MINISTRY OF EDUCATION OF THE REPUBLIC OF BELARUS

BREST STATE TECHNICAL UNIVERSITY

Building Structures Department

Wooden and Plastic Structures Course

LABORATORY TESTING OF WOOD AND WOOD-BASED
BUILDING MATERIALS AND STRUCTURAL MEMBERS

METHODOLOGICAL GUIDELINES
&
TEST DATA LOGS

For full-time 1-70 02 01 specialty civil engineering students

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The Guidelines on the laboratory mechanical testing of wood and wood-based building materials and structural elements are intended to be used by full-time international 1-70 02 01 specialty undergraduate civil engineering students at the lab classes within the Wooden and Plastic Structures course. The topics covered by the Guidelines are in full compliance with the course syllabus.

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GENERAL INSTRUCTIONS

The goals and objectives of laboratory classes in Wooden and Plastic Structures are to provide civil engineering students with theoretical and practical knowledge of basic physical and mechanical properties of wood and wood-based building materials as well as the behaviour of wooden structures and their constituent parts under most typical working conditions. Students are also expected to acquire practical skills to enable them to effectively evaluate the strength and deformability characteristics of wooden structural members as well as to conduct experimental research in their specialty field.

Before starting the lab test, students need to become familiar with the corresponding test method to be followed.

It is required that the actual dimensions of test specimens are determined before the beginning of each test, and all the measurement and test data obtained are tabulated in the corresponding test data log.

The theoretical load-bearing capacity as well as deformability and other mechanical characteristics of specimens needed for a given test to be properly conducted are to be determined prior to testing.

Any detectable acoustic emissions or visible changes of, or related to, the physical state of the specimen under test, such as snapping or crackling sounds, the development of cracks or skewing, should be properly timed and recorded in the corresponding data test log.

Upon the completion of testing procedure, the tested specimens are to be examined for fractures, and the failure modes observed shall be recorded by sketching or photographing and in writing.

In conclusion, a laboratory report shall be compiled with the test results being compared both to the normative values given in the corresponding specifications as well as to the values obtained theoretically. Data discrepancies, if any, and their causes should be critically analyzed, and the actual failure modes of the specimens be properly identified.

All calculations should be performed after the obtained data are plugged into the corresponding formulae. It is advisable to first determine the stresses in kN/cm^2, and only then convert them to MPa units ($1\ kN/cm^2 = 10\ MPa$).

When defending their laboratory work reports, students are expected to answer questions related to the mechanical properties of wood and wood-based materials, the behaviour of structural elements they have tested, the test methods applied, and the like.

LAB WORK № 1

DETERMINATION OF THE ELASTIC MODULUS AND ULTIMATE STRENGTH OF WOOD IN STATIC BENDING

I. Goals & Objectives. To make students familiar with the testing methodology and equipment used to determine basic mechanical properties of solid wood.

II. Materials and Testing Procedure

Prior to testing, several bar-shaped 20x20x300 *mm* test specimens are to be manufactured with the annual rings at the specimen butt ends running parallel to a pair of bar faces. Just before starting the test, the cross-sectional dimensions of each test specimen are to be checked for dimensional accuracy to the nearest 0.1 *mm* using a sliding caliper according to *ГОСТ 166-80.*

To run the test, a test specimen is transferred to the testing machine and placed upon two stationary specimen supports with 25 *mm*-radiused topsides. A loading crosshead attached to the upper grip of the testing machine is equipped with two rollers having the same radius length as the support topsides. Deflections are measured in the region of pure bending using a dial indicator as shown in Fig.1.

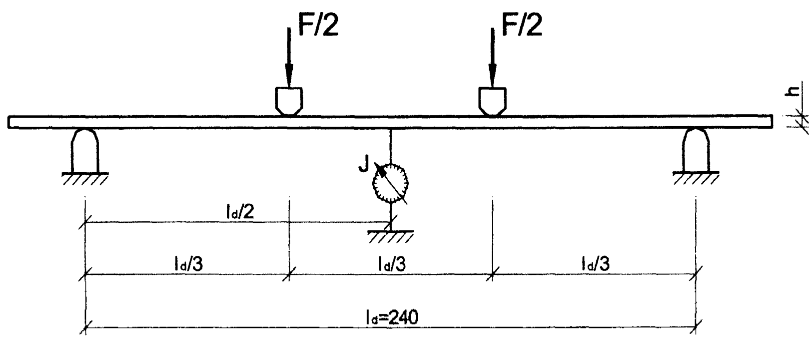


Fig. 1 – Schematic diagram of four-point static bending test

The loading force is applied at a constant rate of crosshead displacement. The displacement rate is set so that the time needed for the specimen to be loaded to the maximum load value is in the range of 2 to 5 minutes.

When the load applied becomes equal to 800 *N*, the specimen is smoothly unloaded back to 200 *N*, and then reloaded up to 800 *N* and unloaded down to 200 *N* once again.

The deflection magnitude is measured with an accuracy of 0.01 *mm* in the course of subsequent three loading cycles each time when the load applied becomes (alternatively) equal to 300 *N* or 800 *N*. The indicator readings are recorded in Table 1. Based on the test data, the modulus of elasticity (elastic modulus) of the wood is determined.

Upon the completion of cyclic loading, a stepwise loading test with load increments of 200 *N* is carried out in order to determine the wood ultimate resistance and to plot the f_i - Δu strain-stress diagram. In the final stage of stepwise testing, the magnitude of failure load is determined and recorded.

Deformational increments at each step of stepwise loading are determined as the difference in relation to the indicator readings at the zero-step loading.

Upon completion of the test, the moisture content of the specimen is determined using an electric moisture meter according to [5, 11], and the air temperature in the laboratory room is measured.

All test data along with the computation and measurement results are summarized in Table 2.

Table 1 – Indicator readings in four-point static bending test

Loading cycle / Step No	Loading steps *F, H*	Indicator readings, *mm*	
		u	*Δu*
1	2	3	4
Cyclic loading			
1	$F_1 = 300$		
	$F_2 = 800$		
2	$F_1 = 300$		
	$F_2 = 800$		
3	$F_1 = 300$		
	$F_2 = 800$		
			$\Delta u_{cp} =$
Stepwise loading			
0	0		
1	200		
2	400		
3	600		
4	800		
5	1000		
6	1200		
7	1400		
8	1600		
9	1800		
10	2000		
11	2200		
12	2400		
13	2600		
14	2800		
15	3000		

Table 2 – Test results

Parameters	Measurement and computation results
1	2
Wood species	
Demensions, mm	$b =$ $h =$
Air temperature, ^{0}C	$T =$
Moisture content, %	$W_b =$
Modulus of elasticity, *MPa*	$E_0 = \dfrac{23 \cdot \Delta F \cdot l^3{}_d}{108 \cdot b \cdot h^3 \cdot \Delta u_{cp}} =$
Modulus of elasticity according to *ТКП45-5.05-146-2009, MPa*	$E_0 = 8500$
Failure load, *kN*	$F_{\max} =$
Ultimate resistance, *MPa*	$f_i^{W,T} = \dfrac{F_{\max} \cdot l_d}{b \cdot h^2} =$
Ultimate resistance at 20 ^{0}C, *MPa*	$f_i^W = f_i^{W,T} + \beta\left(T - 20^0\right) =$
Ultimate resistance at moisture content of 12%, *MPa*	$f_i = f_i^W\left[1 + \alpha\left(W - 12\right)\right] =$
Normative strength, *MPa*	$f_{i.k} = f_i\left(1 - 1.65 \cdot C_V\right) =$
Normative strength according to *ТКП 45-5.05-146-2009, MPa*	$f^*_{i.\alpha.k} = 57$

where: ΔF is the incremental cyclic load, *kN*;
l_d is the distance between support centres, *cm*;
b is the width of specimen section, *cm*;
h is the height of specimen section, *cm*;
Δu_{cp} is the arithmetic mean of the deflection increments in the region of pure bending, *cm*;
C_v is the coefficient of variation equal to 0.175;
α is the correction factor equal to 0.04, Table 1.2 [12];
β is the wood temperature correction factor equal to 4.5 *MPa* for pine, and 3.5 *MPa* for spruce, Table 1.3 [12].

