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Behaviour's Analysis of Load-Carrying Members for Timber Framework Building

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***Atract*—The problem of limited raw material and energy resources can be solved by the replacement of non-renewable structural materials by renewable ones. Using of timber structures enables to decrease impact on the planet. It will also help to reverse some of the effects of industrialization. Structural members from solid and glued laminated timber, cross-laminated timber and other timber-based materials are widely used for one-storey and multi-storey buildings.**

Three-storey timber framework building was considered as an object of investigations. The considered three-storey building has length and width equal to 28 and 13 m, correspondingly. The using of software Autodesk Robot Structural developed FEM model of three-storey platform framed framework building. Load-carrying structures of considered framework building consist from the load-carrying walls, floors and roofs structures, which develop horizontal and vertical diaphragms providing strength and rigidity of the framework. The rational bay of the light framework structures changes within the limits from 300 to 600 mm. The rational span of beams and purlins does not exceed 4 m. Solid timber with the strength class C24 was assumed as a structural material for timber frameworks members. The OSB sheets were considered as a material of the cladding for external structures.

Behaviour of the load-carrying shear walls were analysed by the using of FEM models developed by the software Autodesk Robot Structural and ANSYS 15 so as methods explained in EN 1995-1-1. The software ANSYS 15 was used for the development of separate model of load-carrying shear walls. Initial unit of shear wall – a panel with the dimensions 1.2X2.7 m was considered for the purpose. The bar sub-members of the panel were modelled by the BEAM 188 finite element type. The SHELL 181 and COMBIN 14 finite element types modelled the cladding sub-members and mechanical fasteners. The dependence between the horizontal displacements of the load-carrying wall, intensity of the applied load, area of the openings so as thickness of the wall was obtained as a second power polynomial equation. It was stated, that the obtained FEM models enables to describe the behaviours of the load-carrying shear walls with enough precision.

Keywords*—*FEM model, horizontal displacements, load-carrying shear walls, platform framing.

I. Introduction

Environmental protection is actual problem nowadays. It is important to reduce the quantity of carbon emissions. Timber use in construction can reduce the use of other construction materials, such as concrete, steel and brick, which require a lot of energy for their production and entail higher emissions. So, timber is environmentally friendly, renewable and recyclable natural resource, which can decrease impact on the planet. Structural members from glued laminated timber and other timber-based materials are widely used for multi-storey buildings and constructions [1] – [2]. Construction of multi-storey timber buildings represent the most practical, effective and environmentally responsible solution to the global housing shortage which is caused by the increased urbanization and the densification of cities. Not so far timber use for the multi-storey buildings was mentioned as the most significant limitation of it use as a structural material. But at the present moment this limitation was deleted due to the development of new timber based structural materials which provide development of mass structural members. The mass timber structural members are characterized by the increased fire resistance in comparison with the light timber members with the small cross-sections [3] – [5]. The frame of the world's tallest 18-storeys timber building, the Mjosa Tower, has completed at the present moment in Norway. This multi-storey building is being built using glulam, cross-laminated timber and laminated veneer lumber [6]. But possibility to create more than 30-storey timber building was stated [3].

The spatial stability of the multi-storey frameworks in case of horizontal actions usually is provided by the development of bracing system and shear walls. So spatial stability of the 18-storey frame of the Mjosa Tower is provided by the system of the external bracings (Fig. 1. (a)) [6]. NMIT Arts and Media Building is a first of multi-storey timber framework buildings, which employs an advanced damage avoidance earthquake design (Fig. 1. (b)) [7]. It is provided by the special joints between the panels of shear walls. Development of the shear wall model, which can be used for the behaviour's investigations of multi-storey timber building, is a target of the current investigation. Dependence between the horizontal displacements of the shear wall, intensity of the applied load, area of the openings so as thickness of the shear wall should be obtained for the purpose. Three-storey building is considered as an object of investigation taking in to account tendency in realisation of the similar objects in Latvia during the last years.

