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APLICAÇÃO DE TÉCNICAS COMPUTACIONAIS EM CÁLCULOS E PROJETOS DE MECÂNICA APLICADA

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RESUMO

Objetivo: O artigo explora a aplicação de técnicas computacionais no cálculo e design de estruturas de engenharia, com foco em como esses métodos melhoram a precisão e a eficiência das análises estruturais. O estudo demonstra as vantagens práticas de usar programas computacionais para calcular forças longitudinais, tensões normais e deformações em estruturas.

Métodos: Foi utilizada uma combinação de análise teórica e simulações computacionais com o programa Brus. O estudo examinou uma barra escalonada submetida a forças de tração e compressão. Parâmetros-chave, como tensões, deformações e deslocamentos, foram calculados usando métodos computacionais.

Resultados: As técnicas computacionais mostraram-se altamente eficazes em fornecer resultados precisos e eficientes para análise estrutural. Elas reduziram o tempo necessário para os cálculos e minimizaram erros, permitindo múltiplas iterações de design. Esses métodos também melhoraram a segurança e o desempenho dos projetos de engenharia, permitindo otimizações rápidas.

Conclusão: A integração de métodos computacionais na análise e design de estruturas de engenharia melhora significativamente tanto a precisão quanto a eficiência. Esses métodos oferecem benefícios substanciais para aplicações práticas de engenharia e fins educacionais, preparando futuros engenheiros para os desafios modernos no design estrutural.

Palavras-chave: Métodos computacionais. Mecânica aplicada. Análise estrutural. Educação em engenharia. Estado de tensão-deformação.

APPLICATION OF COMPUTATIONAL TECHNIQUES IN CALCULATION AND DESIGN WORKS IN APPLIED MECHANICS

ABSTRACT

Objective: The article explores the application of computational techniques in the calculation and design of engineering structures, focusing on how these methods improve the precision and efficiency of structural analyses. The study demonstrates the practical advantages of using computational programs to calculate longitudinal forces, normal stresses, and deformations in structures.

Methods: A combination of theoretical analysis and computational simulations using the Brus program was employed. The study examined a stepped rod subjected to tensile and compressive forces. Key parameters such as stress, deformation, and displacements were calculated using computational methods.

Results: The computational techniques proved highly effective in providing accurate and efficient structural analysis results. They reduced the time needed for calculations and minimized errors, allowing for multiple design iterations. These methods also improved the safety and performance of engineering designs by enabling quick optimizations.

Conclusion: The integration of computational methods into the analysis and design of engineering structures significantly enhances both precision and efficiency. These methods offer substantial benefits for practical engineering applications and educational purposes, preparing future engineers for modern challenges in structural design.

Keywords: Computational methods. Applied mechanics. Structural analysis. Engineering education. Stress-strain state.

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1. INTRODUCTION

In the field of applied mechanics, accurate and efficient analysis of engineering structures is crucial for ensuring their strength, rigidity, and stability (Abduev et al., 2024; Aitaliev & Duzelbaev, 1991; Tajibaev, 1994; Vinokurov et al., 1990). Traditional methods of calculation, which rely heavily on manual computations and approximations, are often time-consuming and prone to errors (Petrov, 1984; Titorenko et al., 2023). These limitations can lead to inefficient designs, increased material costs, and, in some cases, structural failures. As engineering tasks grow in complexity, the necessity for more reliable and streamlined analytical techniques becomes increasingly apparent (Duzelbaev, 1996).

To develop the skills of independently solving engineering problems, the Applied Mechanics course for technical specialties includes calculation and design works as homework assignments in its curriculum (Iosilevich, 1989; Kultin, 1998, 1999; Tolmachev et al., 2022). These works involve mandatory calculations of the strength, rigidity, and stability of engineering structures. The wide introduction of computational methods in all branches of public utilities challenges the university to train engineering personnel able to effectively employ modern computational techniques in their practice (Faronov, 1999a, 1999b; Nikolaeva & Suslennikova, 2022). The integration of computational methods into the educational curriculum and practical applications presents a promising solution to these challenges (Kirillova et al., 2023; Knyazeva et al., 2023; Mironenko, 1992). Computational techniques allow for precise and rapid analysis of complex structures, enabling engineers to optimize designs and improve the overall safety and performance of engineering projects (Khominenko, 1998).

