COST FP 1004

STSM Scientific Report:

Structural and seismic analyses of load-bearing CLT panels for one particular building system

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1. Purpose of the visit

Timber structures, despite all benefits and advantages, in Macedonian construction market are not very present. Beside few timber frame residential houses and cottages, there aren't other example buildings executed in accordance with the new technical approaches and materials such as cross laminated timber (CLT). Literature and expertise in this field are insufficient, especially in the manner of design of CLT buildings as well as production of this construction material as there aren't any production units in the surroundings.

Furthermore, the current National Standards are heritage from the former Republic and Its Yugoslavian Standards which are not applicable in all cases of structural analyses. As example, the National Standard for seismic design and construction of buildings in seismic prone area is published in 1980 and timber structures are not part of this standard. For design of timber structures, the currents analyses rely on the theory of permissible stresses which differ from the European Standards and the ultimate limit state of design. In the near future, as Macedonian government pursues to become part of the European family, all European Standards must be implemented and remain National Macedonian Standards. Preparations and trainings upon the Eurocodes are imperative in this moment in aim to enhance the knowledge of all engineers and researchers.

In my current master research, the main objective is to present the CLT structures to the Macedonian academic society with its material characteristics, production and design of CLT load bearing panels and connections with presentation of all applicable design references, approvals and standards regarding this new material. For my overall education upon structural and seismic design of the CLT structures, hosting to the one of the centers for design of CLT, the CBD d.o.o. Contemporary Building Design office in Ljubljana, was crucial benefit forward conducting my master thesis. During the visit, one characteristic building system with long cantilevers has been analyzed in the terms of structural and seismic design. In addition, analogy between the results calculated along with the Eurocode 8 and the National Standard for design and construction of buildings in seismic prone area has been conducted. The conclusion from this comparison of the European and our National Standards are very important in the future understanding and upgrading of the existing buildings in Republic of Macedonia.

With my visit to the CBD Company in Ljubljana, I enhance my experience upon CLT structures, their production, design and construction, which will contribute in my master research and comparison between the European and National Standards.

2. Descrtiption of the work carried out during the STSM

During the hosting at CBD Company in Ljubljana, several engagements were accomplished in accordance with the working plan.

First of all, numerous reading materials and technical literature have been studied as introduction in the CLT design as well as recent research work of this Company in the area of timber construction. Several scientific reports published in the name of CBD were observed which provided some substantially state of the art procedures. Additionally, I have been familiarized with various types of connectors, their technical properties and specifications together with their proper incorporation in the CLT systems.

Next activity was structural design of one characteristic building system. The selected system was 3 – storey commerce building with warehouse in addition. The specific architecture as long cantilevers with length of 8.1 m and interaction of different material as example massive wood, CLT, GLT, concrete fundaments and steel elements made this structure interesting for analyzing.

Seismic analyses were conducted in accordance to Eurocode 8. Although the conditions $T_0 \leq 4 \cdot T_C$ and $T_0 \leq 2.0s$ as well as building regularity in elevation for this building are satisfied, both seismic analyses methods are conducted, lateral force method and multi-modal response spectrum analysis. Additionally, analyses for the long cantilever are obtained with vertical elastic response spectrum which is used for cantilevers longer than 5.0 m and $a_g > 0.25g$ (although this condition wasn't satisfied, the analyses were conducted for this element).

$q=1.5$ for cantilevers

$S=1.0$

$a_g=0.225$

for type 1 spectrum$\rightarrow a_{vg}/a_g=0.90 \rightarrow 0.2025$

S_d=0.2025·1.0·2.5/1.5=0.3375

Comparison with ultimate state limit design:

q_d(ULS)=1.35·1.8 KN/m^2+1.5·3.0 KN/m^2=6.93 KN/m^2

Contribution of the vertical component of the spectrum is given bellow:

q_d(earthquake)=(1.0·1.8 KN/m^2+0.3·3.0 KN/m^2)·(1+0.3375)=3.61 KN/m^2

Conclusion for this case of analyze is that first combination upon ULS is dominant.

As separate part of the seismic design, analyses according to the Macedonian National Standards have been made and the results have been compared with obtained results from the seismic analyzes from EC 8. Remarks and comments upon this comparison are given in the next chapter 3.

During the STSM hosting, there were two site visits of on-going projects, one was the residential house and the other mountain hotel, both constructions were designed from CLT elements. The erection of the first project has been just started where assembling of the load bearing elements could be seen while the construction of the hotel was in the final phase, with all connections mounted as well as the secondary structures. Moreover, visit to the factory Storaenso in Bad St.Leonhard in Austria has been conducted, where I was introduced with the production process of CLT panels, cutting and preparing the elements according to the project details and their packing. I find attending this visits to be an indispensable step in improvement my knowledge upon the production processes and final stage of the implementation of the project i.e. assembly.

3. Descrtiption of the main results obtained

After finishing the both seismic analyses according to the EC 8 and the Macedonian National Standards, the comprehensive comparison has been made, given in addition.

