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The use of a structural monitoring system in deformation surveying of a wooden beam during the destructive test

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Abstract: *The use of a structural monitoring system in deformation surveying of a wooden beam during thedestructive test.* One of the basicconstruction materials is wood. It is used both for the construction of the main structural elements as well as during finishing works. Therefore, it is extremely important to choose the right type of wood as well as to recognize its strength characteristics properly. In the context of civil engineering, it is important to properly apply the material in the context of its load capacity and strength. In the article, the authors evaluated the load-bearing capacity of a pine beam by carrying out a test of its destruction on a testing machine. The assessment of the emerging displacements invoked by the applied load has been verified by a geodetic monitoring system consisting of a precise, robotic electronic total station remotely operated from the controller's position, using specialised software. The obtained results were compared with the values obtained from the testing machine. Furthermore, the accuracy level of the geodesic system and its potential usefulness in deformation monitoring of timber elementswere assessed.

Keywords: deformation monitoring, beam deflection, testing machine

INTRODUCTION

The assessment of the bearing capacity of building materials belongs to one of the keycivil engineering tasks. Materials used in construction works are subject to strict standards, and their appropriate use is a crucial element of the safety of a constructed building. In the case of structural timber, one canmention(depending on the wood type) 12 strength classes for coniferous wood and 8 classes, in the case of hardwood [17]. Designing buildings using wood is described in detail in sets of national [17,18] and EU standards - so-called Eurocodes [5,19]. These documents contain strict recommendations regarding the calculation of the bearing capacity, dependencies between various physical factors and strength, material weight, calculation formulas or the values of appropriate coefficients, which should be used in these formulas. The selection of appropriate construction materials, however, does not preclude the risk of various unforeseen crises, including disasters, during construction and subsequent operation of the building [14,20]. Especially in the era of climate changes, we can expect many hazards related to atmospheric phenomena. It confirms the need to carry out measurements verifying the state of the object's implementation related to its design, as well as researching displacements and deformations of individual structural elements [13]. Metrology distinguishes validation tests conducted under laboratory conditions - oriented to determine own characteristics of the test sample as well as field tests, whichresult in determining the physical properties of a given sample along with systematic errors coming from external sources [1,8].

Measurements performed in laboratory conditions are carried out, among others, using testing machines. Suchdevices allow for precise determination of deformation values of the tested material depending on the force acting on it. Field measurements are performed using physical and metrological instruments [4,11]. Among the physical methods, the use of fibre optics and absolute positioning sensors is becoming increasingly popular [4]. It should be added that very often the result of the test comes out from the integration of various data types obtained from sensors examining specific object features. The assessment of the state of displacements and deformations of objects in the geometrical sense is carried out with the use of special instruments - such as levels or electronic total stations. For example, the results of the examination of wooden beam deflections using a precise digital level were published by the authors in [12]. The results of monitoring the state of an object with a composite (hybrid) timber-concrete structure were also published in [2]. Unlike in the case of levels, total stations allow for direct positioning of points in 3D. Tacheometric measurements, however, are exposed to the impact of different systematic errors, which often translates into lower accuracy. Nevertheless, both hardware, methodical and algorithmic solutions allow for the highest accuracy of positioning - sometimes below 1mm.

Until now, wooden buildings were subject to control measurements under construction law [15,21]. Nevertheless, the constantly increasing dimensions of timber structures, modern structural solutions [13], as well as new solutions in the form of combining wood with other structural materials [10] are undoubtedly a challenge for modern civil engineering and geodesy. This also applies to the metrology of structural components - both in the sense of control measurements and continuous monitoring.

The problem of functional evaluation of a geodetic monitoring system using a precise total station in the context of a destructive examination of wooden structural elements became a motivation for the authors to carry out the measurement test.

