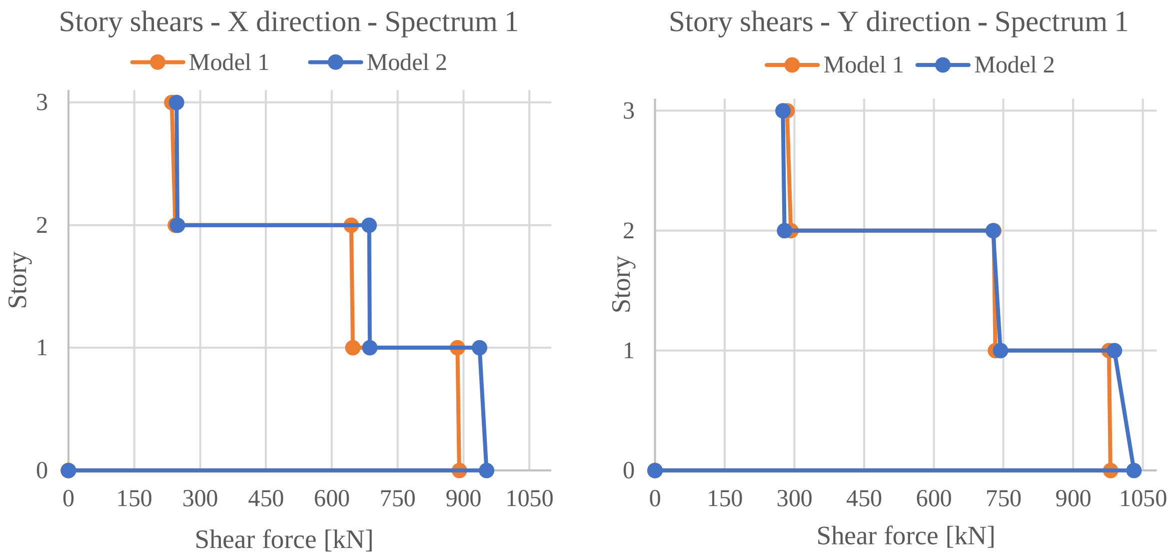


Figure 10. a) Graphic display of story shears in X direction for spectrum 1; b) Graphic display of story shears in Y direction for spectrum 1

a) b)

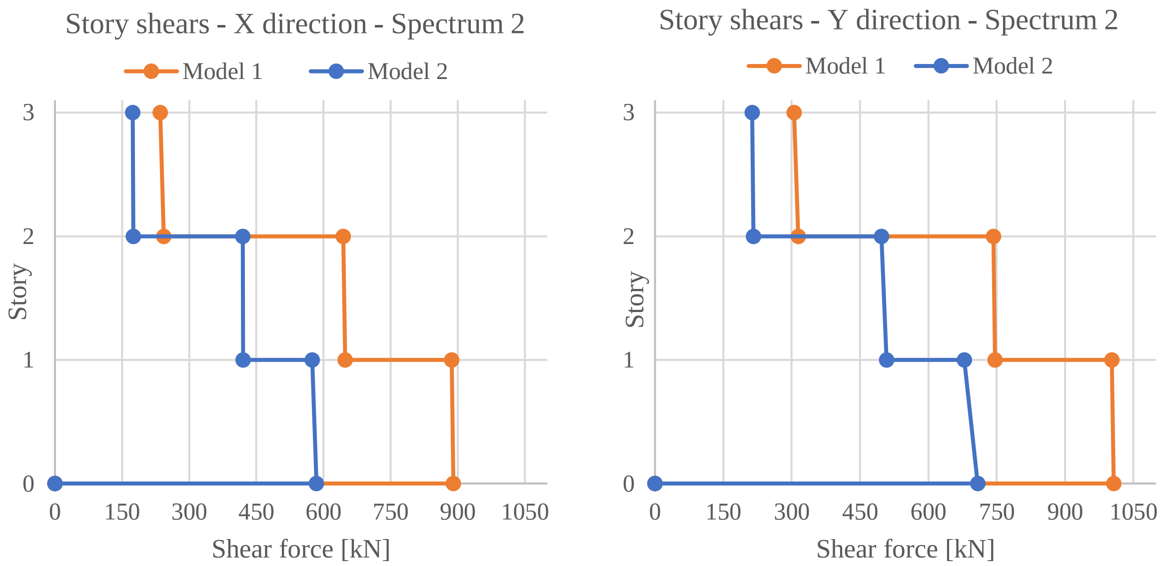


Figure 11. a) Graphic display of story shears in X direction for response spectrum 1; b) Graphic display of story shears in Y direction for response spectrum 2

It is visible that governing response spectrum for Model 2 is spectrum 1. In comparison with response of Model 1, Model 2 has more visible difference between base shear values considering both response spectrums. This is due to higher period of vibration. Base shear in Model 1 isn’t very much different when comparing two response spectrums.

