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STRAIN-STRESS DISTRIBUTION OF BRACED NODE OF FRAMED MULTI-STOREY WOODEN HOUSE

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Abstract. Framed multi-storey wooden residential construction is developing very rapidly in many countries around the world. The use of wooden infill beams made of wooden glued beams and OSB (oriental strand board) increases the efficiency of design solutions. Especial difficult in the design and manufacture of beam structures in multi-storey framed houses are the beam-column joints, which can be hinged or supple. Preferably, these nodes are considered supple, which ensures the spatial operation of the frame and reduces its deformability against the hinges. As a rule, nodes are executed with steel elements which connect beams to columns by means of bolts and nails. The following constructive decision of a frame node is offered: a rectangular glued column and a crossbar in the form of an I-beam with an OSB-wall and regiments from a bar strengthened by glued wood in supporting zones. Support zones of crossbars are made of continuous rectangular section of a glued bar. For support of crossbars on a column the head with projecting beams from sheet steel up to 4 mm thick, with apertures for fastening is put on. The overhanging length corresponds to the width of the support zones of the crossbars. After fixing the crossbars to the projecting beam, the support area of he column of the upper floor is connected to the upper shelf of the crossbars with a fastening element in the form of a corner. The wall of the projecting beam is attached to the column, the projecting beam shelf is attached to the bottom shelf of the beam. The vertical walls of the projecting beam on both sides are attached to the wall of the support zone of the beam. To analyze the stress-strain distribution of the I-beam in the software complex "LIRA-SAPR" was developed a spatial computer model of the node. The stress-strain distribution of the beam was analyzed by the fields of displacements and stresses, as well as by the deformations of the structure. The research results allow us to conclude about the structural reliability of the proposed node solution.

Keywords: constituent wooden beam, wood booms, OSB (oriental strand board), finite elements method, structural model.

Introduction. In the last decade, the construction of multi-storey wooden houses has taken on the markets of many countries. In connection with the need to solve environmental problems, research is being conducted and new technologies for the manufacture of wooden structures are being promoted. Thus, in Finland the share of wooden houses is 40%, in Germany - up to 20% of the construction market, in Austria - about 30%, in the US and Canada more than 80%, in Japan is 43% of all residential buildings under construction [1]. In Ukraine, with the exception of the western regions, wood is practically not used even in low-rise construction. And the reasons are not only in the absence of technology, but above all in the traditional habit of reinforced concrete and steel. Indeed, solid wood has significant limitations on load-bearing capacity, even with small runs. But for many years, the industrial production of glued wood has almost equalized its chances with traditional building materials, opened up opportunities to cover large runs. The second, rather psychological than technical problem is the persistent myth of the significant flammability of wood.

In fact, even untreated wooden beams burn for at least 45 minutes, while the steel beam begins to lose its load-bearing capacity at a temperature of 90 ^{0}C after 4 minutes, and in the reinforced concrete cracks begin to spread, threatening fragile destruction. At the temperature of 500 ^{0}C steel in 15 minutes completely loses its load-bearing capacity, at the same time lowconductivity wood retains the integrity of the structure for a long period and burns slowly. The charred layer smolders and insulates the core, making it difficult for oxygen input, slowing down combustion.

High-rise wooden buildings have been known for more than thousand years. High pagodas in Japan reached 19 floors and to this day still stand in high seismic and humid climates. The main impulse for the development of multi-storey wooden buildings was the development and marketing of various high-strength wood-based structures, such as CLT-panel, glued beams, series SCL - structural composite wood. Technical developments and the growing availability of these materials have allowed them to be used as load-bearing elements of the frame: columns, beams, wall panels, floors, as well as partitions and balconies. Based on this, the question arises about their possible correlations. There are three structural systems, which are currently used in the construction of multi-storey wooden buildings: framed (beam-raiser), wall (panel), combined. The main structural materials of the wall (frameless) system are CLT-panels. All bearing elements of the building are made of them. The floors are placed directly on top of the wall panels, thus forming a platform for the construction of the next floor. Exterior and interior walls receive the load from the interflooring. To transfer the load, ensure stability and rigidity, the load-bearing elements are connected to each other lengthwise by metal brackets, which are attached to the CLT-panel with a large number of nails or bolts.