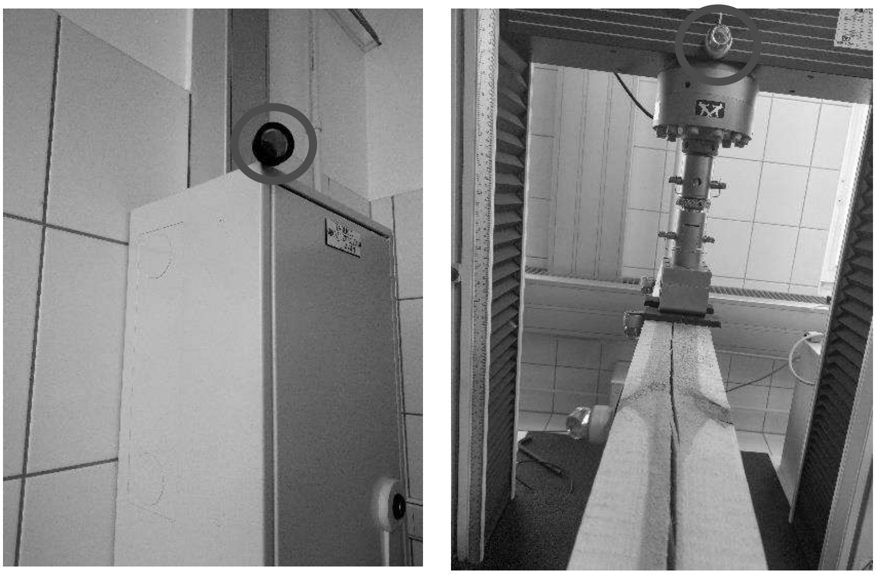
METHODOLOGY

To assess the structural deformation, a pine beam with a size of 10 cm x 10 cm x 200 cm with a moisture content of 8%was used. The laboratory test site consisted of the Instron 3382 testing machine (fig. 1) equipped with a head operating loads up to 100 KN [7], a robotized ZOOM 90 electronic total station byGeoMax (fig. 2) as well as two sets of precision prisms - for the reference (fig. 3) and control points deployed on the tested beam (fig. 4).

Figure 1. View of the testing machine INSTRON 3380
(pic. by Krzysztof Karsznia)

a b c

Figure 2. View of the test stand – geodetic monitoring system (pic. by Krzysztof Karsznia (fig. 2 a) and by Damian Krembuszewski (fig. 2 b,c))



a b

Figure 3. View of the reference points located outside the test stand (a) and on the testing machine (b) (pic. by Krzysztof Karsznia)

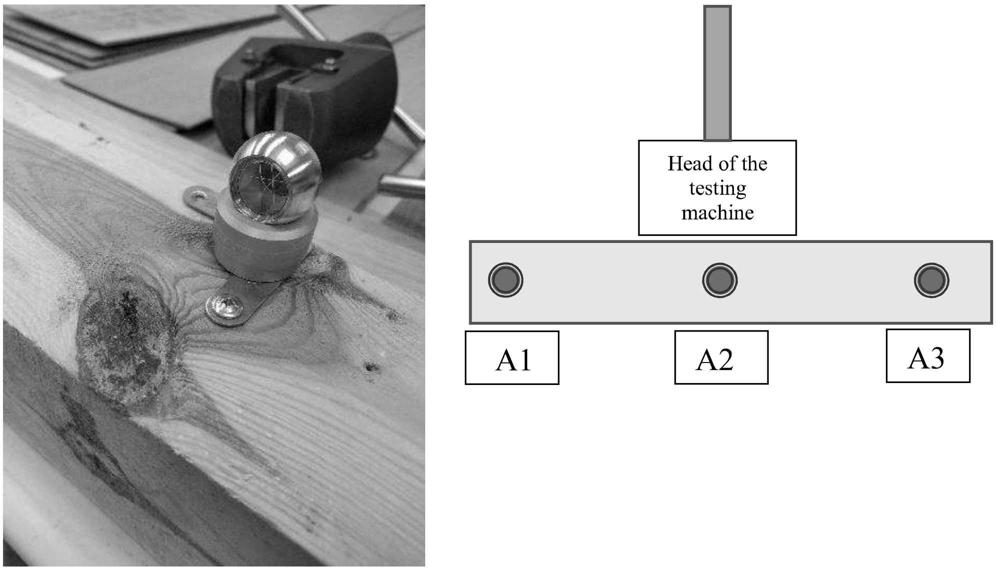


Figure 4. View of monitoring prisms mounted on the examined timber beam with control point numbers (pic. by Krzysztof Karsznia)

The electronic totalstation used[6] is a highly precise measuring instrument equipped with a servomotor enabling automatic positioning of the telescope to the indicated point. The operational accuracy of the device is - in the case of angular measurements: ± 1 " (± 3^{CC}) with the precision of the result display ± 1^{CC} and for distance measurements: ± (1 mm + 1.5 mm / 1 km). The time of a single, standard measurement does not exceed 2.4s, while in the case of continuous measurements, the point measurement time is about 0.15s. The operating range of the ZOOM 90 total station ranges from 1.5 m to 1200 m, however, in the case of precise measurements performed to the single prism, the maximum distance should not exceed 250 m - in practice a maximum of 100-150 m. During the test, the examined object was located 8.5 m from the instrument station. Because the laboratory floor is lined with tiles, the instrument is positioned on a special blocking base to ensure its stability.

