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Automated design of steel-concrete composite structures using TechEditor software

Abstract. This paper addresses the automation of steel-concrete composite structure analysis within modern digital environments. The authors substantiate the necessity for flexible engineering tools that combine high accuracy, computational efficiency, and cost-effectiveness — factors that are critically important for the reconstruction of Ukraine's infrastructure under limited resource conditions. The aim of the study is to develop and implement a computational methodology for steel-concrete composite beams within the TechEditor environment, integrating classical analytical approaches of structural mechanics with numerical modeling via the Finite Element Method (FEM). The research methodology utilizes transformed section properties and a step-by-step determination of the stress-strain state. The proposed approach combines the precision of analytical relationships with the flexibility of FEM, which is used to determine internal forces and deflections under realistic boundary conditions. A key feature of the methodology is its transparency, which eliminates the "black box" issue typical of proprietary commercial software, ensuring full control over the calculation logic and unit consistency at every stage. To demonstrate the capabilities of this parametric approach, a finite element model was developed to investigate the variation of the cross-section utilization factor and relative beam deflections for slab thicknesses ranging from 30 to 150 mm. The validation results confirm that implementing parametric relationships enables rapid optimization of design solutions and reduced material consumption without compromising structural reliability. The resulting digital solution, presented as an interactive report, ensures high accuracy and transparency while significantly improving design productivity and reducing the risk of human error.

Keywords: steel-concrete composite; beam; automation; finite element method; TechEditor; parametric modeling

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Introduction.

In modern structural design practice, there is a clear and sustained trend toward the adoption of automated digital tools. This is driven by the increasing complexity of structures, higher requirements for their reliability and cost-effectiveness, as well as the need to ensure transparency, reproducibility, and control of calculations [1, 4, 14].

The current wartime conditions in Ukraine add an additional layer of complexity to these challenges, as the reconstruction of damaged infrastructure and housing requires the rapid implementation of engineering solutions that combine high accuracy, speed, and cost-efficiency. Therefore, under conditions of limited resources and constant time constraints, it is critically important for designers to rely on flexible computational tools.

One such digital solution is the versatile software environment TechEditor (developed by the Ukrainian technology center Dystlab). Through the automation of calculations, this software enables the rapid and efficient determination of geometric properties, load-bearing capacity, and other characteristics of steel-concrete composite elements, as well as the evaluation of stress-strain parameters and even optimization of steel and concrete consumption within a selected configuration.

Furthermore, TechEditor supports engineers working in distributed environments: due to the parametric nature of calculations, engineers can instantly evaluate various loading scenarios and structural geometries, thereby enhancing the safety and efficiency of reconstruction projects in regions directly affected by hostilities [5–7].

The methodology for the analysis of steel-concrete composite beams, based on the use of transformed cross-sectional properties and a step-by-step evaluation of stress-strain parameters, is scientifically substantiated and widely used in modern engineering practice [15, 16]. It accounts for the composite action of steel and concrete within the cross-section, differences in their elastic moduli, geometric characteristics, and the relative arrangement of components. On this basis, the position of the neutral axis, resultant internal forces, and the ultimate bending moment defining the load-bearing capacity of the beam are determined. A number of scientific studies have been devoted to this topic, in particular: [1, 2–4, 12, 13].

Problem statement. Nevertheless, the practical implementation of this methodology in a manual format is labor-intensive, prone to technical errors, and limited in terms of scalability. This necessitates the development of digital tools that enable the formalization of calculation procedures into parameterized models and ensure their repeated application across structural design projects of various types [6, 7].

A crucial aspect is the integration of classical analytical approaches with numerical methods, specifically the Finite Element Method (FEM). In this formulation, FEM is utilized to determine internal forces — bending moments, shear, and axial forces — as well as deflections, accounting for realistic boundary conditions, diverse loading schemes, and three-dimensional structural behavior. Conversely, analytical methods provide a precise determination of the cross-sectional stiffness and load-bearing capacity. This synergy allows for combining the precision of classical theoretical relationships with the flexibility of numerical modeling [8].

