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Determination of the effective parameters of a triangular corrugated web for crane runway beams

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ABSTRACT

Introduction. The aim of this study is to investigate the performance of crane runway beams with triangular corrugated webs. These beams are increasingly popular in industrial construction because of to their enhanced shear resistance and structural efficiency. Flat webs have several disadvantages, including high stress levels and excessive material consumption. Optimizing the geometry of corrugations makes it possible to improve strength and reduce the overall construction cost. **Methods and Materials.** The study is based on numerical modeling using the finite element method (FEM) in LIRA-CAD 2022 software and full-scale experimental testing. The performance of beams with both corrugated and flat webs was analyzed under wheel loads from cranes with lifting capacities of 10, 30, and 50 tons. Deformations and the distribution of normal and shear stresses were evaluated. **Results and Discussion.** The numerical model demonstrated high accuracy, with a maximum deviation of only 2.9% from experimental results. Crane runway beams with corrugated webs exhibited lower shear and normal stresses, reduced deflections, and more uniform force distribution. They also proved to be more economical due to lower material consumption and reduced labor intensity. Additionally, the corrugated beams showed enhanced economic performance, reducing material costs. **Conclusion.** Triangular corrugated web beams outperform traditional flat web beams in structural and economic terms. The findings support the use of optimized corrugation profiles to increase load-bearing capacity and reduce production costs. These results are relevant for optimizing crane beam design in industrial structures.

KEYWORDS: crane runway beam, flat web, corrugated web, static load, overhead crane, shear force, normal stresses, shear stresses, cost analysis

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Определение эффективных параметров треугольной гофрированной стенки подкрановых балок

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АННОТАЦИЯ

Введение. Цель исследования — изучить поведение подкрановых балок с треугольными гофрированными стенками, которые находят все более широкое применение в промышленном строительстве благодаря повышенной устойчивости к сдвигу и конструктивной эффективности. Плоские стенки имеют ряд недостатков — высокие напряжения и большой расход. Оптимизация геометрии гофров позволяет повысить прочность и снизить себестоимость конструкции. **Методы и материалы.** Работа основана на численном моделировании методом конечных элементов (МКЭ) в программе LIRA-CAD 2022 и полномасштабных экспериментальных испытаниях. Была исследована работа балок с гофрированной и плоской стенкой при нагрузках от кранов грузоподъемностью 10, 30 и 50 тонн. Оценивались деформации и распределение напряжений и сдвига. **Результаты и обсуждение.** Расчетная модель продемонстрировала высокую точность (максимальное отклонение от эксперимента – 2,9%). Подкрановые балки с гофрированной стенкой показали меньшие касательные и нормальные напряжения, меньшие прогибы и более равномерное распределение усилий. Также они оказались более экономичными за счет меньшего расхода. **Заключение.** Гофрированные балки с треугольным профилем превосходят балки с плоской стенкой как по прочностным, так и по экономическим характеристикам. Исследование подтверждает целесообразность применения гофрированных стенок в проектировании подкрановых балок для повышения несущей способности и оптимизации затрат.

КЛЮЧЕВЫЕ СЛОВА: подкрановая балка, плоская стенка, гофрированная стенка, статическая нагрузка, мостовой кран, поперечная сила, нормальные напряжения, касательные напряжения, экономический анализ

ДЛЯ ЦИТИРОВАНИЯ:
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INTRODUCTION

The primary objective of this research is to investigate the performance and deformability of welded crane runway beams with triangular corrugated webs. To address this problem, several key objectives must be achieved: (1) to determine the optimal web configuration for three crane runway beams of different sizes under three loading conditions: a load of 0.95 kN per wheel from a 10-ton capacity overhead crane for the first type of crane runway beam, a load of 2.25 kN per wheel from a 30-ton capacity overhead crane for the second type, and a load of 3.35 kN per wheel from a 50-ton capacity overhead crane for the third type (2) to identify the most efficient corrugation parameters and (3) to compare the weight, labor intensity, and economic efficiency of crane runway beams with flat and corrugated webs.

Corrugated web I-section steel beams have gained attention in structural engineering due to their potential to enhance shear resistance while maintaining overall structural efficiency. This study explores the impact of web corrugation on the flexural and shear performance of crane runway beams through numerical simulations and experimental validation. Using Lira-CAD (Lira-Computer-aided design software), finite element models were developed to analyze simply supported and cantilever beam configurations under concentrated and uniform loading. The results indicate that while corrugated webs have a negligible effect on flexural resistance, they significantly improve shear capacity. Additionally, drop tests on composite beams with corrugated webs highlight their energy absorption characteristics under impact loads, revealing that shorter beams exhibit instability. Further investigations into A parametric study also examined the influence of web openings, showing that their presence can alter ultimate strength by up to 15%. These findings contribute to optimizing the design of crane runway beams by identifying key parameters affecting load capacity, energy absorption [1–5].

In this study, shell elements were used to model the crane runway beam with a triangular corrugated web. The selection of shell elements is justified by their ability to accurately capture both in-plane and out-of-plane deformations while maintaining computational efficiency. The corrugated web was discretized using four-node shell elements with six degrees of freedom per node, allowing for realistic simulation of bending, shear, and axial deformations.

The finite element analysis was conducted using LIRA-CAD 2022, employing a nonlinear static analysis approach. The nonlinear performance was considered to account for geometric imperfections and material nonlinearity. The boundary conditions were applied to represent a simply supported beam, with constraints imposed to prevent rigid body motion while allowing for realistic structural deformations under applied loads.

Mesh convergence analysis was performed to ensure accuracy, where different mesh densities were tested, and the final mesh size was selected based on the balance between computational efficiency and solution accuracy. The numerical results were validated against experimental data, demonstrating good agreement with a maximum deviation of 2.9% in displacement values.

Corrugated web beams are widely studied for their enhanced shear resistance and structural efficiency. This research aims to determine optimal parameters for triangular corrugated webs in crane runway beams by analyzing their mechanical behavior under various loading conditions. Finite element (FE) simulations and experimental tests confirm that corrugation improves shear buckling resistance, influences stress distribution, and affects structural stability. Studies on castellated-corrugated beams highlight reduced load capacities due to combined web post-buckling and flange buckling effects. Additionally, the connection method between crane rails and runway beams significantly impacts local stress distribution. Further analysis of cold-formed built-up beams with corrugated webs reveals that web thickness, shear panel properties, and connection types influence flexural rigidity and bending capacity. FE modeling of trapezoidal corrugated webs also demonstrates distinct torsional performance compared to conventional I-beams. These findings contribute to optimizing crane runway beam design for improved shear resistance and structural performance. [6–10].

Crane runway beams are subjected to complex loading conditions, including lateral-torsional buckling, and geometric imperfections, which can lead to structural failures over time. Studies indicate that factors such as rail-beam connection detailing, and stress concentrations significantly impact the durability and safety of these structures. Furthermore, non-destructive testing methods and numerical simulations provide valuable insights into crack formation and stress distribution, enabling more effective maintenance strategies. The 2021 study by Kovacevic et al. highlights the importance of optimizing design parameters, improving load distribution, and implementing advanced monitoring techniques to enhance the service life and structural reliability of crane runway beams [11–17].

The structural performance of crane runway beams is influenced by various factors, including shear lag effects, lateral torsional buckling, and the impact of crane rails on bending stiffness and load-bearing capacity. Recent research highlights the importance of numerical simulations and finite element analysis in evaluating the stress distribution, deformation, and stability of crane runway girders. Strengthening techniques, such as welding additional steel members to increase load-bearing capacity, have also been explored to enhance the structural integrity of runway beams. These studies provide a foundation for optimizing crane runway design, ensuring safety and long-term durability under varying operational conditions [18–25].

A corrugated beam consists of flanges made from various metal sections and a transversely corrugated (curved) web. The web may feature different corrugation profiles, such as triangular, sinusoidal, trapezoidal, and rectangular shapes. The flanges of such beams are fabricated from steel profiles or shaped sections, or welded sheets. Corrugated web beams have seen widespread adoption in many countries due to their enhanced performance.

In recent years, crane runway beams have gained significant attention owing to the growing construction of industrial buildings. Their reliability, strength, and efficiency contribute to improved production and logistics processes while ensuring safety under heavy load operations. Crane runway beams, as load-bearing elements, transfer loads from crane wheels and provide structural stability by distributing longitudinal and lateral forces, including seismic effects, to connected columns.

Several studies, including those by Wei et al. [26] and Progress in Steel Building Structures [27], have addressed the design of crane runway beams with corrugated webs.

The material used in the study complies with GOST 380-2005 [29], which minimizes the variability of properties within a single steel grade. The mechanical characteristics were applied in accordance with the test report (Appendix A).

Despite prior research on corrugated-web beams, gaps remain regarding the optimal design parameters, including web thickness, corrugation height, and angle. The present study addresses these gaps by systematically analyzing the impact of corrugation geometry on the structural performance of crane runway beams, with a focus on replacing flat webs and stiffeners with corrugated webs to enhance strength and reduce labor-intensive manufacturing processes [30].

Additionally, issues related to crane runway beams, such as weld cracking and damage to fastening joints, highlight the need for further investigation. The study aims to provide practical recommendations for the design and application of corrugated-web beams in industrial settings, ensuring improved safety, reduced material usage, and enhanced structural efficiency.

METHODS AND MATERIALS

2.1. Methods

This research focuses on the feasibility of replacing flat webs with corrugated ones to improve the physical, mechanical, and economic properties of crane runway beams. The selected design is justified by the absence of detailed specifications regarding the thickness, length, depth, and corrugation radius of welded I-section crane runway beams in scientific literature and regulatory documents across the Commonwealth of Independent States (CIS).

In Kazakhstan, triangular corrugations are predominantly used for constructing beams with transversely corrugated webs [28]. Beams with trapezoidal and rectangular corrugations are commonly used in Sweden, Finland, the United States, Japan, and the Netherlands, while sinusoidal corrugations are employed in Austria, Ukraine, Poland, and Russia.

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The methodology includes numerical analysis of crane runway beams with flat and corrugated webs to evaluate their load-bearing capacity, stability, effective parameters, and to improve economic efficiency and reduce labor intensity. The experimental investigation was conducted on a simply supported beam with a triangular corrugated web.

Due to the absence of precise calculation methods for crane runway beams with corrugated webs, physical testing is essential for practical application in construction. The geometric parameters, materials, loads, and boundary conditions used in the experiment are detailed below.

When specifying the dimensions of the corrugation, the following notation is used: a b×c / d, where a is the corrugation length (mm), b is the corrugation depth (mm), c is the web thickness (mm), and d is the corrugation bend radius (mm).

