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SHORT-TERM STRENGTH AND RIGIDITY OF OSB-WEBBED I-BEAMS

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SYNOPSIS. Three composite I-beams of an effective span of 4.5 m and depth of 240 mm made of 38 × 63 mm pine wood flanges and 10 mm thick OSB/3 webs were tested in bending. Each beam was loaded at third point in two cycles: six times up to 6.65 kN and six times up to 10.34 kN to produce mean normal stress in wood flanges at the level of 88% and 137% of the computational tensile strength, respectively. The total deflection at the mid-span of the beam and the deflection at the zone of pure bending were measured with the aid of the depth and dial gauges. Additionally, strains at the wood flanges and the OSB webs were measured with the aid of resistance strain gauges situated in the middle part of the beam. After completing both load cycles each beam was loaded up to failure.

KEY WORDS: composite I-beams, oriented strand board (OSB), pine wood, strength, rigidity, flexibility, failure, load capacity

INTRODUCTION

The interest in oriented strand board (OSB) as a material for the building industry in Poland has considerably increased since 1997, when the domestic production of OSB was started up. OSB is a wood-based product designed especially for the building applications. This material is characterized by high, in comparison to wood, shear strengths and shear modulus (LEICHTI et AL. 1990). OSB panels are a cheaper replacement for high-quality structural grade plywood (NISHIMURA et AL. 2004). At the beginning OSB panels were used only as wall and floor facing or as roof boarding. Nowadays OSB is more and more frequently used as the webs of composite I-beams or, rarely, box beams (HIKIERT 2001). The composite I-beams with flanges made of glued wood and webs made of OSB/3, known as "Kronopol I-beams" are offered by the domestic manufacturer – Kronopol-Żary. These beams hold a Technical Approval ITB (AT-15-5515/2006) but, according to the building law, they must be each time designed with regard to actual elastic and strength properties of wood and OSB and to obligatory standards. There is the problem with this design, because using the current national standards for wood-based panel materials (PN-EN 310, PN-EN 789) or for OSB (PN-EN 300, PN-EN 12369-1) all the needed properties of OSB cannot be stated. The standards mentioned above do not provide, for example, bending tests with the load applied at the plane of the panel, but webs of the composite beams are in such a loading state. Moreover, the investigations made by Wilczyński and Gogolin (1999) or Plenzler and Pałubicki (2006) indicated that the modulus of elasticity (MOE) at the direction parallel to the longer edge of OSB sheet is 1.24-1.5 times bigger than at the transverse direction. Similarly, the modulus of rupture (MOR) of OSB bent by the load applied in the plane of the panel is about 1.44 time bigger at the direction parallel to the longer edge of OSB sheet. Additionally, the values of the modulus of elasticity and bending strength of OSB loaded perpendicular and parallel to the plane of the panel turned out to be completely dissimilar (Prociszewski et al. 2003). This situation requires further investigations of elastic, strength and also rheological properties of OSB and of composite beams made of wood and OSB.

In recent years a number of the investigations were performed on the elastic properties (Wilczyński and Gogolin 1999, Plenzler and Górecki 2002, Plenzler and Pałubicki 2006), the strength properties (Szyperska and Nożyński 1999, Plenzler and Pałubicki 2006) and rheological properties of OSB panels (Pałubicki and Plenzler 2004). The investigations of the rigidity, load capacity or the creep compliance of the whole composite beams with OSB webs were reported in Poland very seldom. Smardzewski et al. (2002) made an attempt of the numerical modelling of the elastic behaviour of composite I-beams with OSB webs and compared results of this simulation with the experimental data from Hikiert et al. (2000). Plenzler et al. (2005) reported tests results of the behaviour of OSB-webbed I-beams subjected to short-term loading. These beams indicated during the tests quite high rigidity, but their load capacity turned out to be not satisfactory. The authors stated that the reasons of the insufficient load capacity of the beams were low quality of the joints and the occurrence of big knots in the wood flanges. This paper presents the results of bending tests performed on the composite beams in a similar manner as reported above, but with wood flanges free of the imperfections mentioned above.