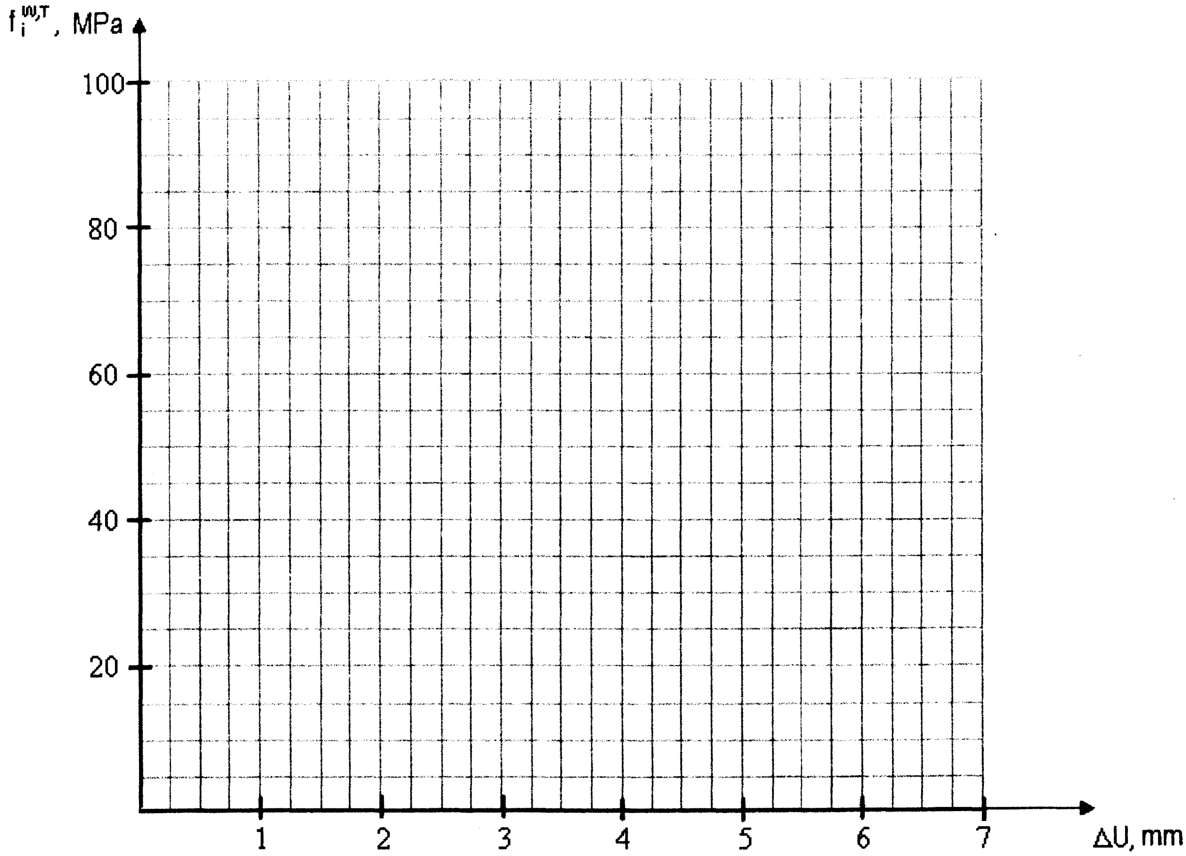


Fig. 2 – Stress–strain graph $f_i^{W,T} - \Delta u$ in four-point static bending test

Fig. 3 – Specimen failure mode

Conclusions:

Key questions for revision and self-check

1. *What is modulus of elasticity (elastic modulus)? What is its use in structural analysis?*
2. *What are the normative and design resistance of wood, and how are they determined?*
3. *What feature does the coefficient of variation specify, and what does it depend on?*

LAB WORK № 2

DETERMINATION OF THE WOOD COMPRESSION STRENGTH PERPENDICULAR TO GRAIN

I. Goals & Objectives. To determine the compression strength perpendicular to grain of a solid wooden block uniformly loaded over the full surface and over part of the length.

II. General Information. Since visible fractures are in most cases unlikely to be detected in small wooden blocks loaded in compression perpendicular to the grain, loading tests are generally conducted to determine the so-called *limit of proportionality* (*proportional limit point*), the value of which is taken to be the compression strength perpendicular to grain.

Two kinds of tests in compression strength are normally distinguished: the test in which a block of wood is loaded in uniform compression over the full surface (the *full area loading* test [19]), and the test where a test specimen is loaded over part of the length (the *partial area loading* test).

For all species of wood, the average value of compression strength perpendicular to grain is approximately a 10^{th} of that parallel to the grain.

A solid wood beam under partial area loading displays a higher compression strength than the one loaded over the full surface since the fibers adjacent to the locally loaded area contribute in taking the load.

III. Materials and Testing Procedure

Prior to testing, two kinds of specimens in the shape of a rectangular prism with a 20x20 *mm* base and the lengths of 30 *mm* and 60 *mm* along the fibers are fabricated to be used for correspondingly full and partial area compression tests (Fig. 4).

In the case of test pieces prepared for a full area loading test, both the length b and the width a are measured to the nearest of 0.1*mm,* the width a being taken at the specimen mid-length. With the specimens to be loaded locally, only the width a is measured with the above-mentioned degree of accuracy, the mean width b of the loading crosshead being equal to18 *mm*.

A special load-applying device is used to conduct the testing. Specimens are continually loaded at the rate of $1 \pm 0{,}2$ *kN/min.* The resulting deformation is measured, without stopping the loading process, after each successive load increment of 0.2 *kN* and 0.4 *kN* for softwood and hardwood specimens correspondingly. The loading process is continued until the compression strength limit is surpassed, which is typically characterized by an abrupt increase of strain rate. All indicator readings taken in the process of testing are reported in Table 3.

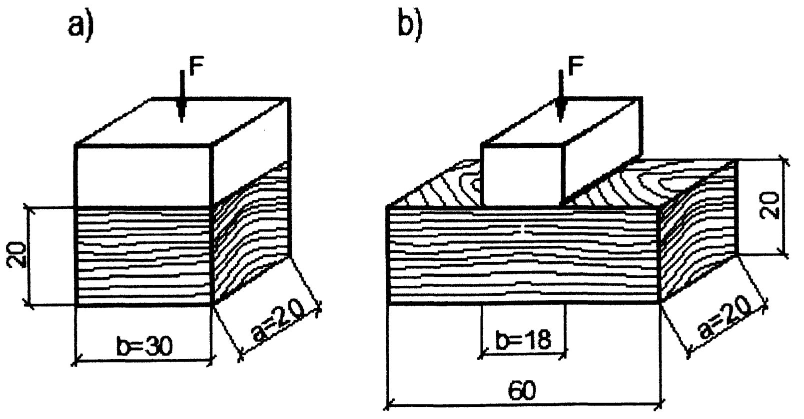


Fig. 4 – Wooden test pieces loaded in uniform compression perpendicular to grain (a) over the full surface and (b) over part of the length

Table 3 – Indicator readings

Trial No	Loading steps F, *kN*	Full area loading		Partial area loading	
		U, mm	*ΔU, mm*	*U, mm*	*ΔU, mm*
1	2	3	4	6	7
0	0				
1	0.20				
2	0.40				
3	0.60				
4	0.80				
5	1.00				
6	1.20				
7	1.40				
8	1.60				
9	1.80				
10	2.00				
11	2.20				
12	2.40				
13	2.60				
14	2.80				
15	3.00				
16	3.20				
17	3.40				
18	3.60				
19	3.80				
20	4.00				
21	5.00				

Table 4 – Test results

Parameters	Full area loading	Partial area loading
Wood species		
Dimensions, *mm*	$a =$ $b =$	$a =$ $b =$
Compression strength perpendicular to grain, *MPa*	$\sigma_y = \dfrac{F_{\max}}{a \cdot b} =$	$\sigma_y = \dfrac{F_{\max}}{a \cdot b} =$

The F_{max} value, which corresponds to the value of the compression strength perpendicular to grain, is determined as an ordinate of the point on the stress-strain curve at which the deviation from the linear relationship between the applied force and the resulting deformation reaches such a magnitude that the tangent value of the angle formed by the load axis and the tangent to the F-ΔU curve is by 50% higher than it is for the rectilinear portion of the curve, i.e. $\mathrm{tg}\,\beta / \mathrm{tg}\,\alpha \geq 1.5$ (Fig. 5).

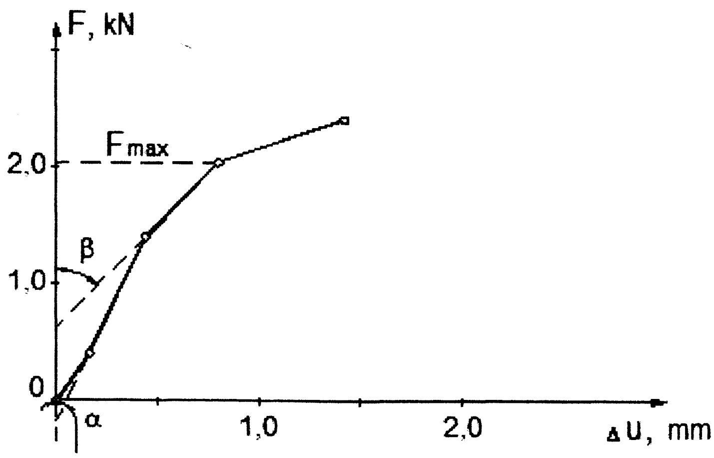
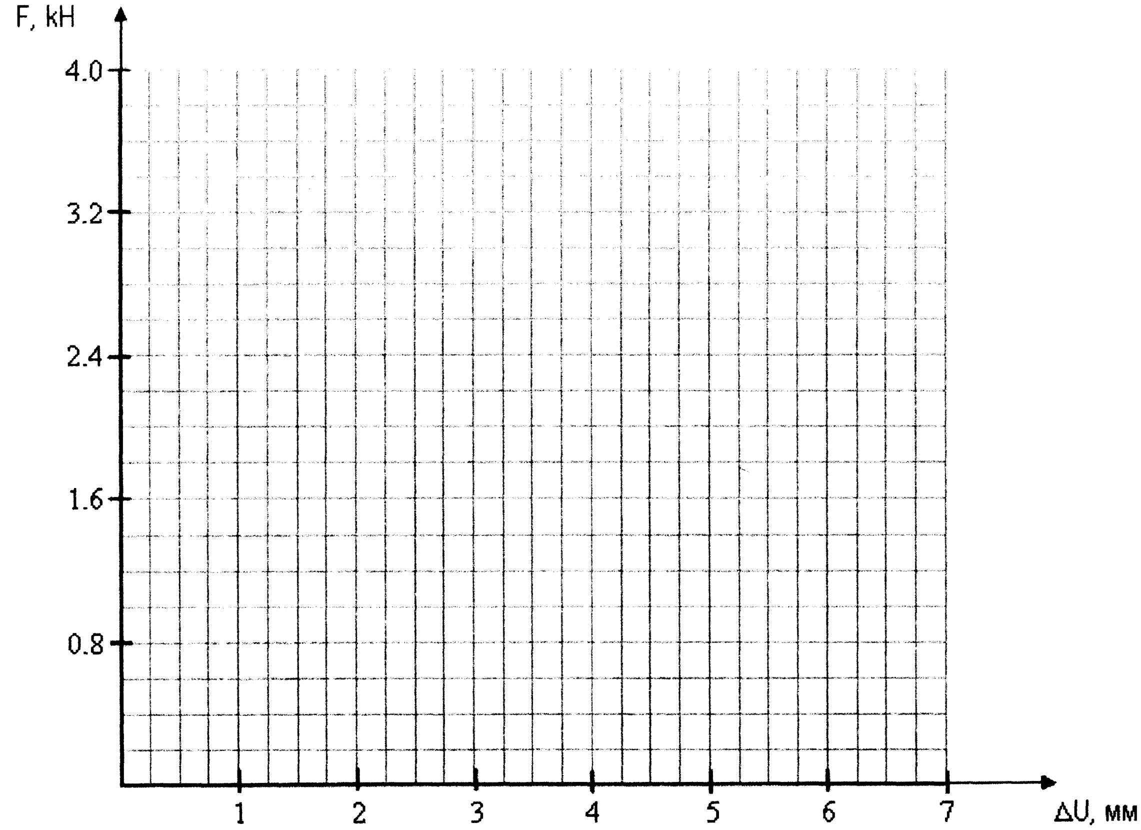


