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APPLICATION OF THE METHOD OF MEASURING DEFORMATION PARAMETERS UNDER MECHANICAL ACTION ON CONCRETE BEAMS USING A FIBER BRAGG GRATING

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In order to study the patterns of deformation and change of concrete structures, studies of the fiber Bragg lattice in the form of a measuring sensor were carried out. Fiber optic sensors have several advantages: small size, resistance to electromagnetic interference, high sensitivity, wide range, simple structure, high reaction rate, corrosion resistance, geometrically versatile and resistant to external influences.

This work is related to the development of the characteristics and behavior of strain sensors acting on a fiber Bragg lattice using computer modeling. The work focuses on the analysis of the operational characteristics and behavior of strain sensors acting on the fiber Bragg lattice. The sensor is used to measure the deformation of an object whose resistance varies depending on the applied force. This is shown by an example of how a fiber Bragg lattice can demonstrate strain sensors. In the work, a simulation was carried out using a computer program to simulate the operation of a fiber Bragg lattice deformation sensor.

When measuring the deformation, calculations with the Young's modulus formulas were used for a more accurate calculation of the data. When measured, the wavelength left from 1662 nm to 1666 nm, as well as a constant temperature from 20 °C to 40 °C. The results show the following, the values of the Young's modulus are 23.25 Pa, the Poisson's ratio is 0.167 br, the modulus of elasticity at shear is 9.96444 Pa. And in this regard, the results of this work show: the first is that changes in the magnitude, position and shape of the deformation can reflect the dynamic evolutionary process of deformation during bending on the structure. The following is the deformation curve has a good corresponding relationship with the change in the applied pressure, which shows software modeling in different types of deformation.

The conclusion shows that the technology of monitoring fiber-Bragg lattice sensors has a good effect on internal deformation and control of mechanical stresses during model tests; it provides new methods and monitoring tools for model tests

Keywords: fiber Bragg lattice, simulation, communication technologies optical fiber, Young's modulus

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1. Introduction

Most communication technologies currently use fiber optics as a means of transmitting information. In the second half of the last century, there was a real evolution of ideas about the future of telecommunications systems. This revolution was made possible by the beginning of a new stage in the development of fiber optics. Solutions were found that made it possible to use optical fiber to transmit information [1].

With the rapid development of optical fiber and optical communication technologies in the 1970s, optical fiber detection technology has become a new type of detection technology that uses a light wave as a carrier for perception and measurement [2]. Bragg Grid fiber has become one of the fastest growing modern technologies for monitoring and detecting engineering structures due to its small size, high accuracy, convenient network connection, integration of sensors and data transmission, etc [3].

Modern methods allow measuring deformation, pressure, temperature, distance, position in space, linear velocity and rotation speed, acceleration, vibration and sound wave parameters, liquid level, refractive index, electric and magnetic field, radiation dose, as well as a number of other physical quantities.

Fiber-optic sensors have a very wide bandwidth, resistance to electromagnetic interference and high ability to work in difficult conditions of temperature, toxicity and pressure. Fiber Bragg grating has a special nature of operation and is used as a sensor. For example, when the fiber is compacted, the fiber Bragg lattice will calculate the deformation. This is due to the fact that the deformation of the optical fiber leads to a change in the microstructure over time.

Today, the use of high-quality optical technologies not only in the field of telecommunications and optoelectronics, but also the application of these technologies in various industries for the benefit of humanity is a very relevant topic.

Therefore, the use of sensors to measure deformation and monitoring of road structures is very important, since road shipments, including road bridges, sometimes diverge and deform, and in order to avoid such problems, it is necessary to carry out dismantling work in time and fix the problems.

2. Literature review and problem statement

With the rapid development of optical fiber and optical communication technology in the 1970s, optical fiber detection technology has become a new type of detection technology in which the light wave is used as a carrier for measurement and measurement [4]. Fiber Bragg gratings have become one of the fastest growing modern technologies for monitoring and detecting engineering structures due to their small size, high accuracy, convenient networking, integration of sensors and transmission, etc. [5]. In 1992 in the work [6] for the first time, Bragg fiber gratings were embedded in a concrete structure to measure deformation and introduced fiber grating measurement technology, which was originally used in the aerospace and aerospace fields, in civil engineering.

In his article [7] describes the use of the inverse problem to reconstruct the deformation distribution using a fiber Bragg lattice. The paper shows that the problem of reconstructing the deformation profile from the lattice spectrum is the so-called inverse problem.

The authors have developed algorithms for simulated annealing to restore the values of deformations. But issues related to deformation changes with the annealing simulation algorithm shows very little sensitivity of the result to the set starting point. All this allows to say that it is advisable to conduct a study, but first it is necessary to start by analyzing the measurement of the first deformation point, then smoothly move to the final point and restore the original deformation point back.

Also, the article [8] presents the results of studies of the spectral characteristics of Bragg fiber gratings based on standard telecommunication fibers pre-saturated with hydrogen to increase photosensitivity. But the issues related to direct strain measurements are not presented. The reason for this may be a fundamental impossibility, since the authors measured only the spectral characteristics of the FBG. However, the results of studies of the spectral characteristics of Bragg fiber gratings saturated with hydrogen to increase photosensitivity in which the wavelength also shifts towards a longer wavelength during exposure are presented. The shift of the Bragg wavelength increased linearly over time, as well as when measuring deformation. All this allows to assert that it is advisable to conduct a study on measuring the shear deformation of the wave at the exposure of the FBG.

Significant attempts have been made to study the dependence of strain transfer in optical fiber-based testing models [9, 10]. However, these published studies are limited to testing the model under static load. To date, the effect of the bonded layer on the strain-sensitive properties FBG sensors under fatigue loads were simply studied in experiments, and it was concluded that accumulated fatigue damage in the binder layer reduces the strain transfer coefficient. The theoretical study of the transmission of deformation of the test model subjected to fatigue load has never been investigated.