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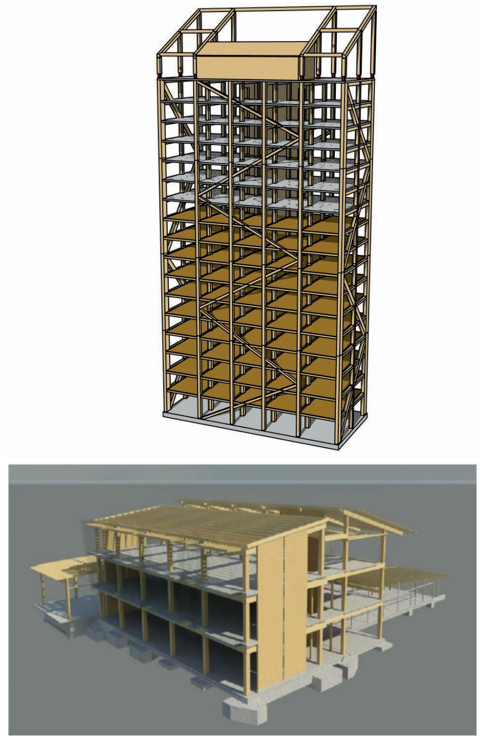


(a)

(b)

Fig. 1. Multi-storey framework timber buildings: (a) the world's tallest timber building, Mjosa Tower, which has 18 floors [6]; (b) NMIT Arts and Media Building [7].

II. Approach to the solution of the problem

A. Choice of structural solution for the multi-storey timber building

Structural solutions of multi-storey timber buildings can be divided in to the following groups:

- heavy framework's structures;
- light framework's structures;
- post-tensioned timber framework's structures [8].

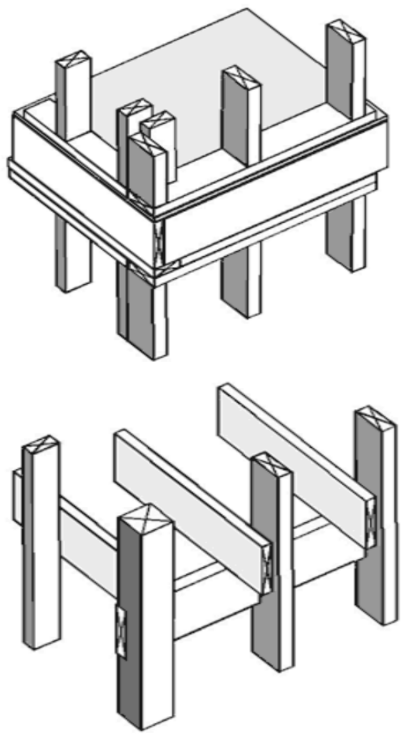
Heavy framework's structures are widely used for modern multi-storey buildings. Heavy framework's structures are characterized by the mass columns and beams cross-sections and pinned or moment joints which are provided by the steel, hardwood or plywood mechanical fasteners. The Mjosa Tower can be considered as an example of the multi-storey building with the heavy framework's structures [6]. Another example of the heavy framework's structure is shown on Fig. 2 (a).

Light framework's structures (Fig. 2. (b)) are widely used for multi-storey timber buildings. This group of structures is characterized by the decreased materials consumption. The major load-carrying members are made from the solid timber and dimensions of cross-sections are within the limits from 70x45 to 245x95 mm. Structures of floors and external walls usually are covered by OSB and plywood sheets. Structures of internal walls are covered by the gypsum boards [8] – [9]. Light framework's structural solutions are divisible on the balloon framing and platform framing dependently from the joining methods of the major structural members (Fig. 3.).

(a)

(b)

Fig. 2. Structural solutions of multistorey timber buildings: (a) heavy framework's structure; (b) light framework structure [8] – [9].



(a)

(b)

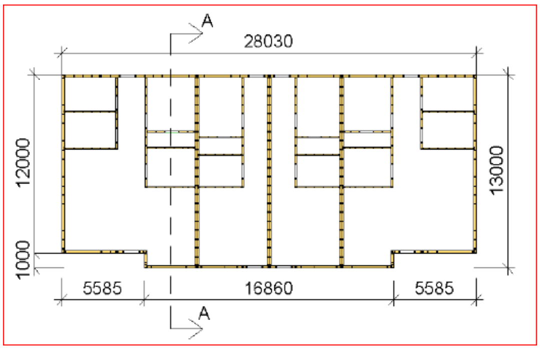
Fig. 3. Light framework's structural solutions: (a) platform framing; (b) balloon framing [8] – [9].

