Manufacturing structural building components from round timber with heartwood rot

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Abstract. Coniferous sawn goods are widely used in construction industry. The quality of round timber deteriorates due to the presence of heartwood rot, which has to be removed in the manufacture of load-bearing structural units. As a rule, rot is removed during the round timber logging. At the same time, healthy sapwood is removed along with that impacted by rot. Therefore, large amounts of quality wood remain in forests. For qualitative ripping of round timber affected by heartwood rot, it is necessary to know the rot shape and size in trunks. The relationship between the round timber cross-sectional dimensions and heartwood rot size along the trunk length is quite accurately described by correlative (allometric) growth equations. As a result of the research, such interrelations were established. Based on the equations obtained, conditional ripping of round log was carried out. As a result, bars for manufacturing I-beams were obtained. They are widely used in low-rise wooden house construction. It was established that the recovery factor was high enough for structural units made of round timber affected by heartwood rot that makes it possible to propose this cutting method for industrial application.

1. Introduction

Coniferous sawn goods are widely used to manufacture load-bearing structural units. Requirements to timber intended for construction do not permit rot presence in it. However, dimensional and qualitative indicators deteriorate recently for raw materials intended for construction. Their average diameter becomes smaller, and saw logs with big diameter are affected by heartwood rot. It occurs due to the fact that trunks used for manufacturing timber assortments, become shorter, and the root parts of the logs with sufficient length and diameter are often affected by heartwood rot.

Crosscutting of such trunks into round logs involves removal of wood areas affected by rot due to difficulties in processing the wood injured with rot and high transportation costs. Therefore, significant amounts of wood are left in forests. Application of the existing technology results, first of all, in losing large amounts of raw wood since it contains high-quality sapwood (up to 70 % of the volume) along with the core injured by rot. Secondly, wood rotting spots are formed, which become sources of wood-destroying fungi and affect healthy timber stands. Therefore, the need appears to develop new ways of processing wood affected by heatwood rot.

Investigations to improve the quantitative and qualitative output of sawn goods from round wood affected by heartwood rot were carried out previously. In a number of studies, the sawn timber yield was compared when sawing low-quality coniferous raw materials through-and-through/ with log squaring at log
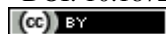
frames and individually in sleeper saw benches. The advantage of open-type sawing was established as compared to sawing at log frames. Studies, carried out by R.E. Kalitievsky showed that the volume yield of sawn goods increased when using bandsaw machines for logs affected by rot. A.N. Pesotskiy and many other researchers proposed to use a circular cutting method that allowed separation of the log rotten part and its exclusion from sawn goods. Having processed experimental data, V.S. Petrovsky established a correlation between recovery factor and the rot relative diameter. The resulting formulas were valid with regard to cutting bottom pinewood logs through-and-through into sawn timber. He proposed that each sawmill would determine the maximum allowable size of rot, depending on the raw material price, production costs and volume yield of sawn goods.

A.S. Toropov has developed cutting methods, protected by Russian Federation patents, for wood affected by heartwood rot, which made possible to efficiently use timber sapwood [1–3]. In particular, patent [3] provides longitudinal cutting of round timber into sections, from which the core zone is removed, for example, by shaping. Resulting blanks are straightened by steaming, bending and pressing. Then, sawn goods are produced by gluing. Other patents also provide efficient cutting of timber affected by rot and production of high-quality sawn goods.

Today, the volume of low-rise wooden house construction is growing significantly. During construction, various wooden beams are used. Beams made of I-shaped wood are of greatest demand. They are used to cover spans 2 m to 6 m long. Flanges are made of solid or glued wood. I-beam webs are made of plywood. In Canada, OSB-3 and OSB-4 material is used for web manufacturing, while in Russia LVL is used for beam webs production. The article [4] considers a method of I-beam units manufacturing from round timber with heart rot. Numerous studies are dedicated to strength characteristics of I-beams made of wood and wood materials with various connection types [5–18].

The accomplished paper review and assessment allows establishing the purpose and objectives of this study. The aim of the work is to improve the cutting method for round timber affected by heart rot to produce structural units, taking into account rot dimensions and location in assortments. Structural units are used in the low-rise wooden house construction. The goal requires to solve several tasks: to obtain dependences of the round timber shape and size; to establish correlation dependences between the heart rot diameter and the cross-sectional assortment diameter; to work out the way for balanced longitudinal cutting of round timber to obtain the maximum yield of structural units and to determine the yield of structural units from round timber with heartwood rot.

