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Oriented particle boards: effect of the tangential load component

Ориентированные стружечные плиты: влияние касательной составляющей нагрузки

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Key words: OSB-plates; inclined plate; tangential load; plate deformation; FE-model as a research tool; construction; civil engineering

Ключевые слова: OSB-пластины; наклонная пластина; тангенциальная нагрузка; деформации плиты; FE-модель как инструмент исследования; строительство; гражданское строительство

Abstract. Object of research: oriented particle boards (OSB) plate under the action of vertical load. As a research tool used standard FE-model of the OSB-plate is used. The functioning of the OSB-plate as an element of the pitched roof structure with a soft tile is considered. In this case, the load on the surface from the snow and the weight of the soft roof has a tangential component distributed over the outer surface of the plate. However the influence of the tangential load on the plate has not been fully studied in well-known literature. The tangential component of the load can cause unevenness in the end joins of the OSB in pitched roofs. The purpose of this study is to identify the causes of unevenness (irregularity) in joints of OSB in structures of inclined roofs and vertical walls, also justify recommendations for addressing these causes. It is obvious that the cost of resources for the implementation of this intention will be justified if the OSB-plates have the prospect of effective use in the construction, including environmental management. For this reason, a brief overview of the OSB evolution is one of the tasks of the presented work. Other actual tasks: modeling the influence of the tangential component of load evenly distributed on one and two surfaces of the OSB-plate, the longitudinal side faces of which were clamped. In each of these two cases of loading, the OSB board can be inclined or vertical. It is shown that the tangential load causes an increase in deflections in the region of one of the end faces of the plate and a decrease in deflections opposite to the edge. This can lead to unevenness at the joints of OSB-plates. In order to exclude the revealed cause of the appearance of unevenness in constructions with OSB, it is suggested that the flexural rigidity of the plates in the area of their ends by stiffeners or carbon fiber strips should be increased.

Аннотация. Объект исследования: ориентированная древесностружечная плита (OSB) под действием вертикальной нагрузки. В качестве инструмента исследования использовалась стандартная FE-модель (конечно-элементная модель) OSB-плиты. Рассмотрено функционирование OSB-плиты как элемента скатной конструкции крыши с мягкой кровлей. В этом случае нагрузка на поверхность от снега и вес мягкой кровли имеет тангенциальную составляющую, распределенную по внешней поверхности пластины. Однако влияние тангенциальной нагрузки на пластину еще не полностью изучено в известной литературе. Тангенциальная составляющая нагрузки может вызвать неравномерность в стыках концов OSB в скатных крышах. Цель этого исследования - выявить причины неравномерности прогибов в стыках OSB в структурах наклонных крыш и вертикальных стен, а также обосновать рекомендации по устранению этих причин. Очевидно, что стоимость ресурсов для реализации этого намерения будет оправдана, если у OSB-пластин есть перспектива эффективного использования в строительстве, в том числе с точки зрения управления окружающей средой. По этой причине краткий обзор эволюции OSB является одной из задач представленной работы. Другие актуальные задачи: моделирование влияния тангенциальной составляющей нагрузки, равномерно распределенной на одной и на двух поверхностях OSB-пластины, продольные боковые грани

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которой были зажаты. В каждом из этих двух случаев загрузки OSB-плита может быть наклонной или вертикальной. Показано, что тангенциальная нагрузка вызывает увеличение прогибов в области одного из торцов пластины и уменьшение прогибов, противоположных краю. Это может привести к неравномерности в стыках OSB-плит. Чтобы исключить выявленную причину возникновения неровностей в конструкциях с OSB, предлагается увеличить изгибную жесткость пластин в области их концов ребрами жесткости или полосами из углеродного волокна.

Introduction

This article deals with the distribution of displacements and stresses in an inclined plate under the action of a vertical load distributed over one surface plate. The relevance of this work is due to the increasing use of oriented particle boards (OSB) in roof structures [1] and, as analysis of the literature has shown, their inadequate knowledge. The practical significance of the work is justified by the fact that the reliability of the roof depends on the durability and safety of the functioning of the structures, made from OSB.