The purpose of the present study is to explore the application of computational methods in the analysis of engineering structures, particularly focusing on the concepts of tension and compression. By demonstrating how these methods can be utilized for calculating longitudinal forces, normal stresses, and deformations, the paper aims to offer a comprehensive understanding of their practical advantages.

2. MATERIALS AND METHODS

To investigate the application of computational methods in applied mechanics, a specific focus was placed on the analysis of a stepped rod subjected to tensile and compressive forces. The methodology involved both theoretical calculations and practical implementation using a computational program. The materials used in this study included engineering textbooks, reference materials on computational mechanics, and specialized software for structural analysis.

The theoretical framework was established by defining key concepts and equations related to tension and compression, as detailed in the preliminary sections of the article.

The computational aspect was executed using the Brus program, which was developed to model the stress-strain state of the rod.

3. RESULTS AND DISCUSSION

3.1 Key concepts and dependencies

Tension or compression is a type of load in which only longitudinal forces (N) are produced in the cross-sections of the rod (bar), and all other internal force factors (transverse forces – Q, bending forces – M, and torque – T) are at zero. Longitudinal force is determined by the method of cross-sections, its value being equal to the algebraic sum of the projections of all external forces on one side of the given cross-section onto the longitudinal axis of the bar. Tensile force is considered positive, compressive force is considered negative.

Only normal stresses occur in the cross-section of a bar under tension and compression σ and it is assumed that they are distributed uniformly in all cross-sections of the stretched and compressed bars. Therefore, normal stress in an arbitrary cross-section of the bar is determined by the ratio of the longitudinal force in this cross-section to its area A, i.e.,

$$\sigma = \frac{N}{A} \tag{1}$$

The rule of signs for σ is the same as for N. The dimension of the stress is Pa, KPa, or MPa.

Per Hooke's law, relative longitudinal strain in tension or compression equals

$$\varepsilon = \frac{\sigma}{E} \tag{2}$$

while relative transverse deformation equals

$$\varepsilon' = -\mu\varepsilon = -\frac{\mu\sigma}{E} \tag{3}$$

where E is the modulus of longitudinal elasticity or Young's modulus, and the dimension of E is the same as the stress; μ is the transverse deformation coefficient or Poisson's ratio, a dimensionless value.

If the bar's material is subject to Hooke's law, then the absolute elongation (shortening) of the bar Δl (at A = const, N = const) is established by formula

$$\Delta l = \frac{Nl}{EA} \quad (4)$$

where EA is cross-section rigidity at (compression); l is the length of the bar.

Strength condition:

$$\sigma \frac{N_{max}}{A_{adm,}{}_{max}} \quad (5)$$

where N_{max} σ_{max} are longitudinal force and normal stress in the dangerous cross-section (i.e., in the cross-section where the highest stresses occur); A is the area of the dangerous cross-section; σ_{adm} is admissible stress.

Plastic materials are equally resistant to tension and compression, for them

$$\sigma_{adm} = \frac{\sigma_y}{n} \quad (6)$$

where σ_y is material yield strength; n is the safety factor.

Brittle materials are known to resist tension and compression differently, so for them

$$\sigma_{adm} = \frac{\sigma_{u,t}}{n};\ \sigma_{adm} = \frac{\sigma_{u,c}}{n} \quad (7)$$

where $\sigma_{u,t}$, $\sigma_{u,c}$ are the ultimate tensile and compression strength of the material, respectively.

The condition of strength (5) provides for the following calculations.

Design calculation, i.e., determination of the required cross-section area, with known N and σ_{adm}:

$$A \geq \frac{N}{\sigma_{adm}} \quad (8)$$

Verification calculation, i.e., determination of the actual stress and its comparison with the admissible stress at given N and A:

$$\sigma_{max} \geq \sigma_{adm} \tag{9}$$

Determination of the load carrying capacity of the structure, i.e., determination of the load, with known A and σ_{adm}:

$$N \geq A \cdot \sigma_{adm} \tag{10}$$

In the calculation of the bar, apart from the strength condition, the rigidity condition must be met, which has the following form for a tensile or compressed bar (at N = const and A = const):

$$\Delta l = \frac{Nl}{EA} \leq \Delta l_{adm} \tag{11}$$

where Δl_{adm} is admissible absolute elongation.