2.   Methods

To efficiently cut round timber with heartwood rot, it is necessary to know the location of the rot in trunks. Therefore, let's consider the basic principles of tree trunk formation and the heartwood rot development in it. During the tree growth, its different organs develop simultaneously. It was found that the change in growth rates occurs synchronously during simultaneous growth of two or more organs. The growth rate ratio remains approximately constant. This ratio is well described by the formula:

$$y = C + ax^b,$$
(1)

where x and y are variable factors;

a and C are initial state constants;

b is the equilibrium constant that features the rate change of y relatively x.

To link the diameter of the heart rot in a random cross section and the diameter of the heartwood rot in the timber butt end, it is converted into an expression:

$$d_h = d_{h0} + al_h^b,$$
(2)

where d_h is the heartwood rot diameter in a random cross section, m;

d_{h0} is rot diameter in the round timber butt end, m;

l_h is the distance from the butt end to the heartwood rot distance,

m; a, b are initial state and equilibrium constants, correspondingly.

The diameters of the heardwood rot at the butt end of the timber and the diameter of heartwood rot and timber at a distance from the butt end was measured on 10 of the round timber with heartwood rot (Figure 1).
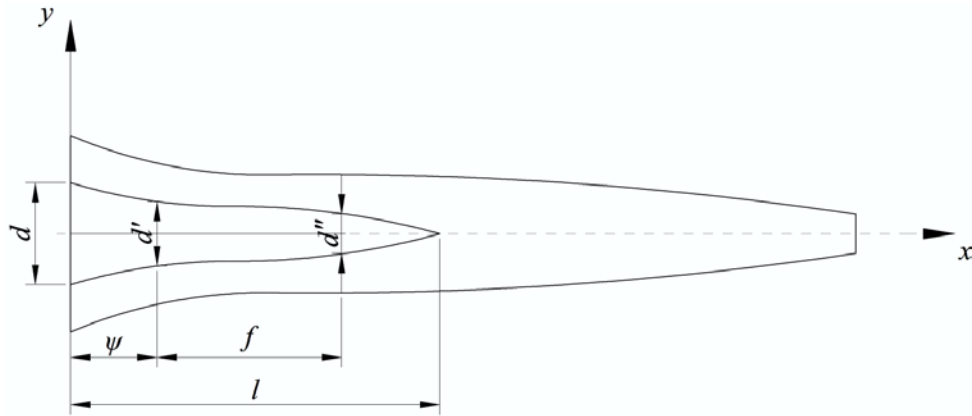
Figure 1. Computational model.

where d_{h0} is the rot diameter in the round timber butt end, m;

l_h is the distance from the butt end to the heartwood rot location, m;

$d_h^{'}, d_h^{''}$ is rot diameter in two locations of diameter measurement along the affected length l_h, correspondingly, m;

ψ and f are the x-coordinate of the location of the first measurement and the distance between the rot diameter measurement points, correspondingly, m.

Log and heartwood rot diameters were measured in meters per every meter of the length, as the length of a straight line that passes through the cross-section centre, perpendicular to the longitudinal axis of the log. Then, the average value was calculated for two measurements within one cross-section.

According to the program METHODS.EXE the values of the initial state constants a and equilibrium b. Values of the constants are calculated by formulas:

$$a = \left(\frac{1}{\psi}\right)^b \cdot \left(d_{h0} - d_h^{'}\right), \tag{3}$$

$$b = \ln\left[\left(d_{h0} - d_h^{''}\right)/\left(d_{h0} - d_h^{'}\right)\right]/\ln\left[(\psi + f)/\psi\right], \tag{4}$$

where d_h' and d_h'' are rot diameter in two measurement locations along the exposure length l_h, correspondingly, m;

ψ and f are the corresponding x-coordinate of the first measurement location and the distance between rot measurement points, m.

Applying the acquired values of the constants made the equation of when the rot diameter at an arbitrary cross section of the timber with the rot diameter at the butt end 10 of the round timber. Using the equations obtained, we calculated the diameters of the rot in the cross sections located 1 m along the length of the timber. The calculated rot diameters were compared with the actual values obtained as a result of measurements.