As a result of theoretical and experimental studies conducted in 2019 [28] at the KazGASA laboratory, effective geometric parameters for a 2 mm thick web were identified. Tests were carried out on a large-scale model (scale 1:1) of a corrugated beam with constant cross-section (flange 150×6 mm, web 600×2 mm, corrugation parameters 280×45×2/30 mm) and a span of 4200 mm in Figure 1.

The load magnitude during beam testing was measured using an electronic dynamometer and confirmed by a manometer.

Deflections were recorded using electronic deflectometers (accuracy 0.01 mm), and the influence of model displacement due to compliance was accounted for and eliminated. Deflectometers measured vertical displacements at load application points and supports. The design load Fp for the tested beams was set at 60 kN. Loading was applied in increments: 10 kN for the first two steps and 5 kN for subsequent steps. Prior to the experiment, a test loading was conducted up to 35 kN with an increment of 5 kN. Due to relatively small deflections, this load step was selected. After each step, a holding period was observed, and deflectometer readings were recorded.

The tests were conducted using a single-span scheme with concentrated load applied at mid-span (Figure 2) and hinged support conditions. The boundary conditions were applied to both ends of the beam model at the nodes of the end plate surface by limiting the required degrees of freedom. The beam at the left part has a fastening along the axes X, Y and Z and at the right part along the axes Y and Z.

The general view of the beam and its geometric dimensions are shown in Figure 2.

The triangular corrugations of the web, with rounded peaks, had a wavelength of L_c = 280 mm and a wave height of h_r = 45 mm. The material selected for the web and flanges was 3SP steel according to GOST 380-2005 [29] corresponding to grade S245 , with the following

Fig. 1. Tested geometry

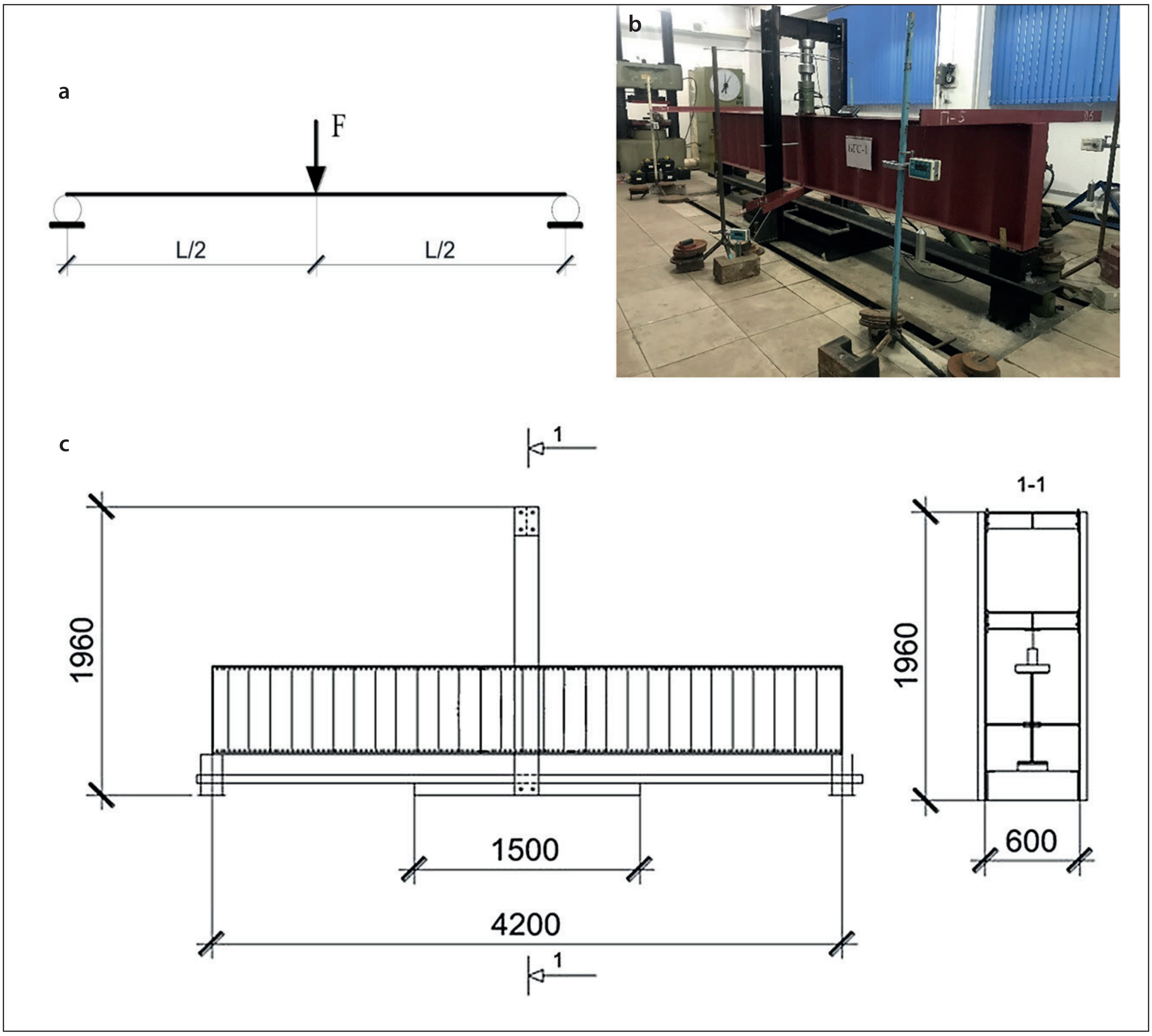

Fig. 2. Loading Scheme, and Test Stand of the Corrugated Beam: a – Loading Scheme of the Tested Model; b – Test Stand for Full-Scale Experiments; c – Experimental setup

characteristics: yield strength σ_y = 245 N/mm² and tensile strength σ_u = 370 N/mm². The actual yield strength was σ_y = 339.7 N/mm², and the tensile strength was σ_u = 435.4 N/mm²[28]. The beams were manufactured at the production facility of Yusem Tau LLP in Almaty, Kazakhstan. The general view of the corrugated beam is shown in Figure 2.

The beams were loaded using hydraulic jack DG-25 hydraulic jacks through a steel plate measuring 100×20 mm and with a length equal to the flange width (L = 150 mm). The loading schemes are presented in Figure 2.

The deformation properties of the beams were examined alongside the analysis of the stress state of the elements, as limited information is available on the deformation behavior of thin-walled corrugated webs, which is of particular interest for construction practice.

The use of the finite element method (FEM) in the Lira-Computer-aided design (LI-RA-CAD) 2022 software for numerical modeling of crane runway beams with corrugated webs was justified by its proven efficiency in solving structural mechanics problems. FEM accurately accounts for the complex geometry of corrugations, the heterogeneity of the stress-strain state, and allows for validation of results by comparing them with experimental data, as was successfully done using the test results (Table 1).

To validate the finite element method (FEM) calculations, we employed a large-scale model (scale 1:1), which allowed us to closely approximate the computa-

Table 1. Experiment Results

Maximum Load $F_{e,max,}$ kN	Bending Moment at Mid-Span M_e, kNm	Shear Force at Supports Q_e, kN	Deflection (mm) Y_t	Y_e, mm	Failure Characteristics of the Specimens
150	157.5	75	8.04	13.28	Local Buckling of the Flange

tional conditions to real-world scenarios. As a result, the discrepancy between experimental and theoretical data was found to be negligible.

The Figure 3 demonstrates the correlation between displacement and force for both experimental and numerical (LIRA) results, showing a similar trend in both cases. The numerical model closely approximates the experimental values, with minor discrepancies. At lower loads, differences are minimal, but as the force increases, the gap widens. At 150 kN, the experimental displacement is 13.28 mm, while LIRA predicts 12.90 mm, a 2.9% difference. This deviation is likely due to boundary condition imperfections and unaccounted residual stresses. Despite this, the LIRA model provides an accurate structural response assessment, with deviations remaining within an acceptable range.

In LIRA-CAD, the finite element method (FEM) is used to analyze the structural performance of crane runway beams. The beam is discretized into finite elements, and for each element, a specific type of finite element is employed to capture its structural response accurately. The software utilizes a numerical solution approach, where the element stiffness matrix defines the relationship between nodal forces and displacements. The analysis type employed in this study includes non-linear analysis, ensuring an accurate representation of the beam's performance under load. After solving the system of equations, the nodal displacements are obtained, followed by the internal forces that characterize the structural response.

Despite the robustness of the numerical modeling approach using LIRA-CAD, challenges could arise regarding the accurate definition of boundary conditions, particularly in the areas of welded joints and supports, optimization of the finite element mesh to capture the complex corrugation geometry, and potential nonlinear

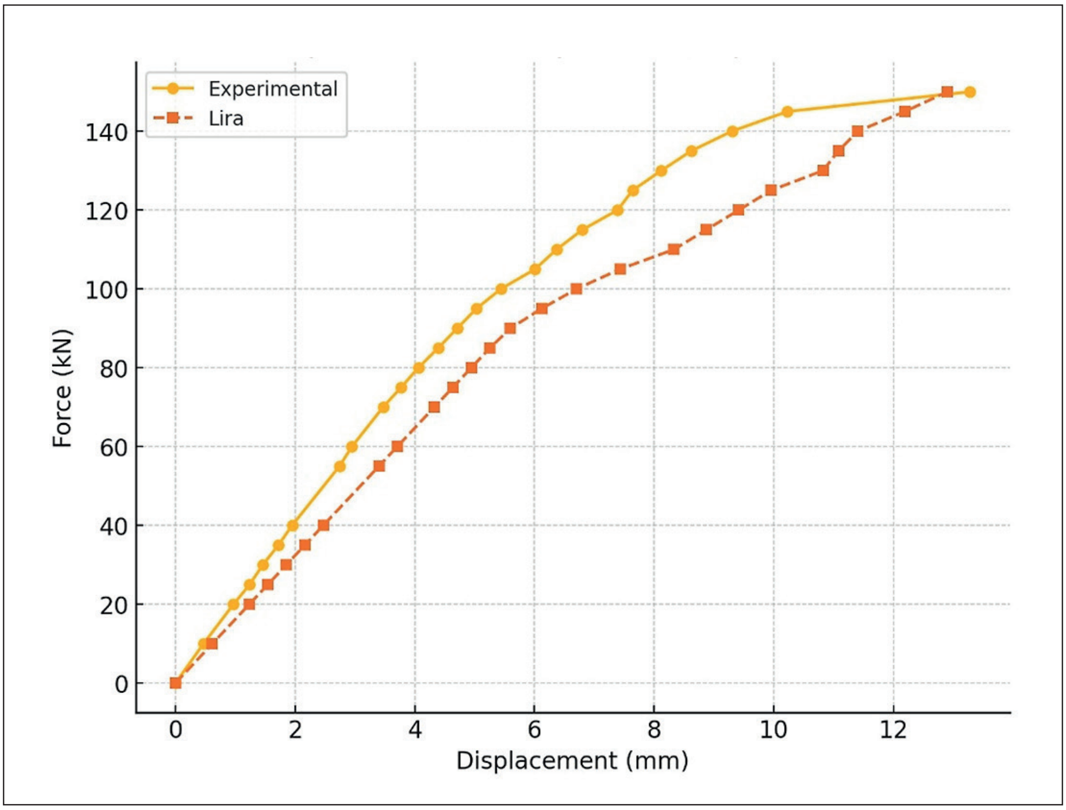

Fig. 3. Comparison of Flange Displacements in the Beam Between Physical and Computer Experiment

effects under high loads. These issues required careful verification and validation of the results.