METHODS

Three composite I-beams of a total length of 4.6 m were constructed in a similar manner as reported earlier (Plenzler et al. 2005) and as in the tests reported by Chen et al. (1989). Each beam consisted of two 38 × 63 mm flanges made of pine wood (*Pinus sylvestris* L.) and 10 mm thick OSB/3 web (Fig. 1). The wood flanges were connected with the OSB web with the tongue-and-groove joint similar in its type to the one reported by Ganowicz et al. (1990) and used in composite I-beams with hardboard webs. Because commercial OSB panels (2500

× 1250 mm by 10 mm thick) were used each web was prepared of 3 OSB panels cut parallel to the longer edge of the OSB sheet. These panels, two 1050 mm long and the central, with the length of 2500 mm, were joined by means of splice plates glued on both sides of the web. The width of the splice plates (6 cm) was designed in accordance with the proposal of Ozelton and Baird (1976). Additionally, pine wood web reinforcements (38 × 26.5 mm) were glued on both sides of the web (at concentrated load points) to prevent the web from a buckling. All the glue joints were realized with the aid of rigid phenol-resorcinol adhesive Dynosol S-205 to eliminate the shear slip at the joints. After the I-beams were prepared, 120-ohm strain gauges were situated in the middle part of each beam: 8 of the active measuring grid length of 10 mm on the wood