Young's modulus is an important physical quantity that describes the elastic properties and deformation resistance of solid materials. It reflects the relationship between material deformation and internal stress. This is one of the parameters for measuring the deformation of a material after exposure to force and is also an important basis for the selection of mechanical components in engineering technology, security and military, biomedicine, and health care [11]. Measuring Young's modulus of commonly used solid materials (such as metals, ceramics, rubber, polymers, etc.) is very important for large-scale civil engineering.

There are many methods, such as the static stretching method, beam bending method and dynamic resonance method [11], etc., the first two methods of measuring Young's modulus are the most commonly used measurement methods, which as the key to measuring these two methods is how to accurately measure micro-deformation and micro-displacement. For this reason, an electrically coupled imaging device (CCD) has been proposed.

Since the advent of fiber Bragg array sensors in 1978, they have attracted a lot of attention in the research of intelligent sensing technology because of their simple structure, small size, low cost, strong noise immunity, corrosion resistance, high measurement accuracy and easy adhesion [12]. When monitoring civil structures, they can be embedded and installed inside or on the surface of concrete, steel, wood and other structural materials [13].

Currently, FBG sensors are widely used:

– in the source [14] measuring the deformation of various structures;

– in his work [15] for measuring the temperature of the internal and external environment;

– the authors of the article [16] notify about the measurement of the frequency of space;

– from the article [17] it was revealed that sensors also measure lateral pressure;

– in [18] for measurements of the refractive index;

– in the article [19], the authors state about the measurements of the Acceleration of motion.

In terms of accurate static or dynamic measurement of other parameters, its biggest feature is that it has high sensitivity and measurement accuracy for measuring micro-displacements [19].

Taking into account the existing method of using fiber-optic sensors to measure micro-displacements of beams, a new method for measuring the Young's modulus of concrete beams based on FBG sensors is proposed in this paper.

The use of optical systems in the form of a Bragg fiber lattice will allow measuring sensors to be placed in hard-to-reach places where it is difficult or expensive to pull conventional wired solutions. They also allow monitoring systems to be deployed and maintained more accurately and quickly.

Taking into account the above analysis, a theoretical analysis of the dependence of the strain transfer of the FBG sensor attached to the surface of a concrete structure exposed to fatigue load is studied. The efficiency of the proposed strain transfer formula is given it is verified by laboratory experiments and numerical modeling. Sensitive parameters affecting the efficiency of strain transfer of the dynamic testing model are discussed, and suggestions for the design of monitoring FBG sensors are recommended.

3. The aim and objectives of the study

The aim of this study is to apply the method of measuring deformation parameters when constructing a sensor model based on a fiber Bragg lattice.

To achieve this aim, the following objectives are accomplished:

– selection of parameters for strain measurement using fiber Bragg grating;

– selection of the Young's method for constructing a model using a Bragg sensor for a concrete beam of a road bridge.

4. Materials and methods of research

The fiber Bragg lattice (Fig. 1) is a section of optical fiber in the core of which the refractive index periodically changes in the longitudinal direction. The peculiarity of the Bragg lattice is the change in wavelength that occurs when the lattice is compressed and stretched. It can be tracked on a photodetector with high accuracy and sensitivity. The change in wavelength can be determined by the formula (1) [20]:

$$\Delta\lambda = 2n\Lambda\left\{1-\frac{n_{eff}}{2}\cdot\left[P_{12}-\nu\cdot\left(P_{11}+P_{12}\right)\right]\right\}\cdot\varepsilon+ +\left(\alpha+\frac{1}{n_{eff}}\cdot\frac{dn}{dT}\right)\cdot\Delta T, \quad (1)$$

where λ_B – the wavelength of the Bragg resonance;

ΔT – temperature change;

ε – applied mechanical stress;

P_{ij} – Pokkels coefficients of the elastic – optical tensor;

ν – Poisson 's ratio;

α – coefficient of thermal expansion of quartz glass;

n_{eff} – effective refractive index of the main mode;

Λ – the period of the fiber Bragg lattice;

$$1-\frac{n_{eff}}{2}\cdot\left[P_{12}-\nu\cdot\left(P_{11}+P_{12}\right)\right]\varepsilon\leq\left(\alpha+\frac{1}{n_{eff}}\cdot\frac{dTN}{d}\right)\cdot\Delta T. \quad (2)$$

The response formula (1) includes dependence on mechanical factors and on temperature factors (2) [21, 22]. Based on formula (1), a graph of the dependence of the wavelength on time and deformation was constructed. Now it is possible to observe that the frequency of the wavelength change is much higher than the deformation, so the deformation indicator looks constant on the graph. Measurements using the Young's modulus give a more visual example of strain measurement (Fig. 2).

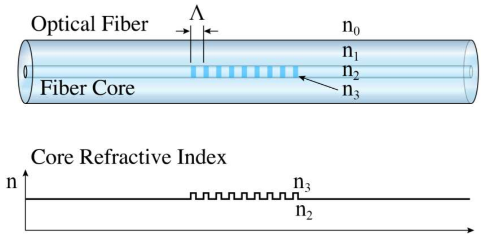

Fig. 1. Fiber Bragg grating

For this work, special algorithms were presented and developed in Autodesk and MATLAB programs. These program algorithms allow to simulate more accurate data close to experimental values. Thanks to these models, it is possible to study in more detail the main aspects of the fiber Bragg lattice during bending deformation and provide the most optimal methods of their application in various fields of production.