The platform framing joining method enables to obtain timber frameworks which are characterized by the increased fire resistance and spatial stability of the framework in comparison with the frameworks obtained by the balloon framing joining method. Decreased length and dead weight of the walls enables to reduce time and cost of the building's erection. The platform framing joining method is considered as a preferable one for the buildings with amounts of the storeys bigger than three [8] – [9].

Post-tensioned timber framework's structures are characterized by the increased resistance to horizontal actions caused by the wind and seismic loads. Post-tensioning is provided by the steel tendons, which usually go through beams and columns and increase the load-carrying member's bending moment's resistance. Increased compliance enables to delete the eccentricities, which can occur in the case of big horizontal actions. Post-tensioned timber framework's structures are characterized by the fast and easy assembling due to the simplicity of the structural joints [8].

So, light framework's structures and platform framing joining method are chosen for the three-storey building which was considered as an object of investigations. Plan and cross-section of considered three-storey building with the structural dimensions are shown on Fig. 4.

(a)



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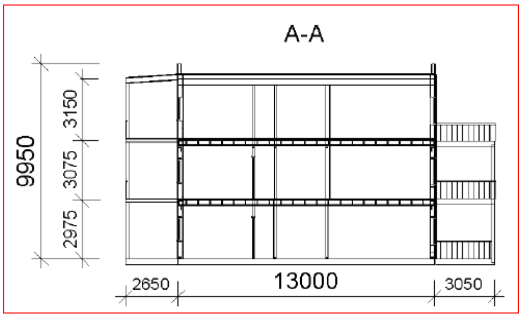

Fig. 4. Plan (a) and cross-section (b) of considered three-storey building [8].

B. *Method of analysis*

Light framework's structures of considered three-storey building are presented by the floor and roof's structures so as external and internal shear walls. The floors and roofs structures are presented by the members subjected to flexure due to the action of snow load on the roof and imposed load on the floor. Dimensioning and check of ultimate limit state for the load-carrying members of the roof and floors should be carried out by the formulas (6.11), (6.12) and (2.2) of EN 1995-1-1. The determinant condition for the dimensioning of the floors and roofs members are strength conditions in flexure, which can be checked by the formulas (1) and (2) [10].

$$\frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1 \qquad (1)$$

$$k_m \frac{\sigma_{m,y,d}}{f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1 \qquad (2)$$

Where: $\sigma_{m,y,d}$ and $\sigma_{m,z,d}$ are maximum normal stresses acting in the cross-section of the members due to the bending moments acting relatively y and z axis, correspondingly; $f_{m,y,d}$ and $f_{m,z,d}$ are the design resistances of timber in bending; km is a factor, equal to 0.7 for rectangular sections.

The main functions of the load-carrying shear walls are taking up of vertical and horizontal loads and actions and transferring it to foundations so as providing of spatial stability of the building's structure. The load-carrying shear wall structure usually is formed by the system of struts placed with the regular spacings joined together by the system of cross-bars and struts. Typical structural solution of load-carrying shear walls for the buildings with the light framework is shown on Fig. 5 [11] – [13].

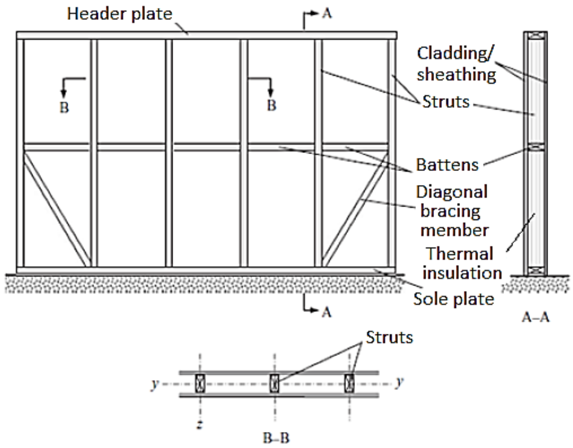

Fig. 5. Typical structural solution of load-carrying shear walls for the buildings with the light framework [12].