The implementation of this approach in a digital environment facilitates extensive opportunities for parametric design and optimization [9–11]. It enables the rapid modification of structural geometries, material properties, and loading conditions, with results being recalculated automatically. This minimizes the risk of error and streamlines the design decision-making process. This research focuses on the development of such a computational tool.

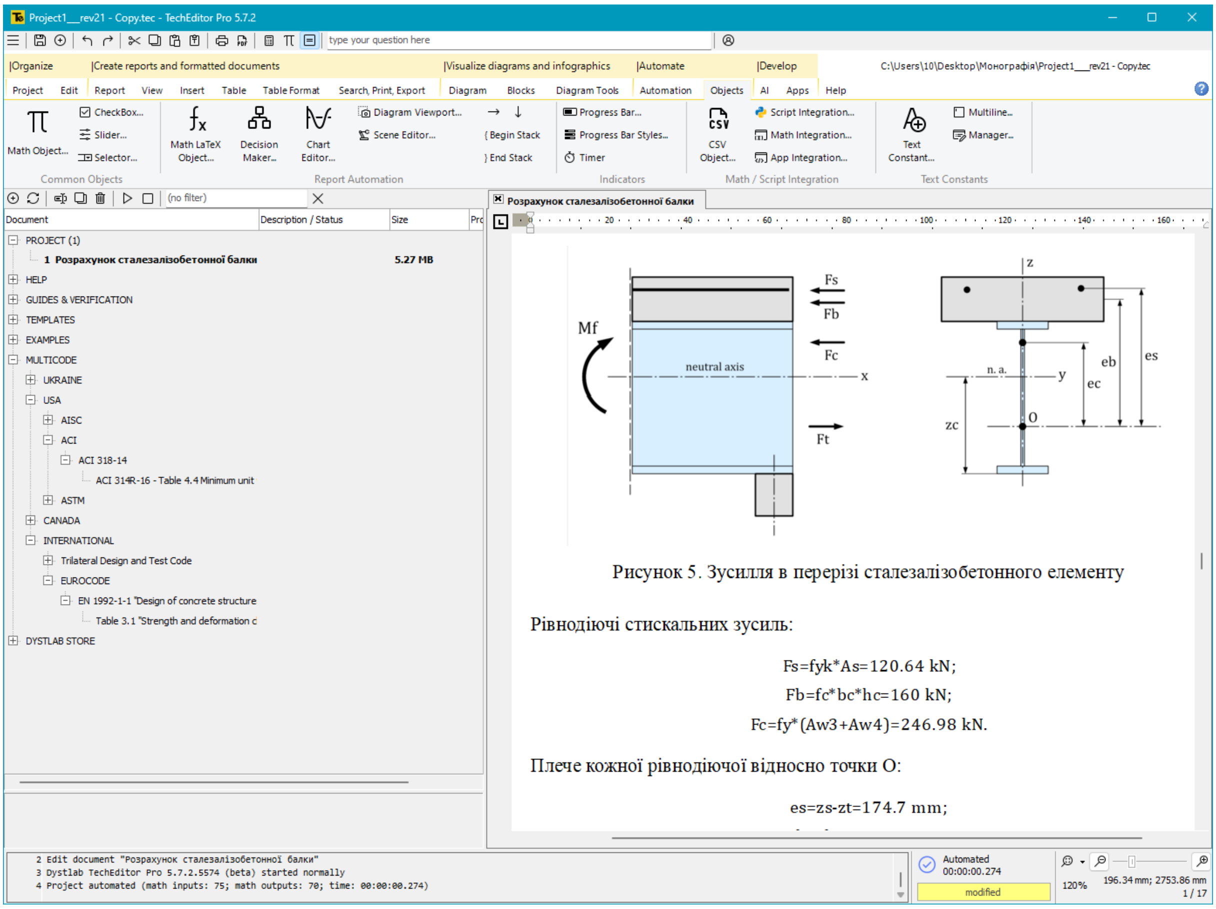


Рисунок 5. Зусилля в перерізі сталезалізобетонного елементу

Рівнодіючі стискальних зусиль:

Fs=fyk*As=120.64 kN;

Fb=fc*bc*hc=160 kN;

Fc=fy*(Aw3+Aw4)=246.98 kN.