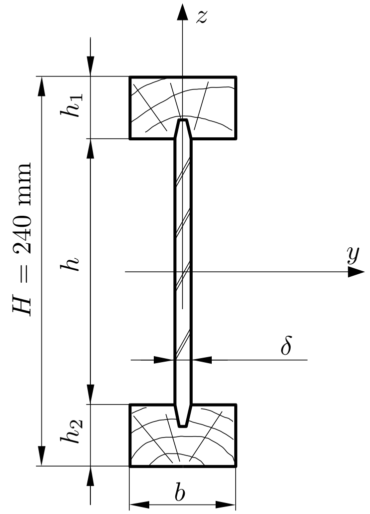

Fig. 1. Cross-section of the composite I-beam

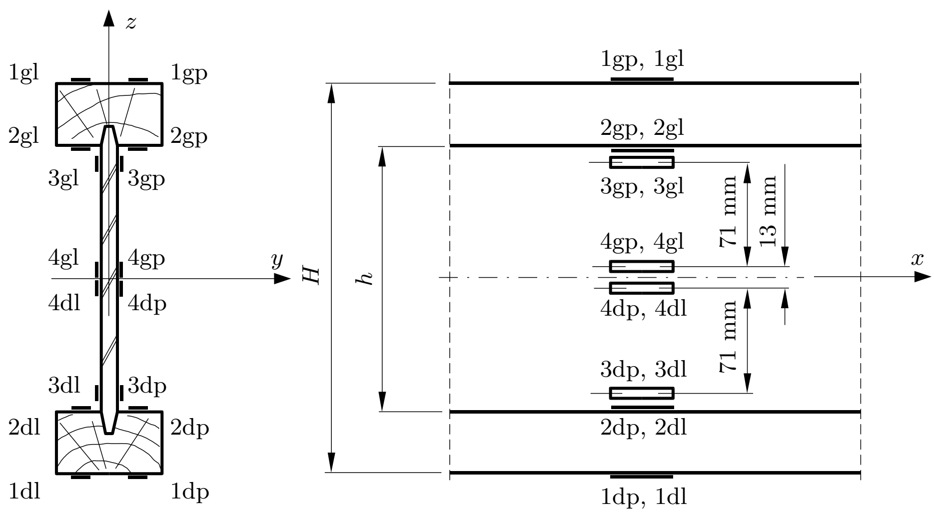

Fig. 2. Arrangement of resistance strain gauges

flanges and 8 of the length of 20 mm on the OSB web (Fig. 2). These strain gauges were connected with a static indicator to direct determination of the strains at the wood flanges and the OSB web. This arrangement of strain gauges exhibited double sensitivity to the bending strains due to the bending about the y axis and was insensitive to the bending about the z axis and the temperature effects (Roliński 1981). The mean mass of the I-beam was 18.23 kg. The composite beams of an effective span L of 4.5 m were loaded at third point along the beam to obtain a wide (i.e. 1.5 m) zone of pure bending (Fig. 3). The load was applied to the beam through the Skamet hydraulic jack and the accuracy of the load measurement was 120 N. The test stand was equipped with two lateral supports with the spacing of 183 cm to avoid the lateral buckling of the beam. Temperature and relative humidity in the lab were monitored within ±1°C and ±1%, respectively. The total deflection at the mid-span of the beam was measured with the aid of the depth gauge with the accuracy of 0.1 mm. Two dial gauges with the accuracy of 0.01 mm positioned close to each end of the beam (at the support points) enabled the calculation of the net flexural deflection. Additional dial gauge positioned at mid-span of the beam was used to measure a deflection at the zone (1500 mm) of pure bending. The following procedure was used to test each beam. The beam was loaded in two cycles: six times up to 6.65 kN and next six times up to 10.34 kN. These levels of load produced in the tension wood flange mean normal stress at the level of 88% and 137% of the computational tensile strength in the flange ($\sigma_{f,t,d} = 11$ MPa), respectively, as for structural lumber grade C 30, according to the Polish Standard PN-B-03150:2000. These levels of load were slightly higher than those reported earlier (Plenzler et al. 2005). The flexural deflections were measured only during the loading of the beams. After completing both load cycles each beam was loaded up to failure.

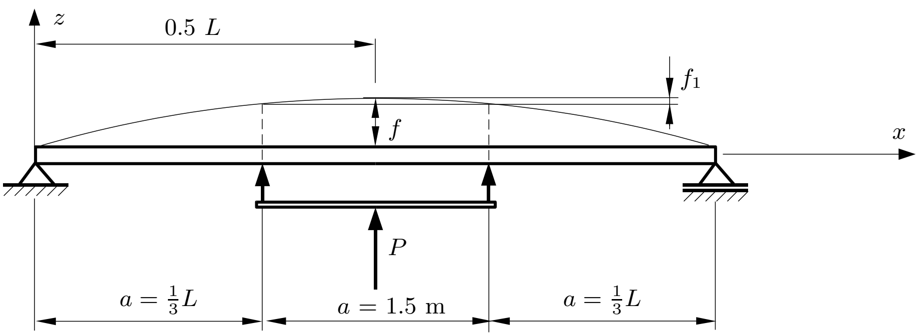

Fig. 3. Diagram of the beam load and deflections measurement

RESULTS

Figures 4 and 5 show typical charts of the force-deflection relationships ($P \sim f$) and ($P \sim f_1$) for the composite beam during the first and the second series of loading, respectively. In these charts, the two flexural deflections are represented: the total deflection (f) and the pure bending deflection (f_1) of the beam. Even though the beams weren't preloaded (i.e. a mechanical conditioning was not applied) the relationships $P \sim f$ and $P \sim f_1$ turned out to be almost linear, so the linear-regression analysis was used to determine the flexural stiffness of the beams. Permanent set after each cycle of loading-unloading was no significant, so the behaviour of the beams during both series of bending tests may be recognized as nearly elastic, de-

