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Computational Models of Building Structures. Visualization and Intelligent Content Design

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Abstract. On the basis of the author's methodology using Wolfram Research technology received and presented science-intensive, adaptive content, which is the result of research in solving problems of modeling, calculation, analysis and visualization of building structures. The article reviewed the main elements, examples of hook up of functions and options of the system Wolfram Mathematica, which provides an extension and addition of electronic resources by means of intelligent computing and interactive visualization.

1. Introduction

In modern conditions, for many problems of mathematical modelling of building structures [1] relevant components are the development of software and the formation of an interactive environment for the visualization of the original information, the selected physical and mathematical model, the results of calculation and analysis, researches' [2], [3]. This work is consistent with the global trend in the development of mathematical, computer modelling. With regard to the problems of calculation and analysis of building structures, the article deals with specific technical issues, the aspects presented in [4] - [6], which are tested and gave good results in applications of computer graphics [7] and computer mechanics [8], geo-ecology [9].

The proposed approach for the preparation of intelligent, interactive electronic resources is based on Wolfram technology, and specifically: the computer algebra system Mathematica [10], the format of computed documents CDF [11]. Examples for illustrations are prepared using a collection of demonstration modules [12].

It should be noted that Mathematica is the most complete system (among other things and for modern technical calculations), which is based on the Wolfram Language [13]. The mathematical model of the object of study in Mathematica is formed on the basis of the laws of continuum mechanics, digital fields of distribution of characteristics in the volume, a description of the object geometry, external conditions and influences. For various problems in Mathematica can get a full set of used formulas, in symbolic and numerical the expression, which makes it possible to check the results and compare them with the theoretical laws of mechanics.

CDF is a format that provides a structured presentation of information and the use of dynamic multimedia objects and models; in fact, it is a digital repository of intelligent mathematical resources and knowledge with a computing engine, formalized as a document, but interactive as an application

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[11]. If the PDF version of the document is hosted on a web server, the viewer is automatically loaded as a browser plug-in. Autonomous work on a personal computer is possible after installation of the corresponding software (freely distributed CDF Player).

2. Examples of interactive analysis of a computer model

Figure 1 shows a beam-type rod element for which four boundary conditions (securing the ends) are possible, the project is used Analysis of a Single-Span Euler-Bernoulli Beam under Different Loading Conditions [12]. The screenshot illustrates of general view of the project software module window.

