Deformation features of cross-glued wooden panel structures for northern construction

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Abstract. Cross-glued wood panels are used in various areas of construction. In recent years, such panels are widely used in multi-storey panel and multi-storey frame construction. The use of panels in multi-storey residential and public construction is based on such an important natural property of wood as dissipativity - the ability to absorb a wide range of dynamic effects, including seismic effects.

The structural form of buildings in modern high-rise construction is based mainly on a steel or reinforced concrete frame. High-rise buildings on a frame made of wooden glued elements, with wooden outer and inner panels began to be introduced into the construction practice 15 years ago. To date, residential and public buildings made of wooden cross-glued panels have been built in many countries of Europe and in the USA, Canada, Australia.

It can be expected that in high-rise construction, the share of residential and public buildings with the use of wooden glued structures will increase, and will stabilize over time in an objectively justified indicator. The demand for wooden high-rise construction will be determined, among other factors, by the seismicity of the construction areas.

1. Seismic activity in the Arctic.
The vast Arctic territories belong to zones with high seismicity, where earthquakes as well as seismic events of technogenic nature are recorded - industrial explosions and other sources of such phenomena. The Arctic, polar and subpolar regions can be classified as regions with high geodynamic risks (Fig. 1).
For example, seismic monitoring networks record each month in the Arctic zone over 100 or more seismic events from various sources. Arkhangelsk network of seismic monitoring, covering the vast territory of the Arkhangelsk region, the Scandinavian and Kola Peninsulas, the Barents Sea to the island of Novaya Zemlya, Franz Josef Land and Svalbard. Every month, the Arkhangelsk network registers over 100 regional and local seismic events from various sources and various origins. Known maps of earthquake epicenters remain relevant and are supplemented by new seismic events [1].

Differentiated consideration of the Arctic territories of the Russian Federation regions shows that in all the northern regions of Russia significant areas of land beyond the Arctic Circle are classified as seismically active, especially in the north of the Republic of Sakha (Yakutia). An extended arc of seismic activity, stretching from the south of Siberia to the east, extending to the northeast, in the form of the Verkhoyansk fold region, going further to even higher latitudes, merges with the seismic belt located along Greenland. (fig. 2).
Norway belongs to the seismic zone with a fairly high activity. The Oslo earthquake in 1904 is known, with a 5.4 magnitude on the Richter scale. There were numerous destructions. As modern observations show, in Oslo itself and in its surroundings, the danger of recurrence of an earthquake remains.

Under these conditions, an increase in the activity of wooden construction is expected. With proper design and chemical measures to protect wood from the effects of fire and biodeterioration, with further improvement of protective paints and varnishes, the durability and reliability of wooden structures will be ensured at a high level. If we consider the durability and reliability of wooden structures to be the same as steel and reinforced concrete structures, when deciding on the type of structures how they will resist dynamic influences becomes decisive. This fact is relevant for Norway, located in the Arctic seismically active zone.

2. A wooden high-rise building in Brumundall, Norway.
A wooden high-rise building was built in the area of Brumundall, in Norway. The building is located on the shores of Lake Mjøsa. The building houses the Wood Hotel, offices and apartments. The project of the architectural firm Voll Arkitekter was implemented and commissioned in 2019. The building frame is made entirely of glued wood, glued elements with a section of up to 600x1000 mm and more. Interfloor ceilings on the upper 7 floors are reinforced concrete to stabilize the impact of wind loads. In the upper part of the building, the wooden glued elements of the frame are open, protected from rain and snow by protective paint and metal plates on the upper side. A group of Russian specialists, including the author of this article, got acquainted with the building itself and with its project. Mr. Harald Lieven, one of the project participants, presented the project (company Moelven Limiento AS). The constructive form of this house was widely covered in the scientific press and in industry literature. We will present only the basic data:
1. Number of floors -18;
2. Height - 85.4 m;
3. Total area - 11300 sq.m;
An important argument when choosing wood as the main structural material was that wood accumulates a significant amount of carbon dioxide, which is relevant from the eco-friendly point of view and environmental protection. The building was designed as energy efficient, the estimated savings in energy consumption is 40% compared with traditional building of such scale.