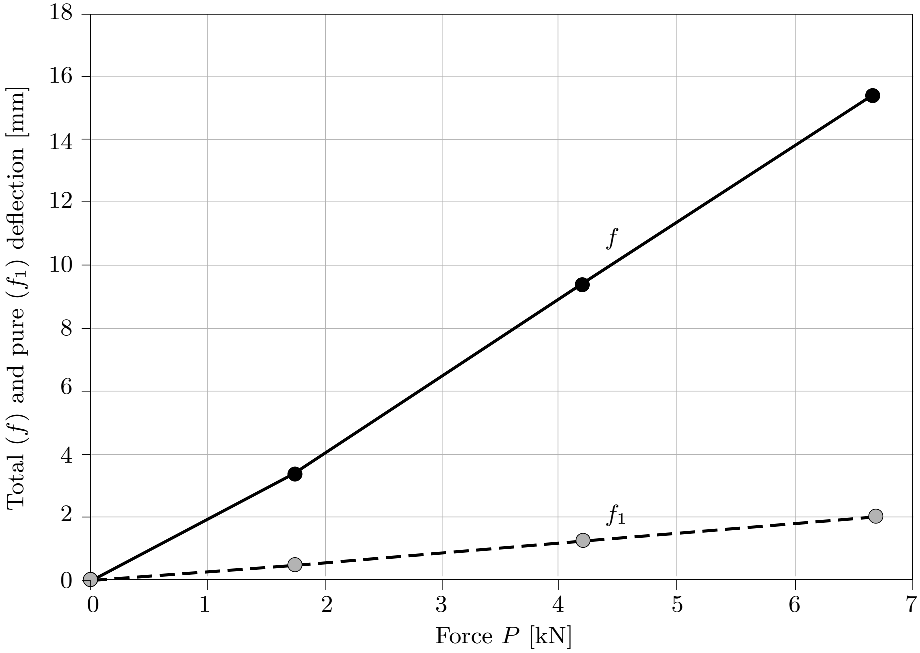

Fig. 4. Force-total deflection ($P \sim f$) and force-pure bending deflection ($P \sim f_1$) relationships for the composite I-beam No. 2 during the first series of loading; $P_{\max} = 6.65$ kN

spite of relatively high – in comparison with the computational tensile strength of wood – level of load: 88% and 137%, respectively. An approximation of the results of all the tests was carried out using the computer program Sigma Plot. The flexibilities k and k_1 of all tested beams, obtained in both series of loading from the total (f) and in pure bending zone (f_1) deflections are summarized in Table 1. The flexibilities k_1 and k were also calculated from the general formulas (Plenzler et al. 2005):

$$f_1 = k_1 \cdot P = \frac{a^3}{16EJ_{y,ef}} \cdot P \tag{1}$$

for pure bending zone and

$$f = k \cdot P = \left(\frac{23}{48} \cdot \frac{a^3}{E \cdot J_{y,ef}} + \frac{S \cdot a}{2A_{ef} \cdot G}\right) \cdot P \tag{2}$$

for total mid-span deflection, where the shear shape factor

$$\begin{aligned} S \;=\; & n_1 \cdot \frac{A_{ef} \cdot b \cdot H^5}{32J^2_{y,ef}} \cdot \left\{\frac{1}{2}\left(1 - \frac{h}{H}\right) - \frac{1}{3}\left[1 - \left(\frac{h}{H}\right)^3\right] + \frac{1}{10}\left[1 - \left(\frac{h}{H}\right)^5\right]\right\} + \\ & + \frac{2A_{ef}}{J^2_{y,ef} \cdot \delta} \cdot \left[C_1^2 \cdot \frac{h}{2} - \frac{2}{3}C_1 \cdot C_2 \cdot \left(\frac{h}{2}\right)^3 + \frac{1}{5}C_2^2 \cdot \left(\frac{h}{2}\right)^5\right] \end{aligned} \tag{3}$$