Fig. 5 – Plotting a stress–strain curve by compression test

Note: The curves showing the *F-ΔU* relationship for fully and locally loaded specimens are allowed to be drawn on one and the same diagram (Fig. 6).



a) full area loading; b) partial area loading
Fig. 6 – Load–deformation graph

a) full area loading; b) partial area loading
Fig. 7 – Specimens failure modes

Conclusions:

Key questions for revision and self-check

1. *Why is the compression strength perpendicular to grain of the specimen uniformly loaded over part of the length higher than that of the specimen loaded over the full surface?*
2. *Give examples of wood structural members with a full area and partial area loading.*

LAB WORK № 3

TESTING OF WOOD-BASED STRUCTURAL PANELS

I. Goals & Objectives. To determine the modulus of elasticity and tensile strength of structural plywood and particle board panels under static bending.

II. General Information

The wood-based panel products refer to the category of multifunctional large-format engineered composite building materials that are fabricated from wood or other raw materials of vegetable origin in the form of veneers, chips, fibers or particles that are mechanically, physically and chemically bonded together with the help of some binding agent or adhesive.

Depending upon the origin of the raw material used, the processing and manufacturing technology employed as well as the nature of the bonds that develop between constituents during the manufacturing process, the wood-based panel products can be divided into the following major groups: plywoods, wood particle boards (chipboards), wood-fiber boards, and wood composite panels.

Structural plywood is an engineered sheet material consisting, as a rule, of an odd number of thin layers of wood called veneers or pliers that are glued together by hot- or cold-pressing, with each layer having their wood grain oriented in perpendicular direction to the adjacent layer.

Wood particle boards are manufactured by hot-pressing specially processed and impregnated with synthetic resins wood chips.

III. Materials and Testing Procedure

To be able to carry out the tests, a given number of specimens having the form of a rectangular plate with dimensions of 150 *mm* x 50 *mm* x *h* and 300 *mm* x 50 *mm* x *h* for plywood and particle board, respectively, are to be provided. Prior to testing, the length and width of specimens are measured with a metal ruler in two positions parallel to its edges according to *ГОСТ 427-79*. The specimen thickness is measured with a caliper at four different positions according to *ГОСТ 166-80*. Deviations, if any, in the sample thickness should fall within the value range specified by the standard for the given species of wood.

To start the testing procedure, specimens are placed on two stationary supports, that the laboratory testing machine is provided with, having the topsides of semicircular shape with a 25 *mm* radius. A traverse carriage equipped with a loading roller of the same radius length is attached to the upper grip of the testing machine. To measure the mid-span deflection, a dial-type indicator is installed as shown in Fig. 8.

The load is continuously applied to test specimens through the machine's loading element at a constant displacement rate. The displacement rate is preset so that the time needed to load specimens up to the ultimate load value is in the range of 30 to 90 seconds.

For the modulus of elasticity to be determined, specimens are initially subjected to the uniform load, the value of which is thrice as large as the load of 2 – 25% of the specimen failure load. All indicator readings are recorded in Table 5. On the basis of these test data the modulus of elasticity is determined.

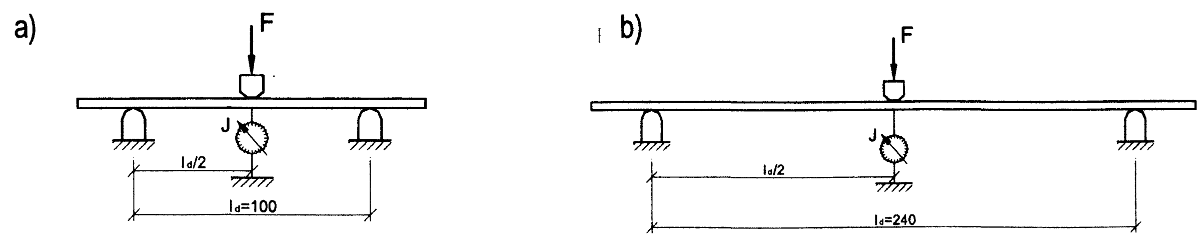


Fig. 8 – Test set-up scheme diagrams of three-point static bending test on a simply-supported (a) plywood and (b) chipboard specimens

To determine the ultimate bending strength and to plot the corresponding diagram in f_i-ΔU axes, a stepwise loading test is conducted following the cyclic loading, with the load being applied in increments of 200N and 50N correspondingly for plywood and particle board specimens. In the final stage of testing, the failure load is recorded and entered into Table 6.

Table 5 – Indicator readings in static bending test

Step No	Plywood			Particle board		
	Step Load F, H	Indicator readings, *mm*		Step Load F, H	Indicator readings, *mm*	
		U	ΔU		U	ΔU
1	2	3	4	5	6	7
Cyclic loading						
1	$F_1 = 300$			$F_1 = 50$		
	$F_2 = 800$			$F_2 = 200$		
2	$F_1 = 300$			$F_1 = 50$		
	$F_2 = 800$			$F_2 = 200$		
3	$F_1 = 300$			$F_1 = 50$		
	$F_2 = 800$			$F_2 = 200$		
			$\Delta U_{cp} =$			$\Delta U_{cp} =$
Stepwise loading						
0	0			0		
1	200			50		
2	400			100		
3	600			150		
4	800			200		
5	1000			250		
6	1200			300		
7	1400			350		
8	1600			400		
9	1800			450		
10	2000			500		
11	2200			550		
12	2400			600		
13	2600			650		
14	2800			700		
15	3000			750		

Table 6 – Test data

Parameters	Plywood	Particle board
Wood species		-
Ratio between the number of veneers oriented along and across the grain		-
Dimensions, *mm*	$b =$ $h =$ $l_d =$	$b =$ $h =$ $l_d =$
Modulus of elasticity, *MPa*	$Ep = \dfrac{\Delta F \cdot l_d^3}{4 \cdot b \cdot h^3 \cdot \Delta u_{cp}} =$	$E_0 = \dfrac{\Delta F \cdot l_d^3}{4 \cdot b \cdot h^3 \cdot \Delta u_{cp}} =$
Standardized modulus of elasticity, *MPa*	9000	1238
Failure load, *kN*	$F_{max} =$	$F_{max} =$
Ultimate resistance, *MPa*	$f_i = \dfrac{3 \cdot F_{max} \cdot l_d}{2 \cdot b \cdot h^2} =$	$f_i = \dfrac{3 \cdot F_{max} \cdot l_d}{2 \cdot b \cdot h^2} =$
Normative resistance, *MPa*	$f_{i.k} = f_i(1-1.65C_V) =$	$f_{i.k} = f_i(1-1.65C_V) =$
Standardized normative resistance, *MPa*	43.5	16.0

where: ΔF is the incremental cyclic load, *kN*;

l_d is the span length between support centres, *cm*;

C_v is the coefficient of variation equal to 0.15 for plywood, and 0.16 for particle board.