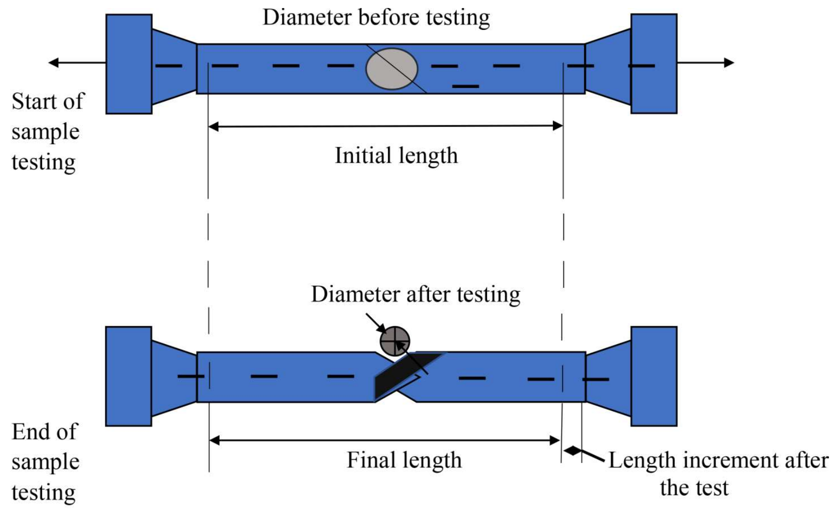

Fig. 2. Young's modulus shift

5. Results of the study of the Bragg fiber grating in the measurement of deformation

5. 1. Measurement of Bragg fiber grating parameters

There is an active development of fiber-optic technologies and their application in other areas, such as medicine, manufacturing, construction, etc. Among current sensors, fiber-optic technologies occupy their niche. It is tasked with measuring the deformation using a Bragg lattice, choosing a method for making measurements and making a mathematical model.

FBG is a lattice in which the refractive index of the fiber core changes cyclically along the axial direction of the fiber. When FBG is used as a sensor, its operating principle can be explained by the correlation between the wavelength λ_B of the reflection peak of the Bragg center and the effective refractive index n_{eff} of the fiber core and the period Λ of the fiber lattice.

The relationship between them is:

$$\lambda_B = 2n_{eff}\Lambda. \quad (4)$$

When the environmental parameters change, the effective refractive index of the fiber core changes accordingly, causing a red or blue shift of the Bragg wavelength. The magnitude of the change in environmental parameters can be perceived by demodulating the signal. Deformation and temperature are the most common environmental parameters that cause the drift of λ_B. When the temperature and voltage of the medium in which the FBG is located change, the value of the Bragg wavelength drift λ_B can be expressed as:

$$\Delta\lambda_B = \lambda_B\left[\left(1-p_e\right)\varepsilon+\lambda_B\left(\alpha_i+\varepsilon_i\right)\Delta T\right], \quad (5)$$

where α and n_{eff} are the coefficient of thermal expansion and the coefficient of thermal radiation of the optical fiber, ε is the axial deformation, ΔT is the magnitude of the temperature change, and p_e is the effective coefficient of elastic radiation.

When the ambient temperature for the FBG is unchanged or changes very little, only the effect of deformation on the FBG is taken into account. At this time, the relationship between the value of the Bragg wavelength drift λ_B and the deformation is equal to:

$$\Delta\lambda_B = \lambda_B\left[(1-p_e)\varepsilon = k\lambda_B\varepsilon\right], \tag{6}$$

where k is the coefficient of lattice sensitivity to voltage. When the fiber lattice is placed in a medium with a constant temperature, the corresponding change in deformation can be measured by the amount of drift of the reflected wavelength [23].

5. 2. Measurement method

To increase the accuracy of measuring the micro-displacements of a concrete beam, a FBG is used. To solve the problem in this paper, the Young's module is used. The deformation measurement scheme is shown in Fig. 1. Fig. 1 shows the two ends of concrete beams A and B, fixed at the two ends by iron-concrete structures.

The two-point bending method is used to apply force to a concrete beam to cause it to bend and deform. The point of application of force is the O point, and the FBG strain gauge is glued to the lower surface of the concrete beam to be tested. The distance between the bonding position FBG and point A is equal to S. After the continuous luminous flux from the light source with broadband self-emitting amplification passes through the circulator, the continuous luminous flux from the light source goes into the input-sensitive FBG. Thus, the reflected light of the FBG, carrying information about the bending deformation, is output through 3 ports of the circulator and the reflection spectrum. In the end, the source passing through the FBG is registered by a spectrum analyzer. Thus, in Fig. 3 it is possible to see that the deformation can be measured in an environmentally friendly way, as well as the most accurate to real measurement calculations.

In the experiment, the relationship between the wavelength of the reflection center of the FBG and various loads on the concrete beam under test is first studied (Fig. 4, 5).

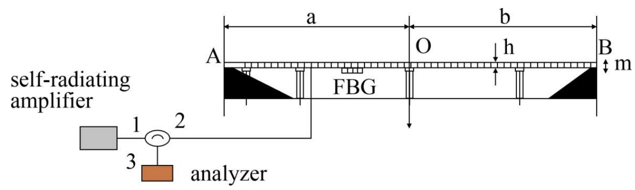

Fig. 3. Deformation measurement scheme

In the experiment, the relationship between the wavelength of the reflection center of the FBG and the various loads on the concrete beam under test is first studied (Fig. 4, 5).

Assume that the height h and width M of the concrete beam to be tested in Fig. 3, and the offset between the point of application of forces O and the ends of the concrete beam A and B, the palm from A to O, is equal to a. Lina from O to in equal.