Three load magnitudes and three sizes of crane runway beams were selected, and their deformations and stresses were analyzed. Each structure was subjected to corresponding static loads from the overhead crane wheels. The experimental investigation was carried out on a simply supported beam with a triangular corrugated web.

Experimental studies of corrugated beams are a crucial part of validating various hypotheses regarding the principles of operation and the efficiency of design solutions. Both Kazakhstani and international construction codes lack specific requirements for the thickness, length, depth, and curvature radius of corrugations.

The conducted tests enabled a comparative analysis of the deformation properties of beams with identical cross-sections under similar operating conditions and allowed verification of the computer simulation data. The results obtained from the LIRA-CAD 2022 simulations confirmed the program's suitability for further numerical studies of corrugated I-beams.

The numerical model was validated using FEM by comparing its results with experimental data from Bryantsev's study (Figure 4), confirming its accuracy and reliability. Subsequently, optimal dimensions for the corrugated web were determined, and effective parameters were identified.

Table 1 presents the results of the experimental data, including key mechanical parameters measured during the study. The table summarizes the maximum load ($F_{e,max}$) in kN, the bending moment at mid-span (M_e) in kNm, the shear force at the supports (Q_e) in kN, and the deflection values (Y_t and Y_e) in mm. The recorded values are as follows: a maximum load of 150 kN, a bending moment of 157.5 kNm, and a shear force of 75 kN. The deflection at measurement points is reported as 8.04 mm and 13.28 mm, respectively. These results provide insights into the structural performance of the tested specimens under applied loads.

Computer modeling of the beams was performed using the LIRA-CAD finite element analysis software. Boundary conditions were applied to both ends of the beam model at the nodes of the end plate surface by restricting the necessary degrees of freedom. The beam was fixed along the Y and Z axes at both ends. The material used for the web and flanges was S245 steel according to GOST 380-2005 [28]. The yield strength is σ_y = 339.7 N/mm². Since the unit of measurement in LIRA-CAD 2022 is t/m², it is converted to 34,639.76 t/m². The elastic modulus is E = 206,000 MPa, and Poisson's ratio is ν = 0.3. The ultimate relative strain under compression and tension was taken as 0.025 (2.5%). Nonlinear deformation of structures is considered in the calculation (Figure 5).

The Table 2 presents the key results of experimental testing conducted on crane runway beams. The parameters listed include the maximum applied load $F_{e,max}$ in kN, the corresponding bending moment at mid-span M_e in kNm, and the shear force at the supports Q_e in kN. Additionally, the table provides the deflection values at mid-span: theoretical deflection Y_t and experimental deflection Y_e, both measured in millimeters. The data highlights the discrepancy between theoretical and experimental deflections, which is critical for validating numerical models and improving the accuracy of future design calculations.

The difference between meshes № 3 and 4 is 0.78%, therefore the calculations were continued with №3 and a plate size of 5×5 mm.

According to the results of computer modeling, the difference in beam deflections between the physical experiment (13.28 mm) and the computer experiment (12.9 mm) is 2.9%. The discrepancy is attributed to inaccuracies in the beam installation within the test stand and the inability to fully account for all parameters in the calculation.

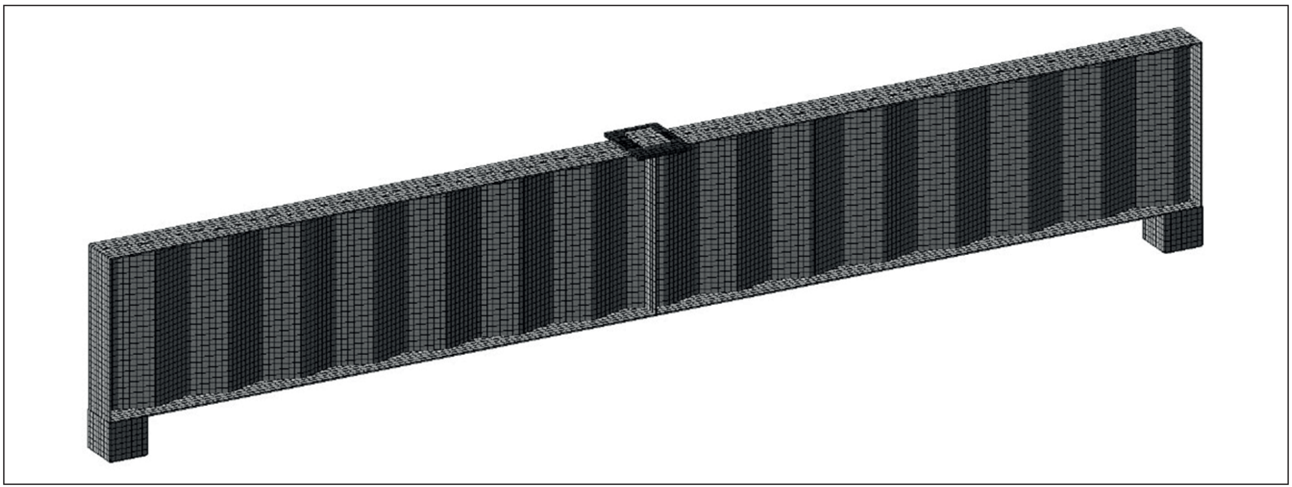

Fig. 4. Model of the Beam

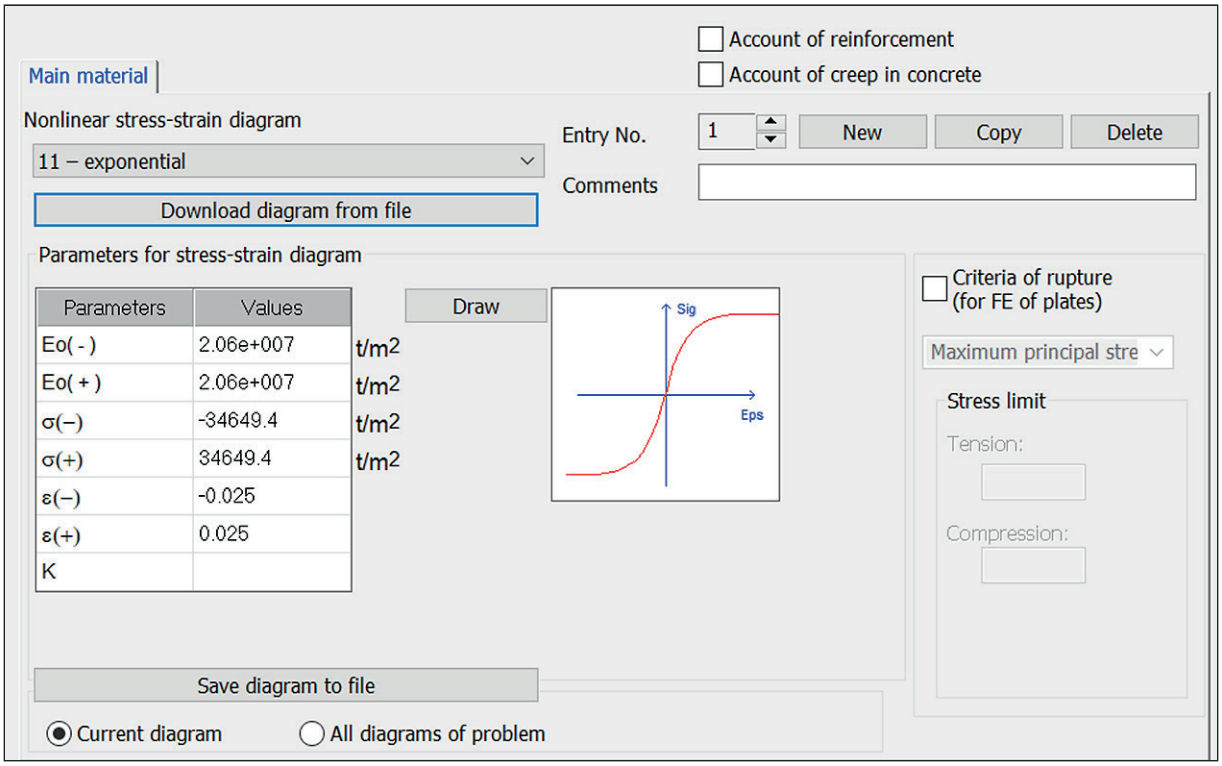

Fig. 5. Setting the Parameters for Nonlinear Material Deformation

Table 2. Results of Experimental Data

Maximum Load $F_{e,max}$, kN	Bending Moment at Mid-Span M_e, kNm	Shear Force at Supports Q_e, kN	Deflection (mm) Y_t	Y_e
150	157.5	75	8.04	13.28

Table 3. Mesh Independence Study

Mesh №	i_x, pcs	i_y, pcs	ε, mm	%
1	211	8	10,1	-
2	421	16	13,6	34,65
3	841	31	12,9	5,1
4	1681	61	12,8	0,78

The dimensional characteristics of the beam with a flat web were taken from the series of crane runway beams issued by the Central Research Institute for Steel Structures (TsNIIproektstalkonstruktsiya), Almaty, in 1982 [31].

Subsequently, models of crane runway beams with corrugated webs were developed, and numerical analyses were performed. The results were compared and described, taking into account all geometric features [32].

These coordinates, shown in Figure 6, were then input into the post-processor of the Structure Computer-aided design (SCAD) Tonus computational suite to determine the geometric characteristics. The Tonus software is designed for the generation of cross-sections and the calculation of their geometric characteristics based on the theory of thin-walled members.