The calculation of the rigidity condition must always be complemented with the calculation of strength.

Example 1. For a given stepped bar (Figure 1a), shear force and bending moment diagrams (SFD and BMD) are plotted for the longitudinal forces, normal stresses, and cross-sectional displacements. $E = 2 \cdot 10^5$ MPa. The bar's own weight is discarded. a = 0.2 m, b = 0.4 m, c = 0.8 m, $A_a = 15$ cm^2, $A_b = 10$ cm^2, $A_c = 5$ cm^2 , $F_a = 120$ kN, $F_b = 60$ kN, $F_c = 20$ kN.

Solution 1. Projecting external forces on the axis, we determine the reaction of the support (Figure 1b):

in the cross-section 3-3 (0.6 m ≤ x ≤ 1.4 m)

$$N_C = -R_A + F_a - F_b = -80 + 120 - 60 = -20\ kN\ =\ -0.02\ MH$$

The calculations suggest that the two outer sections experience compressional deformation while the third one is under tensile stress.

Having chosen a conventional scale, we build the SFD and BMD of N (Figure 1c).

Normal stresses in each section are calculated by formula (1):

a) in the first section (0 ≤ x ≤ 0.2 m)

$$\sigma_a = \frac{N_a}{A_a} = -\frac{0.08}{15 \cdot 10^{-4}} = -53.333\ MPa$$

b) in the second section (0.2 m ≤ x ≤ 0.6 m)

$$\sigma_b = \frac{N_b}{A_b} = \frac{0.04}{10 \cdot 10^{-4}} = 40\ MPa$$

c) in the third section (0.6 m ≤ x ≤ 1.4 m)

$$\sigma_c = \frac{N_c}{A_c} = -\frac{0,02}{5 \cdot 10^{-4}} = -40\ MPa$$

It follows from this that

$$R_A = F_a - F_b + F_c = 120 - 60 + 20 = 80\ kN$$

The values of N in the cross-sections of the rod are calculated through the method of sections. For this, the rod is successively dissected by planes 1-1, 2-2, and 3-3.

The number of sections depends on the stress and rigidity of the rod. Next, each time mentally discarding the part of the rod lying to the right of the cross-section, we consider the equilibrium of the remaining part. From the equilibrium equations of each remaining part, we obtain:

a) in the cross-section 1-1 (0 ≤ x ≤ 0.2 m)

$$N_a = -R_A = -80\ kN = \ \text{-}\ 0.08\ MN$$

b) in the cross-section 2-2 (0.2 m ≤ x ≤ 0.6 m)