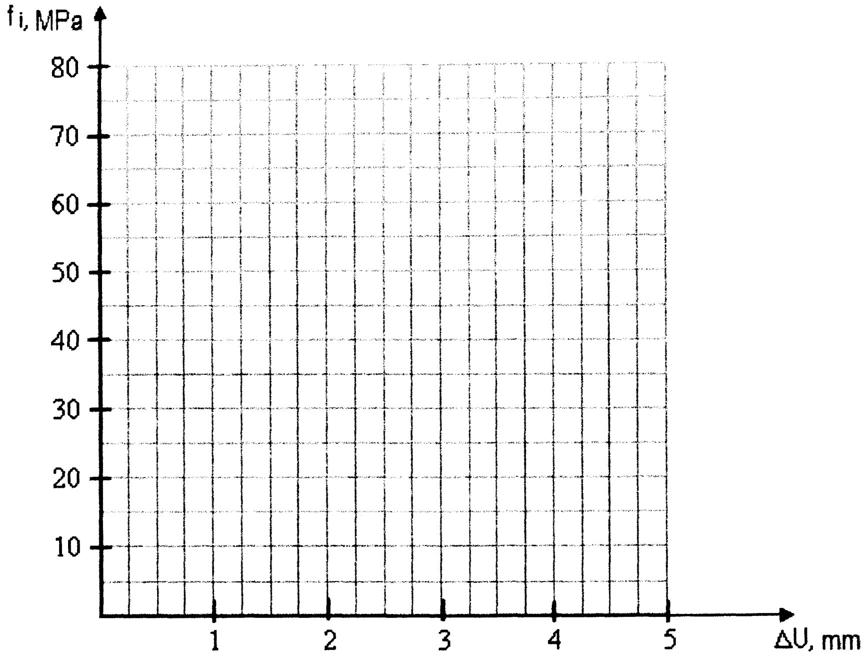


Fig. 9 – Stress–strain diagrams plotted by static bending tests: (a) plywood and (b) particle board

Fig. 10 – Specimen failure modes: (a) plywood; (b) particle board

Conclusions:

Key questions for revision and self-check

1. *In what way does the ratio of the number of wood veneers oriented at right angles to those running along the length affect the strength and toughness of structural plywood panels?*
2. *What kind of plywood panel structure should be considered as structurally effective?*
3. *What are advantages of plywood as a structural material in comparison with solid wood?*
4. *Why are the strength and toughness (properties) of structural plywood panels higher than those of particle boards?*

LAB WORK № 4

TESTING WOOD DOWEL-JOINTS FOR STRENGTH

I. Goals & Objectives

1. To determine the maximum bearing capacity of a dowel-type timber-to-timber joint as well as its deformation characteristics and failure mode.
2. To determine the magnitude of joint deformations.
3. To plot a load vs shear strain diagram.

II. General Information

The strength of timber-to-timber joints is of critical importance for the load bearing capacity and serviceability of built-up timber structural members. One of the ways of joining individual timber elements together to have them function as a system is to make use of mechanical fasteners such as nails, screws, bolts, dowels, toothed- and punched-metal plates, and the like [20].

Tests on timber-to-timber dowel-type joints are typically carried out to get an insight of their mechanical behaviour under load and to assess the load bearing capacity of the corresponding structural member.

III. Materials and Testing Procedure

Prior to testing, several specimens of timber-to-timber joints fastened with steel rods (studs) and common nails made of steel wire are prepared. The shape and size of specimens are shown in Figs. 10*a* and 10*b*.

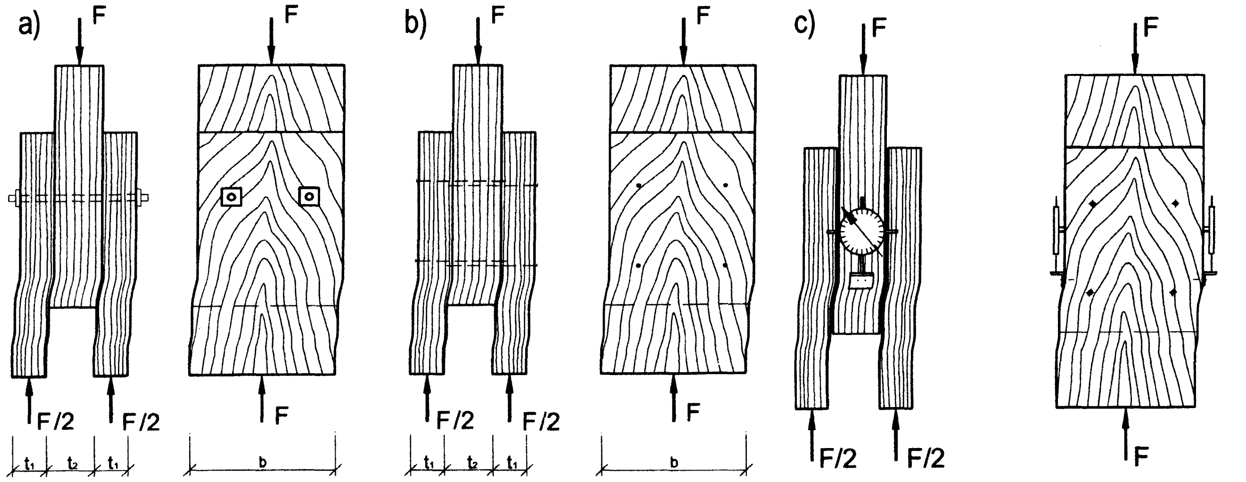
Tests are conducted making use of a tension testing machine *P-10*.

Testing is carried out continuously at a constant rate of approximately 300 *N/s*. The load is increased stepwise. The deflection readings are taken from an indicator and are entered into Table 7 at every loading step as soon as the value of the load applied becomes equal to the one established for the corresponding step. The general layout of dial indicators is shown in Fig. 10*c*. The failure load is determined with the help of the machine's force measuring gauge at the moment when the load readings stop growing while the strain magnitudes are continually increasing.

All test data regarding both the nailed and bolted timber-to-timber joints are summarized in Table 8.

Table 7 – Indicator readings during stepwise loading of bolted and nailed timber joints

Step No	Bolted connection			Nailed connection		
	Step Load	Indicator readings		Step Load	Indicator readings	
	F, kN	*U, mm*	*ΔU, mm*	*F, kN*	*U, mm*	*ΔU, mm*
1	*2*	*3*	*4*	*5*	*6*	*7*
0	0			0		
1	2			1		
2	4			2		
3	6			3		
4	8			4		
5	10			5		
6	12			6		
7	14			7		
8	16			8		
9	18			9		
10	20			10		



a) a three-member bolted joint; b) a three-member nailed joint; c) layout of dial indicators
Fig. 10 – Schematic test set-up and test specimen sketches

Table 8 – Timber joints test data

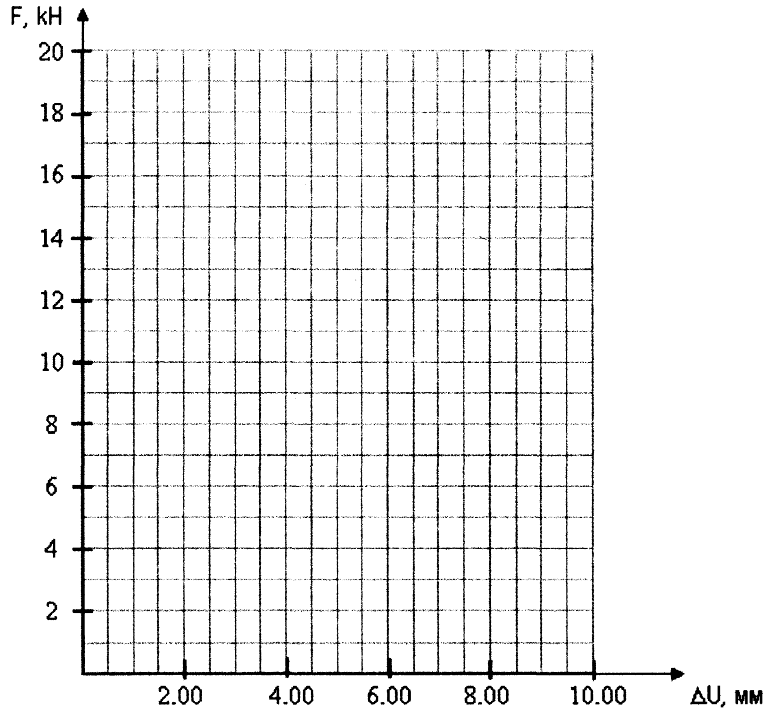
Parameters	Bolted joint	Nailed joint
1	2	3
Wood species		
Thickness of the constituent members of the timber-to-timber joint: - the two side (outer) members - the middle (central) member	$t_1 =$ $t_2 =$	$t_1 =$ $t_2 =$
Dowel diameter, *mm*	$d =$	$d =$
Coefficient β_n	$\beta_n = k_n \cdot \frac{t_1}{d} =$	$\beta_n = k_n \cdot \frac{t_1}{d} =$
Coefficient K_n	0.105	0.063
Coefficient $\beta_{n.max}$	0.624	0.775
Bearing capacity of joint per one shear plane of a dowel, *kN*: - in case of a side element crushing - in case of the middle element crushing - in case of dowel bending	$R_{ld} = f_{h.1.d} \cdot t_1 \cdot d \cdot k_\alpha =$ $R_{ld} = f_{h.2.d} \cdot t_2 \cdot d \cdot k_\alpha =$ $R_{ld} = f_{h.d} \cdot d^2 \cdot (1+\beta_n^2)\sqrt{k_\alpha} =$	$R_{ld} = f_{h.1.d} \cdot t_1 \cdot d \cdot k_\alpha =$ $R_{ld} = f_{h.2.d} \cdot t_2 \cdot d \cdot k_\alpha =$ $R_{ld} = f_{h.d} \cdot d^2 \cdot (1+\beta_n^2)\sqrt{k_\alpha} =$
Design bearing capacity of joint, *kN*	$R_d = R_{l.d.\min} \cdot n_n \cdot n_s =$	$R_d = R_{l.d.\min} \cdot n_n \cdot n_s =$
Failure load, *kN*	$F_{max} =$	$F_{max} =$
Load at shearing deformation, $\delta = 2$ *mm*, *kN*	$F =$	$F =$
Load of long-term duration at shearing deformation, $\delta = 2$ *mm*, *kN*	$F_{dur} = F \cdot k_{dur} =$	$F_{max} = F \cdot k_{dur} =$