Framed buildings are a frame system, or space framework. In practice, the design of frames in reinforced concrete and steel design structural systems are divided into framed, framed-braced and braced. However, for wooden structures, considering suppleness of the joints, the frame system cannot be used. Therefore, all beam frames are considered as braced systems. It should be borne in mind that the joints of the crossbars with the columns can be both absolutely hinged and supple. There can be no absolutely rigid node. Framed houses can be beamless, with support of CLT-panels on columns, with a longitudinal arrangement of crossbars and leaning against them of plates and with a cross arrangement of beams. Plate structures - beams are designed to receive loads acting only in their area. They are used mainly as independent load-bearing structures of coatings or floors. Further development of flat solid and through structures in modern construction are spatial plates, consisting of regular-plate formations, which have the common name of the structure. Cross - beam structure is a beam cage consisting of cross beams. The positive qualities of structures made of glued wooden elements include: aesthetic expressiveness; spatial rigidity, which contributes to the increase of the spans of the coating and the rejection of the braces of rigidity; the possibility of increasing the ratio of the height of the beams to the width without the risk of losing the stability of the elements; the viscosity of the system, which increases the degree of reliability of the structure in case of local destruction; regularity and uniformity of structural elements, simplicity of a constructive form of beam elements and as a consequence possibility of their manufacturing on the automated lines; high degree of factory readiness of a covering.

Analysis of existing research. Dmitriev P.O., Savitsky M.V., Purhov V.V., Inzhutov I.S., Labudin B.V., Karelsky O.V., Belinska T.I. were engaged in research of problems of construction and work of wooden houses. In work [2] the world experience of multi-storey wooden houses is analyzed, recommendations on the decision of fundamental questions of designing are given. In work [3] modern tendencies of wooden house-building are considered, the review of the implemented significant projects is given. In [4] the issues of fire safety of wooden structures in comparison with reinforced concrete are considered. In [5] the combined constructive systems - wood - steel where steel elements provide spatial rigidity of the building and perceive seismic influences are proved. In [6] modern node fastenings of I-beams for low-rise frame construction are described (fig. 1). All fasteners are hinged and can take little effort.

Research objective. Especial difficult in the design and manufacture of beam structures in multi-storey framed houses are the beam-column joints, which can be hinged or supple. Preferably, these nodes are considered supple, which ensures the spatial operation of the frame and reduces its deformability against the hinges. The design of the node is determined mainly by the size, number of connecting elements and the strain in them. As a rule, nodes are executed with steel elements which connect beams to columns by means of bolts and nails. Such units have limited bearing capacity and high requirements for tolerances during installation.

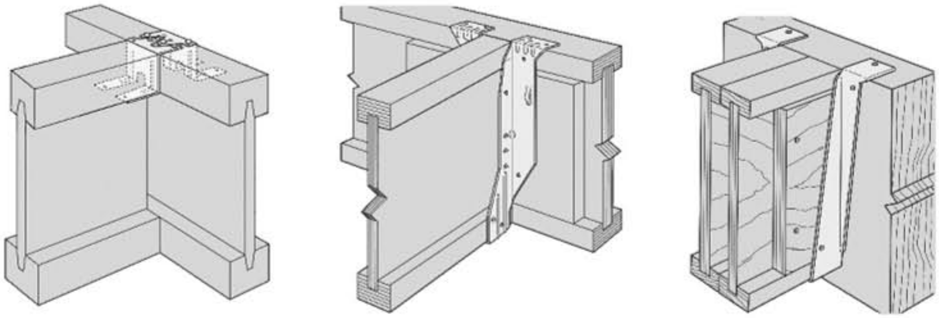

Fig. 1. Supporting nodes of I-beams

All efforts at development of constructive decisions of nodes are directed on reception of equally strong connections with the greatest possible rigidity. This article considers the design and study of the stress-strain distribution of the column assembly with the beam of a frame multi-storey wooden house using a unified steel head with brackets for supporting glued I-beams with a wall of OSB and reinforced support parts.

Constructive solution of the node and stress distribution in its elements. The most vulnerable place in the frames of buildings are the joints of columns with crossbars, which are performed during installation. The following constructive decision of a frame node is offered: a rectangular glued column and a crossbar in the form of an I-beam with an OSB-wall and regiments from a bar strengthened by glued wood in supporting zones.

In the absence of an effective structural solution of the node, in the area of fastening the crossbar to the column with bolts or nails can be observed areas of wrinkling of the wood and the concentration of stresses in the shelves of the crossbars. It is offered for support zones of crossbars - to execute continuous rectangular section of a glued bar. For support of crossbars on a column the head with consoles from sheet steel up to 4 mm thick, with apertures for fastening is put on. The overhanging length corresponds to the width of the support zones of the crossbars.

