Production of wooden I-beams from angular elements for low-rise housing

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Abstract. Due to the deterioration of the environmental situation, an increasing number of coniferous trees are affected by butt heart rot. For a more sustainable use of resources, one needs to use round assortments with the presence of sound rot for the manufacture of sawn products. I-beams are widely used in low-rise wooden housing construction. High installation speed without the use of heavy equipment and ease of assembly increase the speed and adaptability of building construction. A method for manufacturing I-beams from corner elements obtained as a result of cutting round timber with heart rot is proposed. The elements of the angular cross section are glued together to obtain an I-beam. The strength characteristics of an I-beam glued from angular cross-sectional elements are determined. It was established that the design characteristics of I-beams obtained by the proposed technology withstand operational loads. Values of normative and shear stresses arising upon application of loads do not exceed 50% of the permissible values. The beam deflection does not exceed 80% of the permissible deflection value. The use of round timber with core rot increases wood resources for low-rise housing.

1. Introduction

Sustainable use of forest resources is one of the prerequisites for stable economic development of the state. Wood is a renewable natural resource. However, due to the impact of industrial enterprises’ emissions on forest resources and as a result of changes in soil structure, the qualitative composition of forests is significantly deteriorating. Up to 85% of the round assortments arriving for processing fall into the category of low-quality due to the presence of butt (heart) rot [1]. Butt (heart) rot is rot located in the lower part of the trunk of a growing tree. The height of the lesion by butt rot is from 1.5 to 3 m of the trunk length from the root system. Butt rot mainly affects the valuable lump of wood of predominantly coniferous stands.

Current technologies for the harvesting and processing of wood involve the use of wood affected by butt rot only for the manufacture of wood chips or container lumber. But mainly it goes to the production of firewood or remains in the forest. Wood affected by butt rot is left in the forest, since it is not profitable to export it due to the high transportation costs and the low cost of the products made of it. Such wood will hereinafter be called low-grade wood. In order to obtain sawn products from low-grade wood, the following technological scheme is proposed.
Whips are cut in such a way that round timber for longitudinal cutting, obtained from the butt part of the whip, includes both a section of high-quality “guest” wood and a section with sound rot on average 0.5 to 1 m long. This is the so-called “combined” lumber logs [2]. The length of the “combined” lumber logs corresponds to the standard length of round logs.

Studies have established that a change in the diameter of rotten foam along the length of a tree trunk occurs in accordance with the allometric law [3]. In accordance with this law, the diameter of foamed rot in an arbitrary section of a tree trunk is determined by the formula:

\[ d_r = d_{r0} - a l_r^b \]  

(1)

where \( d_r \) - diameter of rotten foam in arbitrary section, m; \( d_{r0} \) - diameter of rot in butt round assortment, m; \( l_r \) - length of butt rot exposure, m; \( a, b \) - respectively, constants of the initial state and equilibrium.

There is a large number of studies on how to cut such round assortments into lumber [4-8]. We propose a fundamentally new method of longitudinal cutting of round timber. This method involves cutting assortments not only with access to one of the ends, but also with access to two ends. As a result of cutting, elements of wood are obtained for the manufacture of load-bearing building structures. Consider one of the types of supporting structures - I-beams.

I-beams made of wood are currently widely used in the construction of buildings and structures. They are used for the installation of ceilings, rafter systems, installation of floors and strapping on the foundation. The cross-sectional shape of the beam ensures good bending performance under operating conditions. In terms of performance, they are not inferior to metal and reinforced concrete structures, but have less weight. Beams can withstand design loads, both on small and large flights up to 12 m. However, modern construction experience shows the feasibility of using I-beams for flights from 2 to 6 m [9]. I-beams have such advantages as low weight, a large margin of safety, ease of transportation and installation, cost-effectiveness. Light weight, about 5 kgf/pm, allows working without the use of heavy equipment. High installation speed and ease of assembly increase the manufacturability of the construction of buildings and structures. After processing with special compounds, the wood of the beams has the necessary fire resistance, anti-decay and insect damage. There is a great need for such beams in seismically dangerous areas of construction. The environmental properties of wood beams are not in doubt. The retail price of I-beams is low. For example, for a beam with a height of 200 mm and a cross-sectional dimension of 42x85, it is about 300 rubles per linear meter. In beams made according to the technology proposed in Canada, calibrated glued timber is used for the manufacture of shelves, and the walls are made of oriented particle boards OSB-3 and OSB-4. In Russian conditions, most often the walls are made of plywood and rarely enough from LVL.