Плече кожної рівнодіючої відносно точки O:

es=zs-zt=174.7 mm;

```
2 Edit document "Розрахунок сталезалізобетонної балки"
3 Dystlab TechEditor Pro 5.7.2.5574 (beta) started normally
4 Project automated (math inputs: 75; math outputs: 70; time: 00:00:00.274)
```

Figure 1 – Design of a steel-concrete composite beam in the Dystlab TechEditor engineering environment

Main material and results.

This study aims to develop and implement a methodology for analyzing steel-concrete composite beams within the TechEditor environment, integrating classical structural mechanics with numerical Finite Element Method (FEM) modeling. To achieve this, the following objectives were established:

- to synthesize classical analytical relationships for composite cross-section design with linear static FEM algorithms;
- to transform traditional calculation procedures into flexible parametric models, ensuring full transparency and traceability of computations at every stage;
- to provide engineers with direct control over the computational logic, enabling model adaptation to specific tasks and real-time structural optimization;
- to implement the methodology as a functional digital solution (a TechEditor project), made available via the Dystlab Store specialized engineering platform [5].

Methodology.

The study considers a T-shaped steel-concrete composite beam consisting of a concrete slab (flange) and a steel I-section. The concrete slab has a width of 200 mm and a thickness of 40 mm, with a modulus of elasticity of 30,000 MPa and a compressive strength of 20 MPa. Two longitudinal reinforcement bars are embedded in the slab, with diameters ranging from 8 to 30 mm across nine analyzed variants. This reinforcement has a modulus of elasticity of 200 GPa and a yield strength of 300 MPa, and is positioned 20 mm from the top surface of the slab. The steel I-section is characterized by a modulus of elasticity of 200 GPa and a yield strength of 350 MPa, featuring a web height of 160 mm (5 mm thick) and flanges 81 mm wide by 7 mm thick.

The initial step in developing the computational model involves determining the geometric properties of the transformed cross-section. Since the beam is composite and consists of multiple materials, the section properties are converted into an equivalent concrete section.

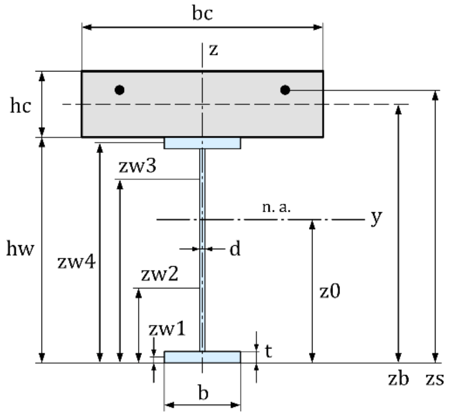


Figure 2 – Section geometry of the steel-concrete composite member

This conversion is performed using modular ratios – specifically, the ratio of the modulus of elasticity of the reinforcement to that of the concrete, and the ratio of the modulus of elasticity of the steel I-section to that of the concrete:

$$A_{red} = A_b + A_w \cdot \eta_w + A_s \cdot (\eta_s - 1) \qquad (1)$$

$$S_{red} = A_b \cdot z_b + A_w \cdot \eta_w \cdot \frac{h_w}{2} + A_s \cdot (\eta_s - 1) \cdot z_s \qquad (2)$$

$$z_t = \frac{(A_{w1} \cdot z_{w1} + A_{w2} \cdot z_{w2})}{A_t} \qquad (3)$$

$$z_c = \frac{(A_{w3} \cdot \eta_w \cdot z_{we} + A_{w4} \cdot \eta_w \cdot z_{zw4} + A_b \cdot z_b + A_s \cdot (\eta_s - 1) \cdot z_s)}{A_s} \qquad (4)$$

$$J_b = \frac{b_c \cdot h_c^3}{12} \ (5) \qquad J_w = \frac{b \cdot h_w^3}{12} - \frac{(b-d) \cdot (h_w - 2 \cdot t)^2}{12} \qquad (6)$$

$$J_{red} = J_b + A_b \cdot (z_b - z_0)^2 + +A_s \cdot (\eta_s - 1) \cdot (z_c - z_0)^2 + J_w \cdot \eta_w + A_w \cdot \eta_w \cdot (\frac{h_w}{2} - z_0)^2 \qquad (7)$$