$$N_b = -R_A + F_a = -80 + 120 = 40\ kN = \ 0.04\ MN$$

$$R_A - F_a + F_b - F_c = 0$$

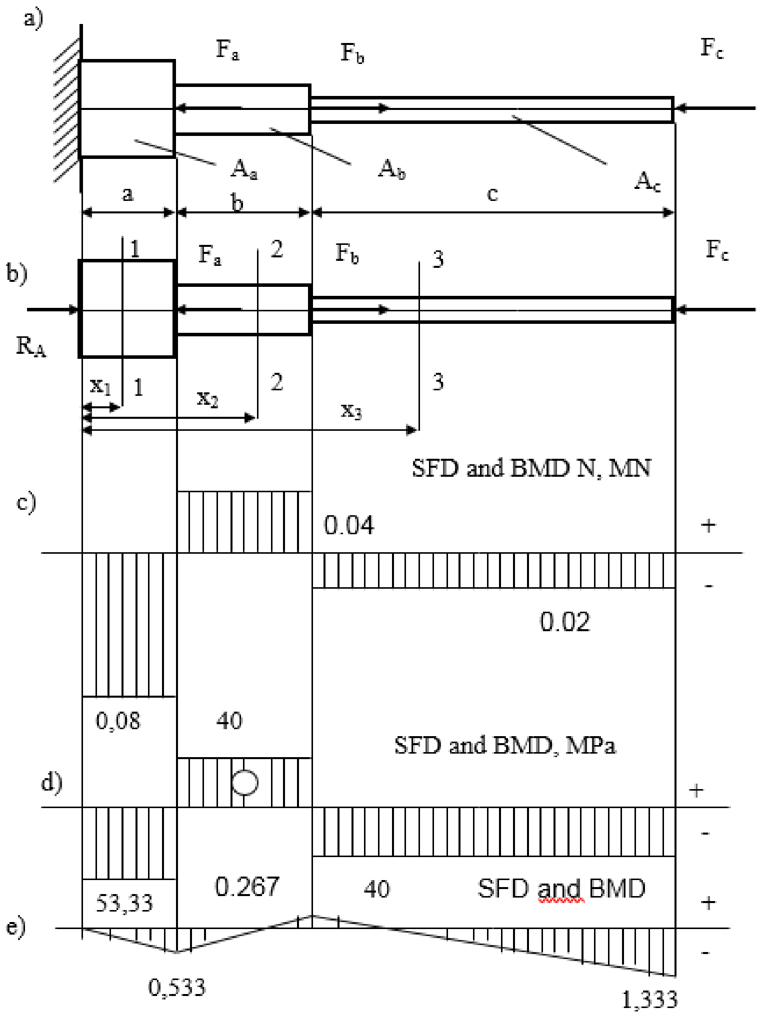

Figure 1. Construction of SFD and BMD

With the scale chosen, the SFD and BMD are constructed based on the obtained data (Figure 1). The SFD and BMD of displacements is built starting from the fixed end (since the displacement of the cross-section is equal to zero) and the displacements of characteristic cross-sections are determined as the algebraic sum of absolute deformations (sections) lying to the left of the considered section.

The absolute deformations of each section are determined by formula (4) and amount to:

a) in the first section ($0 \leq x \leq 0.2$ m)

$$\Delta l_a = \frac{N_a l_a}{EA_a} = -\frac{0.08 \cdot 0.2}{2 \cdot 10^8 \cdot 15 \cdot 10^4} = -0.523 \cdot 10^{-4}\ m$$

b) in the second section (0.2 m $\leq x \leq 0.6$ m)

$$\Delta l_b = \frac{N_b l_b}{EA_b} = -\frac{0.04 \cdot 0.4}{2 \cdot 10^8 \cdot 10 \cdot 10^4} = -0.8 \cdot 10^{-4}\ m$$

c) in the third section (0.6 m ≤ x ≤ 1.4 m)

$$\Delta l_c = \frac{N_c l_c}{EA_c} = -\frac{0.02 \cdot 0.8}{2 \cdot 10^8 \cdot 5 \cdot 10^4} = -01.6 \cdot 10^{-4}\ m$$

The displacement of the respective sections is defined as the algebraic sum of the absolute longitudinal deformations of the bar sections enclosed between the considered cross-section and the anchored cross-section of the bar. In the considered example,

$$\delta_A = 0$$
$$\delta_B = \Delta l_a = -0.533 \cdot 10^{-4}\ m$$

$$\delta_C = \Delta l_a + \Delta l_b = -0.533 \cdot 10^{-4} + 0.8 \cdot 10^{-4} = 0.267 \cdot 10^{-4}\ m$$
$$\delta_D = \Delta l_a + \Delta l_b + \Delta l_c = -0.533 \cdot 10^{-4} + 0.8 \cdot 10^{-4} - 1.6 \cdot 10^{-4} = -1.333 \cdot 10^{-4}\ m$$

Based on the calculated values of δ, the SFD and BMD of displacements is built to scale (Figure 1e).

3.2 Application of computational methods to study the stress-strain state of a stepped bar

3.2.1 Program characteristic

The program realizes an algorithm for solving problem 1.1.

The program is given the name Brus and its text is provided in the annex.