The manufacture of I-beams from round timber with heart rot going to two ends is as follows. Bark is removed from assortments. Longitudinal cutting of assortments is carried out according to the bar-breakup scheme. On the first pass, a two-edged beam with heart rot and lateral unedged thin lumber are obtained. On the second pass, two bars with heart rot, as well as side unedged lumber, are obtained. Then the bars are subjected to chamber drying by mild conditions and their moisture content is adjusted to 14±2°C. Rot is removed by milling and they are cut into elements of angular cross section (Fig. 1). The bars are sorted so that the quality of the wood corresponds to grade 2 according to GOST 8486. This quality corresponds to the strength grade C24 [10]. By gluing from the bars of the corner profile, an I-beam is obtained.
A large number of works have been devoted to studies of the features of I-beams. In particular, the publication [11] presents the test results of an I-beam with a wall made of OSB. In [12], the strength and deformability of composite beams with a wall of oriented chipboard are considered. In the studies [13-19], the issues of the influence of anisotropy of the properties of wood and various methods of fastening and reinforcement on the stress-strain state of the structure were considered. The design and calculation of I-beams made of wood is considered in the article [20].

The aim of this work is to study the possibility of using I-beams made of wooden angular elements as load-bearing building structures for low-rise housing construction. To achieve the goal, it is necessary to calculate the strength characteristics of wooden I-beams and check the possibility of using I-beam wooden beams as load-bearing building structures.

2. Methods

An I-beam wooden beam made of corner elements obtained from their round timber with rot was selected as the object under study.

Pine round timber with heart rot with a diameter of 30 cm at the top and 6.5 m long is subject to conditional cutting. The run was taken equal to 0.8. Thus, the diameter of the assortment in the butt is 35.2 cm. The dependence of the diameter of the rot along the length of the trunk in spruce forest products is determined by the formula [11].

\[ d_r = 0.44 - 0.0576 l_r^{1.0346} \]  

where \( d_r \) - rot diameter, cm; \( l_r \) - distance from end, cm.

On a lump of timber, the diameter of the rot is 15.6 cm.

We ensure a theoretical cutting of these round timber. The maximum theoretical yield of lumber is obtained when sawing on the first pass of a two-edged beam with a thickness equal to 0.707 top diameter. In the second pass, the total width of the central timber should also be close to this size. Based on these provisions, when cutting assortments with a diameter of 30 cm at the apex in the first pass, a two-edged beam with a thickness of 217 mm, a sheet width of 108 mm with rot with dimensions of 156 mm on the butt part of the beam is obtained. Also, side unedged boards with a thickness of 25 mm and a length equal to or less than the length of the assortment are obtained. The cut width is taken equal to 3 mm. On the second pass, from the central part of the two-edged beam, we obtain two bars with a cross-sectional size of 102×217 mm. From the peripheral part of the two-edged beam, side unedged boards 25 mm thick, equal to or less than the length of the assortment are obtained. The bars are laid in drying stacks and dried to a moisture content of 14 ± 2°C. Then, the bars are milled lengthwise and cut into two bars of a corner profile 98 × 103 mm with a wall thickness of 21 and 27 mm.
The output of the bars of the corner profile from the round assortment is 20%. The output of the side unedged boards is 22.5%. The total useful yield is 42.5%.

The bars are glued together in pairs and the blanks obtained in the form of channels are glued together and an I-beam is obtained. The beam has a height of 207 mm, a width of 196 mm, a belt thickness of 27 mm and a wall thickness of 43 mm (Fig. 2).