Input data for the analyzed system:

- Dimensions of the selected system:

Table 1 – building dimensions

Position	z_i [m]	G_{kj}	Q_{kj}
Roof	13.53	2837	3420
Floor 3	10.28	3785	3420
Floor 2	7.03	3867	5262
Floor 1	3.75	798	129

H [m]	13.53		
$\sum \boldsymbol{G_{kj}}$		11287	
$\sum \boldsymbol{Q_{kj}}$			12231

- Fundamental period:

  To estimate the fundamental period, T_0, of the building, procedure from EC8 is used:

  $T_0 = 0.05 \cdot H^{0.75} = 0.36\ s$

- Subsoil class:

Table 2 – subsoil class for observed project in accordance with EC 8 and the National Standard

EC8	**National Standard**
A	I class
S=1.0	$K_d = 1.0$
$T_B = 0.15\ s$	$0 \leq K_d \leq 0.5$
$T_C = 0.4\ s$	
$T_D = 2.0\ s$	

- The importance factor of the structure (residential and commercial building):

Table 3 – the importance factor for observed project in accordance with EC 8 and the National Standard

$\boldsymbol{EC8}$	**National Standard**
III class	II class
$\gamma = 1.0$	$K_0 = 1.0$

- Peak ground acceleration value:

  $a_g = 0.225\ g$

- Seismic class (in accordance with National Standards) is VIII

  $K_s = 0.05$

- Ductility (load reducing factor) for CLT structural elements:

Table 4 – load reducing factor in accordance with EC 8 or ductility in the National Standard for observed project

$EC8$	**National Standard**
the behaviour factor q	Factor of ductility K_p
$q = 2.0$	$K_p = 2.0$ *

* In accordance to the National Standards, factor for ductility for timber constructions is not predicted, thus, for CLT system, this factor is taken from EC8.

Seismic design in accordance with the EC8:

$$S_{d(T)} = a_g \cdot S \cdot \frac{2.5}{q} \; for \; T_B \leq T_0 \leq T_C$$

$$S_{d(T)} = 0.225 \cdot 1.0 \cdot \frac{2.5}{2.0} = 0.281g$$

$$F_b = S_d(T_0) \cdot W \cdot \lambda$$

Because $T_0 < T_C \Rightarrow \lambda = 0.85$

Table 5 – calculation of the masses in accordance with EC 8 for observed project

Position	z_i [m]]	G_{kj}	Q_{kj}	ψ_{2i}	φ	ψ_{Ei}	$W = G_{kj} + \psi_{Ei}Q_{kj}$
Roof	13.53	2837	3420	0.3	1.0	0.3	3863
Floor 3	10.28	3785	3420	0.3	0.5	0.15	4298
Floor 2-storage	7.03	3867	5262	0.8	1.0	0.8	8077
Floor 1	3.75	798	129	0.3	0.5	0.15	817
H [m]	13.53						
$\sum G_{kj}$		11287					
$\sum Q_{kj}$			12231				
$\sum(G_{kj} + \psi_{Ei}Q_{kj})$							17055

$$F_b = S_d(T_0) \cdot W \cdot \lambda = 0.281 \cdot 17055 \cdot 0.85 = 4074\ KN$$

Seismic design in accordance with the National Standards:

The impact factors are given above and with their calculation, the final seismic force is:

$$S = K_o \cdot K_s \cdot K_p \cdot K_d \cdot \sum_{j=1}^{3}(G_j + 0.5 \cdot Q_j) = 1.0 \cdot 0.05 \cdot 2.0 \cdot 1.0 \cdot (11287 + 0.5 \cdot 12231)$$

$$S = 1740\ KN$$

Distribution of the base shear force in elevation:

The distribution of the base shear force, in the both standard is divided to the every floor respectively according to the mass of the floor. Base shear force calculated with the EC 8 is 4074 KN while the base shear force calculated according to the National Standards is only 1740 KN.

In the National Standards, for building with more than 5 floor, 85 % of the force is divided among the floor and 15% should be focus on the top of the building. But that isn't the case with the analyzed structure.

Table 6 – distribution of the base shear force on the floors in accordance with EC 8 and the National Standard for observed project

Position	$z_i = H_i$	**EC 8**			**the National Standard**		
	[m]	W_i	$z_i \cdot W_i$	$F_i = F_b \cdot \frac{z_i \cdot W_i}{\sum z_i \cdot W_i}$	q_i	$H_i \cdot q_i$	$S_i = S \cdot \frac{H_i \cdot q_i}{\sum H_i \cdot q_i}$
Roof	13.53	3863	52266	1362	4547	61521	641
Floor 3	10.28	4298	44183	1152	5495	56489	589
Floor 2	7.03	8077	56778	1480	6498	45681	476
Floor 1	3.75	817	3065	80	863	3236	34
$\sum z_i \cdot W_i$			156293			166927	
$\sum F_i$				4074			
$\sum S_i$							1740