The deformation values were determinedbased on the external reference system which also fulfilled its control function - before each new measuring series, the instrument automatically checked its stability relative to the reference points. Control points were parked using precision surveying prisms [3] with a diameter of 30mm attached to metal surfaces using neodymium magnets. The controlled points, closed with identical prisms, were attached to the pine beam also using magnets attached to metal angles bolted to the wood with screws. The beam thus prepared was placed on a testing machine,and a destructive head was applied at its central point.

During the test, the head exerted pressure with a particular force - at the operator's position both the value of applied force,and the amount of deformation were read out. During each load step, the geodetic monitoring system was started. At that time, the instrument performed an automatic orientation to the reference points and then measured the control points in three series.

Initially, the head of the loading machine pressed the test sample each time by 5 mm, until an audible signal about the strain of wood fibreswas heard. Having heard the characteristic sound, the material was released,and the machine heads returned to its initial position.

During the second test, the head’s loadwas increased until the tested sample was completely broken - the wooden fibres were completely torn off. After applying 30 KN force to the tested element, the woodfibreswere damagedand the beam was broken. The maximum deflection for which the wood structure was retained was 120mm.

During the implementation of both tests, a permanent geodetic measurement was carried out to monitor the emerging vertical deformations. The subsequent measuring series of the total station corresponded to the steps of loading performed on the testing machine.

RESULTS

As a result of loading the timber beam on the testing machine to the moment of a characteristic crack, the maximum deflection of 16mm due to a pressure force of 27KN was read. A graphical picture of the result of loading the beam is shown in figures 5 and 6.

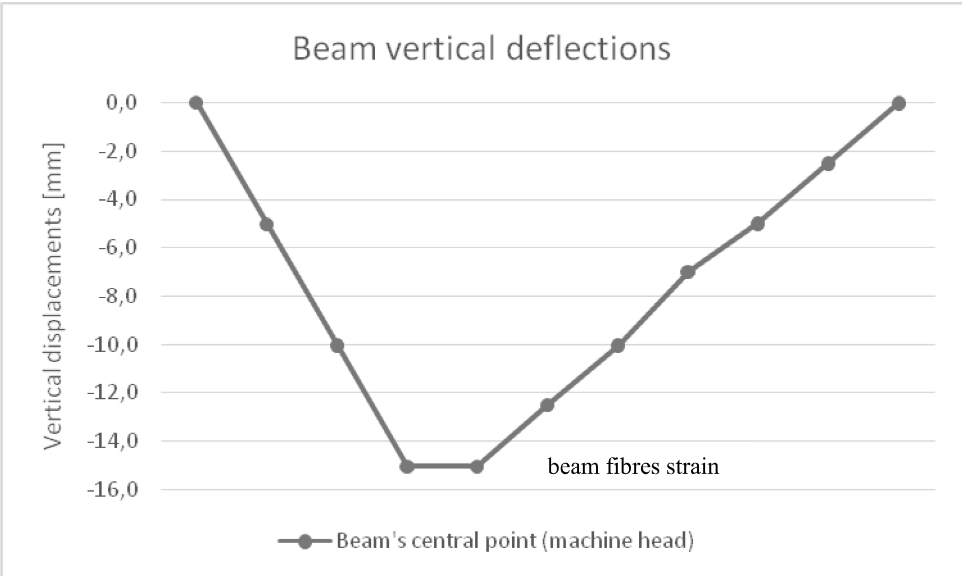


Figure 5. Graphical illustration of vertical displacements of the pine beam - testing machine