3. Results and discussion

The design scheme for determining the strength and deflection of the beam is a statically determinable articulated support beam loaded with a uniformly distributed load. The design span is assumed to be 6 meters. Under the influence of a design load of 1.5 kN/m, the beam experiences a stress-strain state of transverse bending. The standard load is 1.25 kN/m. Strength and deformatvie design characteristics of wood adopted in accordance with SP 64.13330.2017 “Wooden Structures” are given in table. 1. The coefficients for determining the design resistances are given in table. 2.

| Name                                      | Designation | Units | 2 grade/class K24 |
|-------------------------------------------|-------------|-------|-------------------|
| Design deflection resistance              | $R^A_{и}$   | MPa   | 22.5              |
| Estimated shear resistance along wood      | $R^A_{ск}$  | MPa   | 2.4               |
| Average flexural modulus for calculation   | $E_{ср}$    | MPa   | 11.0              |
| of deflection                              |             |       |                   |

| Name                                      | Designation | Value |
|-------------------------------------------|-------------|-------|
| Coefficient of long-term strength of wood  | $m_{дл.}$   | 0.66  |
| Coefficient of long-term strength of wood for elastic characteristics | $m_{дл.}E$ | 1.0   |
| Coefficient taking into account the type of wood | $m_{п.}$   | 1.0   |
| Coefficient taking into account the operating conditions of structures | $m_{обр.}$ | 1.0   |
| Coefficient taking into account the air temperature at which the structures are operated | $m_{т.}$   | 1.0   |
3.1. Checking with regard to normal stresses
Check for normal stresses arising in the beam.

\[ \sigma = \frac{M}{W} \leq R^p_{W}, \]

where \( M \) - maximum bending moment, kN\( \cdot \)m; \( W \) - moment of resistance of the lower stretched belt, m\(^3\); \( R^p_{W} \) - permissible design bending resistance for grade 2.

The maximum bending moment is found by the formula:

\[ M = \frac{q^p l^2}{8}, \text{kN} \cdot \text{m}, \]

where \( q^p \) - calculated load, kN/m; \( l \) - beam span, m.

The permissible design resistance to bending is determined by the formula:

\[ R^p = R^A m_{\text{wt}} \cdot \prod m_i, \]

where \( R^A \) - design resistance of wood at bending, MPa (table1); \( m_{\text{wt}} \) - coefficient of long-term strength (table 2); \( \prod m_i \) - the product of the coefficients of the working conditions \( m_{\text{ll}}, m_{\text{n}}, m_{\text{w}}, m_{\text{t}} \) (table 2). The calculation results of the normal stresses arising in the beam and the permissible design resistance to bending are given in tables 3 and 4.

### Table 3. Normal stress in the beam during bending.

| Name                      | \( q^p \), kN/m | \( l \), m | \( M \), kN\( \cdot \)m | \( W \), m\(^3\) | Result, MPa |
|---------------------------|-----------------|-----------|-------------------------|-----------------|------------|
| Normal stress in the beam during bending | 1.5             | 6.0       | 6.75                    | 0.0011          | 6.14       |

### Table 4. Permissible design resistance to bending.

| Name                      | \( R^A_{W} \), MPa | \( m_{\text{wt}} \) | \( m_{\text{ll}} \) | \( m_{\text{n}} \) | \( m_{\text{w}} \) | \( m_{\text{t}} \) | Result, MPa |
|---------------------------|-------------------|-----------------|-----------------|-----------------|-----------------|-----------------|------------|
| Permissible design bending resistance | 22.5              | 0.66            | 1.0             | 1.0             | 1.0             | 14.85           |

A comparison of the normal stresses in the beam and the permissible design resistance during bending shows that the magnitude of the normal stresses in the beam arising from bending under load is 41% of the allowable design resistance.