The value of the applied force is equal to F, then the corresponding value of the bending moment on the FBG sensor is determined by the formula:

$$M(s) = \frac{Fb}{a+b}\cdot s. \tag{7}$$

When the tested concrete beam bends under the action of a horizontal force, the positive voltage at the insertion point of the FBG on the lower surface of the tested concrete beam is:

$$\sigma = \frac{M(s)}{W} = \frac{6Fs}{mh^2}\cdot\frac{b}{a+b}, \tag{8}$$

where W – the coefficient of the bending cross-section of the concrete beam to be tested. According to Hooke's law, the ratio between the positive voltage s and the Young's modulus E and the strain value ε is equal to:

$$\sigma = E\varepsilon. \tag{9}$$

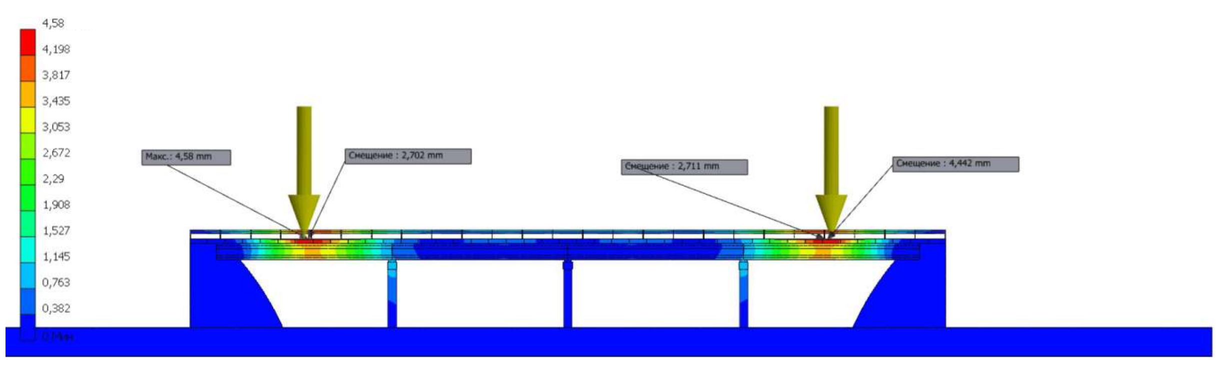

Fig. 4. Bridge with fiber Bragg grating sensor for strain measurement

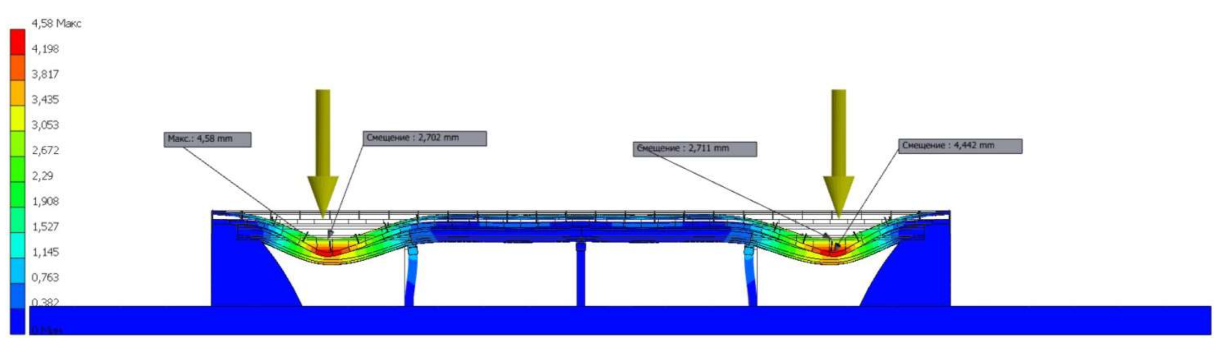

Fig. 5. The bridge is bent by mechanical stress pressure

The comprehensive formulas (7)–(9) have:

$$E=\frac{6ks\lambda_B}{mh^2\dfrac{\Delta\lambda_B}{E}}\cdot\frac{b}{a+b}. \qquad (10)$$

It can be seen from formula (10) that in the experiment, as long as the change in the wavelength of the reflection center of the FBG at the applied force is equal to F is properly measured, the measured beam can be realized.

The effect of temperature on the wavelength of the center of reflection of the FBG during the test can be ignored. In accordance with the experimental conditions, formula (10) can be simplified to:

$$\Delta\lambda_B=\frac{3ks\lambda_B}{mh^2E}F=K\cdot F. \qquad (11)$$

As a result of this work, several types of deformation and displacement of concrete beams were determined in software modeling. On the basis of software modeling, the equivalent and two-point deformations in different stress components were considered. The main characteristics of stretching by sensors are obtained. That is, as a result, a deformation sensor attached to concrete beams measured and showed deformations in the form of axes along the length of the bridge. Also, the exact results of measuring the mechanical stress on the concrete bridge using an optical sensor are derived.

To make sure that the method is applicable for measuring the Young's modulus of other rigid solid materials, instead of an iron beam, a rectangular concrete beam with a length, width and thickness of 1000, 50 and 0.6 m was used for experiments. An FBG sensor with a central reflection wavelength of 1562 nm was inserted at a distance of 100 m from the fulcrum A, and the Young's beam modulus was measured separately using FBG. Due to the small rigidity of the concrete material, the weight added in the experiment has a step size of 0.5 MN per step and was loaded up to 3 MN.

Fig. 6 shows that as a result of these measurements, the first main stress was detected when measuring deformation in a two-point mechanical stress, which has a minimum voltage of –20.64 MPa and a maximum of 68.21 MPa.

Fig. 7 shows that as a result of these measurements, the third main stress was detected when measuring deformation in two-point mechanical stress, which has a minimum stress of –62.19 MPa and a maximum of 24.26 MPa.

Fig. 8 shows that as a result of these measurements, an equivalent deformation in two-point mechanical stress was detected.