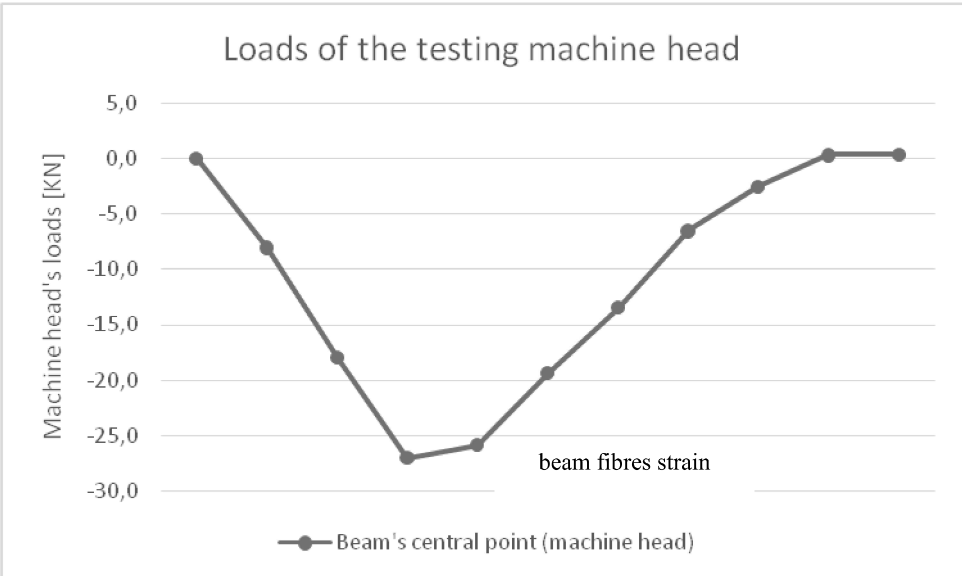


Figure 6. Graphic illustration of forces exerted by the machine head

The A1, A2 and A3 control points (fig. 4) placed on the beam and stabilised with geodetic prisms were subjected to the deflections shown in fig. 7. Placed in the field of the testing machine head, point A2 reached the maximum vertical displacement of -15,1 mm, which corresponds perfectly to value - 15.0 mm obtained from the testing machine (fig. 5). After stress relief, the beam returned to its initial position.

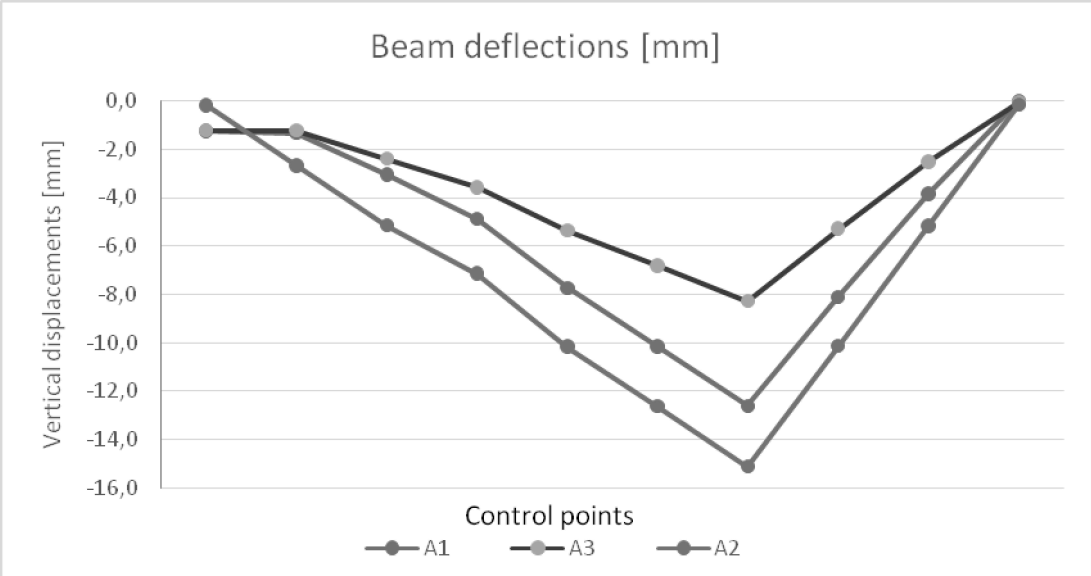
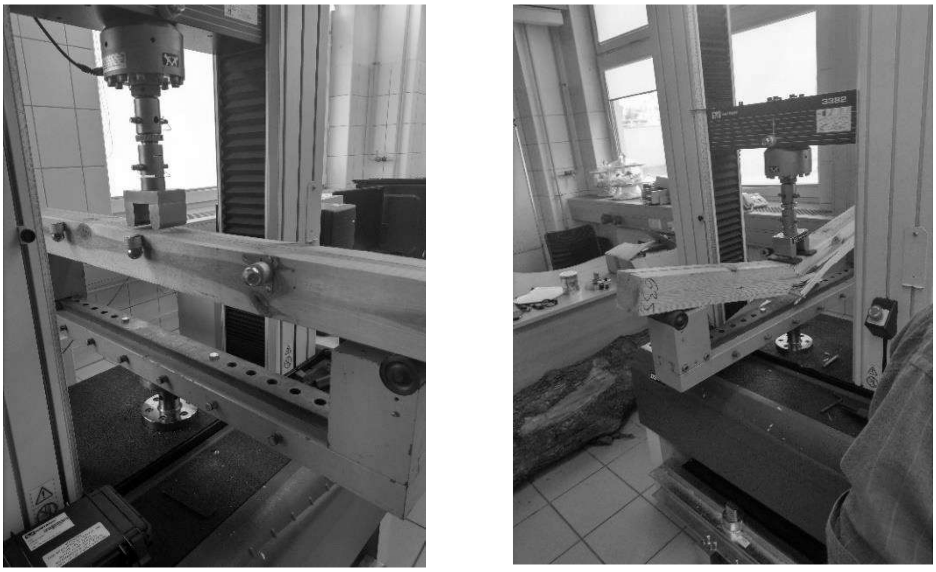