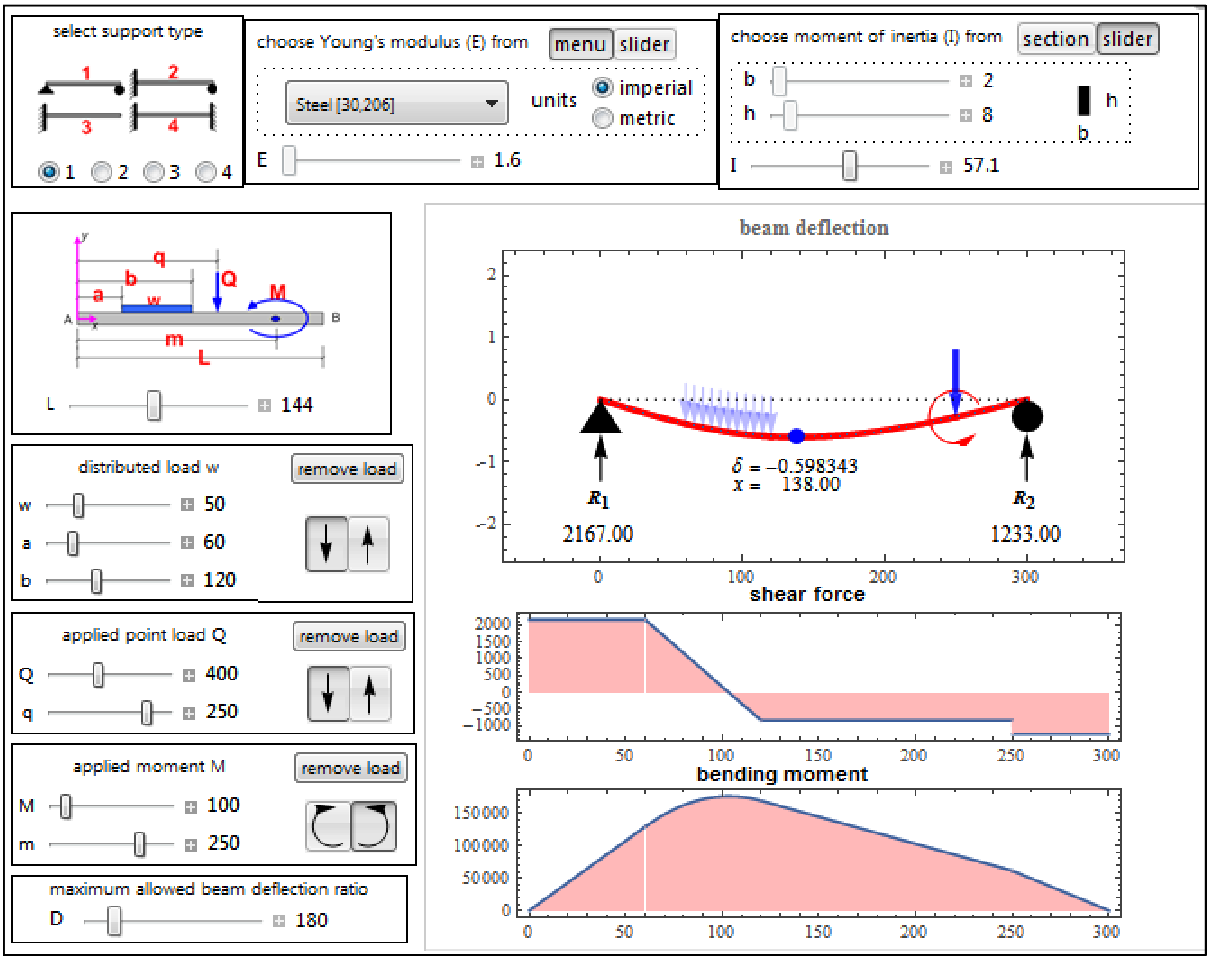

Figure 1. Example of the program module window.

The example demonstrates the bending of the beam from loads, as well as diagrams of the bending moment M and transverse force Q, theoretical aspects of the implementation in [14]. If change the load, boundary conditions, or other parameters, such as young's modulus E, the axial moment of inertia of the beam section I, in the illustration window (header – beam shape/bend) of reflecting the effect of these changes on the deflection and internal forces (Figure 2 –5). The results are obtained on the basis of the classical theory the beam bending (Euler – Bernoulli theory) by solving the differential equation of the curved axis of the beam of constant cross section.

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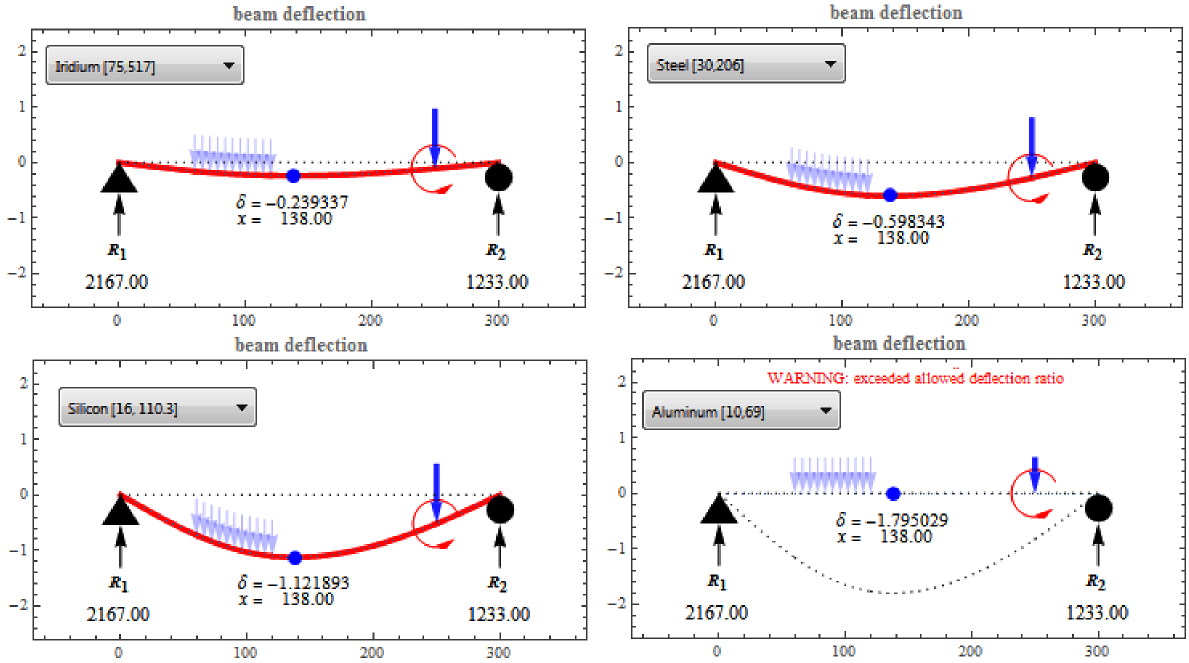