After measuring the equivalent strain, the program measures the safety factor. Fig. 8 shows the minimum and maximum values of the safety factor.

Fig. 9 shows that as a result of these measurements, the safety factor for two-point mechanical stress was determined, which is expressed when the bridge bends.

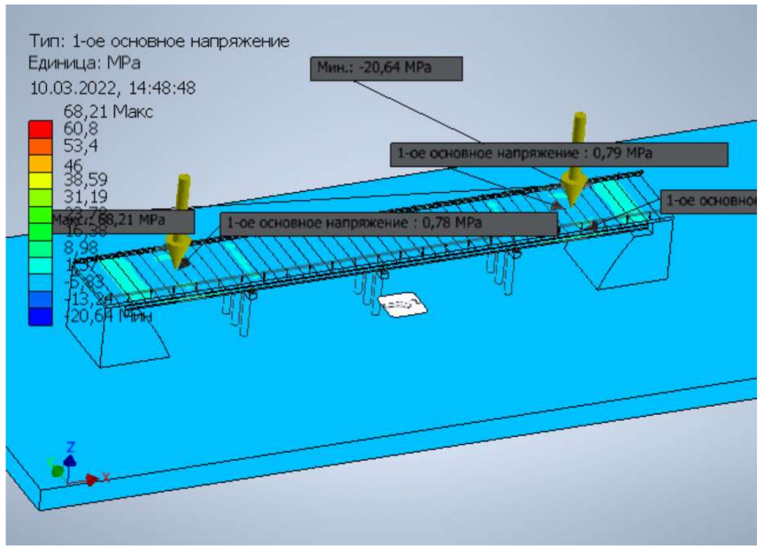

Fig. 6. The first main stress in the measurement of deformation

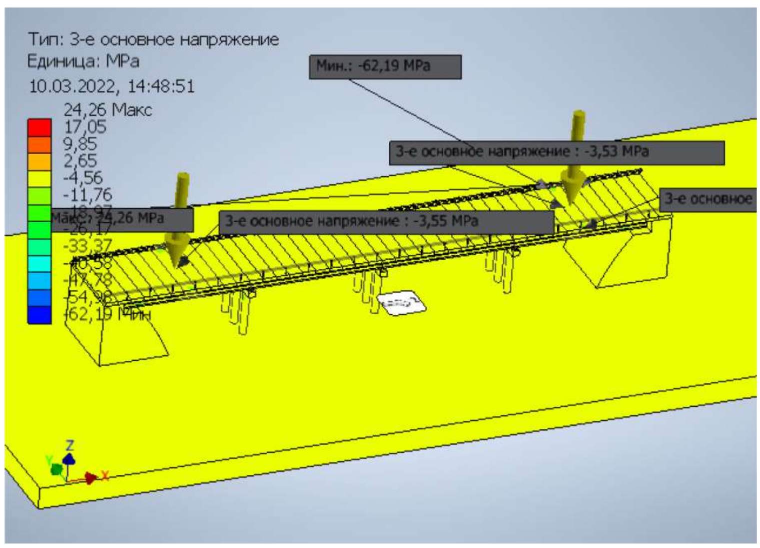

Fig. 7. The third main stress in the measurement of deformation

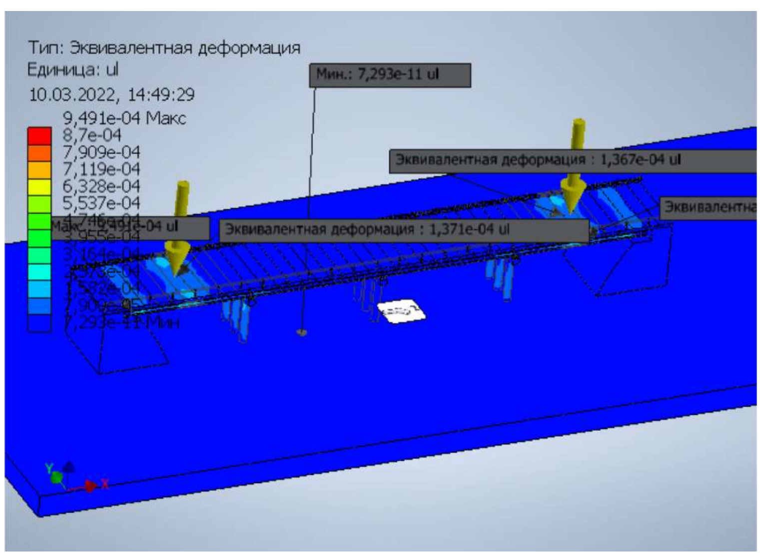

Fig. 8. Equivalent deformation

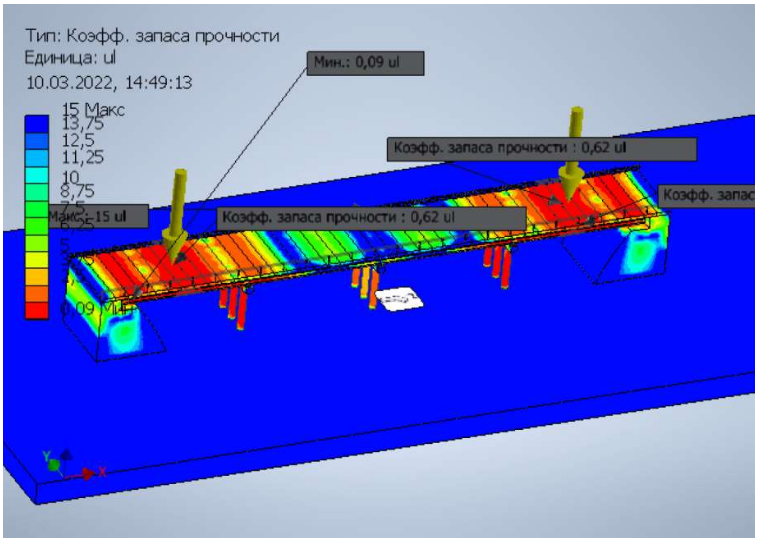

Fig. 9. Safety margin factor

On the basis of the Bragg lattice fiber sensor and the two-point bending test method, a universal sensor has been developed that can measure the parameters of deformations under mechanical stress.