Round timber is conventionally cut in the logs with a length of 6 and 4 m. Logs were cut into squares with the maximum area in the log top part. Then, they were divided in half in a longitudinal direction. Each resulting part contained heart rot with different length. Rot dimensions were made based on the results of actual measurements, the rot at the round timber from which the logs are. The rot minimum size was in the square top, and the maximum one was in the butt end (Figure 2a).

To produce structural units from squares, rot was removed by conventional shaping and obtaining T-section units free from rot (Figure 2b).
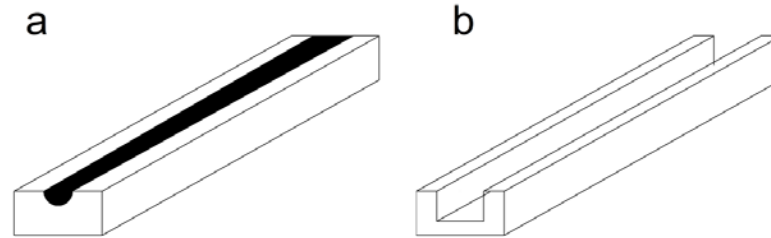
**Figure 2. Shaping layout of the unit affected by rot
a – rot location diagram; b –T-section unit.**

T-section units may be used to manufacture beam structures of different cross-sections. It is possible to use T-section units as I-beam flanges with plywood webs. Another application scheme involves connection of T-section units by a wide sawn face into an I-section beam. After conditional cutting and rot removal, the dimensions of T-section units were measured. The useful wood yield was defined for units made of round timber with rot.

3. Research results

According to the program METHODS.EXE the values of the initial state constants *a* and equilibrium *b* were calculated for the correlation equation of the rot diameter in an arbitrary section along the length with the rot diameter in the timber butt. For calculations, the results of measurements of rot diameters in sections located along the length of the lesion at the same distances from each other were used. The values of the distance from the butt of timber in the first section and the distances between the sections where the sections of rot were measured were applied. These values are based on the results of measurement of the heartwood rot size for ten pieces of pinewood round timber, in accordance with the computational model. Table 1 contains the computation results.

Table 1. Computation results.

Sec. No.	Heart rot diameter in a butt end, [m]	a	b
1	0.063	−0.012	0.658
2	0.082	−0.010	0.783
3	0.108	−0.032	0.512
4	0.097	−0.007	1.035
5	0.082	−0.029	0.387
6	0.093	−0.021	0.603
7	0.091	−0.013	0.759
8	0.076	−0.013	0.734
9	0.086	−0.029	0.344
10	0.076	−0.012	0.776

In an analytical form, dimensional dependence of the stump heartwood rot is as follows for the first trunk:

$$d_h = 0.063 - 0.012 l_h^{0.658}$$

The following diagrams were plotted based on the rot diameter computation data according to relative growth equations and measurement data of the heartwood rot diameter (Figures 3 to 5).

The data from the diagrams demonstrated good match of actual measurement results with the data calculated by relative growth equations.

Taking into account the heart rot shape and dimensions, we have worked out a cutting plan for round timber to produce structural units. Round timber rise has a significant impact on the final product output. Rise is the diameter decrease per one meter of the timber length from the butt end to the trunk top. Round timber was conditionally cut into 6 m long round logs with diameter of at least 20 cm at the top part. If the trunk length was insufficient for cutting into 6 m log, they were cut into 4 m long log. Log diameter was measured at their top and butt end. To exclude the effect of the near-root knar, butt-end diameter was measured at a distance one meter from the butt end. Rise values were calculated for round timber; the results are given in Table 2.