Figure 2. Material effect.

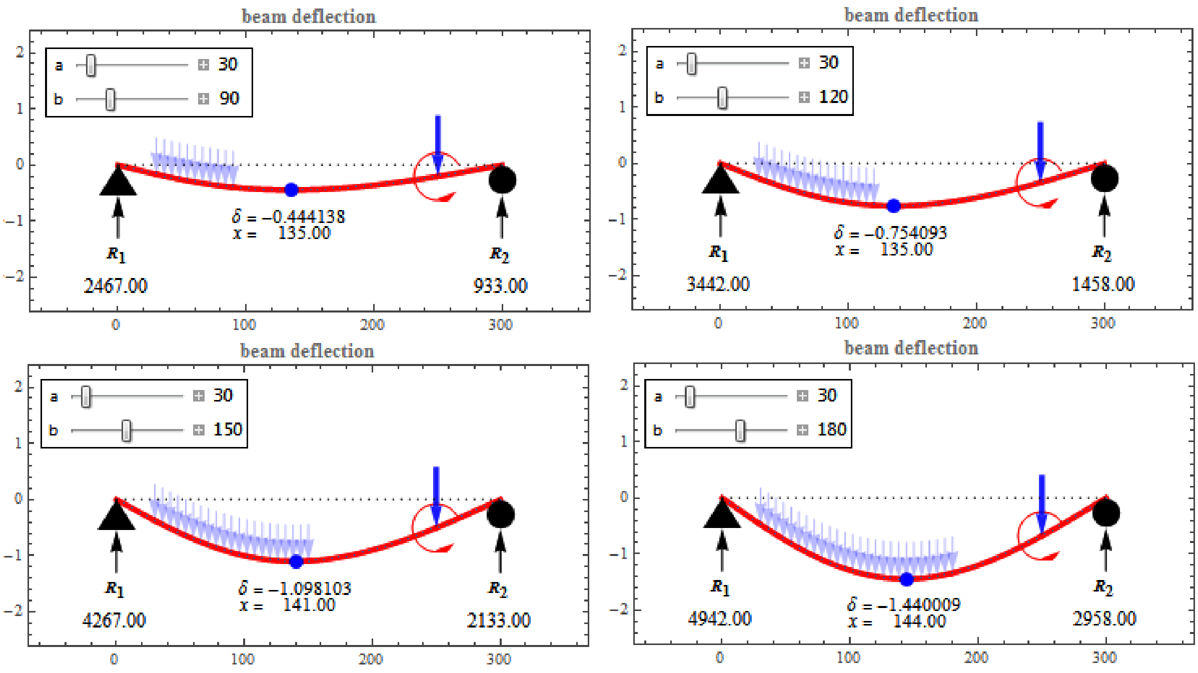

Figure 3. Load distribution effect.