The focus in this paper is on the mutual movement of inclined plates in the area of their end faces under vertical load. Differences in the deflections of adjacent plates in the area of their end faces at functioning of the OSB-plates, as an element of the pitched roof structure with a soft tile, is considered. These differences in the deflections can lead to uneven wear of the roofing material. For the same reason, local damage to the soft roof in the area of the butt joints of the OSB-plates is possible.

As a tool of represented research, the finite element method (FEM) has been chosen, as well-known analytical solutions to plate bending problems under the action of the tangential surface load [2, 3], making their theoretical contribution, have a limited use in applications [4, 5]. So, the object of the study is the FEM-model of the plate, and the subject of the study is the features of the plate deflection distribution and the stresses in its material under the action of the tangential load distributed over the surface of the OSB-plate. In justifying this choice, the known results were taken into account [5, p. 87], namely, the FEM-model of a plate, based on volumetric finite elements used.

Referring to the general characteristics of the represented work, it should be noted that the research of building structures, in the final analysis, is always aimed at resolving a contradiction between strength, reliability, aesthetical design on one side and - cost-effectiveness on the other. Engineering activities to resolve this contradiction, often at the intersection of sciences, leads to the emergence of new, more advanced building materials, technologies and structures. One of the results of this activity are OSB-plates, the development of production and application of which contributes significantly to the solution of the global problem of rational use of wood as a resource created by nature. Taking into consideration the relevance of the topic of the article, the choice of the object of research and the purpose of the work, we note the following.

Wood as a natural polymer has remained one of the main factors in the development of civilization. History shows, that the sustainable development needs consistent improvement of technologies for the rational use of wood. A necessary element of the modern concept of sustainable development is a continuous improvement process aimed at rational use of resources and minimizing the negative impact on the environment. The implementation of the principles of sustainable development includes organizational, economic, environmental and technological aspects [6]. At the same time, the most important tasks are the reducing the amount of waste and its rational use. The waste is known [7], to be inevitable, so it is important to reduce the amount of waste and to use it rationally. So, contribution to the solution of the multifaceted problems that arise in this connection is introduced by applied research to justify new possibilities for obtaining building materials and improving timber structures. In this paper, we study some features of the functioning of oriented particle boards, known as OSB plates (Oriented Strand Board). Such boards are used in the construction of roofs, walls and other building structures [1, 8].

We can name a number of reasons that motivated the appearance of this work. First of all, it should be noted that the development of production and application of OSB boards contributes to the solution of the environmental and economic problems of sustainable development outlined above. The way to modern production of OSB, according to [6], began with the production of plates from wood residues in the 1920s, when the waste accounted up to 60% of the volume of raw materials in the form of round timber. The first industrial production of plates, known as particleboards, from undirected particles of crushed wood, connected by phenolic binders, was carried out in Bremen, Germany in 1941. By 1954, Canada developed a technology for producing the so-called wafer-boards [9, 10].

As the next stage of the plate evolution, in the mid-1970s, the idea to separate the wood particles into three layers was developed and realized. At the same time, in order to increase the strength characteristics of the plate, a strip-shaped wood particle was used, and in each of the layers the chips were oriented in mutually perpendicular directions. This is already an orthotropic plate. From the point of view of the mechanics of materials, the preferential orientation of the particles in the OSB plates in the direction of the principal stress actions makes it possible to reduce the thickness of the plate by increasing [11].

Thus, modern production of OSB-plate is one of the results of the wood processing technology development. The evolution of OSB-plates is described in more detail in [9–11]. In the context of our work, we note that currently in plate manufacturing, waste accounts approximately 20% of the volume of raw materials in the form of round timber [12]. Plates can be from 6 to 32 mm thick. Areas of plate use: roofing [1], walls, sandwich-type plates, floor structures, beam elements [8, 11]. OSB-plates are positioned as an alternative to plywood. With the decrease in the availability of round timber suitable for the production of plywood, in the 1970s, the development of technologies for the production of structured particle boards became one of the main priorities in the study of wood products [12, 13]. The production of OSB started in the 1980s in the USA and Canada [9, 10, 12].