3.2.2 Preparation of the problem

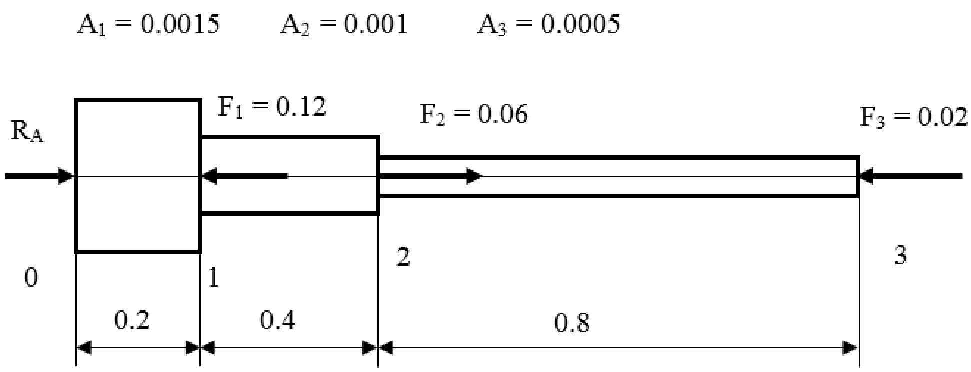

Figure 2. Stepped bar (design scheme)

The stepped bar (design scheme) is drawn to scale and the characteristic points of the bar are numbered from left to right (Figure 2). The numbering starts from zero. External concentrated forces are entered into the program with a positive sign if they stretch the bar relative to the rightmost section. Otherwise, they are entered with a minus sign.

3.2.3 Descriptive part

The descriptive section of the program uses the following identifiers:

M – for the number of characteristic points of the stepped bar;

A[1..M] – array for the areas of stepped bar sections;

L[1..M] – array for the distances between neighboring characteristic points (array of lengths of each stepped bar section);

E[1..M] – array for Young's modulus values (array of the material of each section of the bar);

F[1..M] – array for the values of external concentrated forces.

When formatting the data table, all differences should be converted to meganewtons and meters beforehand.

3.2.4 Output of counting results

The data printed out include:

N[1..M] – longitudinal forces;

SIGMA[1..M] – normal stress;

DELTAL[1..M] – absolute deformation of the section;

DELTA[1..M+1] – displacement of bar cross-sections in characteristic points.

Using example 1.1, we shall demonstrate the formation of input data. For this, we redraw the calculation scheme, number the characteristic points with the length and areas of sections and external concentrated forces in numbers.

The elements of the raw data arrays are listed in the order of their numbering.

The number of characteristic points M = 3. The arrays of input data given in the descriptive part have the following form:

A[1..3] = |0.0015, 0.001, 0.0005|;

L[1..3] = |0.2, 0.4, 0.8|;

E[1..3] = |2E+5, 2E+5, E+5|;

F[1..3] = |0.12, -0.06, 0.02|.

Array elements are listed in the order of their numbering.

Then, the table of initial data takes on the following form:

ENTER INPUT DATA

Number of characteristic points – M 3

Enter arrays element by element – A[M], L[M], E[M], F[M]

0.0015, 0.2, 200000, 0.12

0.0010, 0.4, 200000, -0.06

0.0005, 0.8, 200000, 0.02

COUNTING RESULTS

LONGITUDINAL FORCE	NORMAL STRESS	DEFORMATION OF SECTIONS
-0.08000	-53.33333	-0.00005
0.04000	40.00000	0.00008
-0.02000	-40.00000	-0.00016

CHARACTERISTIC POINT DISPLACEMENT

0	0.00000 1	-.00005
2	0.00003 3	-0.00013

4. CONCLUSIONS

This study demonstrated the significant advantages of integrating computational methods into the analysis of engineering structures, specifically focusing on the concepts of tension and compression. By utilizing a computational program to model the stress-strain state of a stepped rod, the research showed how these methods can enhance the accuracy and efficiency of structural analyses.

The findings highlight several key benefits of computational techniques. First, they allow for precise and rapid calculations, significantly reducing the time and effort required compared to traditional manual methods. This efficiency enables engineers to perform more iterations and optimizations, leading to improved design outcomes. Second, the use of computational tools helps to minimize errors and increase the reliability of results, ensuring the safety and stability of engineering structures. The application of computational methods in the analysis of tension and compression provides a powerful approach to understanding and solving structural engineering problems.

Furthermore, the incorporation of computational methods into the educational curriculum equips engineering students with essential skills that are directly applicable in modern engineering practice.

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