The data in Table 2 illustrated that the rise in round logs achieved 2.0 % to 2.3 %. According to research results presented in [19], rise value was about 1.4 cm/m for butt-end pinewood logs having diameter 26 cm. The higher rise in logs, which we obtained after trunk cutting, was caused by the fact that the biggest rise was typical for logs produced from the trunk butt portion. In this regard, the rise of sawn round timber is less than that for the logs with heartwood rot, which we obtained after conditional cutting.
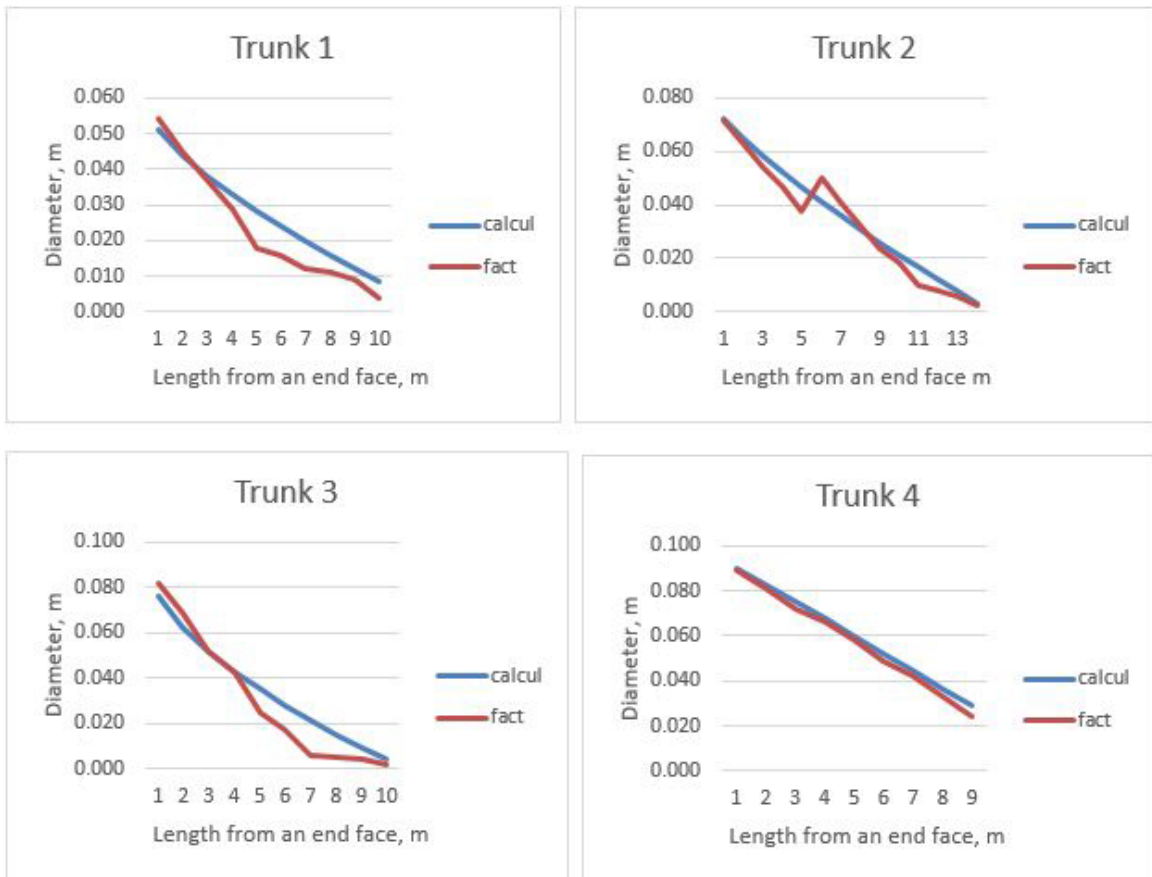
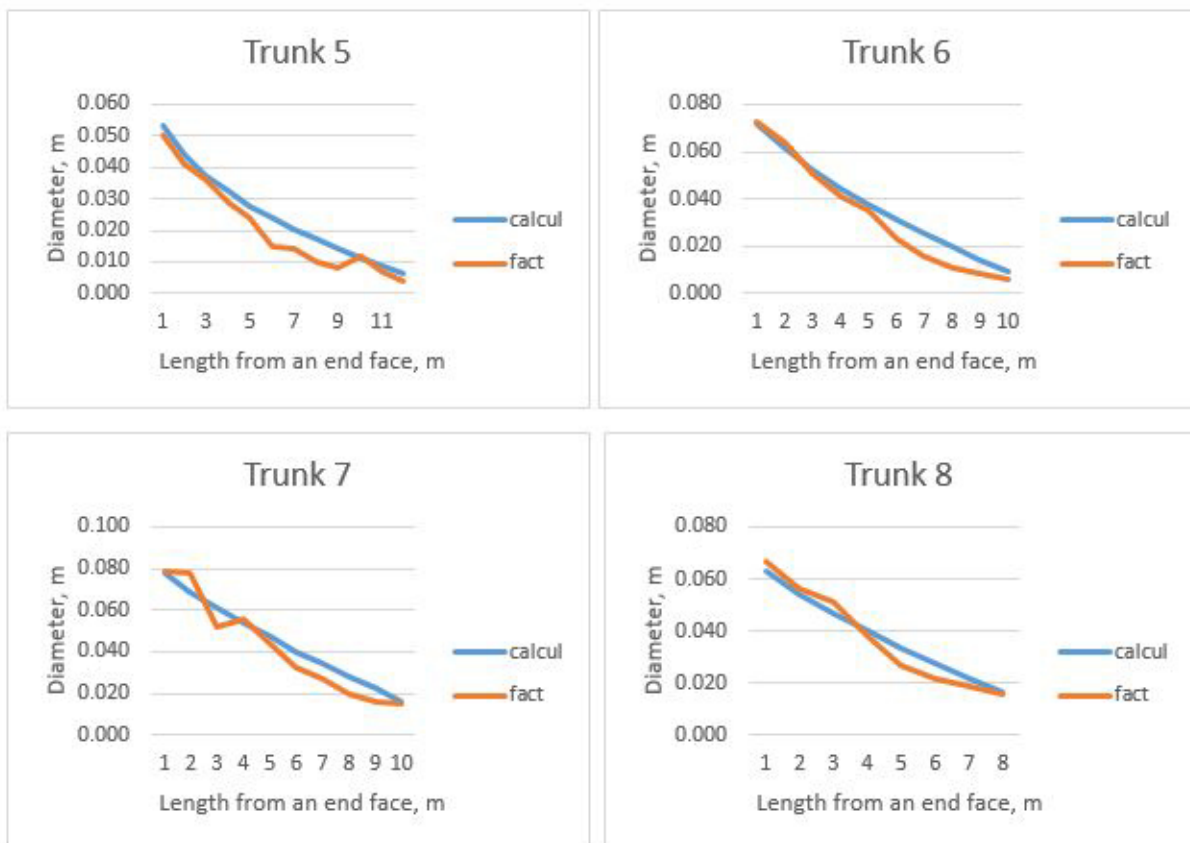**Figure 3. Actual heartwood rot diameters as compared with the calculation data (trunk 1 to 4).**