3.2. Deflection check
The deflection of the beam is found by the formula:

\[ f = \frac{5 \cdot q^H \cdot l^4}{384 \cdot E^{II} \cdot I}, \]

where \( q^H \) - rated load, kN/m; \( l \) - beam span, m; \( E^{II} \) - calculated modulus of elasticity of wood when calculating the limit states of the 2nd group, GPa; \( I \) - moment of inertia of the cross section of the beam, m\(^4\).
The calculated modulus of elasticity of wood when calculated by the limiting states of the 2nd group is calculated by the formula:

$$E^\Pi = E_{cp} m_{\Delta E} \prod m_i$$  \hspace{1cm} (7)

where $E_{cp}$ - mean bending elastic modulus, GPa (table 1); $m_{\Delta E}$ - coefficient for elastic characteristics (table 2); $\prod m_i$ - coefficient for elastic characteristics (table 2).

The results of calculating the deflection of the beam are given in table 5.

**Table 5. Beam deflection calculation.**

| Name                          | $q^{\text{in}}$, kN/m | $l$, m | $E_{\text{cp}}$, GPa | $m_{\Delta E}$ | $m_{\text{II}}$ | $m_{\text{II}}$ | $E^\Pi$, GPa | $l$, m$^4$ | Result, mm |
|-------------------------------|------------------------|--------|----------------------|----------------|----------------|----------------|-------------|-----------|------------|
| Design beam deflection        | 1.25                   | 6.0    | 11.0                 | 1.0            | 1.0            | 1.0            | 11.0        | 99.2·$10^{-6}$ | 19.4       |
| Permissible deflection of the beam | -                     | -      | -                    | -              | -              | -              | -           | $l/250$   | 24.0       |

Comparison of beam deflection and permissible deflection shows that the amount of deflection in the beam that occurs when bending under load is 80% of the amount of permissible deflection. Deflection does not exceed the maximum allowable deflection.

### 3.3. Checking with regard to shear stresses

Tangent stresses arise in the beam wall. The greatest value they arise in the supporting zones, where the transverse load reaches its maximum value. In this regard, the beam shall be checked for shear stresses in the support zone. The magnitude of the transverse force in the support zones is calculated by the formula:

Calculation of the beam for shear strength is carried out according to the formula:

$$\tau = \frac{Q \cdot S}{I \cdot b_{\text{ct}}} \leq R_{\text{ck}},$$  \hspace{1cm} (8)

where $Q$ - design shear force, kN; $S$ - static moment of the movable part of the cross section of the beam, m$^3$; $I$ - moment of inertia of the cross section, m$^4$; $b_{\text{ct}}$ - beam wall width, m.

The permissible design resistance to bending is determined by the formula:

$$R_{\text{ck}} = R^A_{\text{ck}} m_{\Delta E} \prod m_i,$$  \hspace{1cm} (9)

where $R^A_{\text{ck}}$ - design resistance of wood to chipping along wood fibers, MPa (table 1); $m_{\Delta E}$ - coefficient of long-term strength (table 2); $\prod m_i$ - the product of the coefficients of the working conditions (table 2).

The results of calculating the shear stresses and the permissible design resistance are given in tables 6 and 7.

**Table 6. Shear stresses in the beam.**

| Name                          | $q^{\text{in}}$, kN/m | $l$, m | $Q$, kN | $S$, m$^3$ | $I$, m$^4$ | $b_{\text{ct}}$, m | Result, MPa |
|-------------------------------|------------------------|--------|---------|------------|-----------|---------------------|--------------|
| Shear stresses in the beam    | 1.5                    | 6.0    | 4.5     | 4.9·$10^{-3}$ | 99.2·$10^{-6}$ | 0.043               | 0.05         |
### Table 7. Permissible design shear resistance.

| Name                        | \( R^A_{ck} \) | \( m_{t,1} \) | \( m_{n} \) | \( m_{w} \) | \( m_{t} \) | Result, MPa |
|-----------------------------|----------------|--------------|-------------|-------------|-------------|-------------|
| Allowable design resistance to wood chipping | 2.4            | 0.66         | 1.0         | 1.0         | 1.0         | 1.58        |

### Conclusion

A comparison of the shear stresses and the permissible design shear resistance shows that the magnitude of the shear stresses arising from bending under load is only 3% of the allowable design resistance of wood to chipping.

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