In Russia, the first production line for OSB appeared in 2012, and since 2016 there have been five plants producing OSB plates [14]. From 2012 to 2016 the production of OSB-plates increased from 3 to 660 thousand cubic meters [14].

Due to the relative novelty of such plates, the features of their functioning have not been fully studied, which also motivated the appearance of this work. Literature review showed that the influence of the tangential component of the vertical load on the surface of the OSB plate when it is used in the roof structure has not been sufficiently studied, both numerically [4, 5, 8, 15] and analytically [2, 3, 17]. The tangential component (Figure 1) of the load on the surface of the sloping plate is determined by the weight of the snow (Figure 2), the soft roof [1] and the wind effect. As the slope of the plate increases, the tangent component increases too. Note that the snow load appears on planes with an inclination angle of even more than 45° (Figure 2).

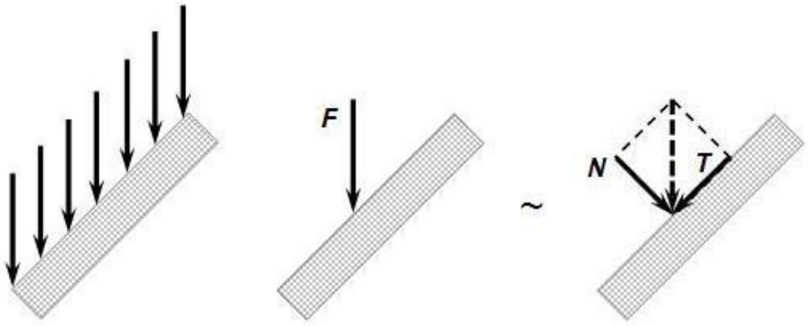

Figure 1. Vertical external force *F* on the plate surface, the normal *N* and tangential *T* components of it

Figure 2. Snow load on the roof

Concerning the choice of the instrument of our research, we note the following. At present, engineering calculations are performed, as a rule, using the finite element method (FEM) [4, 16]. An overview of the FEM-models with reference to the problem of the thick plate bending is given in [5]. Along with numerical methods [11], analytical methods for calculating plates are being developed. The Analysis of publications [15, 17–23] in this area showed that the attention of researchers is focused on the problems of bending under the action of forces normal to the plate surface. However, with a vertical load on the surface of the inclined plate, for example, snow load (Figure 2) and the weight of the soft roof [1], a tangent component appears at each point (Figure 1), which creates a bending moment and a corresponding deformation of a plate with thickness h. As the plate thickness h decreases, the bending moment M decreases linearly (Figure 3).

The following explanation to equivalent transformation in accordance with Figure 3 is required. Let tangential force T be applied at some point of the plate surface. Let two equal in magnitude but oppositely directed forces T_1 and T_2 be applied in a point on the axis. In this case the subsystem of forces T_1 and T_2 is equivalent to zero. Hence, the original system is equivalent to the system of forces T, T_1 and T_2. Equivalence will be retained if all three forces are equal in magnitude: $\mathrm{T} = \mathrm{T}_1 = \mathrm{T}_2$. So, a pair of forces T and T_2 will create a bending moment, and in the median plane along the longitudinal axis will act the force T_1. The magnitude of bending moment is equal $\mathrm{M} = \mathrm{T} \cdot 0.5\mathrm{h}$.