Fig. 3. The most resistant to dynamic impact are solid wood and glued wooden structures.

The construction of the building frame assemblies was solved quite interestingly: when assembling the frame, a number of St 355 steel plates with pre-drilled holes are inserted into the cuts of wooden elements with holes pre-drilled at a factory. The plates are coated with powder anti-corrosion protection. Assembly is carried out by inserting smooth rods of chemically resistant steel into the holes. Holes in wooden glued elements are closed with wooden corks. Wooden structures are covered with a transparent finish that does not cover the wood texture. The diameter of the holes on the plates is 13 mm, the diameter of the rods and the diameter of the holes on the wooden element is taken to be 12 mm. Such accuracy of assembly ensured high mounting accuracy. Deviation of the highest points of the frame from vertical is up to 140 mm, which is acceptable.

According to Mr. Harald Lieven, more than 2,600 cubic meters of glued wood were used in total. This included 250 cubic meters of CLT-panels (cross-glued panels), glued frame elements – 1,400 cubic meters. The cross sections of the corner columns are 1485x625 mm, while the calculated load on them is 1,172 tons. The cross sections of the inner columns are 725x810 mm and 625x630 mm. Beams are applied with sections of 625x585, 625x720, 395x585 mm. Beams under the floors are applied with a section of 395x675 mm. Large braces providing overall rigidity and stability of the frame are used with a cross section of 625x990 mm.

The glued structure of the building frame was made by Moelven Limtre company. Cross-glued CLT panels were made by Stora Enso and WoodCon. The calculated flexural strength of the CLT panels was taken equal to 24 MPa. Data on full-scale testing of the panels could not be obtained.

The weight of steel elements in the nodes of the foundation structures, in the nodes of the frame and in the fastenings of balconies amounted to 120 tons.
In this project, the core of the building rigidity is formed by CLT-panels framing the shaft of elevators and stairs. According to the designers, the spatial rigidity and stability of the building frame is provided only by braces, the work of the rigidity core in the calculations to ensure the lateral stability of the frame is not taken into account. Clearly, possible seismic effects will affect the entire frame and all elements of the building. The actual resistance scheme of the building frame to external influences will include the resistance of the building's rigidity core made of CLT panels. In this regard, the issue of panel strength and deformability remains very relevant. Monitoring of the building’s condition has been organized.

3. Features of the deformation of cross-glued wooden panel structures for northern construction. Numerical simulation.

Today, the research on the topic does not have a full frame on the physics of deformation in cross-glued wooden panel structures on the North. That is, specific deformation as a dynamic developing process. External forces either of nature, weather conditions, physical forces, etc., applied to the structures cause the occurrence of stresses and their subsequent redistribution caused by a complex process of deformation. These stresses and changes after the application of external efforts, before the emergence and subsequent stabilization of a new stress-strain state, might be very time consuming. Full-size structures can have large dimensions in which deformations also develop gradually and over a long period of time. The intricacy of the structural form, the existence of many knobs made of steel and other materials, glued rods and other similar solutions cause a multi-stage gradual redistribution and transfer of forces from some deformed elements of wooden glued structures to others.

In the volume of material, the emergence and stabilization of a new stress-strain state does not occur instantaneously, deformations spread with an eminent, but a definite speed. We can assume that the spreading speed of deformation waves is comparable with the speed of spreading sound in the material under consideration.

In the construction strategy, the tasks of three-dimensional characterization of cracks spreading were defined, starting from the original mark of wounds nucleated and its farther expansion until the complete failure of the test samples. During field tests, these tasks cannot be thoroughly accomplished due to deficiency of the testing equipment. The current practice of testing wooden samples and structures, methodologically covered by the applicable regulatory literature, records commonplace fractures and illustrates the surface manifestations of plastic deformations in the form of lines of loss of local stability of wood fibers, local plane and volume integrity violations. Furthermore,
modern capabilities emerged for a qualitative and quantitative description of the manifestations of deformations on the surface of samples, among other things in the course of wave processes, still only in numerical experiments.