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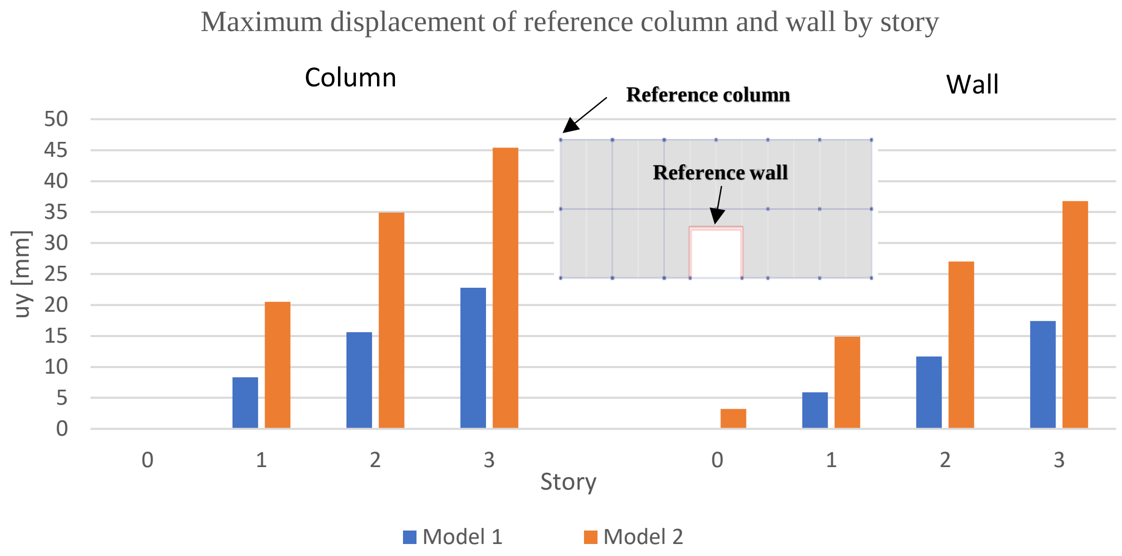



Figure 12. Graphic display of maximum displacement of reference column and wall by story

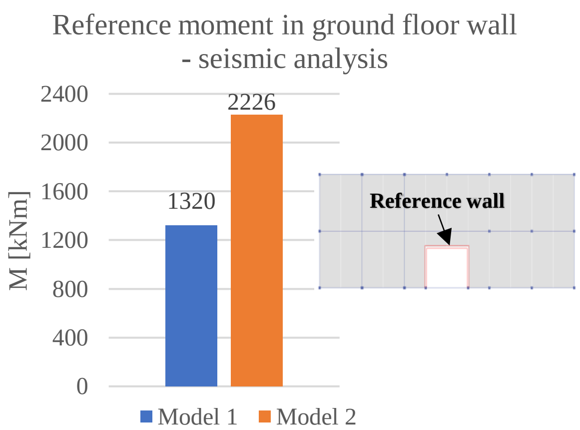
Fig. 12 shows that horizontal displacement of chosen column and beam are much higher in Model 2. Column was chosen so that it's far enough from the core walls, but as it is visible change in displacement is the same and values are similar.

Results shown in Fig. 8 – 11 are expected, they confirm that horizontal stiffness of Model 2 is lesser than that of Model 1, since Model 2 has flexible joint connections in all its structural elements that partake in horizontal load bearing system. As a result, displacement and relative displacement is greater in Model 2 and governing response spectrum for seismic analysis is response spectrum 1.

