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Fiber Optic Sensors for Structural Health Monitoring

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Abstract: Methods based on fiber optic sensors are commonly used for analysis of mechanical stress. They are frequently used for Structural Health Monitoring of machine and building structures. This paper deals with the utilization of these sensors in the experimental analysis of ceiling panels made from cross laminated timber, comparing them with an existing measurement methods and data evaluation process. Based on the analysis of current trends in the construction of buildings the requirements for the measurement data are defined.

Keywords: Fiber Optic Sensor; Inductive Displacement Sensor; Deformation Measurement; Cross Laminated Timber.

1 Introduction

New type of anchoring fiber optic strain sensor is being developed for monitoring of wood construction. Several prototypes of sensors were made with different fiber length and then were mounted on a wooden ceiling panels. Four point bending test [1, 2] was used for their evaluation. Results obtained from FBG sensors were compared with the outputs from the inductive displacement sensors. Two types of optical fiber connections were used for the experiment. The horizontal and vertical displacements of layers were determined by mechanically attached fibers. Normal stress on the lower surface of the panel was determined by the glued fibers.

2 Ceiling Panel

Experimental specimens were made from 5-layer ceiling panels of spruce wood stacked together and screwed by threaded galvanized screws 5/80 mm forming a cross laminated timber (CLT). Two edge layers were in longitudinal orientation (parallel to span) and the middle one was in orthogonal orientation. Four screws per each lamella's crossing were used for the layer connection. Dimensions of each tested floor panel were 2600 × 1000 × 135 mm. Each layer was made of planks with cross section 27 × 170 mm. Mean value moduli of elasticity $E_{0,mean}$ = 13089 MPa of used lamellas were measured before screwing panels by Timber Grader MTG. The measured value was used to determine normal stress from the strain.

3 Experimental Set-Up

Vertical compressive load was generated by a hydraulic actuator. The load from the press was divided into two identical forces using steel rocker arm. Span between supports of panel was 2160 mm. Distance of load points was 810 mm. Samples were placed on the roll bearings. Tests were carried out in load cycles until failure of samples. Four-point bending tests were performed according to European standards [1] and [2] in the laboratory of Faculty of Civil Engineering CTU in Prague. The test set-up is shown in Fig. 1.

4 Sensors

In the experiments, horizontal displacements of the upper two layers relative to each other, the mutual vertical displacement of the outer surfaces of the upper and lower layers, and the surface tension of the lower surface of the panel were measured. Test set-up with the placement of measuring sensors is shown in Fig. 2.

Fig. 1: Bending test of ceiling panel.

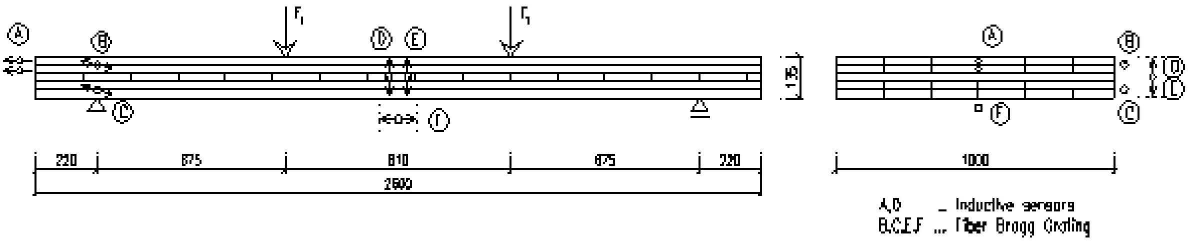


Fig. 2: Scheme of four-point bending test with the placement of measuring sensors.

4.1 Inductive Sensors

Two inductive sensors mounted on the front surface of the panel (position A, Fig. 2) have been applied for measuring the horizontal displacement of layers. The mutual displacement of two edge layers was determined based on the difference between the measured values of both inductive sensors. An inductive sensor mounted on the side surface of the panel in the middle of span (position D, Fig. 2) was used for measuring the mutual vertical displacement.

Displacements of measured points were analyzed with Dewetron DEWE 5000 and program DeweSoft. The sampling frequency of the measured signal was set to 10 Hz. This value is for the building structure sufficient to record all fluctuations.

4.2 Fiber Optic Sensors

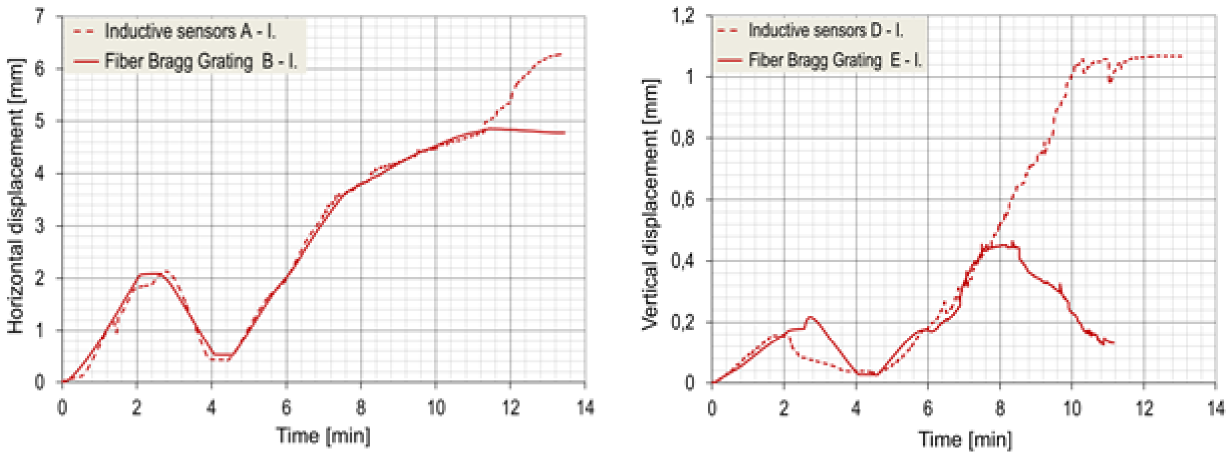
Four series of fiber optic sensors were used for measurements. Fibers of length 280 mm (position B, Fig. 2) and 120 mm (position C, Fig. 2) were used for measuring the horizontal displacement of layers, the fiber with length of 135 mm (position E, Fig. 2) for the vertical displacement of layers and fibers glued to a bottom surface of the panel (position F, Fig. 2) were used for the determination of normal stress lower lamellas panel. For fixation of fibers glued anchors were used. Anchors were attached to the steel angle profiles. The profiles were screwed to the longitudinal wooden lamellae planks. The optical fiber sensor for measuring of surface strain was attached to one of the slats of the lower surface of the panel by the HBM X60 two-component adhesive.

