LVL–structures made as combined section with small-compliance connections, consistent with stress-strain state of structural elements

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Abstract. The use of composite structures of LVL elements of I-beam and box-shaped cross-section is the most expedient from an economic point of view. Applications for connecting the individual parts of the cross-section of ductile connections - self-tapping screws, allows you to assemble such structures at a construction site. The use of self-tapping screws installed in accordance with the direction of the tensile internal forces of the structure makes it possible to force self-tapping screws to work mainly in tension. At the same time, the most rational work of the joints is achieved — minimum work on bending and maximum work on stretching. According to the results of tests, manufactured and designed beams of composite section, it was concluded that box-shaped beams have greater load-bearing capacity and less deformability. The ratio of actual and calculated bearing capacities of composite box-section beams is higher, the required value of the safety factor, and the destruction of the test beams occurred wood, which indicates the safety margin of the connection of the elements of the composite section on the stretched self-tapping screws.

1. Introduction
The use of load-bearing wooden structures of a composite section (I-beam and box-shaped) is more economically feasible in comparison with solid glued wooden structures. The use of LVL for their manufacture significantly increases the prospects of using such structures. The overlapping span increases (up to 40-50 m), the need for anti-shrink cuts in flanges disappears, the need for joining web panels disappears, the size range of individual section elements increases, etc.

Despite their advantages, these structures are not without drawbacks. An important problem is the method of connecting the individual elements of the composite section to each other. The study of composite wooden structures, mainly beams, has been the subject of a large number of works [1-13]. They consider both composite beams on glue, and structures on dowels and metal connecting plates. However, the use of adhesive bonding not only excludes the possibility of construction-based manufacturing, but also carries the risk of non-adhesive, which significantly changes the nature of the SSS of such structures [11]. The use of traditional dowels joints, in which the wood works to crush in the indentation nest and to shear between them, and the metal rod only to bend, in many cases, can hardly be called rational from an engineering point of view. It was noted in [14] that it is much more efficient to use the work of thin rods in tension.
The purpose of the research is to test wooden beams of a composite section (I-beam and box-shaped) from LVL, the section elements of which are connected using self-tapping screws that work in tension.

2. Methods
To achieve the goal, a full-scale experiment of six wooden beams of a composite section of LVL elements was carried out. During the study, the following tasks were set:
1. To develop an approximate methodology for calculating and arranging self-tapping screws working in tension in accordance with the direction of the main tensile stresses.
2. Design and assembly of six experimental beams from LVL elements. Three - box-shaped and three - I-section.
3. Field testing of structures for bending in accordance with [15].
4. Analysis of the results, determination of safety factors according to [15].

2.1. Development of an approximate calculation method, design and manufacture of test beams.
To rationally arrange the stretched bonds between the elements of the composite section, the rule of the “driven and leading” element was formulated. Other authors called the rule "The principle of adaptive matching links" [16]. Figure 1 shows the indicated rule, as applied to the LVL beam of the I-section. The web, being an integral element over the entire height of the section, with bending deformations forces the flange to follow.

![Figure 1. Illustration of the rule of “driven and leading” element on the example of an I-beam wooden beam.](image)

Using the indicated rule, it is quite simple to determine the direction of the formulation of stretched bonds between elements of a composite section. For further research and construction, two main options were identified (Figure 2): at an angle to the wood fibers in one plane, at an angle to the wood fibers in two planes. It can be seen from the figures that the direction of the connectors follows the direction of the trajectory of the main tensile stresses in the beam during bending.

The calculation of the number of self-tapping screws was carried out according to the tangential stresses along the seam of the belt-wall using formula 25 [17]. To do this, the entire beam was divided along the length into several equal sections, each of which has its own step of placing stretched bonds. The bearing capacity of self-tapping screws for pulling wood from the body was determined according to formula 2 [18].