Figure 4. Actual heartwood rot diameters as compared with the calculation data (trunk 5 to 8).
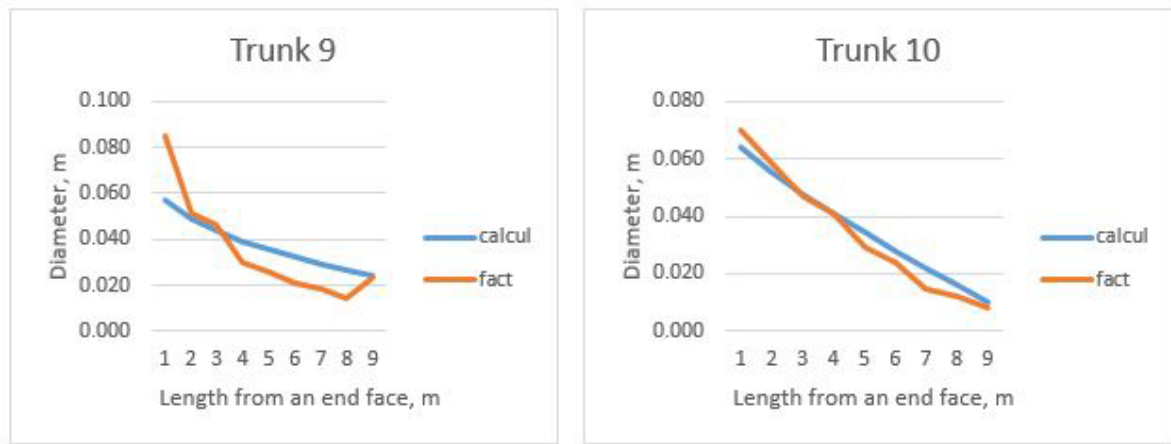
Figure 5. Actual diameter of heartwood rot as compared with the calculation data (trunk 9 to 10).

Table 2. Round log rise values.