Previous research (Maximov et al., 2016) has demonstrated that the implementation of a corrugated web in beams significantly enhances their strength and stability. A steel savings of up to 20% can be achieved by utilizing a thinner web. Theoretical and experimental studies conducted by A.A. Bryantsev in 2019 at the KazGASA laboratory identified optimal geometric parameters for

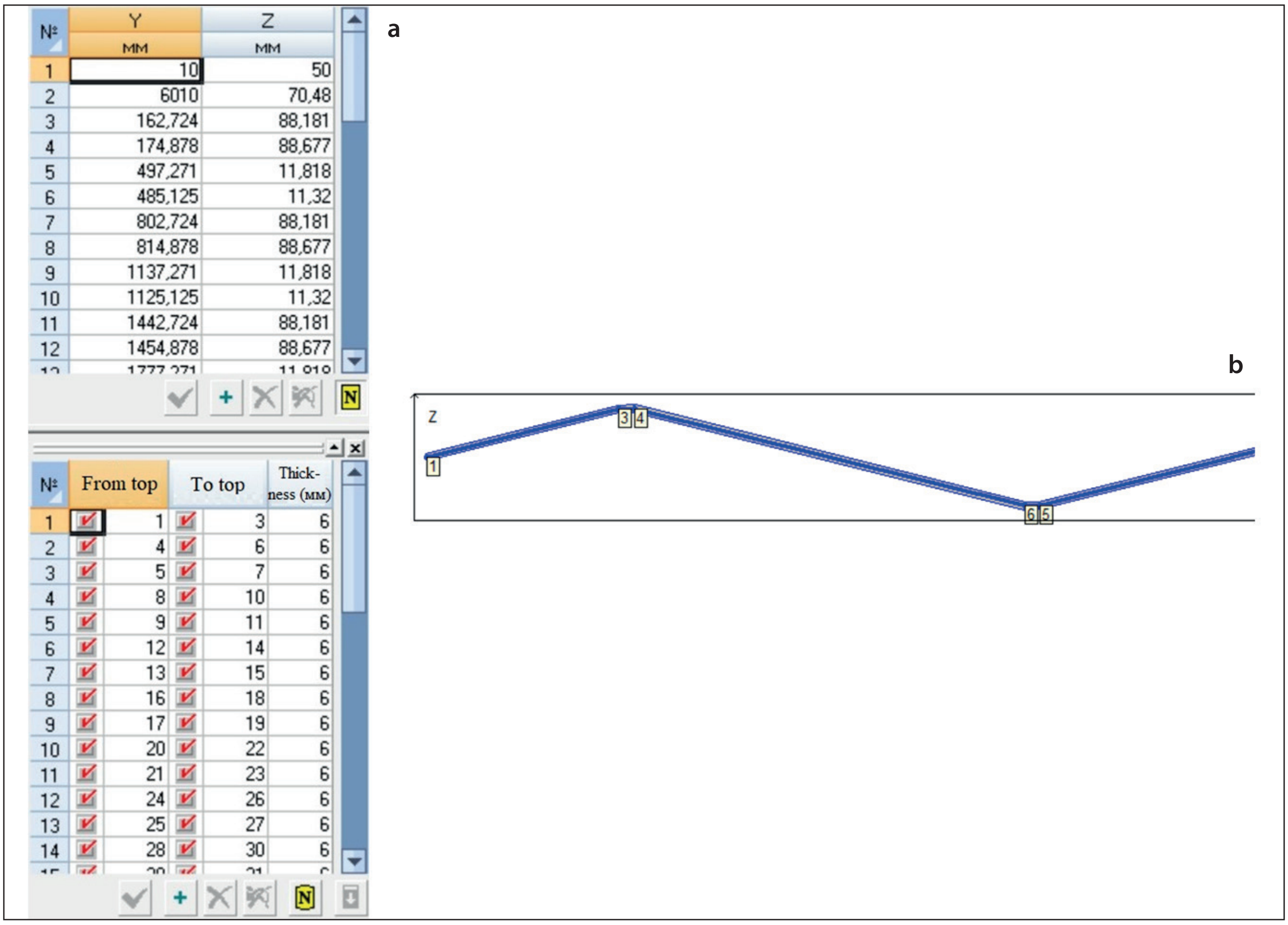

Fig. 6. Assignment of coordinates for the corrugated web 640×80×6/30 in the SCAD Tonus postprocessor: a – Coordinates; b – General view

corrugated webs with thicknesses of 6, 8 and 10 mm. The most efficient configuration is a web with a corrugation length of 480 mm and a corrugation depth of 80 mm [29].

In current study, the results differ due to the specific loading conditions and operational characteristics of crane girders. One plain web girder and eleven triangular corrugated web girders with varying profiles were selected for comparison. The reference object for comparative analysis is a girder with a plain web, illustrated in Figure 4. The dimensional characteristics of the plain web girder are presented in Table 4 [31].

The Figure 7 illustrates the geometric dimensions of a crane girder with a plain web. The web height (h_w) is 640 mm, and its thickness (t_w) is 6 mm. The upper flange has a width (b_f^1) of 250 mm and a thickness (t_f^1) of 10 mm, while the lower flange has a width (b_f^2) of 6000 mm and a thickness (t_f^2) of 10 mm. The total height of the girder (h) is 660 mm. These dimensions serve as a reference for comparative analysis with corrugated web girders in structural performance evaluation.

The coordinates of the extreme points of the corrugated web were also determined, as shown in Figure 8.

The crane girder is subjected to the load from the weight of the overhead crane. Cranes with lifting capacities of 12.5, 32, and 50/12.5 tons were selected. The corresponding wheel loads were taken as 0.95 kN, 2.25 kN, and 3.35 kN, respectively, in accordance with GOST 25711-83 [33]. The calculation considers the weight of the crane-supporting structures, the maximum force exerted by the crane wheel, and the sum of ordinate forces.

The load is applied from two crane wheels with a step equal to the crane base width B (Figure 9). For light cranes, there are two wheels on one side. The crane base for a lifting capacity of 10 tons is 4.4 m, for 30 tons is 5.1 m, and for 50 tons is 5.6 m.

Figure 10 below illustrates the application of a concentrated load of 0.95 kN from the crane wheel, without eccentricity. The analysis was performed using LIRA-CAD 2022.

The Figure 10 presents the numerical models of crane girders analyzed in the LIRA-CAD software. Model (a) represents Crane beam with a flat web, while model (b) represents Crane beam with a corrugated web. These

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Table 4. Comparative Dimensional characteristics of the plain web

h_w – web height	t_w – web thickness	b_f^1 – upper flange width	t_f^1 – upper flange thickness	b_f^2 – lower flange width	t_f^2 – lower flange thickness	h – total girder height
640	6	250	10	200	10	660
840	8	250	10	200	10	860
990	10	320	12	200	10	1012