Figure 7. Graphic presentation of vertical displacements of controlled points generated during the test

Another test led to breaking the pine beam ("destructive test" - fig. 8) with simultaneous monitoring of its deflections using a precise total station.



a **b**

Figure 8. View of the testing machine during the test performed (a) an initial phase, (b)with the destroyed pine beam (pic. Krzysztof Karsznia)

During the test, the authors focused on examining the area of the machine's head pressure. The results of the performed test are presented in fig. 9.

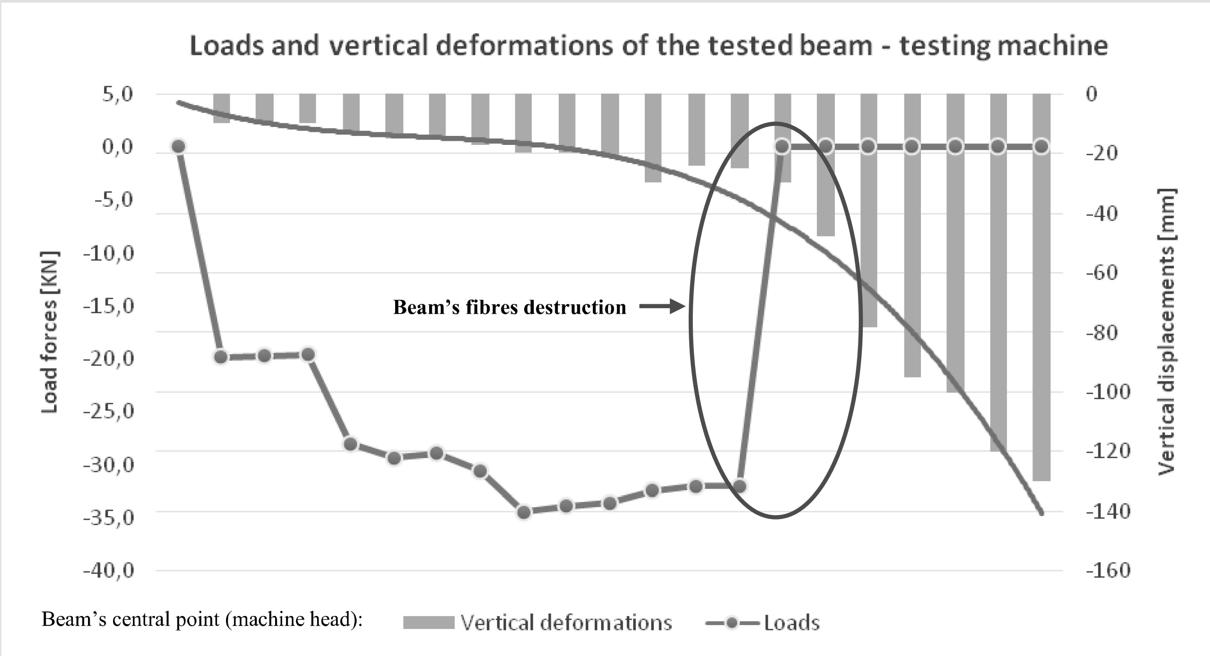


Figure 9. Graphic interpretation of the destructive test of the examined pine beam in the point of the machine head