External load-carrying shear walls are subjected to the action both of vertical and horizontal loads, but internal ones to the vertical loads only. The determinant condition for the dimensioning of the struts, cross-bars and bracings are stability conditions, which can be checked by the equations (3), (4) and (5). The equations (3) and (4) are used in the case, if relative slenderness of the members is less or equal to 0.75 [12], [10].

$$\frac{\sigma_{c,0,d}}{k_{c,z}\, f_{c,0,d}} + k_m \frac{\sigma_{m,d}}{f_{m,d}} \leq 1 \qquad (3)$$

$$\frac{\sigma_{c,0,d}}{k_{c,y}\, f_{c,0,d}} + \frac{\sigma_{m,d}}{f_{m,d}} \leq 1 \qquad (4)$$

Where: $\sigma_{m,d}$ and $\sigma_{c,0,d}$ are maximum normal stresses acting in the cross-section of the arch due to the bending moment and compressive force, correspondingly; $f_{m,d}$ and $f_{c,0,d}$ are the design resistances of timber in bending and compression, correspondingly; $k_{c,y}$, $k_{c,z}$ are factors, which should be determined by the equations (6.25) and (6.26) [10]; other designations as for equations (1) and (2).

The formula (5) is used in the case, if relative slenderness of the members is bigger than 0.75, respectively [10]:

$$\left(\frac{\sigma_{m,d}}{k_{crit}\, f_{m,d}}\right)^2 + \frac{\sigma_{c,0,d}}{k_{c,z}\, f_{c,0,d}} \leq 1 \qquad (5)$$

Where: k_{crit} is a factor which takes into account the reduced bending strength due to lateral buckling; other designations as for formulas (1) – (4).

Light framework's structures of multi-storey timber buildings can effectively withstand to horizontal and vertical loads in the case, if shear wall and floors structures are correspondingly joined by the mechanical fasteners. So, shear walls of the considered building with light framework's structures consists from the framework and plywood sheets joined together by the mechanical fasteners [8], [13]. Software Autodesk Revit was used for development of 3D model of timber framework (Fig. 6.).

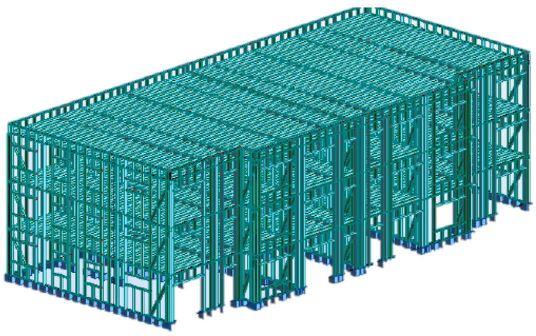

Fig. 6. 3D model of three-storey light framework's structures developed by software Autodesk Revit [8].

Vertical and horizontal members were modelled by the "bar" and "beam" finite element's types, correspondingly. "Cladding" type finite element was used for the modelling of the plywood sheets joined with the framework's members of load-carrying shear walls. Software Autodesk Robot Structural was used to analyse the obtained 3D model of timber framework on the action of permanent, imposed, wind and snow loads [14]. Separate model of load-carrying shear wall was developed by the software ANSYS 15.0. Finite elements types Beam 188, Shell 181 and Combin 14 were used for modelling of timber bars, plywood sheets and nails joined timber bars and plywood sheets [15].

III. Behaviour's analysis of load-carrying members for timber framework building

Behaviour's analyse of load-carrying members of framework structure of three-storey timber building was joined with analyse of the maximum internal forces and stresses, acting in the members of timber framework. Maximum vertical and horizontal displacements of shear walls, roof and floors are taken into account also.

3D model of light framework structure of three-storey timber building (Fig. 6) was analysed by the software Autodesk Robot Structural on the action of permanent load, imposed load, determined as for the residential building, and snow and wind loads determined for Riga climatic conditions. Intensity of design permanent loads acting on the roof and floors are equal to 1.30 and 1.80 kPa, correspondingly. Intensity of characteristic value of imposed load was taken as 2.0 kPa. Design snow load acting on the roof was equal to 2.04 kPa. The maximum values of positive and negative wind pressure are equal to 1.14 and 0.77 kPa, correspondingly [14].

Solid timber with strength class C24 was considered as a structural material of solid timber members [16]. Birch plywood with mean values of density, flexural modulus of elasticity parallel to the fibres of outer veneers equal to 680 kg/m^3 and 10719 MPa, was considered as a material of outer sheets of load-carrying shear walls [12].

It was shown, that maximum compression axial force in 48.18 kN acting in the strut of the first floor. Corresponding values of bending moment and shear force are equal to 1.31 kNm and 2.26 kN, correspondingly.