Safibra FBGuard 1550 multichannel interrogator was used for data measurement and evaluation. FBG sensors were connected to the unit via spliced pigtails with connectors FC / APC connectors. The sampling frequency of the measured signal was set to 10 Hz. Strain of Bragg grating and elongation of fiber between anchoring points were measured

5 Experimental Results

So far, bending tests of CLTs have been performed and time-displacement diagrams for fiber sensors and inductive displacement sensors are evaluated. Example of characteristic curves for sample I. are shown in the Fig. 3, 4 and 5.

The characteristic curves of comparison of displacement of the layers in relation to time for inductive sensors and FBG sensors attached in the support place are shown in Fig. 3.



(a) horizontal displacement to time

(b) vertical displacement to time

Fig. 3: Comparison displacement of layers in relation to time for inductive sensors and FBG sensors.

After seven minute of the test, the optical fiber measuring vertical displacement (Fig. 3b) began to slip at bond between the fiber and the steel anchor. Slip was caused by exceeding shear strength of the adhesive.

For comparison of displacements of layers on the edge of the panel cross-section optical fiber sensor length 280 mm, and 120 mm was used. Horizontal displacement to time diagram for both FBG sensors is shown in Fig. 4. For approximate determination of the normal stress on reaching ultimate limit state of the CLT linear elastic theory can be assumed and dependence of normal stress to the strain. Stress-time diagram of a surface tension measurement is shown in Fig. 5.

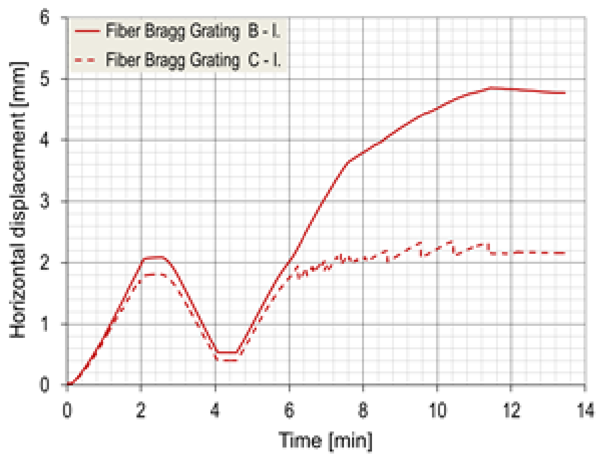


Fig. 4: Comparison horizontal displacement of layers in relation to time for FBG sensors.

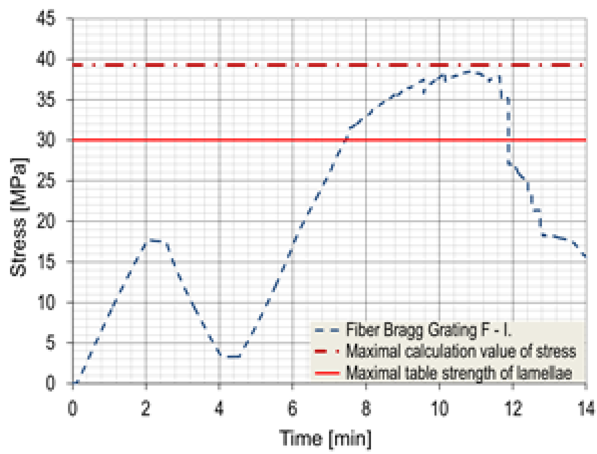


Fig. 5: The normal stress on lower surface of panel cross section.

After 6 minute of the test, an optical fiber of length 120 mm (Fig. 4, fiber C) reached a maximum value of the strain. There was no fiber damage, but fiber was gradually pulled from the adhesive in the anchor. Experimental value of normal stress obtained from the FBG sensors was verified by a table value, which was determined based on the strength of the tested lamellae and by analytical model according to EN 1995-1-1 [3]. The both panel failures were at points where load was applied, because maximum load-bearing capacity was reached, see Fig. 6.

Comparison of the experimental values measured by FBG optical sensors and inductive sensors are shown in Tab. 1. A correlation coefficient R is used for comparison.

Fig. 6: Failure of sample I. at the point of load.

Tab. 1: Comparison between methods – coefficients of correlation R.

specimen	horizontal displacement of layers	vertical displacement of layers
panel I.	0.99	0.98
panel II.	0.89	—

6 Conclusion

Semi-rigid connection of layers CLT caused their mutual displacements. During the tests, there was a gradual displacement of horizontal and vertical layers. These displacements were measured by optical fiber sensors and inductive sensors. It is obvious from the measured data of currently performed experiments that results from both types of measurement methods are almost identical. The obtained data confirm the ability of designed sensors to provide relevant results and therefore they can be used as an input for further development of optical sensors and measurement devices.

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