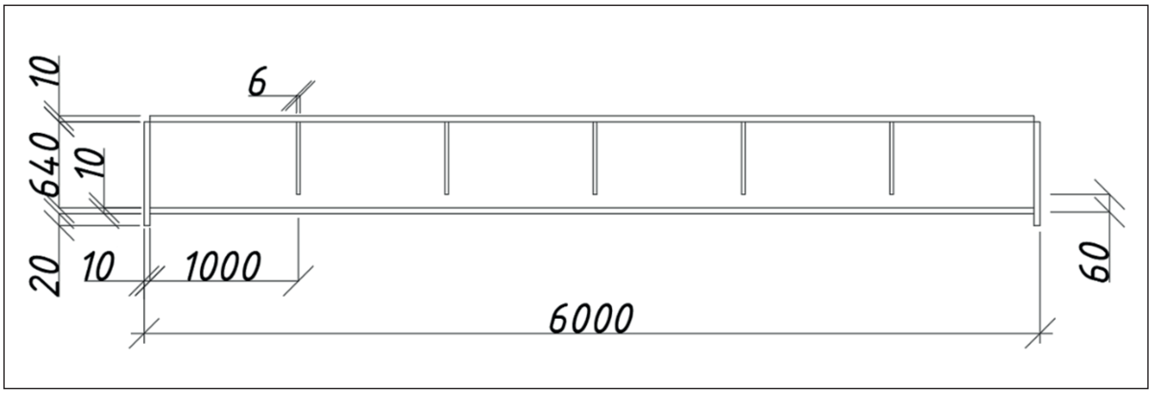


Fig. 7. Dimensions of the crane girder with a flat web

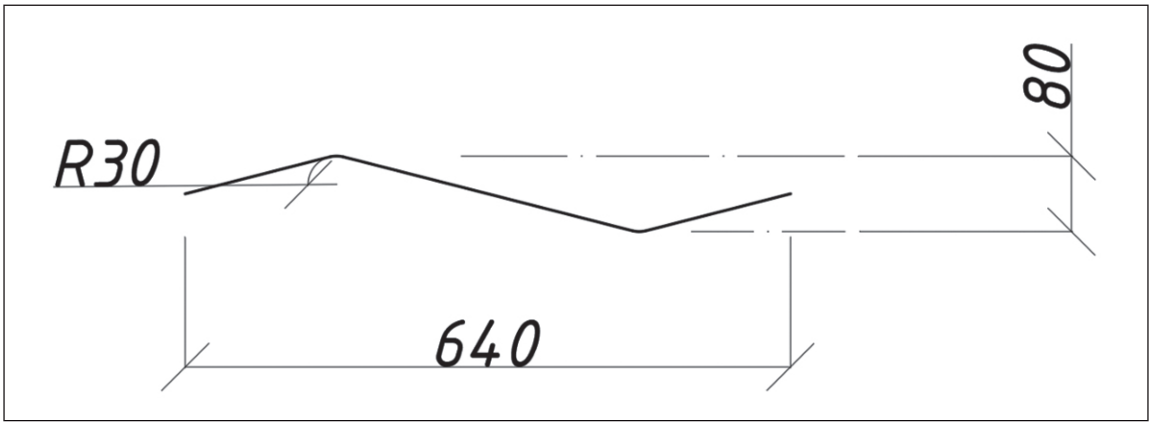


Fig. 8. Dimensions of the corrugated web 640×80×6/30

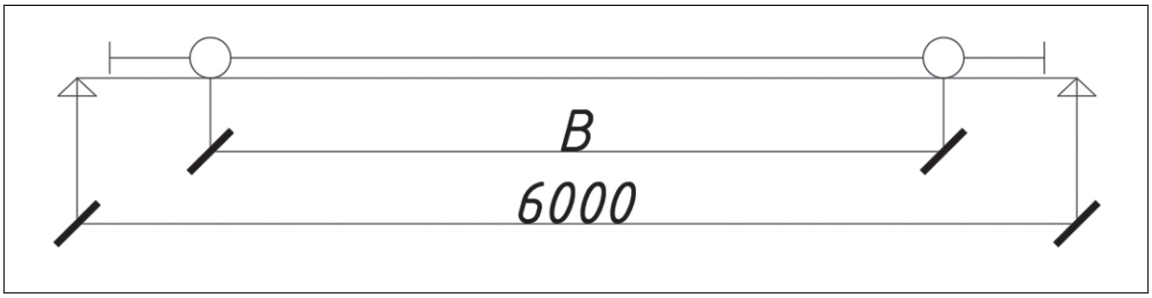


Fig. 9. Load application scheme for the crane runway beam

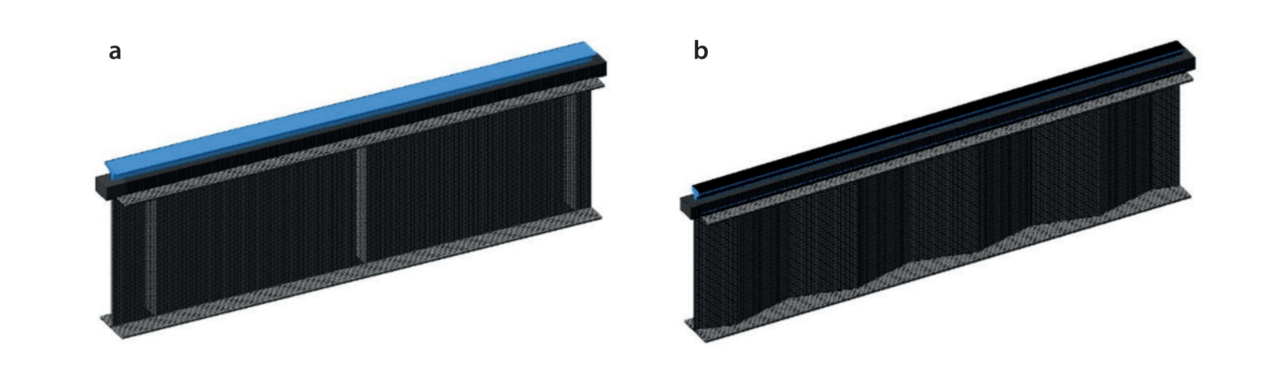


Fig. 10. Beam models in the LIRA-CAD software, where: a – Crane girder with a flat web; b – Crane girder with a corrugated web

models were developed to compare the structural performance of both configurations under crane wheel loads, evaluating parameters such as stress distribution, deformations, and load-bearing capacity.

Cost Efficiency. The cost estimation of crane runway beam fabrication was carried out, considering differences in the manufacturing process.

Input Data:

1. Steel grade: S245.
2. Steel cost: € 1.5/kg.
3. Labor costs:

Assembly and welding of components: € 0.8/kg.

Additional welding of stiffeners (only for the flat-web beam): € 0.4/kg.

4. Beam mass:

Flat-web beam: 440.7 kg.

Corrugated-web beam: 419.3 kg.

The difference in labor intensity lies in the manufacturing process of the beams. The flat-web beam requires three operations, including assembly, welding, and the additional welding of stiffeners. In contrast, the corrugated-web beam involves only two operations, assembly and welding, as stiffeners are not required. The applicable standards governing the materials and production processes include EN 10025-2, which defines requirements for hot-rolled structural steel, including the S245 grade. Additionally, EN 1090-2 specifies the execution of steel structures, outlining the requirements for assembly and welding, while EN 1993-1-1 (Eurocode 3) establishes the design principles for steel structures.

RESULTS AND DISCUSSION

The study evaluates the structural performance of crane girders with flat and corrugated webs under various loading conditions. By integrating numerical simulations and experimental testing, the analysis focuses on stress distribution, deformation performance, and load-bearing capacity. The following results highlight the advantages of corrugated-web girders in terms of mechanical efficiency and material optimization.

To further quantify these advantages, a detailed comparison between flat and corrugated web configurations is necessary. This comparison helps identify the impact of different web designs on the structural efficiency of crane runway beams.

The reduced moments of inertia and reduced moments of resistance will be compared, as a parameter was selected that remains consistent across all established corrugation shapes. This approach allows for a comprehensive evaluation of both the overall stability and the load-bearing capacity of the web.

Figure 11, 12, 13 illustrates the variation in the equivalent moment of inertia and equivalent section modulus relative to the central axis Y1 for different crane girder web types, highlighting the structural efficiency improvements achieved with corrugated web configurations compared to a flat web.

The reduced moment of inertia is calculated using the following formula:

$$\mathrm{Ieq} = \frac{1000 \cdot I}{\rho \cdot A}, \quad (1)$$

where:

I_{eq} is the equivalent moment of inertia, cm^4/kg,
I is the moment of inertia, cm^4,
ρ is the density of steel, g/cm^3,
A is the cross-sectional area, cm^2.

The reduced section modulus is calculated using the following formula:

$$\mathrm{Weq} = \frac{1000 \cdot W}{\rho \cdot A}, \quad (2)$$

where:

W_{eq} is the equivalent section modulus, cm^3/kg,
W is the section modulus, cm^3,
ρ is the density of steel, g/cm^3,
A is the cross-sectional area, cm^2.

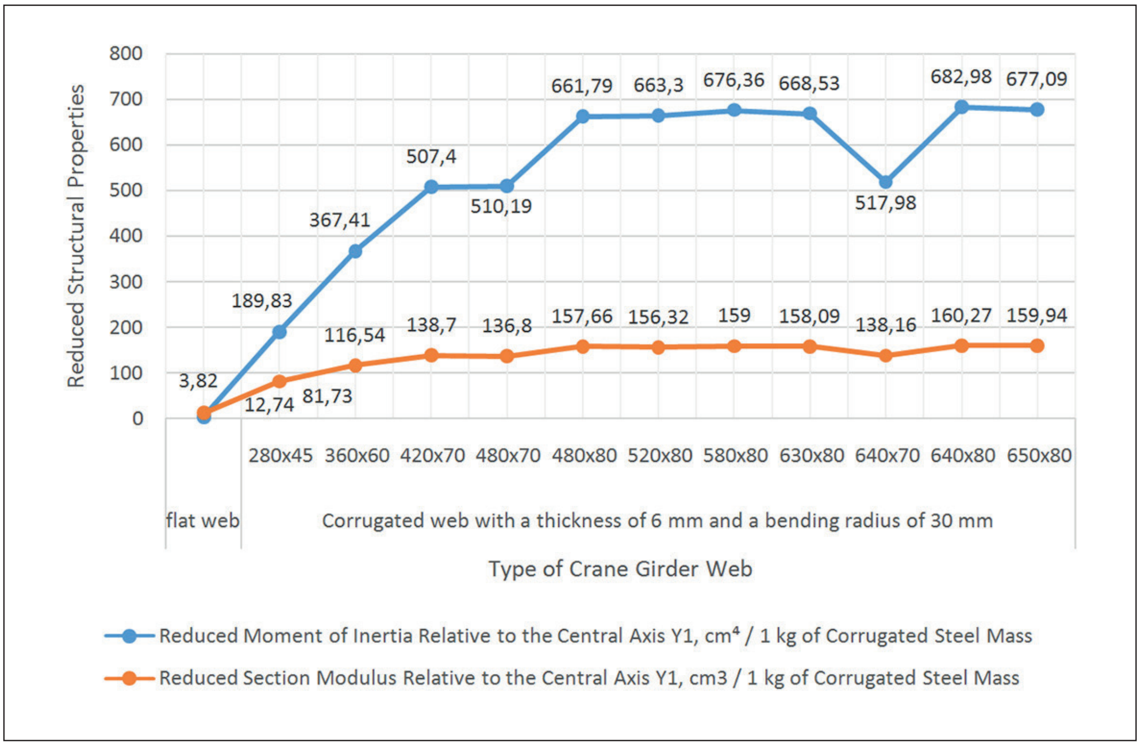


Fig. 11. Equivalent Structural Properties of Crane Girder Webs with a Thickness of 6 mm and a Bending Radius of 30 mm

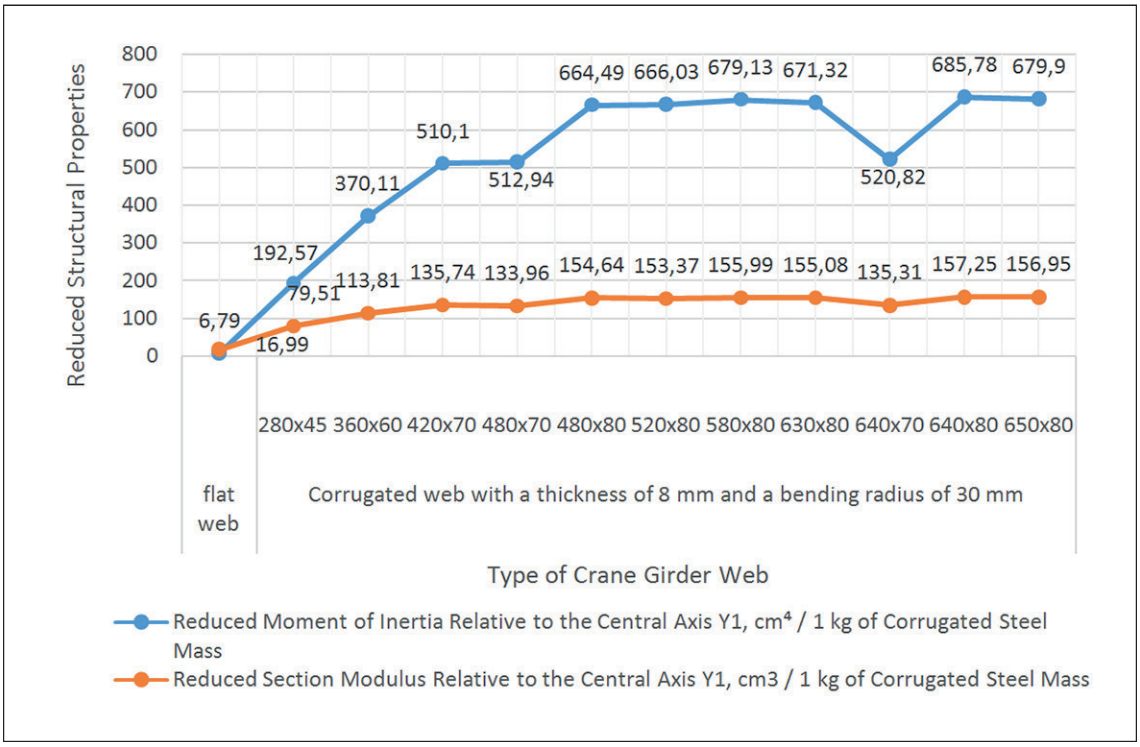


Fig. 12. Equivalent Structural Properties of Crane Girder Webs with a Thickness of 8 mm and a Bending Radius of 30 mm