According to the calculations obtained by the software Autodesk Robot Structural The maximum values of the bending moment and shear forces acting in the beams of the floors are equal to 4.32 kNm and 4.78 kN, correspondingly. Maximum value of instantaneous vertical displacements of the beams is equal to 11 mm.

Design schemes of the struts in plane and perpendicular to the plane of shear wall so as scheme of the frameworks load-carrying members' placement in shear wall are shown on the Fig. 7. Height of the shear wall structure is equal to 2.7 m. One row of the cross-bars is placed in the height's middle of the shear wall structure.

This crossing bars provide support of the struts in the middle of its height in plane of the shear wall. Two head binders provide joining of the struts. The struts are placed with the spacings equal to 600 mm [8]. The depth and width of the struts are equal to 195 and 45 mm, correspondingly. The beams of the roof and floors have solid timber cross-sections with depth and width equal to 220 and 45 mm, correspondingly.

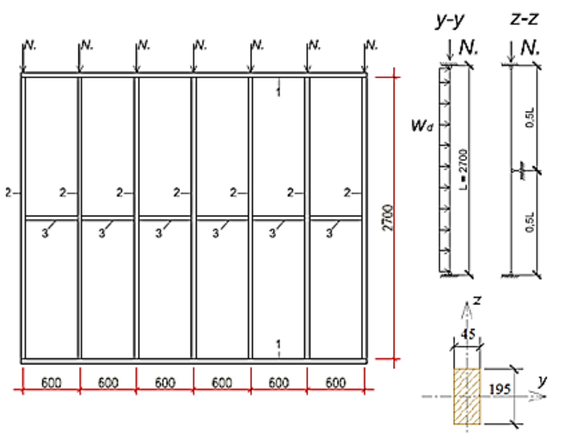

Fig. 7. Design scheme of the struts in shear walls in planes y-y and z-z.1 – head binders; 2 – struts; 3 – cross-bars [8].

The obtained parameters of the struts and beams were used for the development of the 3D models for shear wall by the using of software ANSYS 15.0. Shear wall's panels were considered as the initial members for investigation of shear wall stiffness at the action of horizontal loads. Three variants of shear wall panels were considered: variant without openings, variant with window opening and variant with door opening (Fig. 8).

The maximum horizontal displacements as a function from the thickness of the plywood sheets, areas of the openings so as intensities of the horizontal load was found as a second power polynomial equation [17] – [18]. Thickness of the plywood sheets, areas of the openings so as intensities of the horizontal load changes within the limits from 6 to 9 mm, from 0 to 1.22 m2 and from 0.5 to 2.5 kN, correspondingly.

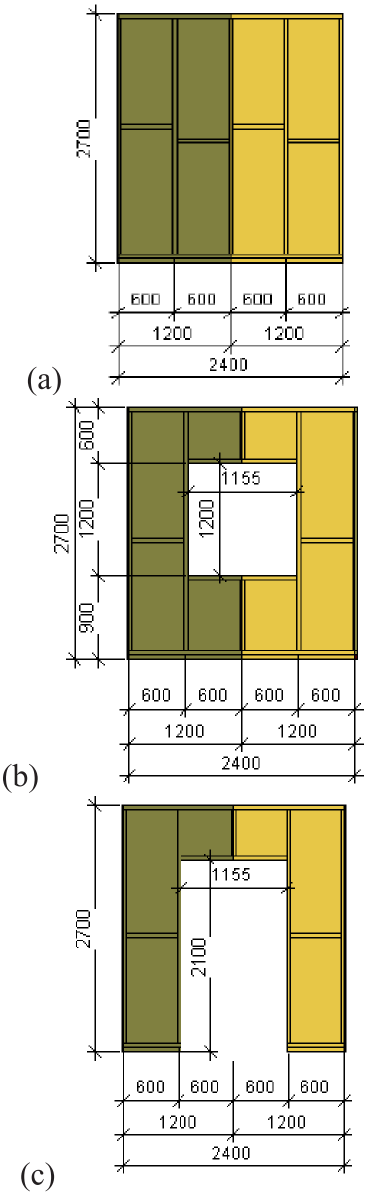

Fig. 8. Three variants of considered shear wall panels: a) – variant without openings; b) – variant with window opening; c) – variant with door opening [8].