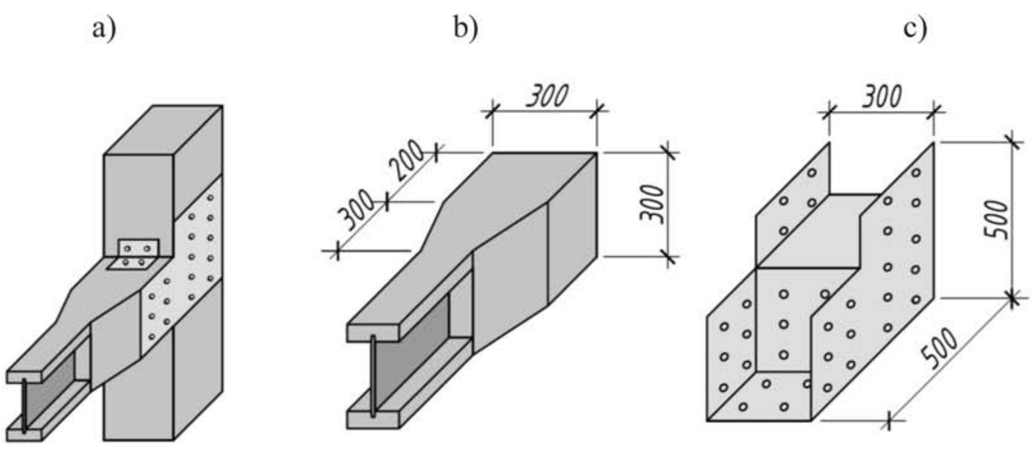

Fig. 2. Constructive solution of the frame node
a) general view of the node; b) the supporting part of the I-beam; c) steel head

After fixing the crossbars to the projecting beam, the support area of the column of the upper floor is connected to the upper shelf of the crossbars with a fastening element in the form of a corner (Fig. 2). The upper stretched fastener in the form of a corner is attached to the column of the upper floor and the upper shelf of the beam. The wall of the projecting beam is attached to the column, the projecting beam shelf is attached to the bottom shelf of the beam. The vertical walls of the projecting beam on both sides are attached to the wall of the support zone of the beam. All fasteners are screws. Plastic deformations in the node occur in the initial stages of loading, so the recommendations for the calculation at the stage of elastic work for such cases are not relevant. It is necessary to study the work of the projecting beam and the fastener in the form of a corner in interaction with the reinforced wall and the shelves of the crossbar.

Description of the structural model. To analyze the stress-strain distribution of the I-beam in the software complex "LIRA-SAPR" was developed a spatial computer model of the node: a beam of wooden beams - belts and walls of OSB, connected by glue, a column - glued wood. Connective head made of steel sheet, which is attached to the elements with self-tapping screws. The stiffness characteristics of bulk finite elements were set taking into account the anisotropic properties of wood and OSB in accordance with the requirements of [7] and [8].

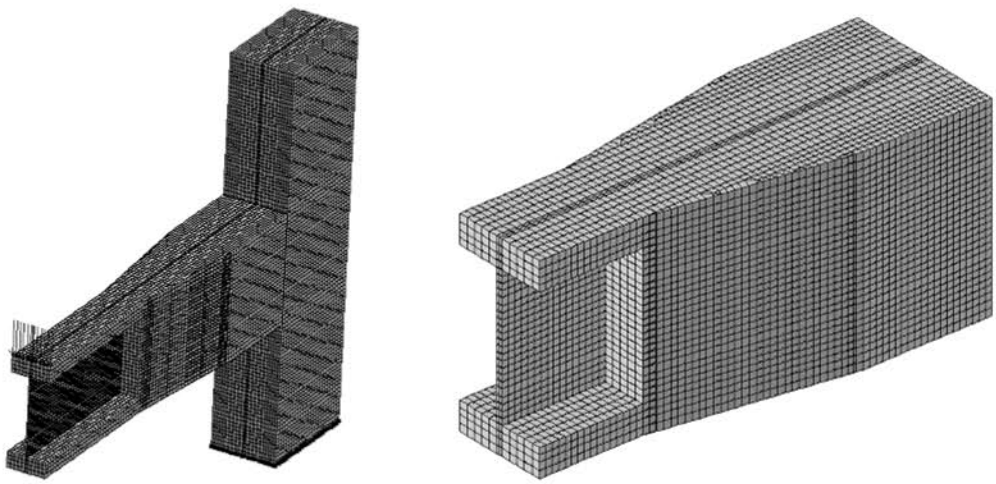

Fig. 3. Fragments of the structural model of the node connection

Belts and beam walls are modeled by universal spatial eight-node isoparametric finite elements (FE №36), metal plates - by universal quadrangular lamellar finite elements shells (FE №44), self-tapping screws - rod elements.