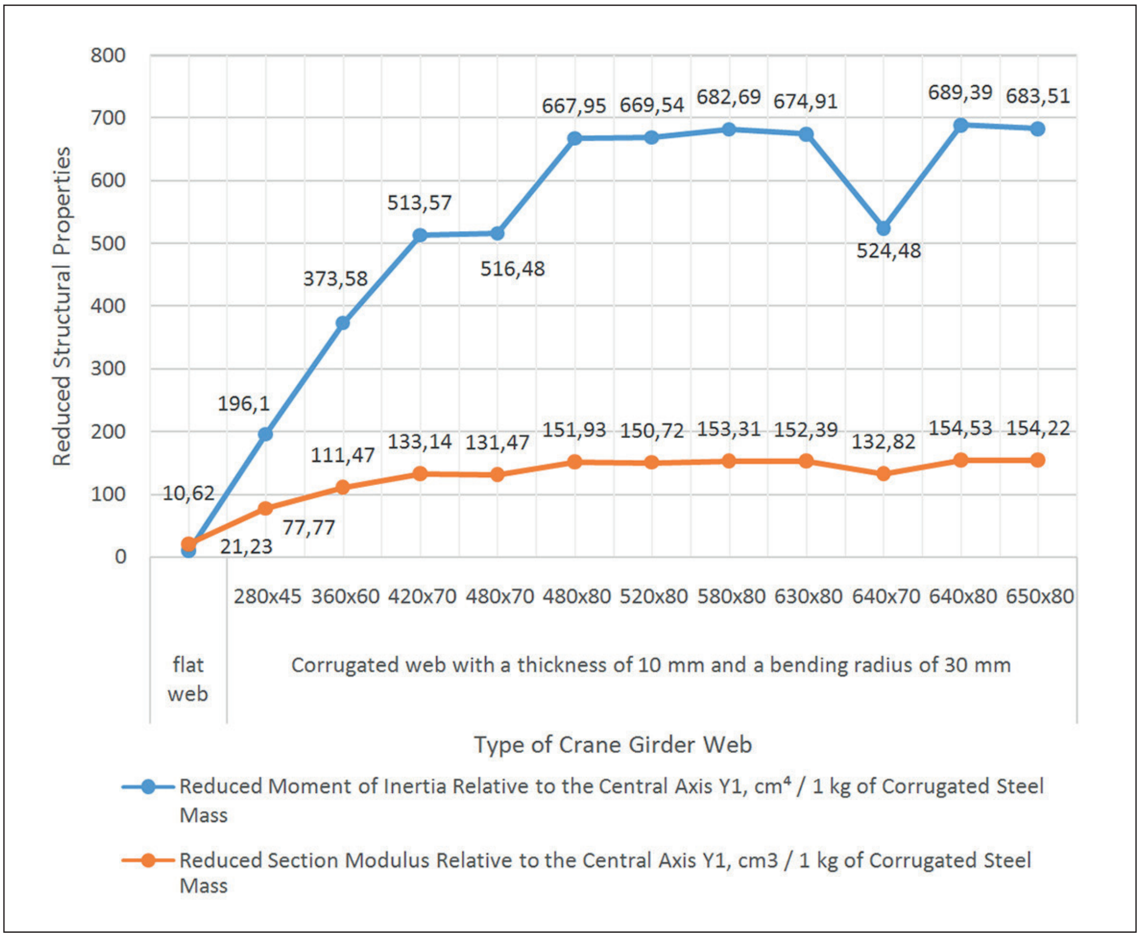


Fig. 13. Equivalent Structural Properties of Crane Girder Webs with a Thickness of 10 mm and a Bending Radius of 30 mm

The Figures 11, 12, 13 illustrate the variation in the equivalent moment of inertia and the equivalent section modulus relative to the central axis Y1 per unit mass of corrugated steel for crane girder webs with different thicknesses (6, 8 and 10 mm).

Taking into account that the flange thickness has a greater impact on the moment of inertia than the web thickness, and that the thickness is uniform in all variants except for the upper flange of the beam with a 10 mm web thickness (where the flange thickness is 12 mm), across all three thicknesses, the equivalent moment of inertia shows a clear increasing trend with the web size, reaching peak values at 640×80 for the 6 mm, 8 mm and 10 mm webs. The highest equivalent moment of inertia is observed in the 10 mm thick web, peaking at 689.39 cm^4/kg. In contrast, the lowest values are seen for the flat web across all cases, with the minimum recorded for the 6 mm web at 3.82 cm^4/kg.

The equivalent section modulus follows a similar pattern but with smaller variations. The highest values are observed in the 10 mm web at 154.53 cm^3/kg, while the lowest occur in the 6 mm web at 12.74 cm^3/kg.

Overall, increasing the web thickness enhances both moment of inertia and section modulus, indicating better structural performance. However, the efficiency gain diminishes for larger web sizes, suggesting an optimal range for thickness selection in crane girder designs.

The data presents a comparative analysis of various corrugated web configurations for metal structures with a standard thickness of 6 mm, 8 mm, 10 mm. The parameters of cross-sectional area, equivalent flat web thickness, and steel consumption provide insight into how modifications in corrugation characteristics influence structural performance. As the corrugation length increases, a positive trend is observed, with improvements in the equivalent section modulus and moment of inertia. Additionally, increasing the corrugation depth enhances these properties, indicating improved load-bearing capacity. The most optimal results are recorded for the 640×80 configuration, where the highest values are achieved.

The Figure 14 illustrates the stress characteristics of crane girder webs under different wheel loads. As the load increases from 0.95 kN to 2.25 kN, all stress values become more negative, indicating higher stress levels.