### 3.3 Internal forces in the elements of the structure

In this chapter graphic displays of internal forces are given for structural elements that make horizontal load bearing system. In Fig.13 values of moment and shear force on the bottom of the ground floor wall and on Fig.14 of the first floor wall are shown. Fig.15 shows axial force in reference bracing element. Since Model 2 is softer horizontally than Model 1, different distribution of internal forces is expected.

a) b)



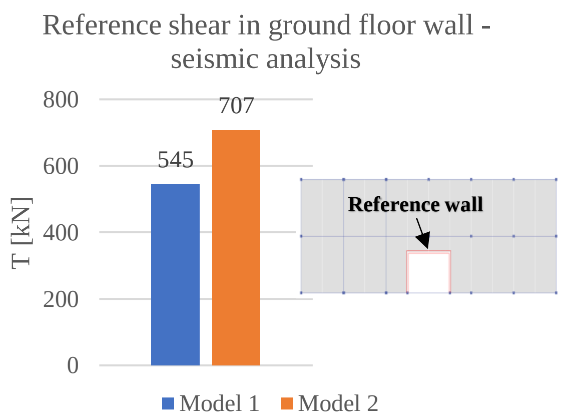




Figure 13. a) Bending moment comparison in reference wall – ground floor; b) Shear force comparison in reference wall – ground floor

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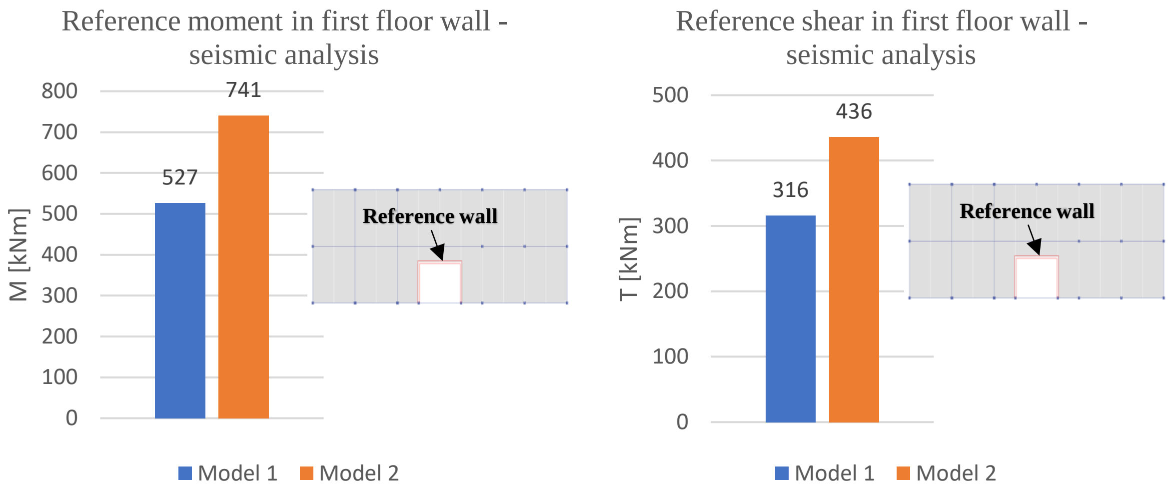


Figure 14. a) Bending moment comparison in reference wall – first floor; b) Shear force comparison in reference wall – first floor

In Fig.13 and Fig.14 bending moment and shear force on the bottom of reference walls are shown. Raise of both values of bending moment and shear force are observed. Which is interesting, since stiffness of core is lower than in Model 1.

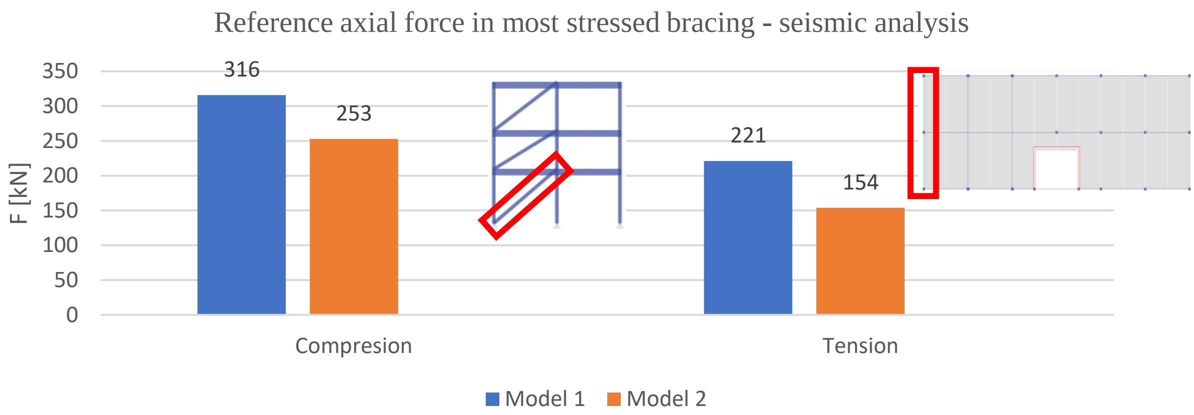


Figure 15. Graphic display of axial force in most stressed bracing element for seismic combination