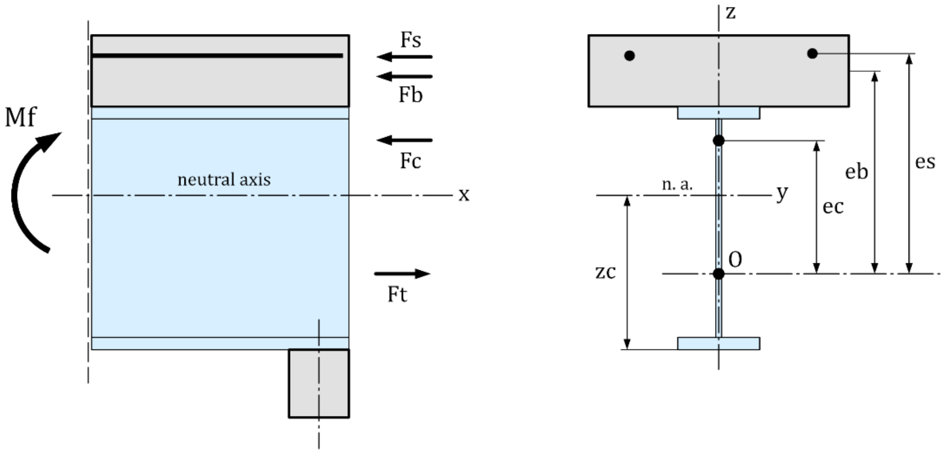


Figure 3 – Internal forces in the cross-section of the steel-concrete composite element

The total moment of the load-bearing capacity of the cross-section is determined as the sum of the moments generated by the resultant compressive forces in the concrete F_b, the reinforcement F_s and the portion of the steel I-section located above the neutral axis (F_c):

$$F_s = f_{yk} \cdot A_s \text{ (8); } F_b = f_c \cdot b_n \cdot h_c \qquad (9);$$

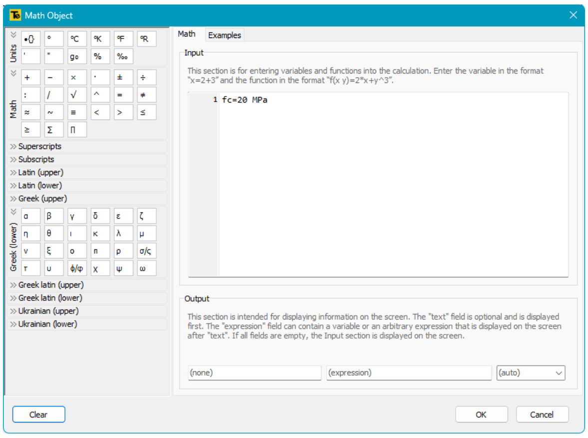
$$F_c = f_y \cdot (A_{w3} + A_{w4}) \qquad (10);$$

$$M_r = f_s \cdot e_s + F_b \cdot e_b + F_c \cdot e_c \qquad (11).$$

The analytical relationships presented are well-established and form the foundation for the linear static analysis of steel-concrete composite members, as confirmed by decades of engineering practice. However, the modern design paradigm is shifting toward Computer-Aided Engineering (CAE) systems, which are predominantly based on the Finite Element Method (FEM).

While acknowledging the power of FEM, it should be noted that most commercial software products based on this approach suffer from a significant drawback — the so-called “black box” effect, i.e. the lack of transparency of computational algorithms and the inability to intervene in the calculation logic. This limits the engineer’s ability to flexibly adjust parameters, thereby reducing or even eliminating the key advantages of classical analytical methods.

The scientific novelty of the proposed approach lies in the transparent automation of the analytical framework. In contrast to conventional “closed-box” systems, the developed algorithm provides comprehensive control over every variable and unit of measurement while maintaining a clear, structured format for reporting documentation. This enables the full exploitation of both normative and empirical relationships, providing engineers with a verified automated tool that ensures rigorous calculation logic and seamless unit conversions within the TechEditor environment.