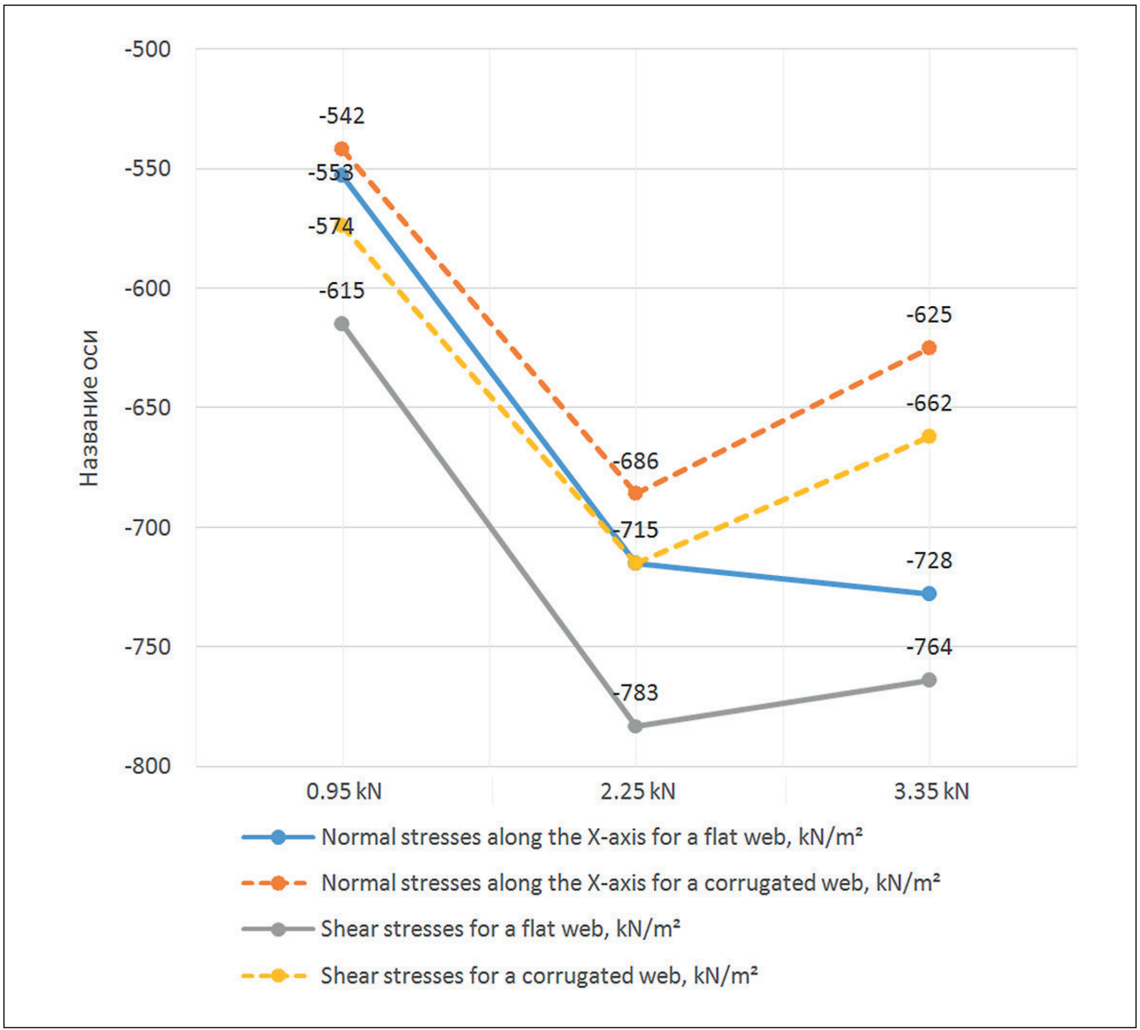


Fig. 14. Stress distribution in crane girder webs under different wheel loads

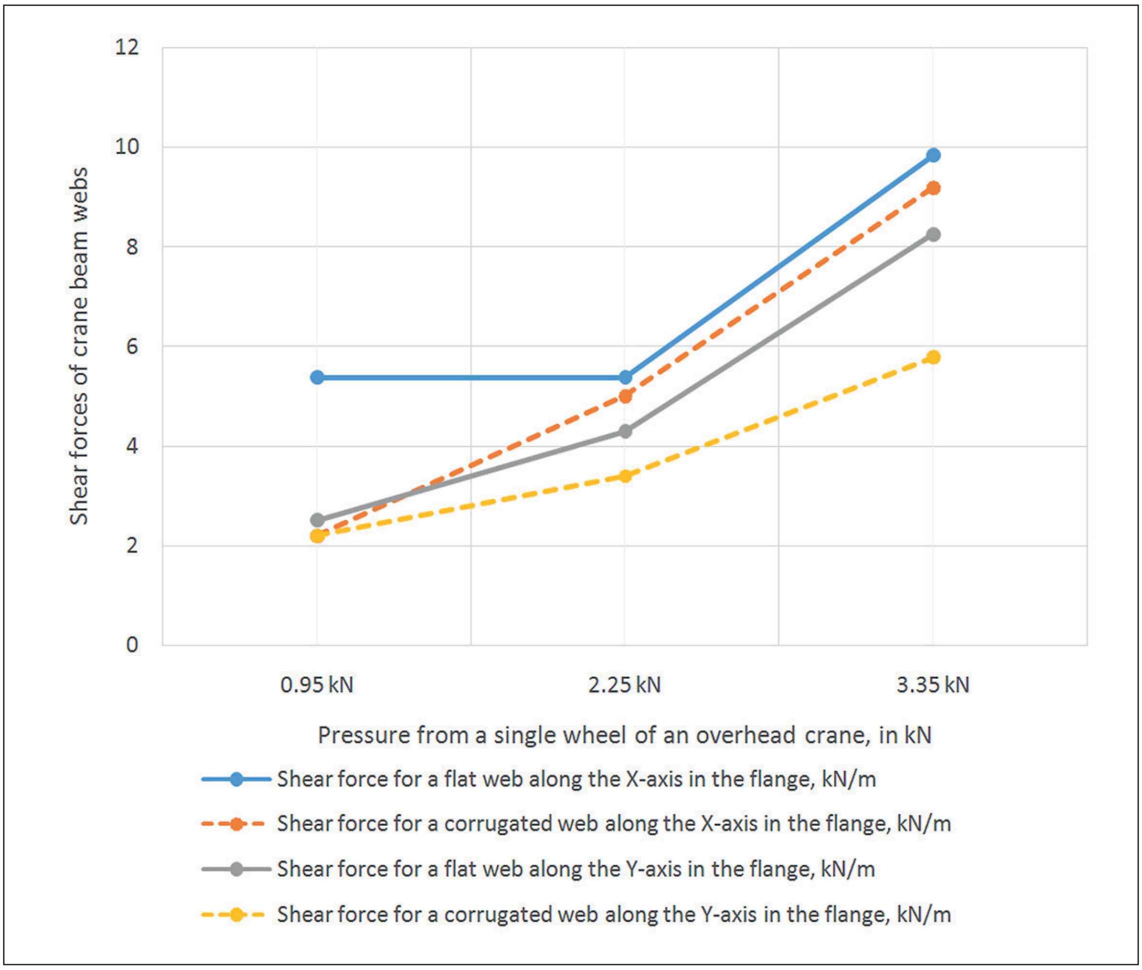
The shear stress for a flat web reaches the most negative value at –783 kN/m² under a 2.25 kN load, representing the maximum shear stress recorded. Conversely, the normal stresses along the X-axis for a corrugated web demonstrate the least negative values, with a minimum of –542 kN/m² at 0.95 kN and -625 kN/m² at 3.35 kN, indicating lower stress levels compared to the flat web. The shear stresses for both flat and corrugated webs show an increasing trend after 2.25 kN, suggesting a redistribution of forces at higher loads. These findings highlight that flat webs experience higher stresses than corrugated webs, reinforcing the structural efficiency of corrugated designs in reducing both normal and shear stresses.

The Figure 15 demonstrates the shear force distribution for flat and corrugated web crane beams under increasing loads. The maximum shear force along the X-axis in the flange is observed for the flat web at 10.5 kN/m under 3.35 kN of load, while the corrugated web reaches 10 kN/m under the same load. At 0.95 kN, the shear force along the X-axis is significantly lower, with values of 5.5 kN/m for the flat web and 5 kN/m for the corrugated web. For the shear force along the Y-axis in the flange, the flat web reaches a peak of 8.5 kN/m at 3.35 kN, while the corrugated web records 6kNt/m under the same conditions. At the lowest load of 0.95 kN, shear forces remain minimal, with values of 2.5 kN/m for the flat web and 2. kN/m for the corrugated web.

The trend indicates that shear forces increase proportionally with applied load, with flat web configurations generally experiencing higher shear stresses than their corrugated counterparts. However, the corrugated web shows a more uniform stress distribution, reducing the peak values compared to the flat web.

The displacements of the flanges along the X-axis are consistently lower for the corrugated web compared to the flat web, indicating improved structural stability under increasing crane wheel pressure, as shown in Figure 16.

The Figure 16 illustrates the displacements of the flanges along the X-axis for both flat and corrugated web configurations under increasing pressure from a single



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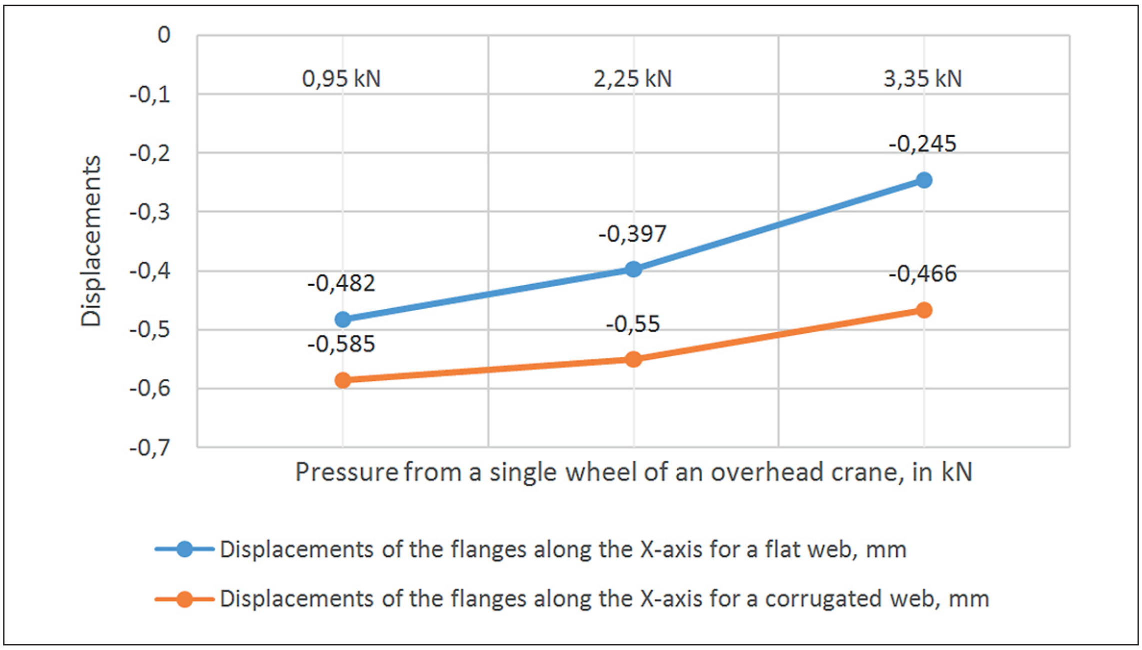

Fig. 16. Flange Displacements Along the X-Axis Under Different Load Conditions

Table 5. Cost comparison

Beam Type	Total Mass (kg)	Material Cost (€)	Welding Cost (€)	Total Cost (€)
Flat-Web Beam	440.7	661.05	528.84	1137.70
Corrugated-Web Beam	419.3	628.95	335.44	940.20

wheel of an overhead crane. Although the displacement values for the corrugated web are consistently greater than those for the flat web, both remain within acceptable limits.

All three graphs consistently demonstrate the advantages of the corrugated web over the flat web in terms of structural performance. The graphs illustrate the differences in the stress-strain characteristics of flat and corrugated web crane girders. In the flat web (represented by the blue and gray lines), stresses are higher than in the corrugated web (orange and yellow lines), indicating a greater susceptibility of the flat web to both normal and shear stresses. The corrugated web, in turn, distributes loads more efficiently, reducing localized stress concentrations.

In terms of shear forces, the flat web (solid lines) experiences higher transverse forces than the corrugated web (dashed lines) along both the X and Y axes. This suggests that the flat web is more susceptible to transverse forces, whereas the corrugated web redistributes loads, minimizing shear force concentration.

Additionally, the deflection magnitude in the flat web (blue line) is higher than in the corrugated web (yellow line), indicating that the corrugated web exhibits greater stiffness, thereby reducing vertical deformations in the structure.

Since the connection of the flanges to the web is performed using automatic welding, the influence of residual welding stresses was not analyzed separately in this study and was not included in the computational model. The primary focus was placed on the general stress-strain states of the structure under static loading. It is assumed that the effect of welding-induced stresses may have a localized nature, which does not significantly impact the overall structural strength within the adopted assumptions.

Overall, the corrugated web demonstrates superior performance by reducing stresses, transverse forces, compared to the flat web, highlighting its structural efficiency.

Economic Analysis

A comparative cost analysis was conducted for both flat-web and corrugated-web crane runway beams. The analysis takes into account material costs, welding and assembly costs, and the final total cost of manufacturing each type of beam.

For the flat-web beam, the material cost is calculated as 661.05 €, based on a total weight of 440.7 kg and a steel price of 1.5 €/kg. The manufacturing process involves three operations: assembly and welding of elements, as well as welding of stiffeners. The cost for assembly and welding is 352.56 €, while the additional cost for welding stiffeners is 176.28 €. Consequently, the total welding cost amounts to 528.84 €, leading to a final total cost of 1137.70 €.

In contrast, the corrugated-web beam requires fewer operations, as no stiffeners need to be welded. The material cost is slightly lower at 628.95 €, due to a reduced total weight of 419.3 kg. The welding and assembly cost is calculated at 335.44 €, resulting in a final total cost of 940.20 €.

The comparative results demonstrate that the corrugated-web beam is a more cost-effective option due to lower material consumption and the elimination of stiffener welding, reducing both labor intensity and overall manufacturing costs in Table 5.

CONCLUSION

The finite element method (FEM) in LIRA-CAD 2022 has proven effective for modeling crane runway beams with corrugated webs, accurately accounting for complex geometry and stress-strain heterogeneity. The comparison between experimental and numerical results (Figure 3) demonstrates a close correlation, with deviations remaining within an acceptable range. At 150 kN, the experimental displacement was 13.28 mm, while the LIRA model predicted 12.80 mm, showing a 2.9% difference due to boundary condition imperfections and unaccounted residual stresses. Despite minor discrepancies, the numerical model provides a reliable assessment of structural performance.