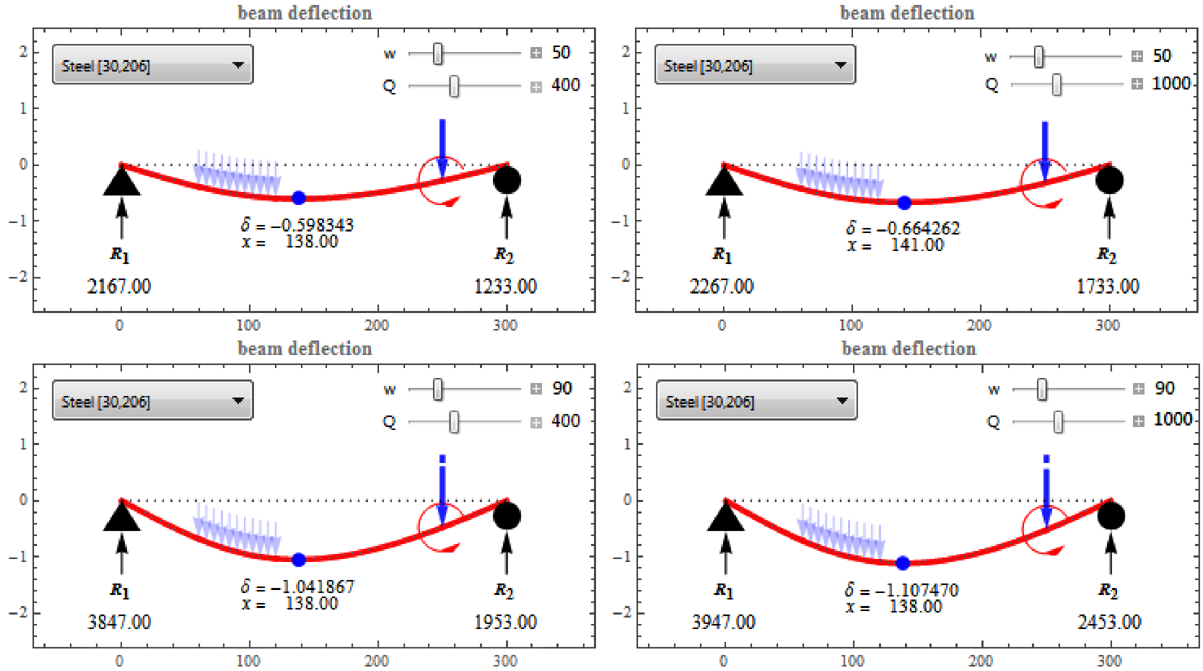

Figure 4. Load intensity effect.

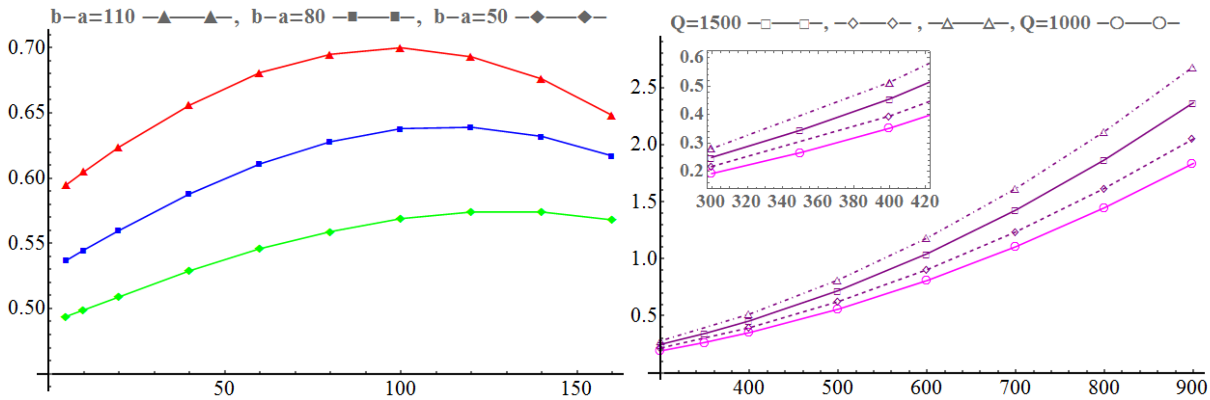

Figure 5. Load intensity and position effect.