Distribution of stresses by the considered shear wall panel surface, which was obtained by the software ANSYS 15.0, is shown on the Fig. 9. It was shown, that the maximum stresses in 0.84 MPa, acting in the plywood sheets, were obtained for the panels with the door openings. The maximum stresses are equal to 0.25 MPa for the panel without openings. The stresses and horizontal displacements were determined using recommendations for simplified analysis of wall diaphragms reflected in the clause 9.2.4.2. of EN 1995-1-1. The dependences of maximum horizontal displacements from the thickness of the plywood sheets, areas of the openings so as intensities of the horizontal load are shown on the Fig. 10.

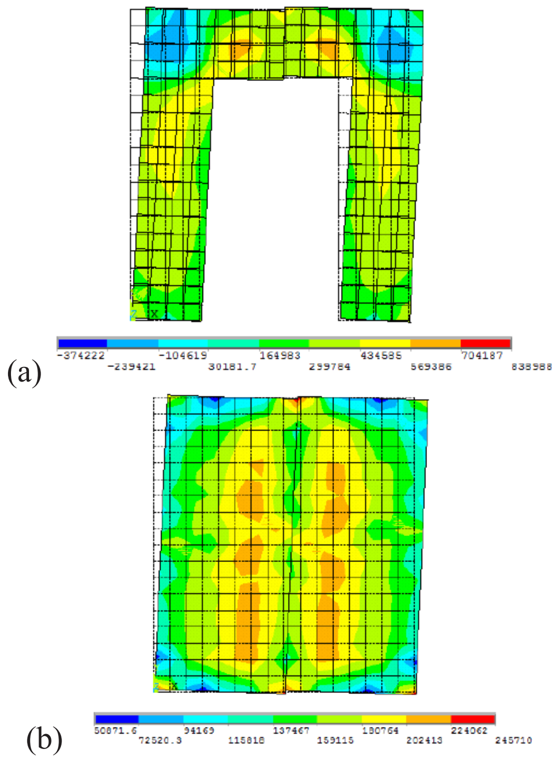

Fig. 9. Distribution of stresses (N/m^2) by the considered shear wall panel surface obtained by the software ANSYS 15.0: (a) – variant with door opening; (b) – variant without openings [8].

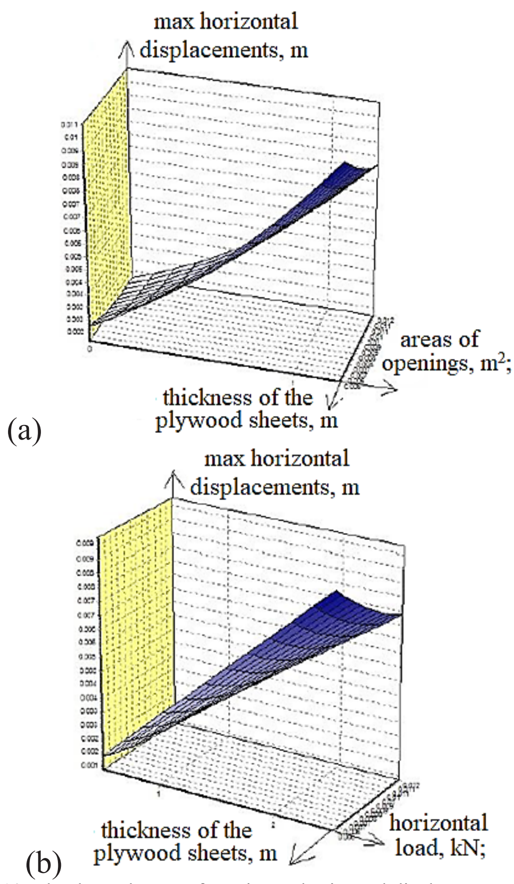

Fig. 10. The dependences of maximum horizontal displacements from the thickness of the plywood sheets, areas of the openings so as intensities of the horizontal load [8], [19].

The obtained dependence enables to conclude, that thickness of the plywood sheets has the most significant influence on the horizontal displacements of the shear walls. It was shown that the values of the maximum horizontal displacement changes within the limits from 0.67 to 16.36 mm. The maximum shear force acting at the mechanical fastener joined together plywood sheets and elements of framework was equal to 128 N.