This section is for entering variables and functions into the calculation. Enter the variable in the format "x=2+3" and the function in the format "f(x y)=2*x+y^3".

```
fc=20 MPa
```

This section is intended for displaying information on the screen. The "text" field is optional and is displayed first. The "expression" field can contain a variable or an arbitrary expression that is displayed on the screen after "text". If all fields are empty, the Input section is displayed on the screen.

Figure 4 – Concrete strength defined via a mathematical object in TechEditor

The next step involved the development of a finite element computational model of the beam. The model is analytical in nature (generated through script-based commands of the TechEditor FEM engine), is parametrically driven by input data, and is directly integrated into the document. The nodal mesh is uniformly discretized along the beam length. The first node is assigned boundary conditions corresponding to a pinned-fixed support, while the last node is defined as a pinned-movable support. All beam elements in the system are connected sequentially and are primarily subjected to bending. In the general case, these elements are capable of resisting tension and compression, biaxial bending, and torsion.

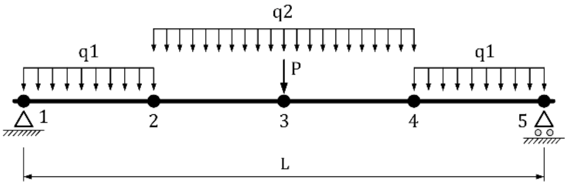


Figure 5 – Finite element model of the beam

Below is a fragment of a TechEditor document containing script commands for creating four beam (bar) elements that sequentially connect five beam nodes. The shear modulus and other properties associated with torsion and bending in the horizontal plane are not considered (they are assigned zero values).

TechEditor FEM engine

```
…
E=Eb
G=0 MPa
A=Ared
Ix=0 cm⁴
Iy=Ired
Iz=0 cm⁴
fembeam{1 2}(E G A Ix Iy Iz)=1
fembeam{2 3}(E G A Ix Iy Iz)=2
fembeam{3 4}(E G A Ix Iy Iz)=3
fembeam{4 5}(E G A Ix Iy Iz)=4
…
```

Interpretation of results and their approval.

Results analysis within TechEditor is conducted through specialized post-processing functions. These tools extract data on internal forces, support reactions, and displacements for individual nodes and elements, as well as global extreme values for the entire model.

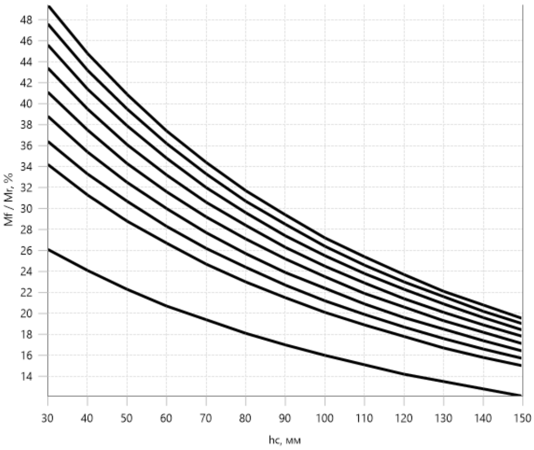


Figure 6 – Dependence of the cross-section utilization factor on slab thickness for the steel-concrete composite beam

Using the developed model, the dependence of the cross-section utilization factor and beam deflections on slab thickness was investigated. The thickness of the concrete slab was varied from 30 to 150 mm in 10 mm increments. The utilization factor was calculated as the ratio of the design bending moment Mf to the moment resistance of the cross-section Mr, expressed as a percentage (Fig. 6).

The variation of beam deformations as a function of the same parameter was also analyzed (Fig. 7). In this case, the vertical axis of the nomogram represents the inverse relative deflection of the beam, expressed as the dimensionless ratio L/Δ. In practice, these values make it possible to easily assess the limiting beam deflections, which in design codes are typically specified in the form of criteria such as L/150, L/300, etc.