Notes:

- the dimensions of the side and middle elements, as well as the dowel diameter shall be given in the formulas in centimeters (cm);
- the $f_{h.1.d}$, $f_{h.2.d}$, and $f_{h.d}$ design resistance values shall be converted from *MPa* to *kN/cm*^{2} units;
- the value of the coefficient β_n must not exceed the value of $\beta_{n.max}$.

where: $f_{h.1.d}$ and $f_{h.2.d}$ are the design wood fiber crushing resistance values in a blind dowel hole (for symmetrical bolted and nailed timber-to-timber connections $f_{h.1.d} = 8$ *MPa* and $f_{h.2.d} = 5$ *MPa*, respectively, Tables 9.2 and 9.3 [15]);

$f_{h.d}$ is the design dowel bending resistance ($f_{h.d}$ = 18 *MPa* for bolted and $f_{h.d}$ = *25 MPa* for nailed timber-to-timber connections, respectively, Table 9.4 [15]);
n_n is the number of dowels in a given joint; n_s is the number of shear planes in a joint per one dowel;
β_n is the coefficient depending on the ratio of the thickness of the thinner element to the dowel diameter;
$R_{l.d.min}$ is the minimum value of the shear resistance of a single dowel in the joint;
k_α is the coefficient taking into account the value of the angle α between the force and grain direction, Table 9.5 [15];
k_{dur} = 0.67 is the coefficient taking into account a reduction in the wood strength under the load of long-term duration.



a) bolted connection; b) nailed connection
Fig. 11 – Load vs shear strain diagram

a) bolted connection; b) nailed connection
Fig. 12 – Specimen failure modes (see [20, p. 117])

Conclusions:

Key questions for revision and self-check

1. *How is the design bearing capacity of a cylindrical dowel calculated per a single timber-to-timber joint?*
2. *What is a typical spacing arrangement of fasteners in bolted and nailed timber-to-timber joints?*

LAB WORK № 5

STATIC BENDING TEST OF A BUILT-UP TIMBER ELEMENT WITH DOWEL-TYPE FASTENERS

I. Goals & Objectives

1. To determine the value and distribution pattern of normal stresses along the cross-section height of solid and built-up structural timber elements.

2. To plot load-deflection graphs for solid and built-up structural timber elements and make their comparative analysis.

3. To plot a load vs shear strain diagram for a built-up structural timber element and determine the required number of connections.

4. To experimentally determine the values of the k_w and k_i coefficients for a built-up element and compare them with the standard ones according to *ТКП 45-5.05-146-2009.*

II. General Information

Due to a limited assortment of timber, wooden structures are commonly made up using structural elements of built up sections which are joined together by means of nails, bolts, dowels, screws, metallic toothed plates and other kinds of mechanical fasteners. The resulting built-up structural elements must be good at taking shear loads in order to prevent displacement of constituent parts relative to each other and ensure thus their integral structural performance.

Since all types of mechanical connections are prone to local yielding, partial displacement of constituents relative to each other is likely to occur within such built-up structural elements under load. As a result, the built-up structural elements have a lower bearing capacity in comparison to the elements of the same cross-sectional area but made of one-piece solid timber. The design peculiarity of built-up structural timber elements consists precisely in taking into account the local yielding proper to the dowel-type connections. Calculations are typically made on the basis of the formulas adopted for solid timber structural elements, with the corresponding correction factors being entered in equations to allow for the geometric peculiarities of built-up timber elements to be taken into account. So, for a built-up timber element with locally yielding connections, the geometric characteristics are:

$$W_{ef} = k_w \cdot W_d;$$

$$I_{ef} = k_i \cdot I_{\sup},$$

where: W_d, I_{sup} are, correspondingly, the moments of resistance and inertia determined as for a solid timber section;

k_w is the coefficient taking into account the change in the moment of resistance for built-up timber beams with locally yielding connections, Table 7.3 [15];

k_i is the coefficient taking into account the change in the moment of inertia for built-up timber beams with locally yielding connections, Table 7.3 [15].

The number of connections per one half of the span is calculated from the equation:

$$n_n = \frac{T_v^{l/2}}{R_{l.d.\min}},$$

where: $T_v^{l/2}$ is the total shear force exerted on the portion of the beam length running from the support to the cross-section with the greatest moment value:

$$T_v^{l/2} = \frac{S_{\sup}}{I_{\sup}} \int_0^{l/2} V \cdot d_x = M_{\max} \frac{S_{\sup}}{I_{\sup}},$$

where: $R_{l.d.\min}$ is the minimum bearing capacity value of one shear plane of a dowel in the connection;

$S_{\sup}$ is the gross static moment of the shifted portion of the element cross-section with reference to the neutral axis;

$I_{\sup}$ is the gross moment of inertia of the element cross-section with reference to the neutral axis;

M_{max} is the maximum bending moment.

III. Materials and Testing Procedure

Two beam-like specimens – *B1* and *B2* – are fabricated to be tested in static bending at this lab. Specimen *B1* is a solid element of rectangular cross-section, while specimen *B2* is a composite element built up of two overlapping bars of square cross-section joined together by means of nails, Fig. 13.

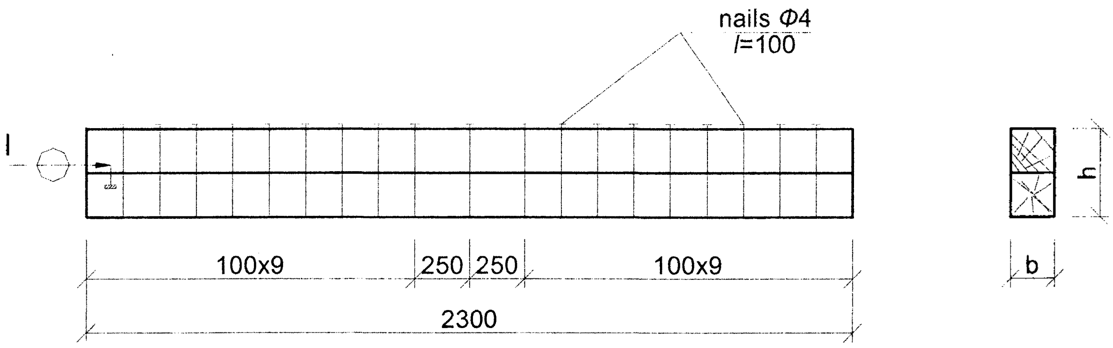


Fig. 13 – General lay-out of nailed connections in built-up timber element B2

The specimens have the same overall dimensions, and are tested under the two-point loads of the same magnitude. The load is applied at third points using test weights, Fig. 14. The mid-span deflections are measured by two deflection meters, *P1* and *P2*.

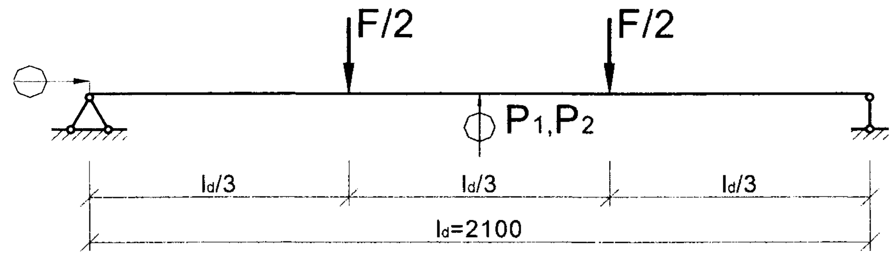
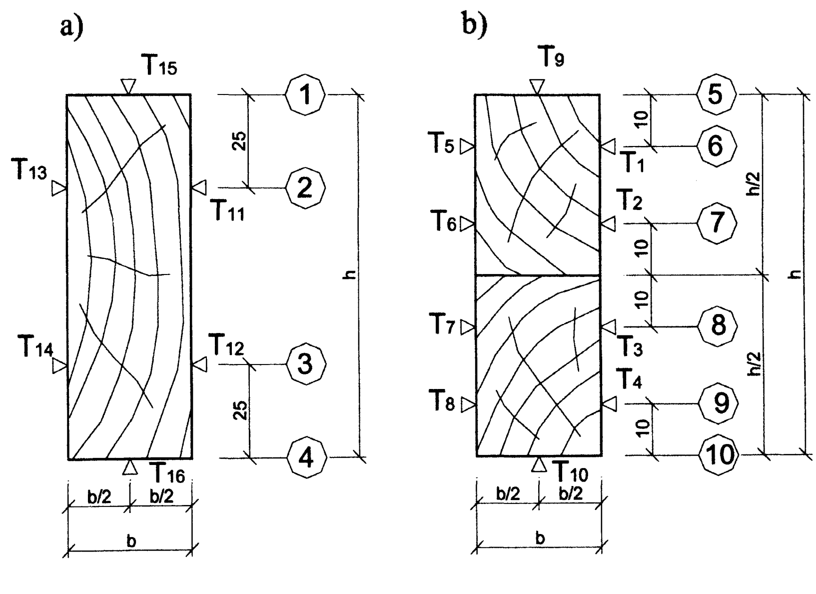


Fig. 14 – Schematic diagram of static bending test for specimens B1 & B2

To determine relative deformations, strain gauges are symmetrically glued onto the four sides of both elements at the level of corresponding cross-sections (see Fig. 15). Readings are automatically taken from the strain gauges by means of a special-purpose *ТИССА-В-485/65* strain measuring complex. To measure the shear strains in the contact zone of the two nailed bars of element *B2*, dial indicator *I* is installed at one of the specimen's ends near the support. The loading of each element is carried out stepwise with load increments of ΔF = 0.2 *kN* until the maximum load of F = 1.0 *kN* is reached, which is within the region of elastic behaviour of both elements. The readings taken from the strain gauges are recorded in Table 9, while those taken at each loading step from the deflection meters and the indicator are entered into Table 10.