The Young's modulus formula of the material and the Young's modulus measurement of the concrete beam have been studied. Experimental results have shown that the reflection of the FBG to the wavelength of the core has a good linear dependence on the load, and the position of the FBG has little effect on the measurement results.

By experimentally measuring the reflection spectrum of the FBG, the relationship between the displacement of the central wavelength of the FBG and the applied pressure is obtained using a Lorentz fit. By its slope K, one can obtain the Young's modulus of an iron beam [23]:

$$E = \frac{3ks\lambda_B}{mh^2K}. \tag{12}$$

The following Table 1 presents data for constructing dependencies according to the selected method of Young's modulus for deformation measurements.

According to these measurements, a graph of the dependence of the mechanical stress on the wavelength of the fiber Bragg lattice is plotted (Fig. 10).

Table 1

Basic data for building dependencies of the FBG

λ, nm	Strain, με	T, °C	S Transmission, dB	L, mm
1562	0.7486	20	–20	0.00005
1562.5	0.7488	20	–18	0.00006
1563	0.7490	20	–16	0.00007
1563.5	0.7492	20	–14	0.00008
1564	0.7496	20	–12	0.00009
1564.5	0.7498	20	–10	0.00010
1565	0.7500	20	–8	0.00011
1565.5	0.7502	20	–6	0.00012
1566	0.7504	20	–4	0.00013

Fig. 10 shows the change in the reflection spectrum of a fiber Bragg lattice at an applied voltage. The graph provided has wavelength parameters along the X axis and voltage parameters applied to the grid along the Y axis.

If there is shown in Fig. 10 the dependence of the voltage on the wavelength during modeling, then Fig. 11 and Table 2 show experimental data that were carried out in the laboratory, where studies were conducted to measure the strain with FBG.

Fig. 11 shows the change in the reflection spectrum of a fiber Bragg lattice at an applied voltage. The presented graph shows the wavelength parameters along the X axis and the voltage parameters applied to the grid along the Y axis.

By increasing the bending of the lattice length, its reflection coefficient can be increased. If to take into account that the recording speed of the lattice is approximately 1.07 mm/s, corresponding to the second-order resonant reflection at 1562 nm (Fig. 12).

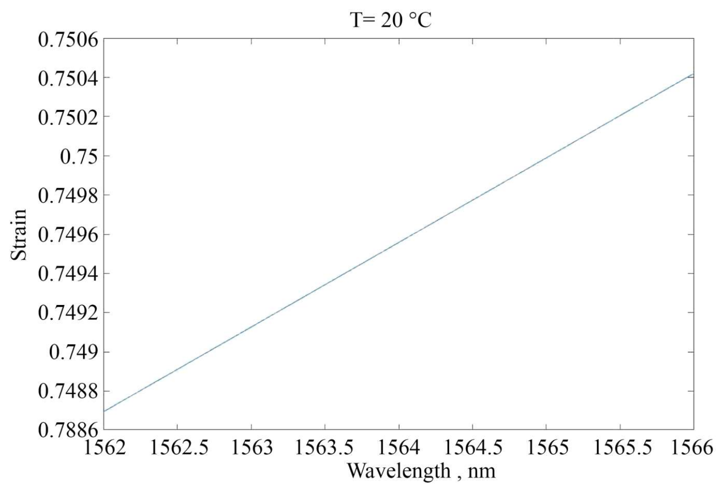

Fig. 10. Change in the reflection spectrum of the fiber Bragg grating at applied pressure

Table 2

Experimental data

No.	L	λv	ΔL
1	0.1000	1562.9760	0.0990
2	0.1001	1563.0080	0.0991
3	0.1002	1563.1200	0.0992
4	0.1003	1563.2400	0.0993
5	0.1004	1563.3760	0.0994
6	0.1005	1563.4880	0.0995
7	0.1006	1563.6120	0.0996
8	0.1007	1563.7400	0.0997
9	0.1008	1563.8600	0.0998
10	0.1009	1563.9800	0.0999
11	0.1010	1564.1000	0.1000
12	0.1011	1564.2080	0.1001
13	0.1012	1564.3440	0.1002
14	0.1013	1564.4600	0.1003
15	0.1014	1564.6280	0.1004

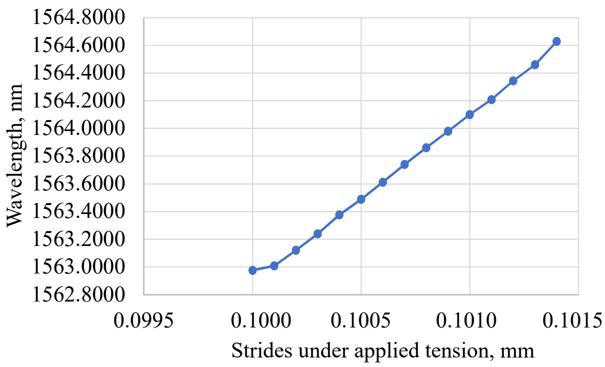

Fig. 11. Dependence of a fiber Bragg grating under applied pressure

The distribution of the spectrum depends on the wavelength. If to consider Bragg lattices, it is possible to see that this distribution is harmonious (Fig. 13). In turn, it is a spectral characteristic of the incoming signal.