Geometric characteristics: belts of a beam with a section of 150x50 mm are made of wood of 1 grade, the wall is made of an OSB-3 plate 12 mm thick. Beam span 6 m, total height of I-beam section - 300 mm. Column - made of glued wood with a cross section of 300x300 mm. Thickness of steel plates - 3 mm, diameter of self-tapping screws - 6 mm. The I-beam is loaded with an evenly distributed load of 1.5-3 kN / m.p.

Research results. The stress-strain distribution of the beam was analyzed by the fields of displacements and stresses, as well as by the deformations of the structure.

In joints of this type, the vulnerable zone is the adhesive joint of the belts and the wall of the beam. The analysis of stresses in this zone shows that increasing the cross section in the support zone with glued wood significantly reduces the stress and increases the bearing capacity of the node by 1.5-2 times.

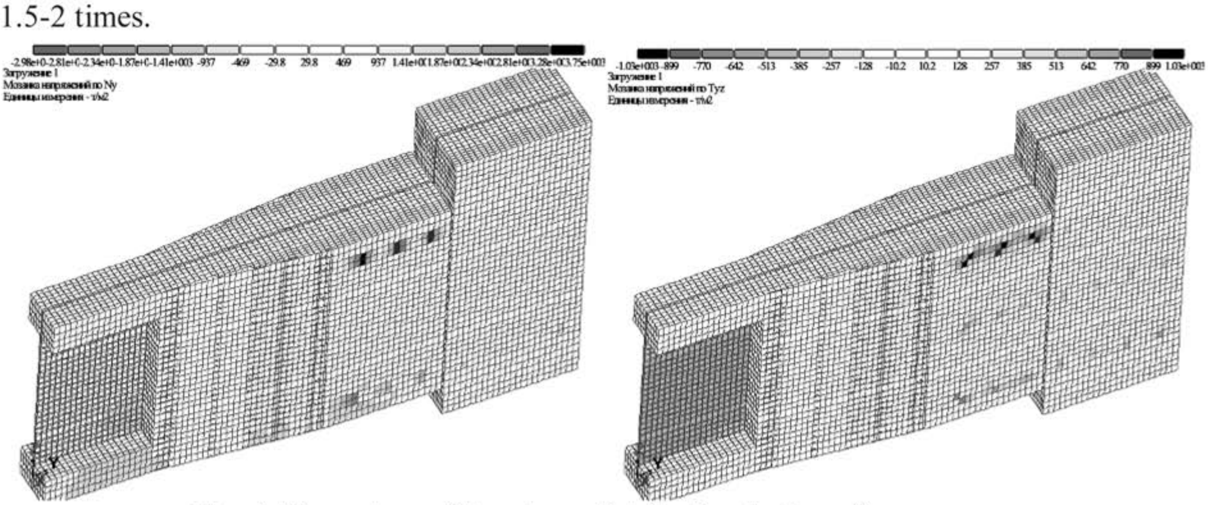

Fig. 4. The nature of the stress distribution in the reference zone
a) normal; b) tangential

In addition, at the I-beam section, the wall practically does not perceive the bending moment in the node. When strengthening the support zone, the wall is included in the work on the areas adjacent to the belts (Fig. 4). The design of the unit ensures the reliability of the connection due to the rigidity of the box head and the corner fastener, which includes the column of the upper floor. The proposed design solution reduces the normal stresses in the shelves and in the adhesive joint of the shelves with the wall, reduces the stress at the junction of the corner fastener with the column.

Summary. The results of calculations of the SC "LIRA-SAPR" indicate that the proposed design solution of the node connection can be used as a node of the frames of multi-storey buildings. Increasing the cross section in the support area with glued wood significantly reduces the stress and increases the bearing capacity of the node by 1.5-2 times. The research results allow us to conclude about the structural reliability of the proposed node solution.