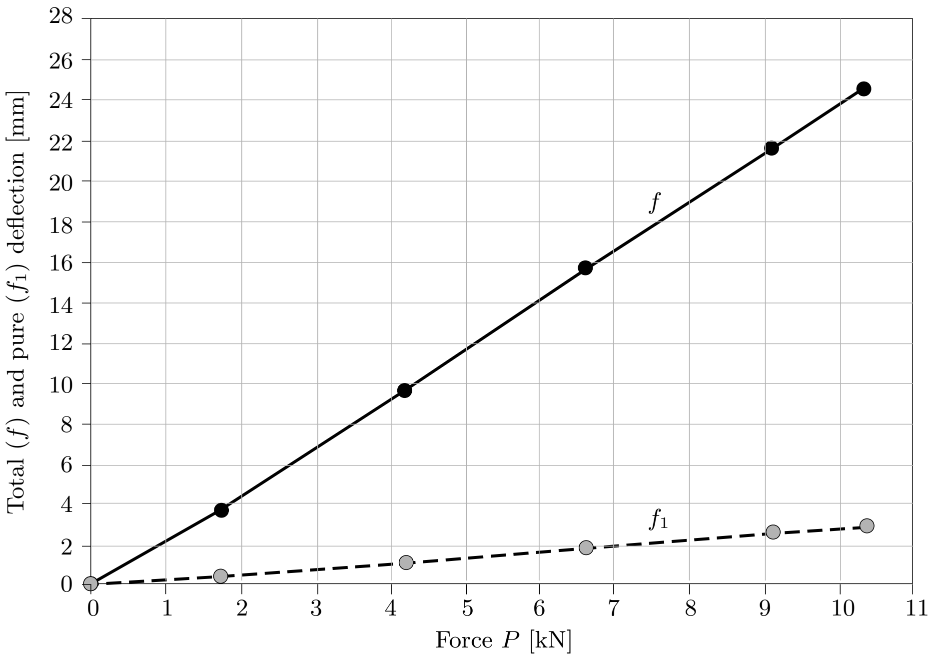

Fig. 5. Force-total deflection ($P \sim f$) and force-pure bending deflection ($P \sim f_1$) relationships for the composite I-beam No. 2 during the second series of loading; $P_{\max} = 10.34$ kN

and

– A_{ef}, $J_{y,ef}$ – effective area and moment of inertia, respectively,

– $C_1 = n \cdot \dfrac{\delta \cdot h^2}{8} + \dfrac{b}{2} \cdot \left(\dfrac{H^2}{4} - \dfrac{h^2}{4}\right)$,

– $C_2 = n \cdot \dfrac{\delta}{2}$,

– $n = \dfrac{E_{\mathrm{OSB}}}{E}$,

– $n_1 = \dfrac{G_{\mathrm{OSB}}}{G}$,

– $E = E_{0,\mathrm{mean}} = 12$ GPa and $G = G_{\mathrm{mean}} = 750$ MPa – moduli of elasticity and rigidity, respectively, of structural lumber grade C 30 according to PN-B-03150:2000,

– H, h, b, δ, a – cross-section and beam dimensions, according to Figures 1 and 3.

The values of the moduli of elasticity and rigidity of OSB/3 panels: $E_{\mathrm{OSB}} = 6323$ MPa and $G_{\mathrm{OSB}} = 1996$ MPa were taken from the earlier investigation (Plenzler and Górecki 2002, Plenzler and Pałubicki 2006). Observing the values of the flexibilities k and k_1 in Table 1, we can see that the actual mean flexibilities of the tested beams turned out to be about 16.6 or 18.9% lower than the calculated from formulas (1) or (2), respectively. Presumably, the modulus of elasticity

Table 1. Flexibility of the composite I-beams

Property	Cycle of loading	Beam number 1	Beam number 2	Beam number 3	Mean value	Value calculated from formulas (1) or (2)
Flexibility (pure bending) k_1 [mm/N] $\cdot 10^{-3}$	I $P_{\max} = 6.65$ kN	0.2767	0.2827	0.2496	0.2694	0.3346
	II $P_{\max} = 10.34$ kN	0.2863	0.2834	0.2495	0.2731	
Flexibility (bending and shear) k [mm/N] $\cdot 10^{-3}$	I $P_{\max} = 6.65$ kN	2.3519	2.2962	2.2526	2.3002	2.7703
	II $P_{max} = 10.34$ kN	2.3994	2.3598	2.2050	2.3214	

Table 2. Results of destructive tests

Beam number	Ultimate load P_u [kN]	Ultimate moment M_u [kNm]	Factor of safety	Beam failure mode*
1	17.73	13.30	2.35	failure in the tension flange
2	22.91	17.18	3.04	break in the compression flange
3	18.23	13.67	2.42	failure in the tension flange and next in the compression flange – in a knot place
Mean value	19.62	14.72	2.60	

*Every time the failure at the zone of pure bending.