Let us note the examples of work with the application, in which several clarifications and methodological additions are made. The functionality of the application is very wide: the software module can be used in the educational process and in research. In article are only a few of the more typical positions. For explanations, in the illustrations are fragments of screenshots with the results of calculations that the user sees on the panel (in the window) of the application – the General view is shown in the screenshot of Figure 1. It is important that all results obtained in the module can be imported into dxf, Tex, rtf, XLs ([7]) documents. Figure 1 – 5 show examples of how the beam shape will change under the same load distributed over the length (shown by blue vectors) and single near the loose end of the beam. Figure 2 shows the variety of calculations for the conditions of use of the beam from different materials. The library of the module includes variants: Osmium, Iridium, Chromium, Steel, Cobalt, Carbon steel, Iron, Uranium, Platinum, Copper, Silicon, Gold, Silver, Aluminium, Magnesium, Pine wood, fibreboard. The effects the position and length of the area where the distributed load (a to b) is applied illustrate the results of Figure 3. Changes the position and width of the area – the values in the upper right corner of each fragment.

The results of calculations of different load variants are shown in Figure 5. The graphs of the category "b–a" illustrate the change of the beam deflection δ (ordinate axis) from the value a of the mark of the left edge of the application area of the distributed load for three variants of the zone position: b–a = 110 (markers primitives – triangle's), b–a = 80 (markers primitives – small square's), b–a = 50 (markers primitives – diamond's), when Q = 1000, L = 300, M = 100, m = 250, W = 10. The graphs of category "Q" illustrate the variation of the beam deflection δ for two variants Q = 1500 and Q = 1000 for different the beam lengths L (abscissa axis). In this case, M = 100, W = 10, b–a = 100, a = 50, q = L–50, m = L–50 (marker primitives – circumferences and small squares), m = L–40 (marker primitives - diamond's), m = L–60 (marker primitives – triangle's).

Summarizing the results, it can be further noted that, according to the Euler–Bernoulli beam's theory, the transverse deflection of a beam subjected to transverse and axial loads is governed by (e.g. Timoshenko, 1961):

$$\frac{d^2}{dz^2}\left[E(z)\,I(z)\frac{d^2 u(z)}{dz^2}\right] \pm \frac{d}{dz}\left[P\frac{d\,u(z)}{dz}\right] = q(z)\,, \tag{1}$$

In the above examples includes in equation (1) indicators E, I, P were taken constant, so the classical exact analytical solution was used. Wolfram Mathematica tools allow you to calculate solutions for inhomogeneous materials when mentioned functions are not constant. For certain types of functions E(z), I(z) it is possible to obtain exact analytical solutions using Wolfram Mathematica DSolve (solve differential equations), for other variants – approximate ones using NDSolve (solve numerical differential equations).

3. Examples of the construction of geometric models, interactive visualization

One of the factors that should be taken into account when modelling is the need for the formation and mathematical description of the geometry of the object. It is important not only to visually reproduce the form, but also a mathematical description of all the components, as it is required for the calculation of parameters and characteristics. The following example illustrates the interactive visualization options for the Gateshead Millennium Bridge model – Figure 6, 7.