In Fig.15 it's visible that there's a decrease in axial force in bracing elements in Model 2 and is expected since flexibility of bracing connections was introduced in Model 2.

Results clearly show that CLT core took more shear force from seismic load and that axial force in bracing has decreased. Since we introduced axial flexibility for bracing elements this internal force distribution is not unusual, it shows that CLT core is stiffer than bracing when joint connection flexibility is introduced in these elements. Drops are not gigantic, but they are significant and show how the structure behaves. It can be assumed that if needed we can increase stiffness of bracing connections with columns and beams to alleviate the CLT core and its connectors.

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### 3.4 Model 3 and forces in link elements

For last comparison and result showcase, a new model is introduced. From now on it will be called Model 3. Model 3 is similar to Model 2 because it also has link elements connecting joints, but all link elements in this model are rigid. In this way we can obtain forces from links and compare them to forces in flexible links from Model 2. Results of forces in link elements are shown in Fig.16.

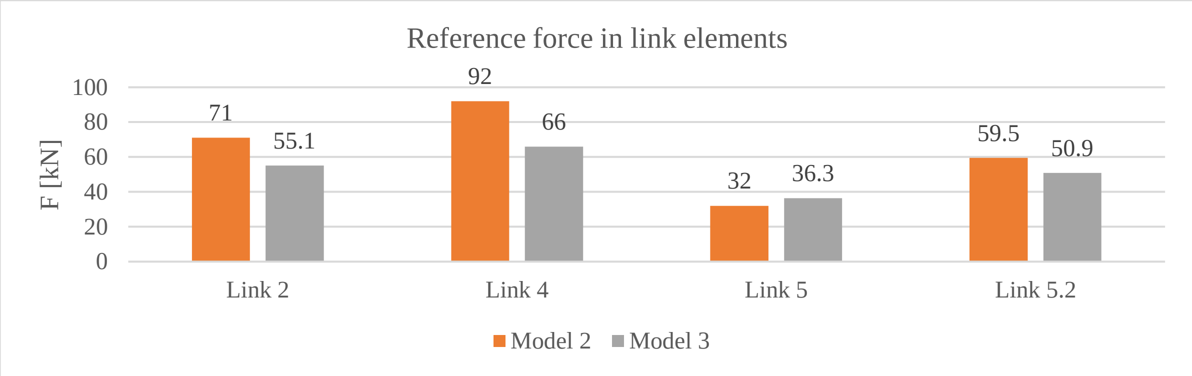


Figure 16. Graphic display of shear force in link elements

Viewing results of forces in link elements clearly shows us that forces in shear connectors (Links 2 and Link 4) are higher in Model 2, which corresponds with previous chapter and greater shear force in core walls. It can also be seen that forces in link elements 5 and 5.2 are similar.

## 4. Conclusion

In this paper influence of modelling connection stiffness in horizontal load-bearing system of a mass timber building was observed. Two structural models were made with real dimensions of structural elements, one with rigid joint connections and the other with flexible links that connect the joints. Horizontal load -bearing system consists of diagonal bracing and a core made of CLT wall panels. Connections between CLT wall panels and diagonal bracing end connections were taken into account with calculation of slip modulus that represented effective stiffness of link elements that connected the joints. Dynamic parameters, displacements, deformations and internal forces of the structure were observed and compared.

Comparison of models with rigid joint connections (Model 1 and Model 3) and the one with flexible joint connections (Model 2) lead to following conclusions:

- Flexible joint connections in the diagonal bracing and CLT core result in changes to the dynamic parameters, an increase in the vibration period, and a shift in the vibration modes
- Maximum displacement and story drift increase with introduction of flexible joint connections.
- Change in vibration periods leads to change of reference response spectrum.
- Distribution of internal forces in horizontal load bearing elements changes with introducing flexibility of its connections.
- Modelling joint connections with link elements gives a more accurate way of determining internal forces that are used for the design of connections. With correct mesh and distribution of links we can be close to real layout of connectors and forces that they transfer.
- Connections are critical elements of a structure with its design we can impact dynamic parameters, distribution of internal forces and displacements of a structure.