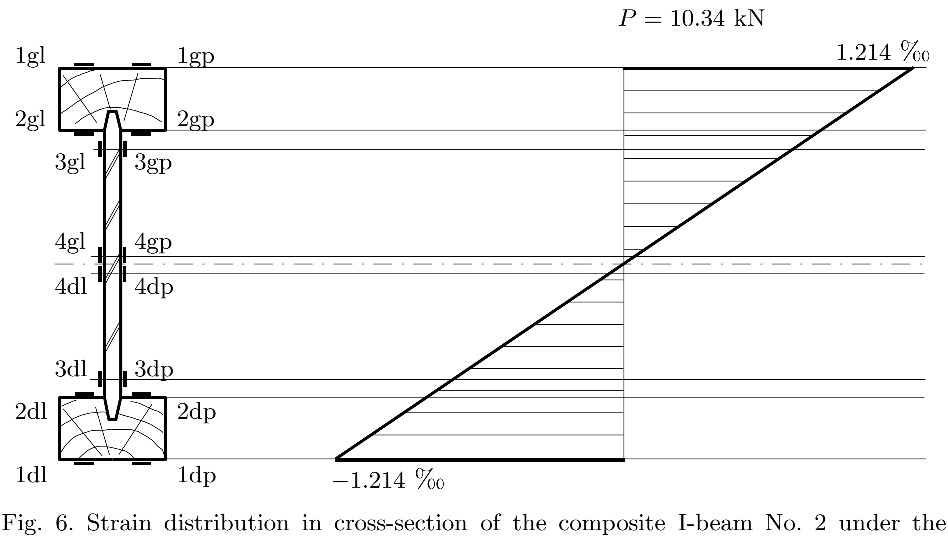

Fig. 6. Strain distribution in cross-section of the composite I-beam No. 2 under the maximum load during the second series of loading

of wood flanges turned out to be higher than 12 GPa (as assumed for structural lumber grade C 30) and the effective area and moment of inertia of composite cross-section was higher too. Figure 6 shows typical chart of the strains measured by means of the resistance strain gauges situated on the surface of wood flanges and OSB web (Fig. 3). From Figure 6, it is evident that the strains vary linearly from the neutral axis of the cross-section of the composite beam, i.e. that plane sections perpendicular to the beam's longitudinal axis remain plane, according to the most basic assumption of classical beam theory – the hypothesis of Bernoulli (Willems et al. 1981). This shape of the strain chart proves that the interaction between the flange and web was complete and there was no slip between those elements during the short-term tests reported above. After the nondestructive tests were completed each beam was loaded up to failure using the same loading system as earlier. The data relative to the destructive tests are summarized in Table 2. We can see from Table 2 that failures of the beams occurred in two modes only, either in tension flange (2 beams) or in compression flange (1 beam). All the beams were broken down in the zone of pure bending. None glue joint between wood flange and OSB web failed which indicated that the construction of tongue-and-groove joint was adequate. Despite of this that the elastic section modulus ($W_{y,ef}$) for the beams tested was about 3 times lower than for the beams examined by Plenzler et al. (2005) their mean load-carrying capacity turned out to be about 38% higher, however somewhat lower than in tests reported by Chen et al. (1989). The destructive forces varied between 17.73 kN and 22.91 kN for the individual beams, at the average of 19.62 kN and the average value of the breaking moment was then 14.72 kNm. The effective factor of safety, relative to the computational force of 7.53 kN averaged out at 2.60 and was significantly higher than in earlier tests (1.81) reported by Plenzler et al. (2005). The obtained flexibilities of the tested I-beams turned out to be similar to the ones reported by Plenzler et al. (2005) or Chen et al. (1989). After the composite I-beams were destructively tested, wood and OSB samples were collected from each beam to determine their moisture content. Moisture content for all wood flanges and OSB webs ranged from 7.7% to 8.3% and from 6.2% to 6.3%, respectively. Average moisture content of wood flanges was 8.0% when for OSB webs 6.25%. Those investigations were performed according to the national standards PN-EN-322 and PN-77/D-04100.

CONCLUSIONS

1. The application of clear wood flanges instead of lumber flanges with finger joints turned out to be decisive for the increase of the load-carrying capacity of the composite I-beams.
2. The force-deflection relationship at bending of the composite I-beams made of pine wood flanges and OSB/3 webs appears to be nearly linear, even as the mean stress in the tension flange reached 137% of the computational strength of wood.

3. The flexural rigidity of the tested I-beams turned out to be about 19% higher than it was expected, presumably due to the underestimation of the actual modulus of elasticity of used pine wood.
4. The results of the strains measurements made by means of resistance strain gauges showed that the strains vary linearly from the neutral axis of the cross-section of the I-beam, i.e. the interaction between the wood flanges and the OSB web was complete, owing to used phenol-resorcinol adhesive.
5. The effective factor of safety, relative to the computational force amounted about 2.60 and was significantly higher than for I-beams with the flanges joined lengthways with the finger joints.

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