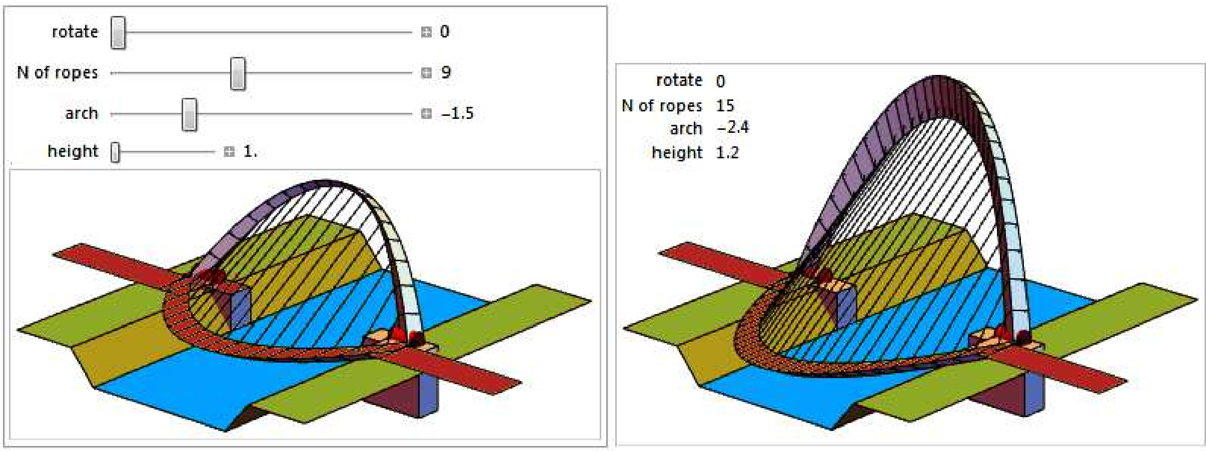

Figure 6. Model of the Gateshead Millennium Bridge. Different construction sizes.

At formation was used Gateshead Millennium Bridge project [12]. Figure 6 in the left part contains a screenshot of the software module window, on the top left there is a menu with settings, on the right there is a graphics window. The menu shows the basic values for this series: the number of floors 3, the ratio of radius/height 0.9, the thickness of the contours 0.02, the inner radius 0.2, the height of the railing

0.2, included a display of steps and fences, set the output mode double fence. Also, on the right are 2 additional fragments of graphics windows with views of the same design in different angles. Figure 6 illustrates the options for studying the design of the staircase when the parameters change. In particular, the output mode of the double fencing is disabled, and displays the trunk of the construction. On the right fragment the number of floors is 4, changed the output scale in the vertical direction.

The key constructions of code the program module (function) are: Manipulate, Initialization, Show, Plot3D, ParametricPlot3D. Separately, we note that the arguments of the Wolfram Mathematica Plot3D, ParametricPlot3D functions are formulated, descriptive elements of constructions in space; the descriptions also include parameters that determine the relative dimensions.

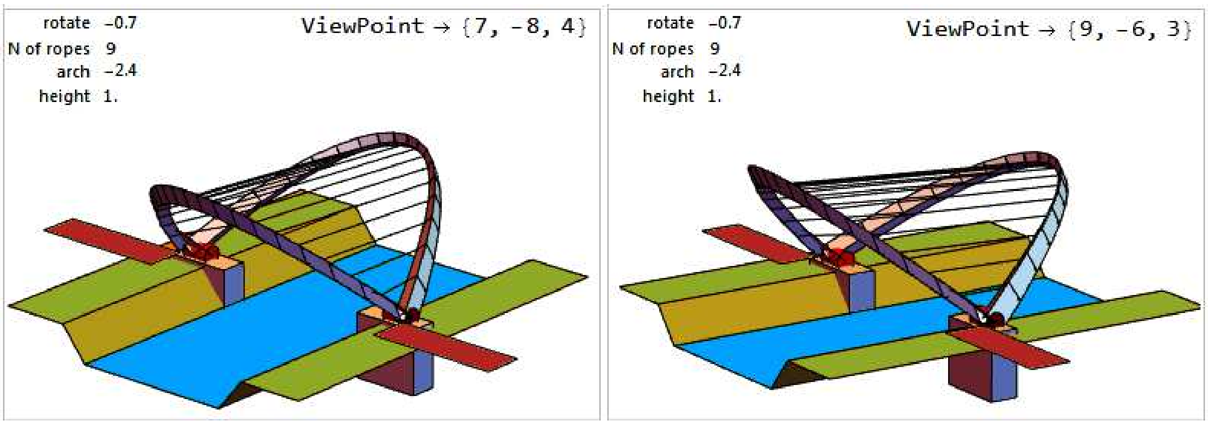

Figure 7. Model of the Gateshead Millennium Bridge. Different viewing angles.