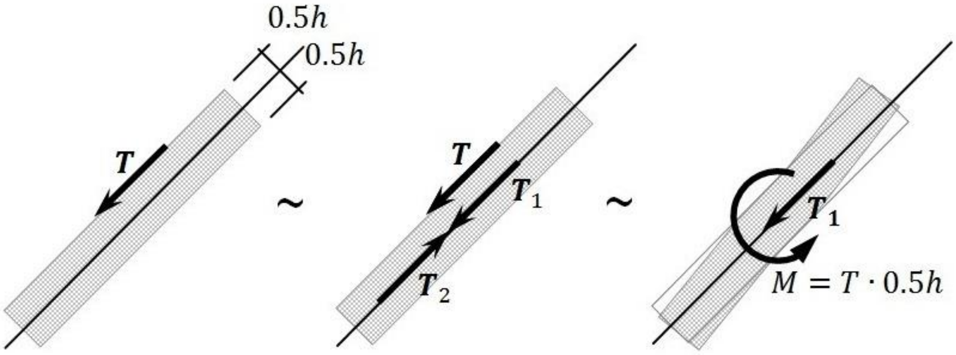

Figure 3. The tangential component of *T* as the cause of the appearance of the bending moment *M*

It is known that a plate, with the thickness more than five times smaller than its width, is called a thin plate. Thin plates usually have a constant thickness. The scheme of a thin plate is represented in the form of its median plane. The reference connections and the load on the thin plate are referred to the middle plane. In the case below, the ratio of the span to the thickness of the plate is ~ 50, which makes it possible to use the model in the form of a thin plate. Then the effect of the tangential load distributed over one of the surfaces of the plate can remain out of sight.

As it has been noted, the effect of the tangential component of the load distributed over the surface of an inclined plate has not been investigated enough for engineering and construction practice. The need to investigate this effect is due to its practical significance and is explained by the fact that in the case of using OSB-plates in the roof skin, the tangential component on the of inclined plates surface can cause unequal deflections of the plates to be joined at their ends. Namely, in the case under consideration (Figure 3) the tangential load on the plate surface causes a decrease in the deflection of the upper end of the plate and an increase in the deflection of the lower end. For this reason, unevenness and, consequently, damage to the soft roof can occur in the area of the butt joints of the OSB-plates.

Methods

In this study we have used the generally accepted methods of mechanical system modeling and finite element analysis of building structures, which reviews can be found in [5, 15, 23]. These methods are used as a tool for applied research of plate deformations and stresses in material, taking into account the tangential component of the load distributed on one of the plate surfaces.

From a methodological point of view, the results presented below can be practically applied after their being adaptated to specific conditions. Experimental and theoretical studies [11, 12] have established that the OSB material can be considered orthotropic. The elastic moduli in the longitudinal and transverse directions of the plates are determined according to the standard procedure EN 310 and according to the standard EN 300 must have values of at least 3500 and 1400 MPa in the longitudinal and lateral directions, respectively [9].

As a research tool, SolidWorks were used. The software generates mesh with one of the two types of elements: linear tetrahedral solid elements or so called parabolic tetrahedral solid elements. A linear tetrahedral element is defined by four nodes in vertexes of tetrahedron. A parabolic tetrahedral element is defined by the same four corner nodes and additionally six mid-side nodes on the edges of a tetrahedron. Therefore for the same mesh density (number of elements), parabolic elements yield better results than linear elements. Parabolic tetrahedral solid element ensures a quadratic interpolation of nodes displacement and is well suited to model irregular meshes. However, parabolic elements require greater computational resources than linear elements. Nevertheless, their advantages are used in various FE-complexes, for example in ANSYS (finite element SOLID 98). In this paper we used linear tetrahedral elements.

Results and Discussion

Let us consider the results of FEM-modeling using the OSB plate with the dimensions 1250 × 625 × 12 mm as an example; The long edges of the plate are fixed to the areas 1250 × 20 mm to two supporting platforms (Figure 4.0); The material of this plate is orthotropic, the moduli of elasticity are 3500 MPa and 1400 MPa, the approximate Poisson's ratio is 0.23.