Based on the calculation results, four types of composite beams of LVL elements 6.6 m long were designed:
1. I-section with self-tapping screws installed at an angle to the wood fibers in the same plane
2. I-section with self-tapping screws mounted at an angle to the wood fibers in two planes.
3. A box-shaped section with self-tapping screws installed at an angle to the wood fibers in one plane.
4. A box-shaped section with self-tapping screws installed at an angle to the wood fibers in two planes (Figure 3)

Test beams were manufactured in the mechanical laboratory of SPbGASU. In total, six beams of four types were collected during the research.
Figure 2. a) Arrangement of stretched bonds in a composite I-beam at an angle to the wood fibers in one plane. b) Arrangement of stretched bonds in a composite I-beam at an angle to the wood fibers in two planes.

| Marking | Type of Beam                                      |
|---------|--------------------------------------------------|
| BD-1    | I-beam with self-tapping screws installed at an angle to the wood fibers in two planes |
| BD-2    | I-beam with self-tapping screws installed at an angle to the wood fibers in two planes |
| BD-3    | I-beam with self-tapping screws installed at an angle to the wood fibers in one plane |
| BK-1    | Box-section beam with self-tapping screws installed at an angle to the wood fibers in two planes |
| BK-2    | Box-section beam with self-tapping screws installed at an angle to the wood fibers in two planes |
| BK-3    | Box-section beam with self-tapping screws installed at an angle to the wood fibers in one plane |
Figure 3. The arrangement of screws working in tension installed at an angle to the wood fibers in two planes in a composite box-section beam.

2.2. Testing.
Beams were tested according to the scheme shown in Figure 4. The design was mounted on pivotally movable supports, fixed from the plane of bending and was subjected to eight concentrated forces. In the center of the span, deflection meters with a division value of 0.01 mm were installed. Loading took place at a constant speed of 5 mm / min in steps of 1000 kg, with a shutter speed of 5 minutes at each step and recording values from measuring instruments. During the test, the values of the total deformation and the differences of the total deformations between the steps were determined. In Figure 5 shows a beam BD-1 installed in a testing machine.

Figure 4. Test scheme of a composite wooden beam made of LVL elements of I-section.
3. Results
As a result of tests, the BD-1, BD-2, BD-3 beams of a composite I-section of LVL elements connected by self-tapping screws installed at an angle to the tensile wood fibers collapsed due to the action of shear stresses on the support. The maximum breaking load reached 14 tons with a deflection value of 42.1 mm. The nature of the destruction of the beam BD-3 is shown in Figure 6.

The destruction of the beams BK-2 and BK-3 of the composite box section occurred at normal stresses in the center of the span. The maximum value of the breaking load is 21 tons with a deflection of 53.09 mm for the BK-2. The destruction of the beam BK-1 occurred from shear stresses on the support at a load of 22.5 tons and a deflection of 49.93 mm. The nature of the destruction of the beam BK-2 is shown in Figure 7, the nature of the destruction of the beam BK-1 in Figure 8.

A summary graph of the total strain versus load for all test beams is shown in (Figure 9) Values of safety factors for load-bearing capacity for the tested structures (Table 2).
Figure 7. The nature of the destruction of the beam of the composite box section of the LVL elements BK-2 in the center of the span.

Figure 8. The nature of the destruction of the beam of the composite box section of LVL elements BK-1 on the support
Figure 9. The graph of the dependence of total deformations on load for all tested beams BK-1, BK-2, BK-3, BD-1, BD-2, BD-3.

Table 2. Values of Safety Factors according to [15] for the tested structures.

| Marking | Actual bearing capacity, $N_{exp}$, kg | Safety Factor value, $K_b$ | Design bearing capacity, $N_d$, kg | Ratio $N_{exp}/N_d$ |
|---------|---------------------------------|--------------------------|-------------------------------|------------------|
| BD-1    | 10500                           | 2.14                     | 8840                          | 1.19             |
| BD-2    | 12500                           | 2.14                     | 8840                          | 1.41             |
| BD-3    | 14000                           | 2.20                     | 8840                          | 1.58             |
| BK-1    | 22500                           | 2.17                     | 9602.5                        | 2.34             |
| BK-2    | 21000                           | 2.17                     | 9602.5                        | 2.19             |
| BK-3    | 21000                           | 2.17                     | 9602.5                        | 2.19             |

4. Conclusions
1. The type of destruction of all tested LVL beams was “fragile” in accordance [15].
2. According to the test results of composite beams with connections of elements on self-tapping screws at an angle to the wood fibers, it was found that box-shaped beams have greater load-bearing capacity and less deformability than I-beam beams.
3. The ratio of the actual and estimated bearing capacities of the composite box-section beams is higher than the required value of the Safety Factor according to [15], which indicates the necessary and sufficient bearing capacity of the tested design.
4. The destruction of the test beams occurred on wood, which indicates the safety margin of the connection of the elements of the composite section on the stretched self-tapping screws.
5. It is necessary to continue research in order to more accurately establish the relationship between the angle of the formulation of bonds, deformations and bearing capacity of structures.

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