4. Examples of visualization of calculation results by finite element method

Most of the practical problems of calculation of building structures are reduced to the determination of the stress-strain state arising in the structural elements during their work under load. In addition to solving the above-mentioned problems of describing the geometry of structural elements, the interaction of component parts, it is necessary to assess the operational quality, bearing capacity, conditions of loss of stability, occurrence of deflections, settlement, cracking, excessive deformations. This task difficult to solve on the basis of analytical solutions.

In each case, the complex problems in the subject area of solved by methods of applied mathematics, as a rule, by unique methods, and, most often, standard approaches do not work, author's solutions are needed. The corresponding computer models involve the preparation and justification of a mathematical model, the development of an approximate method, the software implementation of approximation algorithms, calculations and analysis of the results. Except, actually, modules of calculation of distributions of the controlled parameters (in volume, sections, on profiles) computer modelling include primary processing of initial data, preservation and comparison of the results saved up in protocols (databases), their analysis and interpretation. All of the above is of computational experiments service, its presence is required, and the development of their own tools requires considerable effort. Therefore, it is important to use the service of computer mathematics systems. In this example, Wolfram Mathematica tools are used in programming in the Wolfram Language [13] of the approximate solution algorithm (finite element method), as well as in the analysis and visualization of the results.

The project Stress Strain Analysis by the Finite Element Method from the collection was adopted as a basis [12]. The figures show maps of the density of the stress-strain state in a material tthe construction, and calculated curvilinear grid is shown on the left fragment. In both cases, the red arrows (on the right side of the structure) show the distribution of external forces, the red dots – where the object is fixed.