The influence of tangential external forces distributed over the surface of the plate. We consider an inclined plate, whith a vertical load of 3000 N/m2, uniformly distributed over the plate face. Based on the results of the simulation, the largest resulting displacements occur in the lower and upper end of the plate, respectively, 1.692 mm and 1.551 mm, i.e. the edge effect is evident (Figure 4.3). The difference in deflections creates unevenness at the joint of the plate ends. (Figure 4.2). The reason for the appearance of these differences has been explained above (Figure 3): the tangential load on the surface of the plate causes a decrease in the deflection of the upper end of the plate and an increase in the deflection of its lower end (Figure 4.3 and 4.4).

The greatest stresses (according to Mises) do not exceed 2.6 MPa (Figure 4.5). It is known that the bending strength of OSB boards 11-17 mm thick along the main axis is not less than 20 MPa, and not less than 10 MPa along the minor axis. Criteria for the strength of isotropic and orthotropic materials have been considered in [24–27].

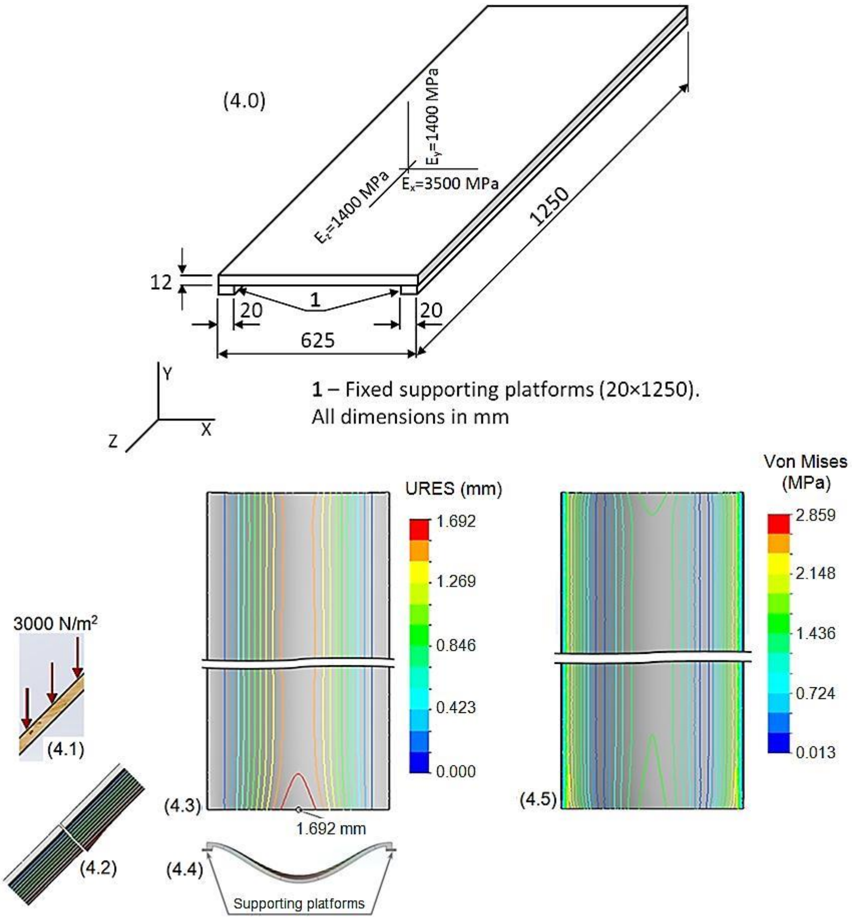

**Figure 4. The design scheme of the plate (4.0); the load on the plate (4.1);
the joint of the lower end of the upper plate and the upper end of the lower plate, side view (4.2);
the displacement isolines of points on the plate face (4.3);
the cross-section of the deformed plate (4.4); The stresses von Mises on the upper plate face (4.5)**

In the case above, the tangential forces are distributed not only over the outer plate surface, but are transferred to the lower plate surface through the support pads (Figure 4.4). To estimate the effect of these forces, let us consider a model example by repeating the calculation of the same plate under the load in Figure 5. In this case (Figure 5), the bending moment M (Figure 3) of the tangential components of the load is zero.