The drawing shows that the total break of the beam fibres occurred during the impact force of 34.4KN. Their subsequent fractures led to the complete break of the beam structure - the maximum displacement reached was -130mm.

The results of vertical displacements of the controlpoints obtained from the geodetic monitoring system were then compared to the results read from the testing machine. This comparisonis presented in Table 1.

Table 1 Comparison between height differences determined during thebreak test

ΔH total-station [mm]	ΔH testing machine [mm]	difference [mm]
-0,11	0,00	-0,11
-10,06	-10,03	-0,03
-15,05	-15,03	-0,02
-19,95	-19,99	0,04
-25,00	-25,01	0,01
-29,81	-29,56	-0,25
-47,71	-47,57	-0,14
-78,61	-78,47	-0,14
-95,13	-94,99	-0,14
-100,14	-100,00	-0,14
-110,03	-110,00	-0,03
-120,11	-120,00	-0,11

The presented list shows very high compliance of the results obtained from geodetic monitoring and from the testing machine. The standard deviation in this case is σ = 0.1 mm. Taking into account the measurement accuracy offered by the total station, the obtained results confirm the high reliability of the geodetic surveying systems. It also underlines the usefulness of optical spatial points positioning in the assessment of structural elements.

CONCLUSIONS

The performed tests showed high usefulness of geodetic monitoring in the study of displacements and structural deformations. The obtained results can be considered as promising because the obtained value of the standard deviation of height differences determined with both tested methods (geodetic monitoring and testing machine) returns the sub-millimetre values. It means a much higher positioning precision than the nominal values presented by manufacturers. Obviously–the monitoring performed concerned short distances and was carried out in indoor conditions, where the impact of systematic errors was practically eliminated. Nevertheless, while maintaining the appropriate measurement regime, geodetic methods can be used to determine displacements of objects below ±1 mm.

During the tests, the assumptions regarding the strength of the wooden material used for the construction of building structures were also verified. The values obtained refer to the specific test performed under very favourable conditions. Based on that, assuming 2 or 3 times greater displacement limit error as a permissible value, we can determine the actual value of the permitted load ofaparticular structural element. This is an extremely important element of risk assessment related to the construction and exploitation of wooden structures.

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Streszczenie: *Zastosowanie systemu monitoringu deformacji konstrukcji budowlanych w pomiarach odkształceń belki drewnianej podczas testu niszczącego*. Jednym z podstawowych materiałów budowlanych jest drewno. Wykorzystuje się je zarówno do budowy głównych elementów konstrukcyjnych, jak również podczas prac wykończeniowych. Stad też, niezwykle istotny jest wybór właściwego rodzaju drewna, również należyte rozpoznanie jego cech wytrzymałościowych. W kontekście budowlanym, ważne jest należyte zastosowanie omawianego materiału w kontekście nośności I wytrzymałości. W artykule, autorzy dokonali oceny nośności belki sosnowej przeprowadzając test jej zniszczenia na maszynie wytrzymałościowej. Ocena stanu pojawiających się przemieszczeń w zależności od przyłożonego obciążenia została zweryfikowana geodezyjnym systemem monitoringu składającym się z precyzyjnego, zrobotyzowanego tachimetru elektronicznego obsługiwanego zdalnie z pozycji kontrolera, przy użyciu specjalistycznego oprogramowania. Otrzymane rezultaty porównano z wartościami otrzymanymi z maszyny wytrzymałościowej. Oceniono następnie poziom precyzji działania systemu geodezyjnego w kontekście monitoringu deformacji element konstrukcji drewnianej.

*Słowa kluczowe:*monitoring deformacji, ugięcie belki, maszyna wytrzymałościowa

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