Cross-sections of (a) solid timber element B1 and (b) built-up timber element B2
Fig. 15 – General layout of strain gauges

Table 9 – Experimental results

Strain gauge No	ΔT, $x10^{-5}$	Element cross-section No	Relative deformations, $\varepsilon x10^{-5}$	Normal stresses, $f_i = \varepsilon E_0$, MPa
1	2	3	4	5
T_1		1		
T_2		2		
T_3		3		
T_4		4		
T_5		5		
T_6		6		
T_7		7		
T_8		8		
T_9		9		
T_{10}		10		
T_{11}				
T_{12}				
T_{13}				
T_{14}				
T_{15}				
T_{16}				

Table 10 – Indicator readings during testing

Loading steps, F, kN	Element $B1$			Element $B2$			
	Deflection meter $P1$		Deflection U,mm	Deflection meter $P2$		Indicator I	
	U, mm	ΔU,mm		U, mm	Deflection U_{ef}, mm	I, mm	Shear deformation V, mm
1	2	3	4	5	6	7	8
0							
0.2							
0.4							
0.6							
0.8							
1.0							
	ΔU_{mean}=						

IV. Test Data Processing

Relative cross-sectional deformations are determined in each element as the arithmetic mean ΔT of the set of readings taken from the strain gauges that belong to the corresponding section (in Fig. 15, cross-sections are indicated by circled numbers). Normal stresses in these sections are calculated after the modulus of elasticity of wood is determined with the formula given in Table 11 and using the data taken from Table 10 (column 3).

In Table 10, the values of ΔU (column 3) are determined as the difference between the adjacent readings corresponding to $\Delta F = 0.2\ kN$. The deflection and shear deformation values (columns 4, 6, 8) are determined as the increments calculated with reference to the zero load step values.

Based on the normal experimental and theoretical stress values (Table 9 and Table 11 respectively), the corresponding diagrams are plotted for elements $B1$ and $B2$, while the deflection and shear curves are plotted being based on the deformation data (Table 10).

In Table 11:

$W_d = b \cdot h^2/6 =$ is the section modulus of the solid timber element;

$W_{d.c.} = b \cdot h^2/12 =$ is the section modulus of the built-up timber element without connections.

$\sigma_{ef} = \dfrac{|\sigma_c| + |\sigma_t|}{2} =$ is the maximum compressive and tensile stresses in the cross-section of the solid element;

$\sigma_{ef} = \dfrac{|\sigma_c| + |\sigma_t|}{2} =$ is the maximum compressive and tensile stresses in the cross-section of the built-up element;

R_{ld} is the lowest bearing capacity of a single connection determined by the formula:

$$R_{1d} = \min \begin{cases} f_{h.2.d} \cdot t_1 \cdot d \cdot k_\alpha = \\ f_{h.d} \cdot d^2 (1 + \beta_n^2) \cdot \sqrt{k_\alpha} = \end{cases}$$

where: $f_{h.2.d}$ = Design crushing resistance of wood in a blind dowel hole (for single-shear nailed wood joints $f_{h.2.d}$ = 3,5 *MPa*, Table 9.2 [15]);

$f_{h.d}$ is the dowel design resistance in bending (for nailed connections $f_{h.d}$ = 25 *MPa*, Table 9.4 [15]);

$t_1 = h/2 - 1{,}5d =$,where d is the nail diameter;

β_n is the coefficient whose magnitude depends on the ratio of the thinner timber element thickness to the dowel diameter, and is calculated by the formula:

$$\beta_n = k_n \cdot {}^{t_1}\!/_{d} = \qquad ,$$

where k_n is the coefficient whose magnitude depends on the dowel type (for conventional steel wire nails k_n = 0.063, Table 9.4 [15]).

The value of the coefficient β_n must not exceed the value of $\beta_{n.max}$, the latter being equal to $\beta_{n.max}$ = 0.775 for nails, Table 9.4 [15].

Table 11 – Test results

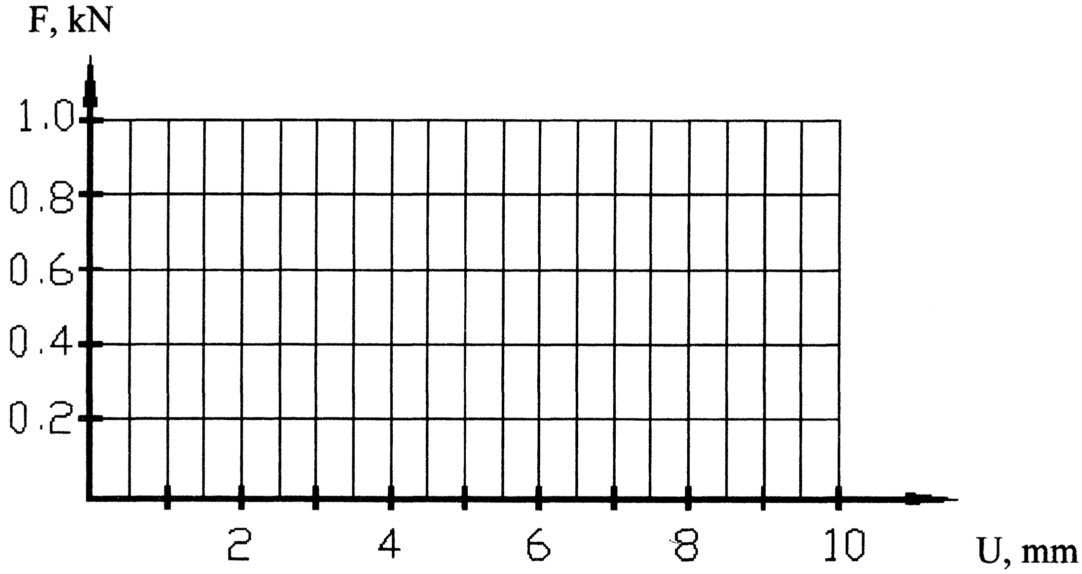
Parameters	Measurement and computation results
1	2
Wood species	
Dimensions, mm	
– element *B1*	$b =$ $h =$ $l_d =$
– element *B2*	$b =$ $h =$ $l_d =$
Modulus of elasticity of wood, *MPa*	$E_0 = \dfrac{23 \cdot \Delta F \cdot l_d^3}{108 \cdot b \cdot h^3 \cdot \Delta U_{cp}} =$
Maximum theoretical stresses at F = 1 *kN* in element *B1*, *MPa*	$\sigma = \dfrac{M_{\max}}{W_d} =$
Maximum theoretical stresses at F = 1 *kN* in element *B2* (without connections), *MPa*	$\sigma_0 = \dfrac{M_{\max}}{W_{d.c.}} =$
Correction coefficients for the built-up element *B2* :	
– experimentally obtained coefficient values	$k_w' = \dfrac{\sigma}{\sigma_{ef}} =$ $k_i' = \dfrac{U}{U_{ef}} =$
– normative coefficient values (as the *ТКП* 45-5.05-146-2009)	$k_w = 0{,}71$ $k_i = 0{,}46$
The required number of connections (nails) per one half of the span for element *B2*	$n_n = \dfrac{M_{\max} \cdot S_{\sup}}{I_{\sup} \cdot R_{l.d.\min}} =$
The actual number of connections (nails) per one half of the span	$n_n =$

a) experiment; b) theory

Fig. 16 – Normal stress distribution along the cross-sectional height of element B1

a) experimental values; b) theoretical values (with no fasteners)

Fig. 17 – Normal stress distribution along the cross-sectional height of element B2



a) solid timber beam B1; b) built-up timber beam B2
Fig. 18 – Load-deflection diagrams

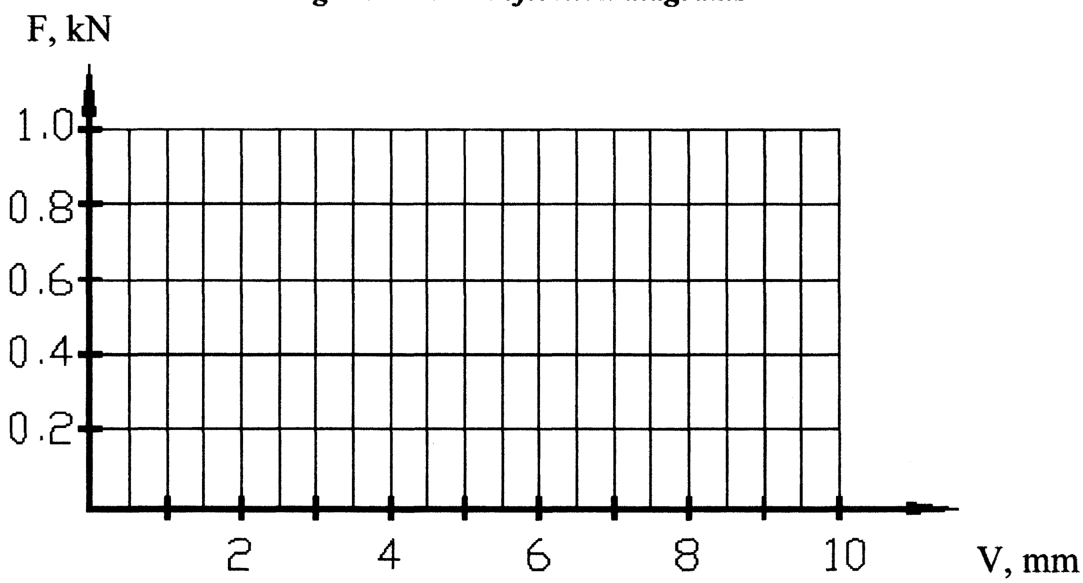


Fig. 19 – Load vs shear strain diagram

Conclusions:

Key questions for revision and self-check

1. *Why is the deflection of a built-up timber beam larger than that of a solid beam?*
2. *What are the specific features of a built-up timber beam structural analysis?*

LAB WORK № 6

TESTING OF A GLUED TIMBER-PLYWOOD STRUCTURAL ELEMENT IN STATIC BENDING

I. Goals & Objectives

1. To determine (both experimentally and theoretically) the magnitude and distribution of normal stresses along the cross-section height and width of a glued timber-plywood ribbed structural element.
2. To plot the load-deflection diagram for a glued timber-plywood structural element under test load and make a comparison between experimental and theoretical data.