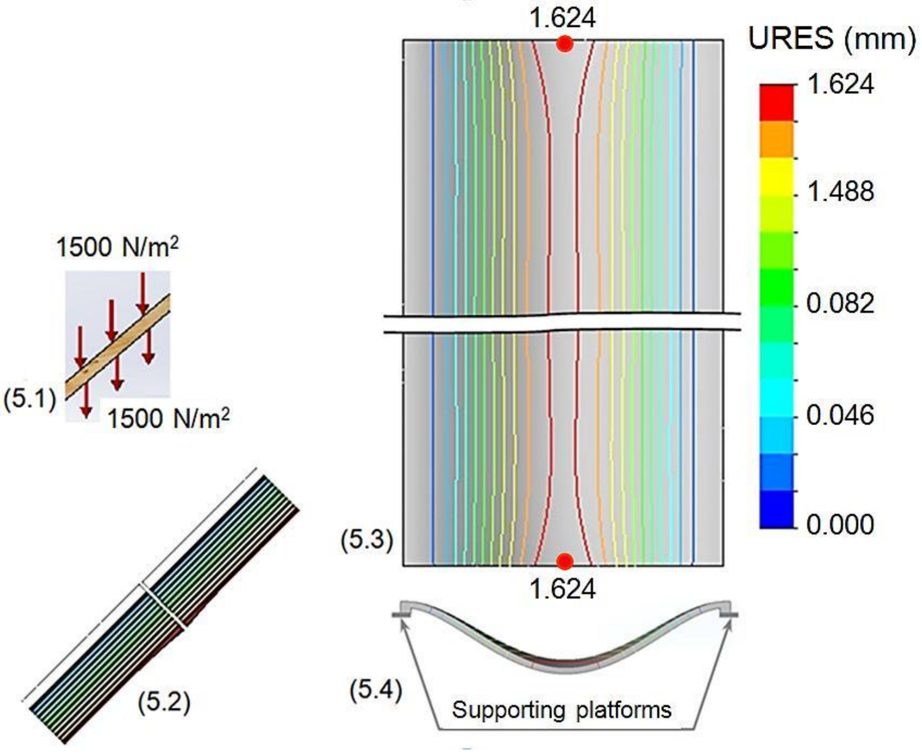

**Figure 5. The load on the plate (5.1);
butt joint of the lower end of the upper plate and the upper end of the lower plate, side view (5.2);
the displacement Isolines of the points on the plate face (5.3);
the cross-section of the deformed plate (5.4)**

As in the case above (Figure 4), the largest displacements take place at the ends of the plate, i.e. the edge effect is manifested. The deflections of the plate at the ends (~1.62 mm) are almost the same (Figure 5.3), the unevenness in the joint of the plates can be neglected (Figure 5.2). However, in real situations, the load by Figure 4 occurs.

Influence of support conditions. The support conditions (Figures 4.4 and 5.4) of the plate considered above were asymmetric with respect to the middle plane of the plate. Let us consider the same plate, but with the fixed side edges. Namely, all the nodes on the lateral faces with dimensions of 1250 × 12 mm are stationary. For OSB structural element the fixation of side edges can not provided. This "extreme" case, nevertheless the analysis of which will give a more complete idea of the effect of only the tangential load on the plate. Another "extreme" case is a horizontal plate with a vertical load, when the tangential component of the load is zero. It is technically difficult and Impractical to implement the first of these "extreme" cases in practice. But the second case is often encountered in practice. The plate which is placed under the angle $0° < \alpha < 90°$ refers to the intermediate cases in relation to the above two "extreme" cases.

For the case considered below, if the tangential external forces of 3000 N/m2 intensity are uniformly distributed over only one plate surface, then according to the simulation results we get the following picture of the deformations and stresses according to Mises (Figure 6). The largest displacement is 0.14 mm. Deflections (Figure 6.1) appear as a result of the action of tangential external forces distributed over one surface of the plate. The longitudinal axis of symmetry of the plate is similar to the S-shaped curve (Figure 6.2), which agrees with Figure 3. In the corners of the plate (Figure 6.3), there is a concentration of stresses, the greatest stress is ~ 0.7137 MPa.