The results of this study highlight the structural advantages of corrugated web crane girders over their flat web counterparts. The findings confirm that the corrugated web provides better load distribution, reduces stress concentrations, and improves overall stiffness, which aligns with previous research on the mechanical efficiency of corrugated steel structures.

In terms of stress characteristics, the corrugated web consistently exhibited lower normal and shear stresses compared to the flat web, as demonstrated by the graphical data. This reduction in stress values suggests that the

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corrugation enhances the web's ability to redistribute loads, minimizing localized stress peaks and potential structural weaknesses. These findings are consistent with earlier studies on the mechanical performance of corrugated plates, which indicate improved resistance to buckling and increased durability under cyclic loading conditions.

The analysis of shear forces further supports the structural efficiency of the corrugated web. The flat web showed higher transverse forces along both the X and Y axes, indicating a higher susceptibility to shear deformations. Conversely, the corrugated web exhibited a more uniform force distribution, which can contribute to longer service life and reduced maintenance needs.

Regarding vertical displacements, the results demonstrate that the corrugated web exhibits significantly lower deflections than the flat web. The increased stiffness observed in the corrugated web suggests improved stability under varying load conditions, a key factor in ensuring the long-term reliability of crane girders. This outcome aligns with numerical simulations and experimental studies on the deformation behavior of corrugated steel beams, where optimized wave geometries effectively enhance rigidity without excessive material consumption.

Despite the evident advantages of the corrugated web, further investigations are necessary to refine design methodologies and optimize geometric parameters for specific applications. Future research should focus on parametric studies analyzing different corrugation shapes, angles, and thicknesses, as well as experimental validation under dynamic loading conditions.

Overall, the study confirms that the use of corrugated webs in crane girders leads to significant improvements in stress distribution, shear force reduction, and deflection control. These results contribute to the broader understanding of corrugated steel applications in structural engineering and support the continued development of innovative, high-performance design solutions.

The obtained conclusions are specific to the investigated triangular corrugation profile and cannot be directly extrapolated to other corrugation geometries. Significant differences in the shape and configuration of corrugations, such as trapezoidal, sinusoidal, or rectangular profiles, result in variations in structural behavior, load distribution, and stress concentration. Therefore, additional studies are required to assess the applicability of these findings to alternative corrugation profiles.

In future studies, additional analysis should be conducted to account for potential residual stresses from welding in order to assess their impact on the structural performance and compare the results with existing experimental and regulatory data.

REFERENCES

1. Li J., Yu J., Li Y. Drop Tests and Numerical Simulation of Composite Beams with Corrugated Web. *Nanjing Hangkong Hangtian Daxue Xuebao/Journal of Nanjing University of Aeronautics and Astronautics* 2023: 55. https://doi.org/10.16356/j.1005-2615.2023.01.006

2. Al-Mawashee, H.S. Al-Kannoon, M.A.A. Flexural Strength of Castellated Beams with Corrugated Webs. In Proceedings of the Journal of Physics: *Conference Series*. 2021; 1973.

3. Lukačević I., Ungureanu V., Numerical Parametric Study on Corrugated Web Built-up Beams with Pinned End Supports. *In Proceedings of the Cold-Formed Steel Research Consortium Colloquium*; 2022.

4. Kováč M., Ároch R. Influence of Imperfections in the Design of Crane Runway I-Beams. *Conference papers*. 2023; 6. https://doi.org/10.1002/cepa.2302

5. Euler M., Kuhlmann U., Fatigue Verification of Crane Runway Beams According to Eurocode 3. *Stahlbau*. 2019;88. https://doi.org/10.1002/STAB.201900093

6. Agüero A., Baláž I., Koleková Y., Moroczová L. New Interaction Formula for the Plastic Resistance of I- and H-Sections under Combinations of Bending Moments My, Ed, Mz, Ed and Bimoment BEd. *Structures*. 2021;29. https://doi.org/10.1016/j.istruc.2020.11.059

7. Dürr A., Dreiling A., Bartenbach J. Existing Crane Runway Girders and Crane Runway Supporting Structures: Assessing & Evaluation, Damage Profiles and Further Operation. *Stahlbau*. 2019; 88. https://doi.org/10.1002/STAB.201900091

8. Ellifritt D.S., Lue D.M. Design of Crane Runway Beam with Channel Cap. *Engineering Journal*. 1998; 35. https://doi.org/10.62913/engj.v35i2.699

9. Dakov D., Belev B. Durability Issues Related to Detailing Links of Steel Crane Runway Beams to Columns. In Proceedings of the IABSE Congress. Christchurch 2020: *Resilient Technologies for Sustainable Infrastructure – Proceedings 2020.*

10. Seeßelberg C. On the Economic Design of Rolled Section Runway Beams for Top Mounted Overhead Cranes. *Stahlbau*. 2002;71. https://doi.org/10.1002/stab.200202190

11. Kossakowski P., Wciślik W., Bakalarz M. Failure of the Overhead Crane Runway. *MATEC Web of Conferences*. 2019;284. https://doi.org/10.1051/matecconf/201928409001

12. Citarelli S., Feldmann M. Fatigue Failure of Runway Beams Due to Wheel Loads. *ce/papers* 2019; 3. https://doi.org/10.1002/cepa.1110

13. Caglayan O., Ozakgul K., Tezer O., Uzgider E. Fatigue Life Prediction of Existing Crane Runway Girders. *J Constr Steel Res*. 2010;66. https://doi.org/10.1016/j.jcsr.2010.04.009

14. Keilpflug F., Kamenzky R., Alarcón D.J., Mallareddy T.T., Blaschke P. Structural Health Monitoring on Industrial Structures Using a Combined Numerical and Experimental Approach. *In Proceedings of the Conference Proceedings of the Society for Experimental Mechanics Series*. 2020.

15. Mudenda K., Kabani M. A Proposed Approach for Obtaining the Shear Centre and Monosymmetry Constant for an I-Section Beam with a Welded Channel Cap. *International Journal of Steel Structures*. 2020;20. https://doi.org/10.1007/s13296-020-00411-8

16. Kornilova A.V., Safina L.K. On the Issue of the Admissibility of Defects in the Lower Chord of Crane Beams. *Bezopasnost' Truda v Promyshlennost.i* 2023; 2023. https://doi.org/10.24000/0409-2961-2023-6-23-28

17. Kovacevic S., Markovic N., Ceranic A. Bendic, M. Unfavorable Imperfection Shapes in Steel Plate Girders for Web Local Crippling. In Proceedings of the *Proceedings of the Annual Stability Conference Structural Stability Research Council*. 2021.

18. Kirill, N. Nikolay, L. Igor, G. Crane Runway Beams: Endurance Test. 2017.

19. Bessimbayev Y.T., Niyetbay S.E., Awwad T., Kuldeyev E.I., Uderbayev S.S., Zhumadilova Z.O., Zhambakina Z.M. The Creation of Geotechnical Seismic Isolation from Materials with Damping Properties for the Protection of Architectural Monuments. *Buildings*. 2024;14:1572. https://doi.org/10.3390/buildings14061572i

20. Moga, C. Drăgan, D. Nerișanu, R. Effects of Shear Lag in Steel Box Girders of a Crane Runway. Ovidius University Annals of Constanta - Series Civil Engineering 2020; 22. https://doi.org/10.2478/ouacsce-2020-0003

21. Citarelli S., Feldmann M. Derivation of a New Fatigue Class for Top Flange to Web Junctions of Runway Beams. *In Proceedings of the Procedia Structural Integrity*. 2010;19.

22. Kraus M., Mämpel S., Crisan A. Influence of Rails on the Stability of Crane *Runway Girders*. *ce/papers*. 2017; 1. https://doi.org/10.1002/cepa.143

23. Sitthipong S., Meengam C., Chainarong S., Towatana P. Design Analysis of Overhead Crane for Maintenance Workshop. *In Proceedings of the MATEC Web of Conferences*. 2018; 207.

24. Movaghati S. Strengthening Beam Sections of Industrial Buildings against Lateral Torsional Buckling. *In Proceedings of the Structural Stability Research Council Annual Stability Conference*. 2019; 2.

25. Özkılıç Y.O., Bozkurt M.B. Numerical Validation on Novel Replaceable Reduced Beam Section Connections for Moment-Resisting Frames. *Structures* 2023; 50. https://doi.org/10.1016/j.istruc.2023.02.027

26. Wei G.Q., Dong H.T., Li Y., Fan Q. Mechanical Performance of Crane's Main Girders with Corrugated Webs. *Lecture Notes in Electrical Engineering*. 2015; 286. https://doi.org/10.1007/978-3-662-44674-4_23

27. Kettler, M. Unterweger, H. Ebner, D. Lokale Spannungen in Kranbahnträgern Mit Längssteifen: Experimentelle Und Numerische Untersuchungen. *Stahlbau* 2021: 90. https://doi.org/10.1002/stab.202000069

28. Bryantsev A.A., Absimetov V.E., Lalin V. V. The Effect of Perforations on the Deformability of Welded Beam with Corrugated Webs. *Magazine of Civil Engineering*. 2019; 87. https://doi.org/10.18720/MCE.87.2

29. GOST 380-2005. Carbon steel ordinary quality. 2005. Available online: https://meganorm.ru/Data2/1/4293837/4293837742.pdf (accessed on 9 Decembet 2005).

30. Bryantsev A., Absimetov V., Laboratory Tests of Welded Corrugated Beams with Perforations. *In Lecture Notes in Civil Engineering*. 2020; 70.

31. Melnikov N., Kuznetsov V., Bakhtutskiy V., Shuvalov L., Sorokina I., Assortment from Series 1.426.2-3 Steel crane beams. TsNIIProektstalkonstruktsiya 1982; 1.

32. GOST 25711-83 Electric overhead crane's general purpose with loading capacity from 5 to 50 tons Available online: Available online: https://meganorm.ru/Data2/1/4293837/4293837742.pdf (accessed on 12 April 1983).

ADDITIONAL INFORMATION

The authors declare that generative artificial intelligence technologies and technologies based on artificial intelligence were not used in the preparation of the article.

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Dias A. Okanov – writing an article scientific editing of the text identification of dependencies conducting the experimental part of the study.

Aleksandr A. Bryantsev – scientific guidance research concept development of methodology scientific text editing final conclusions.

Mehmet B. Bozkurt – preparation of samples writing an article processing of experimental data accumulation of material.

Sayat E. Niyetbay – conducting a literary review conducting the experimental part of the study.

Zhangazy N. Moldamuratov – conducting a literary review conducting the experimental part of the study.

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