II. General Information

Glued timber-plywood structural elements are those that consist of separate pieces of timber bars and plywood sheets glued together with some structural adhesive. They can be used both in load-bearing (beams, arches, frames) and enclosing (panels, screens) function.

The glued timber-plywood panels and screens consist of longitudinal bar-like timber ribs and plywood sheathing that are glued together to form a one-piece structural element of a box- or T-shaped cross-section. The box-shaped panels are used in heated buildings and comprise two separate sheathings (the upper and the lower one), with the space between them being filled with thermal insulation material. The screens are normally used in unheated buildings and comprise only one (upper) sheathing (Fig. 20) onto which a build-up roof membrane is cemented.

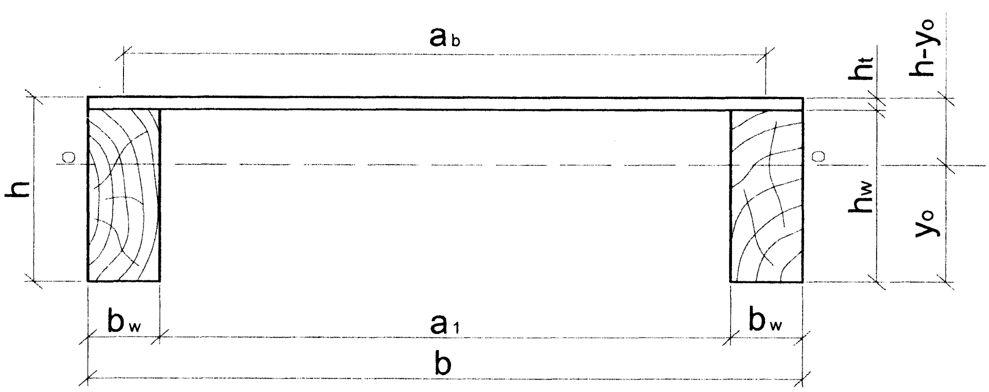


Fig. 20 – Glued timber-plywood structural element

Structural analysis of glued timber-plywood structural elements is carried out under the assumption that the connection between the plywood sheathing and the timber ribs is rigid (without taking into account the local yielding of the glue line). Since the species of wood from which the ribs (coniferous wood) and sheathing (usually birch plywood) are produced differ in their physical and mechanical characteristics, the design is carried out being based on the effective geometric characteristics. The latter are determined with reference to the physical and mechanical characteristics of the upper plywood sheathing.

The effective cross-sectional geometric characteristics of the element under test:
The design width of plywood sheathings is taken equal to:

$$b_d = 0.9 \cdot b \text{ at } l \geq 6a_b; \; b_d = 0.15\frac{l \cdot b}{a_b} \text{ at } l < 6a_b,$$

where:
b is the full cross-sectional width of the glued timber-plywood structural element;
l is the element span;
a_b is the distance between the axes of longitudinal timber ribs;
$b_d =$.

The distance between the center of gravity of the effective section and its lower side:

$$y_0 = S_{ef} / A_{ef} = \quad ,$$

where: $S_{ef} = S_p + (E_0/E_p)S = b_d \times h_t \times (h - h_t/2) + 2[(E_0/E_p) \times b_w \times 0.5 \times h_w \times h_w]$ is the effective static moment relative to the lower side of the element;

$S_{ef} =$;

$A_{ef} = A_p + (E_0/E_p)A = b_d \times h_t + 2[(E_0/E_p) \times b_w \times h_w]$ = effective cross-sectional area;

$A_{ef} =$;

S_p and S are the static moments relative to the lower side of the element for the plywood sheathing and longitudinal ribs, respectively;

A_p and A are the cross-sectional areas of the plywood sheathing and longitudinal ribs, respectively;

E_0 is the modulus of elasticity of wood parallel to grain equal to 8500 MPa, sec. 6.1.5.1 [17];

E_p is the modulus of elasticity of plywood equal to 9000 MPa in the plane of the sheet, Table 6.12 [17] for five- and seven-layer birch plywoods of the *ФСФ* grade of no less than III / IV class.

The effective moment of inertia of the cross-section relative to the neutral axis:

$$I_{ef} = I_p + (E_0/E_p)I_0 = \quad ;$$

$$I_p = b_d h_t^3/12 + b_d h_t (h - y_0 - 0.5 \times h_t)^2 = \quad ;$$

$$(E_0/E_p)I_0 = (E_0/E_p) \times 2\left(\frac{b_w h_w^3}{12} + b_w h_w (y_0 - 0.5 \times h_w)^2\right) = \quad ,$$

where I_p and I are the moments of inertia of the cross-section relative to the neutral axis for the plywood sheathing and longitudinal ribs, respectively.

The effective plywood section modulus:

– relative to the lower side of the element $W_{ef}^{н} = I_{ef}/y_0 =$;

– relative to the upper side of the element $W_{ef}^{в} = W_0 + k_{pf} W_p =$,

where $W_0 = \dfrac{(E_0/E_p) \times I_0}{h - y_0} =$; $W_p = \dfrac{I_p}{h - y_0} =$.

The stability coefficient of plywood sheathing:

$$k_{pf} = 1 - \frac{(a_1/h_t)^2}{5000} \text{ at } a_1/h_t < 50, \quad k_{pf} = \frac{1250}{(a_1/h_t)^2} \text{ at } a_1/h_t \geq 50,$$

where a_1 is the clear distance between longitudinal ribs, and h_t is the plywood thickness.

III. Materials and Testing Procedure

In this lab session a glued timber-plywood structural element is tested. The element is a fragment of a glued timber-plywood structural panel consisting of two longitudinal timber ribs with a plywood sheathing glued onto them. The load is applied to the element through four concentrated forces (Fig. 21). The mid-span deflection of the element is measured by means of two deflection meters *P1* and *P2*. Relative deformations along the mid-span cross-section of the element are determined using strain gauges. The general lay-out of strain gauges is shown in Fig. 22. Readings from the strain gauges are recorded automatically by means of a specialized *ТИССА-В*-485/65 strain measuring complex. The load is applied stepwise with increments of ΔF=0.4 *kN* until the maximum load of F = 1.2 *kN* is reached, which is within the elastic region of the element deformation behaviour. The increment readings taken from strain gauges are entered into Table 12, while the deflection values taken from the deflection meters at each loading step are recorded in Table 13.

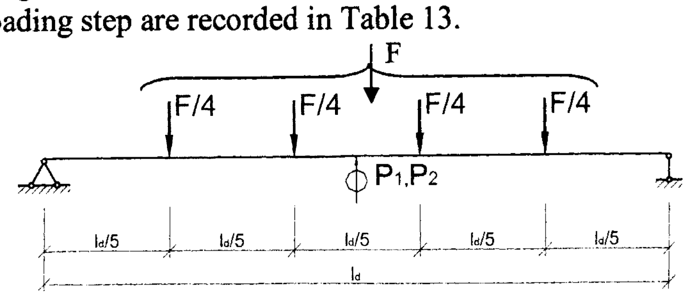


Fig. 21 – Schematic diagram of a glued timber-plywood structural element under six-point loading

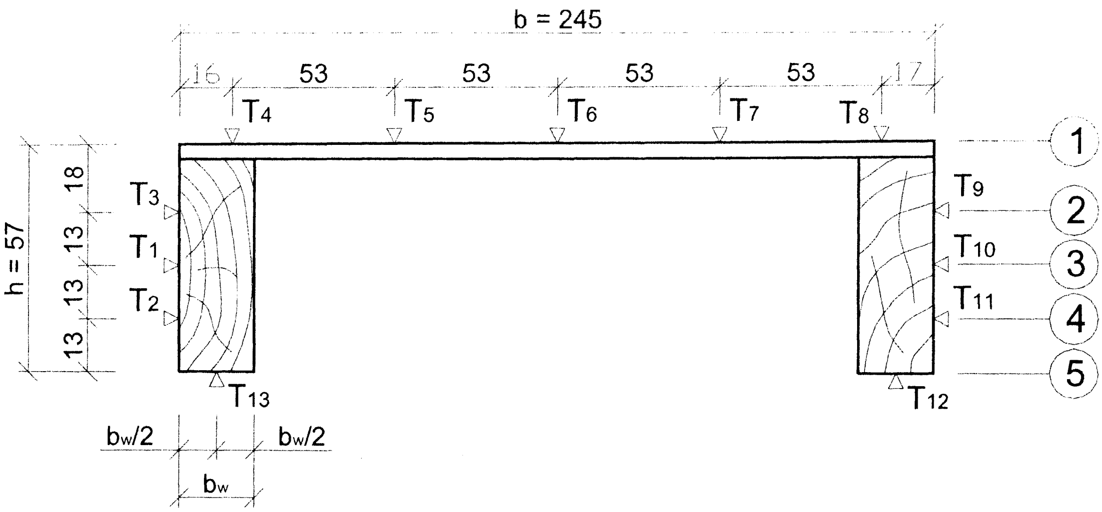


Fig. 22 – General layout of strain gauges

IV. Test Data Processing

Relative deformations are determined in each element cross-section as the arithmetic mean ΔT of the set of readings taken from the strain gauges that belong to the corresponding sections (in Fig. 22, cross-sections are indicated by circled numbers). To determine normal stresses, the elastic moduli for timber and plywood are correspondingly taken equal to $E_0 = 0.85 \cdot 10^4$ *MPa* and $E_p = 0.9 \cdot 10^4$ *MPa*.