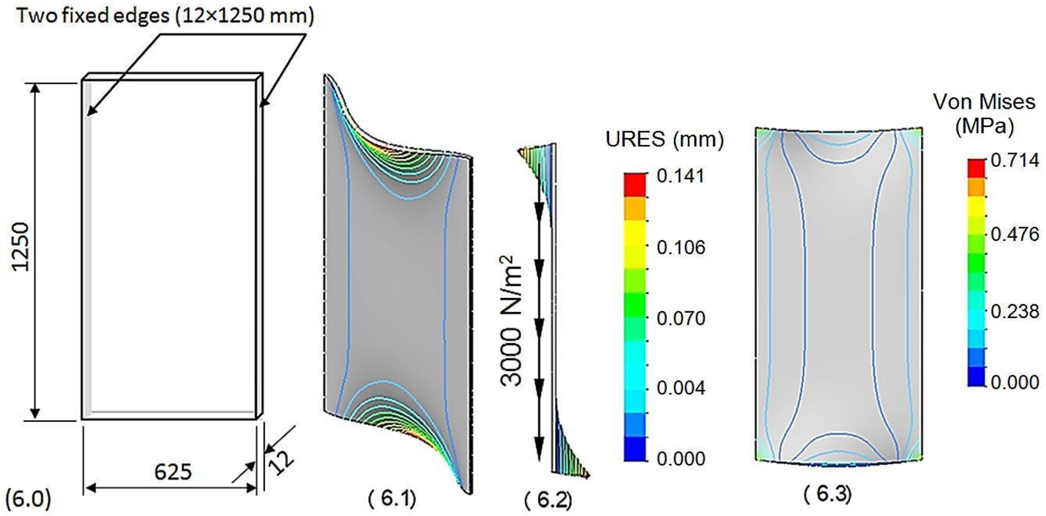

Figure 6. The design scheme of the plate (6.0); the deformed state of the plate (6.1) with pinched lateral vertical faces, the tangential load is evenly distributed only along the left side of the plate (6.2); the stresses von Mises on the right side of the plate (6.3)

At the level of qualitative reasoning it can be seen that in this case the influence of the tangential load distributed over the surface of the plate is analogous to the action of the eccentric longitudinal force on the rod. If the tangential load is symmetrical relatively to the middle surface of the plate (Figure 7.2), then the deformation of the plate bending is zero. However, there will be deformations in the plane of the plate (Figure 7.1). According to the results of modeling under a symmetrical load, flexural deformations are not detected either in the side view (Figure 7.2) or in the view from above (Figure 7.3). This confirms that the bend appears if the tangential load acts on one of the surfaces of the plate.

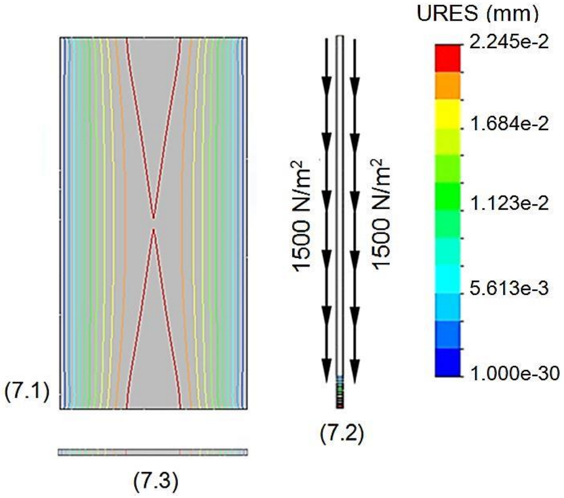

Figure 7. The total deformation of the plate with pinched lateral faces (7.1) under symmetrical loading (7.2) are not accompanied by bending deformations; Longitudinal section of the plate (7.2); The cross-section of the plate (7.3)