This article presents the results of a numerical experiment to describe the occurrence and spread of strains in the volume of a loaded sample.

The authors also pointed out in a previous work that “the numerical implementation was performed on the FEniCS open source computing platform, on the resources of the Arian Kuzmin computing cluster at NEFU [3].

A numerical simulation of the spread of elastic waves in a wooden sample with idealized anisotropy of elastic properties were taken into account during simulation. The calculations were performed using finite element methods for approximation in space and limited variations for discretization in time.

The existing basic one-dimensional and planar models of the appearance and spread of a single deformation wave on the sample surface align well with the descriptions of surface waves of various physical bodies accepted by wave process researchers [2].

Authors of the study carried out at the North-East Federal University theoretical studies of the spreading models of single transverse strain waves on the surface of bodies that have boundary conditions in the form of loading areas and a sample cross section for solving planar tasks. The conditions of the task were the elastic properties of the wood, the transverse dimensions of the sample, the length of the sample (finite or infinite) specified as a fragment of one part of the sample relative to the median plane, the speed of the wave [3]. When formulating the hypothesis, the works of P. V. Sivtsev, P. N. Vabishchevich and other researchers are taken into account [4, 6-10]. The model sample had an orthotropic structure in a cylindrical coordinate system; the elastic parameters of the wood were modeled according to E.K. Ashkenazi [5]. For calculations in a Cartesian coordinate system, the elastic parameters were transformed using the corresponding transition matrix. In paper [3], an isotropic sample with dimensions A x H x L in 50x150x600 mm was considered as a model.

In this case, loading and wave deformation of an analogue of a CLT wall panel are observed. It is assumed that the panel cross-glued from individual boards is isotropic.

As a model, we consider an isotropic sample with dimensions A x H x L in 200x2700x600 mm. A model with a uniform breakdown into solid tetrahedra was calculated, with the number of tetrahedrons varying over a wide range, with the corresponding number of common points of their vertices according to the adopted breakdown. We apply a short-term, distributed load prompting a single wave and consider the qualitative picture of deformation in a conventional time scale (Fig. 5).

The load is distributed in the form of a triangle, increasing from the left edge of the panel. The maximum value is applied to the right edge of the panel. The load simulates a short-term load applied from the bottom up. The prop along the upper edge is absolutely rigid, deformations and displacements in the plane of obstacles bearing are not provided.
T=200  (условный отсчет времени)

T=140

T=090
Fig. 5. The sequence of deformation.
The authors also noted [3] that “wave manifestations of deformations, as a result of the resistance of the sample material, upon completion of the application of an external test load can be fixed in the future using appropriate equipment. The dynamics of the spread of wave deformations on the surface of samples during field tests can be shot with high-speed video. The resulting qualitative picture can be processed and quantitatively described as the process of the emergence of the front of the array of deformation waves, the movement of this wave over the material, the wave reaching the boundary conditions, returning and cyclic oscillation to complete attenuation, and stabilization to a state of rest. Naturally, the most characteristic picture of the visualization of these wave manifestations in their entirety and in the spectrum of wave characteristics would be presented on the surfaces of large-sized planar structures, such as CLT panels.

4. Conclusions.
A qualitative picture of the deformation on the outer surface of the test sample shows that areas hazardous to the material can be identified when quantitatively describing the deformation gradient. In this case, it would be possible to determine the areas with the highest values of relative deformations, and take constructive measures to adjust the structural shape of the panels in order to prevent failures of wooden CLT structures. Based on their nature of loading, it is possible to make changes to the structural form of panel elements.

The areas for practical application of the research results will be the design practice and operation of large-sized wooden structures, for example, widely used CLT panels. An example of the use of such panels in a wooden high-rise building in Brumundall, Norway, confirms these prospects.

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