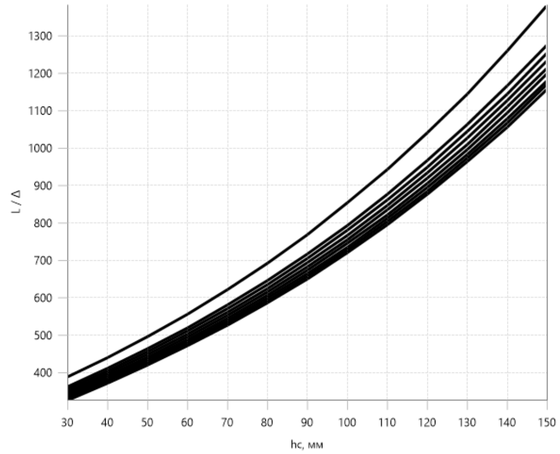


Figure 7 – Dependence of composite beam deflections on slab thickness

Conclusions.

As a result of this study, a methodology for the automated analysis of steel-concrete composite structures has been developed and validated, leading to the following conclusions:

1. The synergy between classical analytical structural mechanics and numerical Finite Element Method (FEM) modeling has been validated. The use of analytical relationships ensures high-precision determination of transformed section properties, while the FEM approach enables accurate simulation of three-dimensional structural behavior, realistic boundary conditions, and complex loading scenarios.

2. The implementation of the algorithm in a transparent digital environment addresses the “black box” issue prevalent in proprietary engineering software. The proposed approach ensures full traceability and verifiability of the computational workflow — from the input of material properties to the final assessment of limit states. This grants the engineer direct oversight and the ability to refine the calculation logic at any stage.

3. The integration of parametric relationships transforms conventional linear analysis into a dynamic framework suitable for real-time multi-variant optimization. The investigation into the effect of geometric parameters (specifically slab thickness) on the stress-strain state demonstrates that such automation is a key driver in optimizing design solutions.

4. The identified patterns indicate significant potential for material savings without compromising structural integrity or stability. In the context of resource constraints and the urgent need for infrastructure reconstruction, automated optimization offers substantial economic benefits through the balanced and efficient use of steel and concrete.

5. The application of TechEditor for automated computation and unit consistency enabled the integration of a rigorous research framework with a structured engineering report. The resulting interactive report streamlines design timelines and enhances productivity while mitigating risks associated with human error. Furthermore, the availability of this digital solution via the Dystlab Store ensures its accessibility for practical application by the professional engineering community.

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Автоматизація розрахунків сталезалізобетонних конструкцій у програмному середовищі TechEditor

Аннотація. У статті розглянуто актуальну проблему автоматизації розрахунків сталезалізобетонних конструкцій у сучасному цифровому середовищі. Автори обґрунтовують необхідність впровадження гнучких інженерних інструментів, що поєднують високу точність, швидкість та економічність, що є критично важливим для відбудови інфраструктури України в умовах обмежених ресурсів. Метою роботи є розробка та програмна реалізація методики розрахунку сталезалізобетонних балок у середовищі TechEditor на основі інтеграції класичних аналітичних підходів будівельної механіки з чисельним моделюванням методом скінченних елементів (FEM). Методологія дослідження базується на використанні приведених геометричних характеристик композитного перерізу та поетапному визначенні параметрів напружено-деформованого стану. Запропонований підхід дозволяє поєднати прецизійну точність аналітичних залежностей із гнучкістю FEM-апарату, що застосовується для визначення внутрішніх зусиль та прогинів з урахуванням реальних граничних умов. Ключовою особливістю підходу є прозора автоматизація обчислень, яка вирішує проблему «чорної скрині» закритих комерційних продуктів, забезпечуючи повний контроль над розрахунковою логікою та одиницями вимірювання на кожному етапі. Для ілюстрації можливостей параметричного підходу в роботі реалізовано скінченно-елементну модель, на прикладі якої досліджено зміну коефіцієнта використання перерізу та відносних прогинів балки у діапазоні висот бетонної плити від 30 до 150 мм. Результати цієї апробації підтверджують, що впровадження параметричних зв'язків дозволяє швидко оптимізувати проєктні рішення та мінімізувати матеріаломісткість конструкцій без втрати їхньої надійності. Підсумкове цифрове рішення у вигляді інтерактивного звіту не лише забезпечує високу точність та прозорість обчислень, а й значно підвищує загальну продуктивність проєктування, нівелюючи ризики помилок, спричинених людським фактором.

Ключові слова: сталезалізобетон, балка, програма, автоматизація, метод скінченних елементів, TechEditor

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