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## References

[1] Kuzman, K. M. 'Drvo kao građevni materijal budućnosti', Građevinar, vol.62 4, pp. 313 – 318; 2010. Available: http://casopis-gradjevinar.hr/assets/Uploads/JCE-62-2010-04-04.pdf

[2] Bogdan, A. 'Drvo u modernom graditeljstvu', Građevinar, vol.72, pp. 70–76; 2020. Available: http://casopis-gradjevinar.hr/assets/Uploads/JCE-72-2020-8-Zelenaa.pdf

[3] Jeleč, M., Varevac, D., Rajčić, V. 'Cross-laminated timber (CLT) - a state of the art report', *Građevinar, vol. 70* 2, pp. 75-95, Available: https://doi.org/10.14256/JCE.2071.2017

[4] Bjelanović A, Rajčić V. Drvene konstrukcije prema europskim normama. Second issue. Zagreb: Faculty of civil engineering, University of Zagreb, Hrvatska sveučilišna naklada, Zagora-Zagorje d.o.o.; 2007

[5] Pollmeier, 'Baubache GL75 - Declaration of performance' , str. 3, 2022. Available: https://www.pollmeier.com/product/beam-baubuche-gl75/#gref

[6] 'CLT by Stora Enso – Technical brochure' [Interent]. Available: https://www.storaenso.com/-/media/documents/download-center/documents/product-brochures/wood-products/clt-by-stora-enso-technical-brochure-en.pdf

[7] Eurocode 8: Design of structures for earthquake resistance -- Part 1-1: General rules, seismic actions and rules for buildings, HRN EN 1998-1:2011. Zagreb: Croatian Standards Institute, 2011

[8] Eurocode 5: Design of timber structures - Part 1-1: General - Common rules and rules for buildings, HRN EN 1995-1-1:2013. Zagreb: Croatian Standards Institute, 2013.

[9] 'CLT Engineer Manual' [Internet]. Available: https://calculatis.storaenso.com/Dokumentation/CLT-Engineer_Manual.pdf

[10] Buzjak R, Influence of connecting elements on the dynamic parameters of a wooden building [master's thesis]. Faculty of civil engineering: University of Zagreb

[11] Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings, HRN EN 1991-1-1:2012. Zagreb: Hrvatski zavod za norme, 2012.

[12] Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings – National annex, HRN EN 1991-1-1:2012/NA:2012. Zagreb: Hrvatski zavod za norme, 2012.

[13] Eurocode 1 - Actions on structures - Part 1-3: General actions - Snow loads, HRN EN 1991-1-3:2012. Zagreb: Hrvatski zavod za norme, 2012.

[14] Eurocode 1 - Actions on structures - Part 1-3: General actions - Snow loads – National annex, HRN EN 1991-1-3:2012/NA:2012. Zagreb: Hrvatski zavod za norme, 2012.

[15] Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions, HRN EN 1991-1-4:2012. Zagreb: Hrvatski zavod za norme, 2012.

[16] Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions – National annex, HRN EN 1991-1-4:2012/NA:2012. Zagreb: Hrvatski zavod za norme, 2012.

[17] "Karte potresnih područja Republike Hrvatske." Available: http://seizkarta.gfz.hr/hazmap/karta.php (Accessed 18.1.2025).

[18] 'Plates and connectors for timber' [Internet]. Available: https://www.rothoblaas.com/catalogues-rothoblaas

[19] 'European Technical Assessment ETA-19/0167', 2019. Available: https://www.rothoblaas.com/products/fastening/brackets-and-plates/angle-brackets-and-plates-for-buildings/slot#documents

[20] Vojnovic, L., Toumpanaki E. , and Norman J.A.P. 'Experimental study of a typical external wall-floor-wall connection in a CLT platform type construction.' *The 13th World Conference on Timber Engineering*. 2023. Available : https://www.proceedings.com/content/069/069179-0187open.pdf

[21] Computers & Structures, Inc. [CSI] (2019.) CSI Analysis Reference Manual For SAP 200, ETABS, SAFE and CSiBridge.