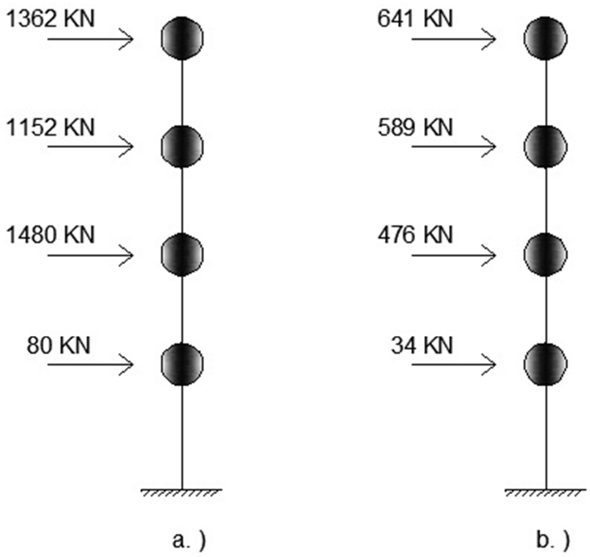

Fig.1 – a.) Distribution of the base shear force over the floor in accordance with EC 8;
b.) Distribution of the base shear force over the floor in accordance with the National Standard

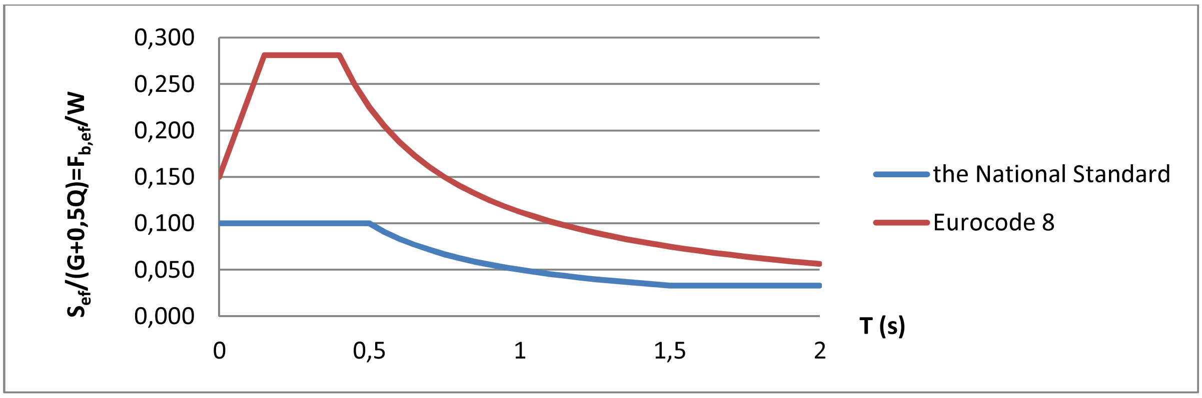

Fig.2 – Variation in the effective values of the seismic forces calculated in accordance with EC 8 and the National Standards

In the figure 2 are presented the effective values of the seismic force, calculated for various T_0, for subsoil class A. The red curve determines the values of effective seismic force calculated regarding EC 8 while the blue curve defines the values of effective seismic force calculated with the existing Macedonian National Standards for seismic design and construction of buildings in seismic prone area. As conclusion can be added that, seismic analyses in Eurocodes predict higher seismic force in contrast to the seismic analyses from the National Standard. These results determine calculating of all connections in the observed system and their serviceability during and after the earthquake.

4. Future collaboration with the host institution

Future collaboration with the host institution will be based on exchanging professional literature and latest research reports upon timber structures as well as new practices in designing and construction of CLT buildings. In addition, publication of an article is planned in one and only Macedonian engineering magazine, where I work as freelance journalist. The idea is, through interview and explanations of the newest CBD researches, to promote CLT construction and its benefits.

5. Acknowledgments

The work described in this report was conducted in CBD d.o.o. Contemporary Building Design office in Ljubljana – Slovenia as part of COST Action FP 1004 "Enhance of mechanical properties of timber, engineered wood products and timber structures". I would like to acknowledge representatives of COST office for approving this Short Term Scientific Mission as well as Prof. Richard Harris as chair of this Action.

In addition, I want to thank to the local host, dr. Bruno Dujic and his team, for accepting my STSM as well as for their full professional guidance through the research work.

In the end, special appreciation to my supervisor, Prof. Kiril Gramatikov, who was the initiator for this STSM. His advices and assistance have indispensable contribution regarding preparation of my master thesis.

6. Confirmation by the host institution of the successful execution of the STSM

Ms. Biljana Stojanovic has conducted short term scientific mission within our company, CBD d.o.o. Contemporary Building Design office in Ljubljana, in the period from December 09th till December 19th, 2013 year. In accordance with the approved Research Proposal, all of the planned working activities were accomplished with great engagement and scientific approach. Ms. Stojanovic has shown excellent collaboration skills and I hope this research visit will contribute in finalizing her master thesis.

On behalf of host institution:

CBD
gradbeno in poslovno projektiranje d.o.o.

dr. Bruno Dujic