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НАПРУЖЕНО-ДЕФОРМОВАНИЙ СТАН В' ЯЗОВОГО ВУЗЛА КАРКАСНОГО БАГАТОПОВЕРХОВОГО ДЕРЕВ'ЯНОГО БУДИНКУ

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Анотація. Каркасне багатоповерхове дерев'яне житлове будівництво стрімко розвивається в багатьох країнах світу. Використання дерев'яних двотаврових балок з дерев'яного клеєного бруса і плити OSB (oriental strand board) підвищує ефективність конструктивних рішень. Особливу складність при проектуванні і виготовленні балкових структур в складі багатоповерхових каркасних будинків представляють вузли сполучення балок з колонами, які можуть бути шарнірними або податливими. Переважно ці вузли вважають податливими, що забезпечує просторову роботу каркаса і зменшує його деформативність в порівнянні з шарнірними. Як правило, вузли виконуються зі сталевими елементами, які з'єднують балки з колонами за допомогою болтів і нагелів. Телевізори з таким конструктивне рішення рамного вузла: прямокутна клеєна колона і ригель у вигляді двотаврової балки з OSB-стінкою і полками з бруса, посиленими клеєної деревиною в опорних зонах. Опорні зони ригелів виконуються суцільного прямокутного перерізу з клеєного бруса. Для обпирання ригелів на колону одягається оголовок з консолями з листової сталі товщиною до 4 мм, з отворами для кріплення саморізами. Виліт консолі відповідає ширині опорних зон ригелів. Після закріплення ригелів до консолей опорна зона колони верхнього поверху з'єднується з верхньою полицею ригелів кріпильних елементом у вигляді куточка. Стінка консолі кріпиться до колони, полку консолі кріпиться до нижньої полиці балки. Вертикальні стінки консолі з двох сторін кріпляться до стінки опорної зони балки. Для аналізу напружено-деформованого стану двотаврової балки в програмному комплексі «Ліра-САПР» була розроблена просторова комп'ютерна модель вузла. Напружено-деформований стан балки аналізували по полях переміщень і напружень, а також за деформаціями конструкції. Результати досліджень дозволяють зробити висновок про надійність пропонованого рішення вузла.

Ключові слова: складова дерев'яна балка, пояси з деревини, плита OSB, метод кінцевих елементів, розрахункова модель.

НАПРЯЖЕННО-ДЕФОРМИРОВАННОЕ СОСТОЯНИЕ СВЯЗЕВОГО УЗЛА КАРКАСНОГО МНОГОЭТАЖНОГО ДЕРЕВЯННОГО ЗДАНИЯ

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Аннотация. Каркасное многоэтажное деревянное домостроение стремительно развивается во многих странах мира. Использование деревянных двутавровых балок из деревянного клееного бруса и плиты OSB (oriental strand board) повышает эффективность конструктивных решений. Особую сложность при проектировании и изготовлении балочных структур в составе многоэтажных каркасных домов представляют узлы сопряжения балок с колоннами, которые могут быть шарнирными или податливыми. Преимущественно эти узлы считают податливыми, что обеспечивает пространственную работу каркаса и уменьшает его деформативность по сравнению с шарнирными. Как правило, узлы выполняются со стальными элементами, которые соединяют балки с колоннами с помощью болтов и нагелей. Предлагается следующее конструктивное решение рамного узла: прямоугольная клееная колонна и ригель в виде двутавровой балки с OSB-стенкой и полками из бруса, усиленными клееной древесиной в опорных зонах. Опорные зоны ригелей выполняются сплошного прямоугольного сечения из клееного бруса. Для опирания ригелей на колонну одевается оголовок с консолями из листовой стали толщиной до 4 мм, с отверстиями для крепления саморезами. Вылет консоли соответствует ширине опорных зон ригелей. После закрепления ригелей к консолям опорная зона колонны верхнего этажа соединяется с верхней полкой ригелей крепежным элементом в виде уголка. Стенка консоли крепится к колонне, полка консоли крепится к нижней полке балки. Вертикальные стенки консоли с двух сторон крепятся к стенке опорной зоны балки. Для анализа напряженно-деформированного состояния двутавровой балки в программном комплексе «Лира-САПР» была разработана пространственная компьютерная модель узла. Напряженно-деформированное состояние балки анализировали по полям перемещений и напряжений, а также за деформациями конструкции. Результаты исследований позволяют сделать вывод о надежности предлагаемого решения узла.

Ключевые слова: составная деревянная балка, пояса из древесины, плита OSB, метод конечных элементов, расчетная модель.