Influence of plate thickness on its deflections under surface tangential loading. If we compare the effects of normal and tangential loads on the plate (Figure 1), it can be seen that the influence of the surface tangential load depends on the thickness of the plate. As the thickness of the plate increases, the bending moment increases linearly (Figure 3). However, the deflections of a sufficiently flexible isotropic plate are known to be inversely proportional to the cylindrical rigidity, which is directly proportional to the cube of the plate thickness [22]. Thus, the deflections of the plate with a one-sided tangential load are inversely proportional to the square of the thickness of the plate. This non-strict regularity makes it possible to predict approximately the state of plates under the action of a tangential surface load.

Concerning the practical significance of the presented results, we note the following. The roofing is made from separate plate of certain dimensions. Therefore it is necessary to join the plates to each other.

In this case, the lower end of the upper plate contacts the upper end of the lower plate. The long (lateral) edges of the plates are deadly fixed to the 1250 × 20 mm areas indicated above, so that the butt end of the plates on these platforms is close to the ideal scheme. However, in the middle part of the span of plates the maximum deflection of the lower end is greater than the maximum deflection of the upper end of the plate.

The maximum displacements at the ends of the joined sloping plates (Figure 4.2) differ the more, the greater the slope angles of the plates are, i.e. the tangential load on the face of the plate is greater. As it is noted above, in this design there will be unevenness in the middle part of the span at the plate joints, which may cause damage, for example, to the soft roof [1]. To eliminate the cause of these irregularities, it is necessary to increase the stiffness of the lower end of the upper plate by setting the stiffener. The shape and dimensions of the stiffener should be specified taking into account the peculiarities of the manufacturing technology, packaging, transportation, installation and operating conditions of the plate as an element of the roof structure.

To exclude these irregularities, metal parts to join the OSB-plates in the roof structure can be used. However, the results of the examining of wooden structures with metal joint-elements presented in [25] show that over time, the wood around such a compound begins to deteriorate due to the effects of temperature and humidity. When heated and cooled, the metal parts heat up and cool down much faster than the wood of the plates. At the same time, moisture condenses on the metal part, penetrates into the plate material and gradually destroys it. Reducing the difference in these deflections at the joint of the OSB-plates with stiffeners at the ends will eliminate this disadvantage without the use of metal parts. Flexural stiffness and load-bearing capacity of plates in the area of their ends can be increased by stiffeners, external reinforcement by carbon composite materials and etc. [28–32].

Conclusions

Logic and the results of the work performed lead to the following conclusions.

Based on the results of FEM-modeling of the OSB plate, it is shown that the tangential load distributed over one of the plate surfaces is the cause of plate bending deformations (Figures 4 and 5).

It is established that in the structure of a soft roof, this tangential component of the vertical load causes unevenness at the joints of OSB inclined plates (Figure 6). Based on the results of the simulation, the largest resulting displacements occur in the lower and upper ends of the plate, respectively, 1.551 and 1.692 mm. The differences cannot be attributed to the catastrophic for new structure. But at repeated influences from snow and the dynamic loading wind, these irregularities can lead to defects in the roof over time. These circumstances also indicate the advisability of continuing research in the area.

In a model example of a finite element model of a vertical plate, it is shown that for such a plate the vertical load, evenly distributed over one of the plate surfaces, causes bending with a curvature of the tangential component line in the form of an S-shaped curve with maximal deflection 0.141 mm. For vertical plates the most dangerous may be a dynamic load of wind. Thus, the obtained results contribute to a better understanding of the board functioning. But at this point dynamic load of wind is the direction for future research.

In order to exclude the revealed cause of the unevenness in the structure of the roof with OSB plates, it is suggested to increase the flexural rigidity of the plates at their ends. For this purpose it is recommended to use OSB plates with stiffening ribs or with external reinforcement with the use of carbon composite materials.

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