In Table 13, the deflection values of Δu_1 and Δu_2 are determined as the increments with reference to the zero load step.

Based on the normal experimental and theoretical stress values (Table 12 and Table 14, respectively) the corresponding stress diagrams are plotted along the height of the cross-section, while the deformation values (Table 13, column 6, and Table 14) are used to plot the load-deflection graphs.

Table 12 – Experimental results

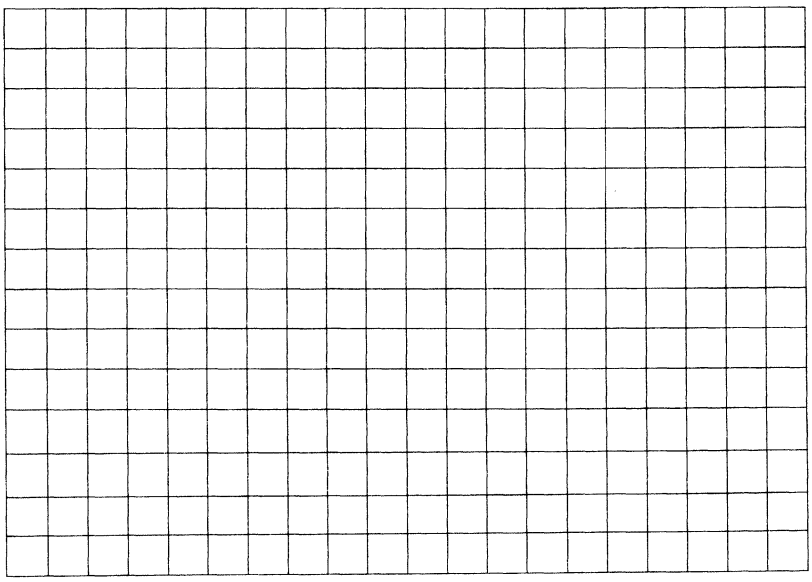
Strain gauges No	$\Delta T, x10^{-5}$	Cross-section No	Relative deformation, $\varepsilon x10^{-5}$	Normal stresses, $f_i = \varepsilon E_0$, *MPa*
1	2	3	4	5
T_1		1		
T_2		2		
T_3		3		
T_4		4		
T_5		5		
T_6				
T_7				
T_8				
T_9				
T_{10}				
T_{11}				
T_{12}				
T_{13}				

Table 13 – Deflection meters readings under loading

Loading steps, F, kN	u_1, mm	Δu_1, mm	u_2, mm	Δu_2, mm	$u=(\Delta u_1+\Delta u_2)/2$
1	2	3	4	5	6
0					
0.4					
0.8					
1.2					

Table 14 – Test results

Parameters	Computation and measurement results
1	2
Wood species:	
– longitudinal timber ribs	
– plywood sheathing	
Dimensions, *mm*	$h_w =$ $h =$ $b =$
	$b_w =$ $h_t =$ $l_d =$
Maximum theoretical stresses, *MPa*:	
– in plywood sheathing	$\sigma_{t_q} = \dfrac{M}{W^{в}_{ef}} =$
– in longitudinal timber ribs	$\sigma_w = \dfrac{M}{W^{н}_{ef}} =$
Maximum theoretical deflection, *cm*, at $F = 1.2$ kN,	$U = \dfrac{Fl_d^3}{64E_p \cdot I_{ef} \cdot 0,7} =$
Average normal stresses in the sheathing (cross-section No1), *MPa*	$\sigma_{mod} =$
Maximum normal stresses in the sheathing, *MPa*	$\sigma_{max} =$
Coefficient of nonuniformity of normal stress distribution across the width of the sheathing	$k = \sigma_{\text{mod}} / \sigma_{\text{max}} =$



a) experiment; b) theory

Fig. 23 – Normal stress distribution along the cross-sectional height of the glued timber-plywood structural element

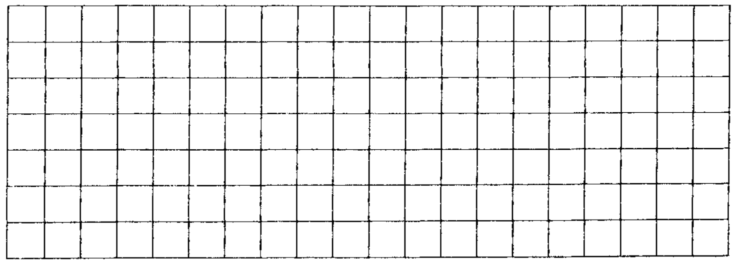
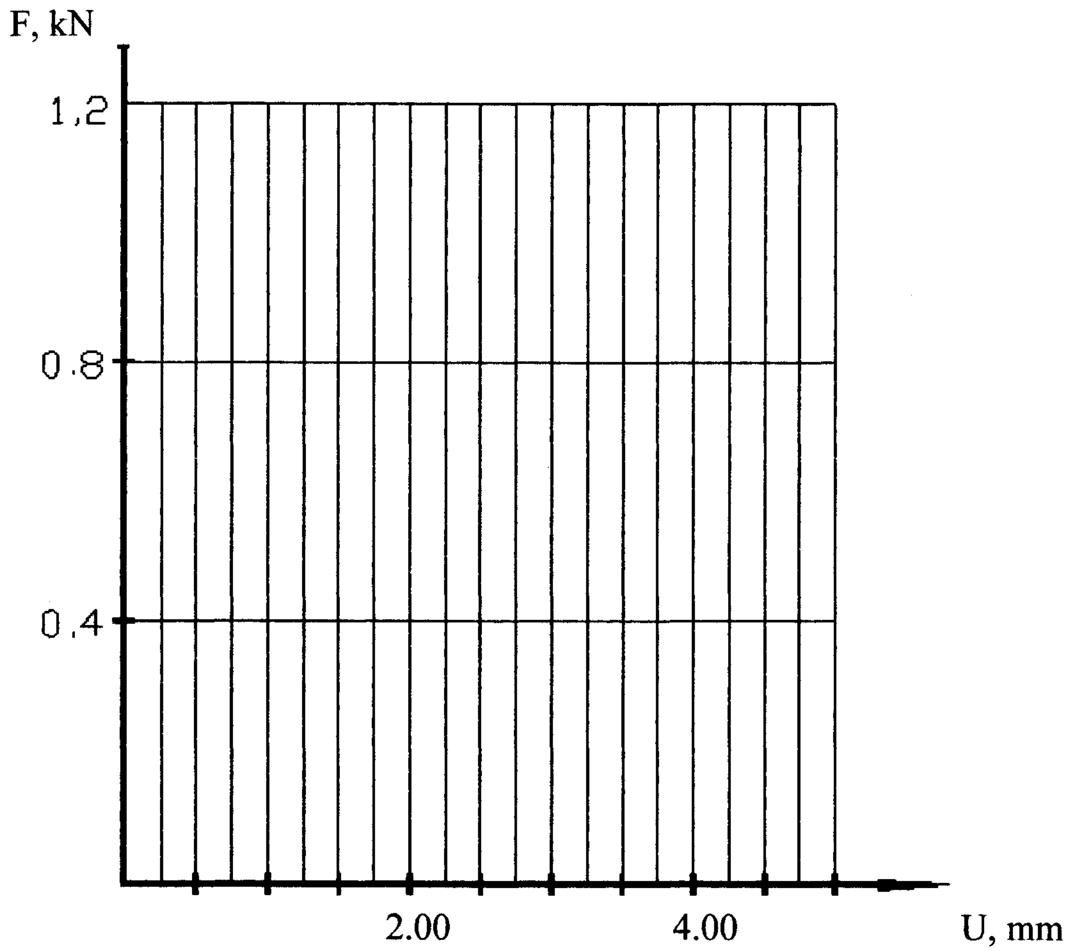


Fig. 24 – Normal stress distribution along the cross-sectional width of the glued timber-plywood structural element



a) experiment; b) theory
Fig. 25 – Load-deflection diagram

Conclusions:

Key questions for revision and self-check

1. *What features make the structural analysis of glued timber-plywood structural elements specific?*
2. *Why are the normal stresses distributed nonuniformly across the plywood sheathing width?*

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