Fig. 13 shows the deformation shift along the wavelength at a constant temperature with the experimental data obtained.

Now in Fig. 14 it is possible to see a model of shear deformation along the wavelength at a constant temperature.

Fig. 14 shows the calculated spectrum. Both the measured and calculated spectrum show almost identical characteristics. Only the deep poles on the calculated graph differ. The reason for this is that the requester obviously cannot track the very fast slopes of the pole signals.

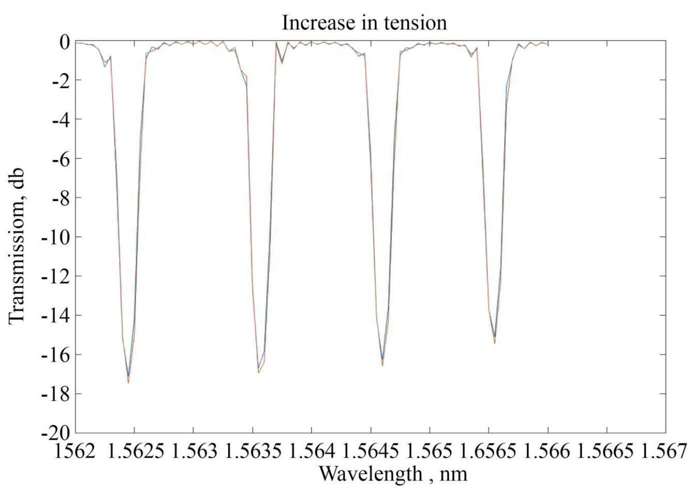

Fig. 12. Variation of the deformation spectrum at the wavelength of Bragg gratings

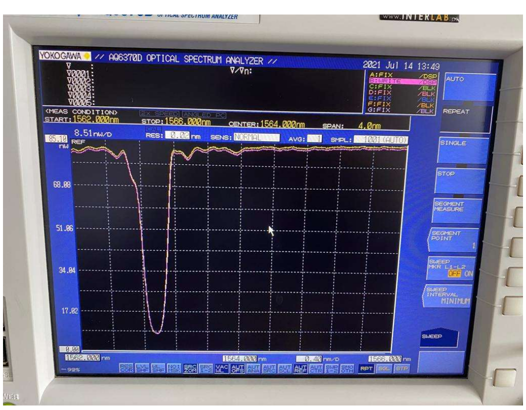

Fig. 13. Shift of deformation along the wavelength at a constant temperature

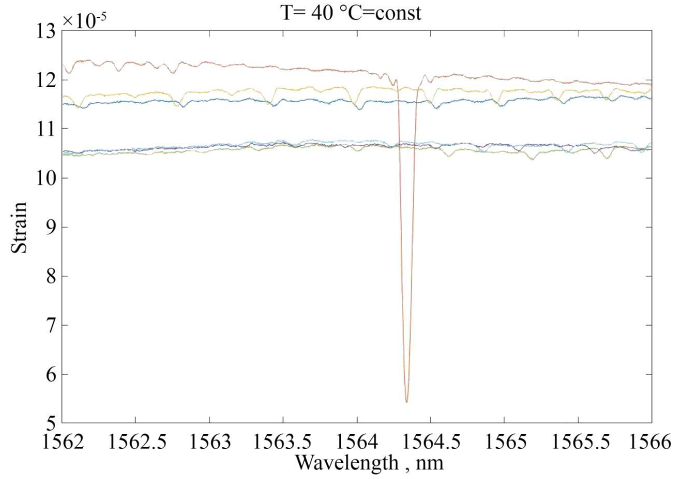

Fig. 14. The shift of deformation along the wavelength at a constant temperature

6. Discussion of the results of a study comparing the main characteristics of fiber Bragg gratings under deformation

In contrast to [23], which describes a model for measuring deformation on a fiber-optic sensor based on the magnetostriction effect, which shows the result, the measurement of the controlled parameter is carried out during compression-decompression of the fiber, but the control is formed by changing the wavelength using a Bragg lattice. It is shown that the proposed fiber-optic sensor based on the magnetostriction effect should theoretically have increased accuracy due to micro-compression/micro-compression, be less sensitive to temperature changes and cheaper compared to analogues, but there are unresolved issues related to installation and data transmission, since the sensor is not installed directly on the conductor in comparison with the analog. That is, theoretically, the sensor has accurate indicators, but the results are not shown in a practical study. Thus, thanks to the use of a Bragg grating to measure deformation, a fiber-optic sensor that is installed directly on a concrete beam will give more accurate measurements.

Based on the fiber sensor of the Bragg lattice and the method of bending testing at two points, a universal sensor has been developed that can measure any solid material, in our case concrete. To make sure that the method is applicable for measuring the Young's modulus of other rigid solid materials, instead of a concrete beam, a rectangular concrete beam with a length, width and thickness of 1000, 50 and 0.6 m was used for experiments. The FBG sensor with a central reflection wavelength of 1562 nm was installed at a distance of 100 mm from the fulcrum *A*, and the Young beam module was measured separately using FBG. Due to the high rigidity of the concrete material, the weight added in the experiment has a step size of 1 N per step and was loaded up to 3 MN. The formulas of the Young's modulus of the material and the measurement of the Young's modulus of a concrete beam have been experimentally studied. Experimental results show that the reflection of the FBG at the wavelength of the core has a good linear dependence on the load and the position of the vertical voltage downwards, the FBG has a negligible effect on the measurement results. But at the same time, data was obtained and graphs of values were plotted. The measurement results are shown in Fig. 6. Fig. 6 it is shown that the response curve of the displacement of the central wavelength FBG and the applied pressure has good linearity. Since if to consider the temperature constant, it is possible to take an average of 20 °C (temperature does not matter much).