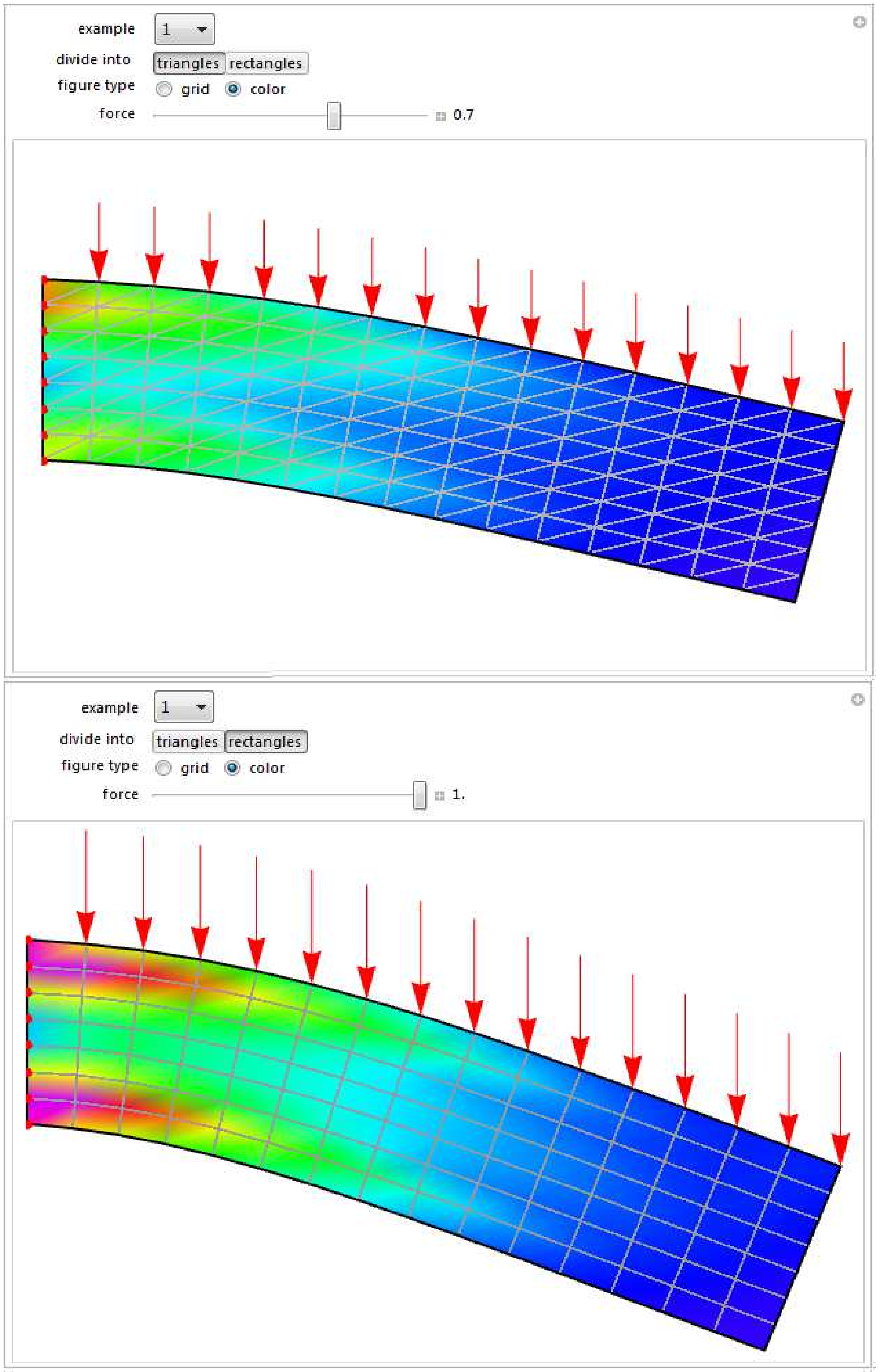

Figure 8. Stress-strain state of the structure.

Figure 8 contains screenshots of windows of the software module with interactive control tools at the top and results at the bottom.

The key constructions of the program module code (functions and options) are as follows: Manipulate, Initialization, Show, Array, Switch, Table, ControlType, PopupMenu, RadioButtonBar, Polygon, VertexColors, Length.

5. Conclusions

Presented the results of research in solving the problems of modeling, calculation, analysis and visualization of building structures, which allow to evaluate the design features of the object of study, interactively change the specified parameters and load parameters for the calculated object, providing an opportunity to visually assess and analyze the results of the calculations of the considered model.

References

[1] V. A. Bazhenov, A. V. Perelmuter, and O. V. Shishov, Structural mechanics. Computer technologies and modelling, *Publisher Association building universities, SCAD SOFTWARE*, p. 912, 2014.
[2] A. A. Samarsky, A. P. Mikhailov, Mathematical modeling: Ideas. Methods, *M.: Fizmatlit*, p. 320, 2005.
[3] G. P. Bonneau, T. Ertl, G. M. Nielson, Scientific Visualization: The Visual Extraction of Knowledge from Data, *Springer*, p. 434, 2006.
[4] O. A. Kovalchuk, The development of the superelement approach applied to models of rod elements, *MATEC Web of Conferences 251, 04045, IPICSE-2018*, pp. 1–6, 2018.
[5] V. N. Orlov, E. P. Detina, and O. A. Kovalchuk, Mathematical modeling of emergency situations at objects of production and gas transportation, *MATEC Web of Conferences 251, 04012, IPICSE-2018*, pp. 1–5, 2018.
[6] O. A. Kovalchuk, A. N. Leontiev, Modeling of core elements of the building frame, *Bulletin of Belgorod state technological University*, vol. 7, pp. 152–156, 2017.
[7] V. B. Taranchuk, V. A. Kulinkovich, On the preparation and distribution of interactive graphics applications using Mathematica, *Computer Algebra Systems in Teaching and Research, University of Natural Sciences and Humanities*, pp. 380–387, 2015.
[8] V. B. Taranchuk, M.A. Zhuravkov, Development of interactive teaching materials for computer mechanics, *Vestnik of Belgorod state University*, vol. 3, pp. 97–107, 2016.
[9] V. B. Taranchuk, The integrated computer complex of an estimation and adapting of digital geological models, Studies and Materials, vol.2, pp. 73–86, 2017.
[10] http://www.wolfram.com/ mathematica/ online: 05/2019.
[11] http://www.wolfram.com/cdf/ online: 05/2019.
[12] http://demonstrations. wolfram.com/ online: 01/2019.
[13] http://www.wolfram.com/language/elementary-introduction/2nd-ed/ online: 05/2019.
[14] J. M. Gere, S. P. Timoshenko, Mechanics of materials, *Boston PWS Pub Co.*, p. 936, 1997.

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