IV. Conclusions

Behaviour's analyse of load-carrying members of framework structure of three-storey timber building was carried out. 3D model of light framework structure of three-storey timber building was developed and analysed by the software Autodesk Robot Structural on the action of permanent, imposed, snow and wind loads determined for Riga climatic conditions, for this purpose. 3D model was developed by the software ANSYS 15.0 to analyse behaviour of separate shear walls with and without openings in the case of horizontal force action.

The dependences of maximum horizontal displacements from the thickness of the plywood sheets, areas of the openings so as intensities of the horizontal load was obtained for shear walls of considered three-storey timber building. It was shown, that the values of the maximum horizontal displacement changes within the limits from 0.67 to 16.36 mm when thicknesses of the plywood sheets, areas of the openings so as intensities of the horizontal load changes within the limits from 6 to 9 mm, from 0 to 1.22 m2 and from 0.5 to 2.5 kN, correspondingly.

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References

[1] M. Green and E. Karsh, The case for tall wood buildings. Vancouver: MGB, 2012.

[2] V. Goremikins, D. Serdjuks, K. Buka-Vaivade, L. Pakrastins, and N.I. Vatin, "Prediction of behaviour of prestressed suspension bridge with timber deck panels," The Baltic Journal of Road and Bridge Engineering, vol. 12(4), pp. 234-240, 2017. DOI:10.3846/bjrbe.2017.29

[3] M. Green and J. Taggart, Tall wood buildings design, construction and performance. Basel: Birkhauser, 2017. DOI:10.1080/24751448.2018.1497379

[4] O. Nedryshkin, M. Gravit and K. Grabovyy, "Modeling fires in structures with an atrium in the FDS field model," MATEC Web of Conferences. vol. 193, 03023, 2018. DOI:10.1051/matecconf/201819303023

[5] J. Schmid, M. Klippel, A. Just, A. Frangi and M. Tiso, "Simulation of the fire resistance of cross-laminated timber (CLT)," Fire Technology, vol. 54(5), pp.1113-1148, 2018. DOI: 10.1007/s10694-018-0728-9

[6] "18-storey MJOS Tower in Norway to be world's tallest timber tower in 2019," Panels and Furniture Asia, 2017. ISSN:0219-5704

[7] T. Holden, C. Devereux, S. Haydon, A. Buchanan and S. Pampanin, "NMIT Arts and Media Building – Innovative structural design of a three-storey post-tensioned timber building," Case studies in structural engineering, vol.6, pp.76-83, 2016. DOI: 10.1016/j.csse.2016.06.003

[8] I. Virbule, "Behavioural analysis of load-carrying elements of three-storey timber framework building. M.S. thesis, Riga Technical university, Riga, Latvia, 2015.

[9] A. Buchanan, A. Palermo, D. M. Carradine and S. Pampanin, "Post-tensioned timber frame buildings," The Structural Engineer, vol. 89(17), pp. 24-30, 2011.

[10] Eurocode 5: Design of timber structures - Part 1-1: General - Common rules and rules for buildings.

[11] J. Vebsy, Shear walls for multi-storey timber buildings. Växjö: School of Technology and Design, Växjö University, 2008, 28 p.

[12] J. Porteous and A. Kermani, Structural timber design to Eurocode 5. Malden, MA: Blackwell Publishing Ltd, 2007, 542 p.

[13] Timber frame construction (3rd Ed.). Trada Technology, 2001, 145 p.

[14] Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings Eurocode.

[15] ANSYS 15.0 ANSYS Fluent User's Guide. Ansys Inc., 2013.

[16] EN 338: Structural timber. Strength classes

[17] T. Saknite, D. Serdjuks, V. Goremikins, L. Pakrastins and N.I. Vatin, "Fire Design of Arch-type Timber Roof," Magazine of Civil Engineering, vol. 64(4), pp. 26-39, 2016. DOI: 10.5862/MCE.64.3

[18] A. Stuklis, D. Serdjuks and V. Goremikins, "Materials consumption decrease for long-span prestressed cable roof," In Proc. of the 10th International Scientific and Practical Conference. Environment. Technology. Resources, June 18-20, 2015, Rezekne, Latvia, vol. 1, pp. 209-215.

[19] J. Auzinsh, EdaOpt software user manual. Riga, 2007.