Seq. No.	Round timber diameter, cm	Length, m	Round timber volume, m³	Rise value, cm/m
1	24	6	0.330	0.9
2	24	6	0.330	2.0
3	20	6	0.230	2.1
4	26	6	0.390	1.4
5	22	4	0.178	2.3
6	24	6	0.330	2.0
7	22	4	0.178	0.9
8	22	4	0.178	2.3
9	20	6	0.230	1.3
10	20	4	0.147	1.0

Having performed a conditional timber cutting, we obtained the dimensions of T-section units. Then, we calculated the yield of T-section units from logs. Calculation results are given in Table 3.

Table 3. Yield of T-section units from round logs and unit dimensions.

Seq. No.	Round log diameter, mm	Length, m	Round log volume, m³	Unit height, mm	Unit width, mm	Flange thickness, mm	Web thickness, mm	Unit volume, m³	Yield of T-section units, %
1	24	6	0.330	175	85	55	55	0.155	47.0
2	24	6	0.330	175	85	51	51	0.149	45.1
3	20	6	0.230	150	72	20	20	0.061	26.5
4	26	6	0.390	175	85	51	51	0.149	38.2
5	22	4	0.178	150	72	30	30	0.056	31.6
6	24	6	0.330	175	85	41	41	0.129	39.2
7	22	4	0.178	150	72	30	30	0.083	46.4
8	22	4	0.178	150	72	37	37	0.064	36.2
9	20	6	0.230	150	72	32	32	0.087	38.0
10	20	4	0.147	150	72	36	36	0.064	43.5

The results shown in Table 2 indicate the possibility to produce structural units of 150 mm, 175 mm high and 4 m and 6 m long. The yield of bars for T-section units was about 40 % for round timber. The study performed [20] showed that, for example, the total timber yield from logs of 26 cm in diameter was about 57 %. It may be stated that the presence of rot in logs reduces the yield by 17 %. However, it should be kept in mind that approx. 40 % of the yield is made up by bars; and cutting will be performed for round timber, which is currently not allowed for manufacturing construction sawn goods; and wood remains in forests or is used to produce fuel chips at the best.

4. Conclusion

1. Application of allometric method during the trunk of the heartwood rot size permits to efficiently cut round timber.

2. It is possible to produce structural units from pinewood round timber affected by heartwood rot.

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3. It is possible to use T-section structural units when manufacturing beam structures with different cross section. The most efficient way of their application is to use them as I-beam flanges or to connect directly into an I-beam.

4. Rise values for logs with heart stump rot significantly exceed the ones for the logs produced from trunk according to valid regulatory documents.

5. The yield of T-section structural unit from round timber with heartwood rot was approx. 40 %.

6. Application of round timber impacted by rot for manufacturing building structures increases wood resources for low-rise wooden house construction.

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Получение элементов строительных конструкций из круглых лесоматериалов с сердцевинной гнилью

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Ключевые слова: круглые лесоматериалы; сердцевинная ядровая гниль; уравнения аллометрического роста; элементы строительных конструкций; полезный выход.

Аннотация. В строительстве широко применяются пиломатериалы хвойных пород. Качество круглых лесоматериалов ухудшается. В них часто встречается ядровая гниль, которую приходиться удалять при изготовлении несущих строительных конструкций. Как правило удаление гнили происходит на этапе заготовки круглых лесоматериалов. При этом вместе с древесиной поражённой гнилью удаляется здоровая заболонная часть. Поэтому большое количество качественной древесины остаётся в лесу. Для качественного продольного раскроя круглых лесоматериалов с ядровой гнилью необходимо знать форму и размеры гнили в сортименте. Взаимосвязь размеров поперечного сечения круглых лесоматериалов и ядровой гнили по длине сортиментов достаточно точно описывается уравнениями соотносительного (аллометрического) роста. В результате проведения исследований были установлены такие связи. На основании полученных уравнений проведён условный продольный раскрой круглых сортиментов. В результате раскроя получали элементы для изготовления двутавровых балок. Такие балки находят широкое применение в малоэтажном деревянном домостроении. Установлено, что полезный выход элементов строительных конструкций из круглых лесоматериалов с сердцевинной ядровой гнилью достаточно высокий. Это даёт возможность предложить данный способ раскроя для промышленного применения.

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