In this regard, in this work, the material for the experiment is concrete, which is a conglomerate of two components – cement stone and aggregates. A complex stress state occurs in an inhomogeneous structure. Stiffer particles take the main load, and areas with transverse tensile forces are formed around the pores and voids. A large aggregate with a high Young's modulus increases the elastic properties of concrete. Fine dust particles, pores and voids reduce their amount. The higher the material class, i.e. the greater its compressive strength and density, the better it resists deforming loads. Concrete B60 has the highest modulus of elasticity – 39.5 kPa, the minimum index for a class B composite is 10–19 kPa.

The Young's modulus of a concrete beam can be calculated by substituting the value in formula (12) as E=23.25 kPa, which coincides with the nominal value of E=23 kPa. Based on our values, it is possible to conclude that the calculated indicator corresponds to the modulus of elasticity of the concrete module. Thus, it is possible to check whether our experimental calculations are correct. The measurement error is about 0.75 %, which meets the requirements.

As part of the simulation of the work, various values and types of deformations during the stretching of the bridge were also shown. Fig. 6 shows the first main stress when measuring deformation, the values of which are the minimum stress – 20.64 MPa and the maximum – 68.21 MPa. Fig. 7 shows the third main stress when measuring deformation, the values of which are the minimum stress – 62.19 MPa and the maximum – 24.26 MPa. Fig. 8, 9 shows the results of equivalent deformation and the safety factor, which serves to ensure that the bridge can withstand the loads applied to it.

One of the main advantages of fiber optic networks in the Bragg network is their ability to cover large areas with a single fiber optic cable. This makes them ideal for monitoring structures such as bridges, dams and pipes, as well as for environmental monitoring applications such as detecting seismic activity or ocean temperature changes.

Another advantage of Bragg gratings is their high sensitivity and accuracy. They can detect temperature, strain, and pressure changes with high accuracy, making them ideal for applications requiring precise measurements. In addition, fiber optic networks with Bragg grids are immune to electromagnetic interference, which makes them more reliable than other strict detection technologies.

However, fiber optic networks with Bragg grids also have some limitations. Their installation can be expensive and requires special equipment for analysis. In addition, their accuracy may be affected by factors such as temperature fluctuations and the slope of the fiber-optic cable. Also, each work has limitations, in our case, these are changes in external influences on the material (temperature, mechanical stresses, pressure, etc.), leading to changes in its geometric parameters. But, in addition, a change in its geometric characteristics leads to a change in the parameters recorded in it, in particular their period. In particular, this entails a shift in the wavelength of the Bragg resonance and, as a consequence, a change in the reflection and transmission spectra of the gratings. But despite this, Bragg gratings are very sensitive to micro-deformations, so this method is also suitable for measuring the Young's modulus of other rigid solid materials with less deformation and is based on this. This method also allows to measure the modulus of elasticity of some large civil structures to monitor the condition of important parts of the structure.

During this study, experimental difficulties have been encountered due to the installation of sensors for Bragg gratings. During installation, its temperature and deformation dependences were revealed, which are reliable results with a comparison according to theory. Also, in mathematical modeling, it was not easy to take into account the bending of bridges and the wavelength that were successfully modeled.

According to the data obtained from the temperature, and also from the wavelength, the gratings will be used in the design of sensors on bridge structures. That is, these sensors are used to detect deformation in bridge structures, and according to their results, it can be concluded that the wavelength for the Bragg lattice during deformation and temperature change is a consequence of the change in wavelength.

The disadvantage of this study is to obtain experimental data by computer modeling, that is, during computer modeling, we did not take into account the sensor errors.

In the development of this study, it can be said that, despite the existing norms for the construction of various structures and laws to improve the system of construction of road bridges, overpasses and other artificial structures, today thousands of bridges are in an emergency or unusable condition due to the impact of natural, including underground or river waters, as well as non-compliance with these rules and regulations during their construction or operation, in this regard, the proposed systems for monitoring the condition of road bridges using fiber-optic sensor systems will provide timely information on the condition of structures and help detect deformations in the observed objects.

7. Conclusions

1. For a better interpretation of the dynamic deformation of structures with FBG sensors, the mechanism of transmission of deformation of superficially attached FBG sensors to a concrete beam under extreme load was studied in this article. Based on this study, a formula for measuring the limiting load of the Young's modulus for determining the imposed dynamic deformation is presented, the effectiveness of which are confirmed laboratory tests, as well as a software model is built. The theoretical conclusion takes into account the influence of temperature and dynamic coupling on the deformation of the FBG sensor and the main material of the concrete structure. Analysis of these loads shows significantly lower strain coefficients in the present model, which means that correction of errors in the transmission of deformation plays a much more important role in measurement of dynamic deformation. According to the results of the first approach, it can be argued that Young's modulus is very suitable for measuring the deformation of concrete structures. The exact formula for measuring the deformation of the bridge was determined, and as a result, dependency graphs were constructed. A sensitive analysis of the parameters shows that the wavelength, the shear modulus are much more sensitive to the strain transfer coefficient in this model. Therefore, in order to obtain a more accurate dynamic deformation of the controlled structure, FBG sensors must be designed exactly in accordance with the proposed theory of strain transfer. The results of the study can be used to determine the optimal, more accurate measurement using FBG sensors applied to structures subjected to extreme load.

2. According to our data, a model of the bridge with parameters 1000, 50, and 0.6 m was built. Sensor F BG with a central reflection wavelength of 1562 nm. According to the constructed parameters, we measured the deformation, which amounted to the values of Young's Modulus of 23.25 Pa, Poisson's ratio of 0.167 br, and modulus of elasticity at shear 9.96444 Pa.

Conflicts of Interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

Manuscript has no associated data.

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