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ТРАНСПОРТНЕ БУДІВНИЦТВО

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Modern Designs of Arch Load-Bearing Systems of Public Buildings

Purpose. The main purpose of the publication is a comparative analysis of the structural variants of the load-bearing arch system for public buildings with insulated covering. The relevance of the work is associated with the modern trend of creating public buildings of various types without internal intermediate supports. The subject of the work is also due to the desire to apply for this purpose known arch systems, which allow to significantly improve the architectural and aesthetic indicators of the building. **Methodology.** To achieve this goal, a project of a grocery and non-food store located in the Lviv region of Ukraine was considered. A circular steel arches with a span of 17.5 m and a sweep angle of 90 º is the basis of its supporting frame. During the analysis, a comparison of different types of arch cross-sections was performed – welded and rolled I-beam, welded rectangular pipe and seamless round pipe. The finite element method based on the SCAD design and computing complex (Ukraine) was used for the research. **Findings.** The comparative analysis made it possible to determine the geometry of the most rational constructive solution for the given conditions in the form of an I-beam welded cross-section. All other types of cross-sections considered have a lower level of efficiency and manufacturability of manufacture. Additionally, the main «weak» points of such a cross-section were identified and recommendations were given for their elimination. **Originality.** It consists in the fact that the comparative analysis made it possible to assess the possibility of using an arched load-bearing system as a load-bearing element of an unsupported frame of a public commercial building with an insulated roof structure. **Practical value.** It consists in the fact that a structural solution of a small-span steel arch in the form of a welded I-beam has been developed and proposed for practical implementation, which turns out to be approximately 1.5 times less material-intensive than possible analogues. The nature of the distribution of the material efficiency coefficient for given construction conditions has also been obtained.

Keywords: steel arch; supporting frame of a building; welded I-beam; public building; grocery and non-food store

Introduction

Public buildings are nowadays the main place of live communication between people, where they can not only fulfil their social needs, but also have the opportunity to directly contact each other. Surprisingly enough, in the 21st century, due to the extremely powerful and massive development of various means of video communication, the problem of off-line communication is becoming more acute. Therefore, public buildings, along with their direct functions, are increasingly taking on a communicative social function. It is no wonder that they occupy a special place in the modern classification of buildings and structures [1].

Traditionally, public buildings solve a fairly wide range of public tasks, such as providing educational and training processes, providing health and recreation services, creating conditions for leisure and entertainment, providing public services,

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social protection, conducting scientific research and solving design and engineering problems of various levels of complexity, and organising public utilities. However, a significant group of public buildings consists of commercial buildings. And while with respect to non-food products, every year an increasing part of the retail sector is moving to the sphere of direct Internet services, retail space remains necessary for food products. This is due to people's psychology, as people perceive food and the process of eating as something that should be available physically, i.e. off-line. At the same time, people also need to smell the food, which significantly reduces the volume of online sales. Therefore, it is public buildings for food trade and catering that remain the centre of live communication that humanity increasingly seeks in the third millennium.

With this in mind, architects and engineers are also trying to contribute to this process by creating architecturally attractive and imposing commercial buildings. For this purpose, unconventional roof types, non-standard planning solutions or special building materials are often used. Among the engineering systems, arched structures are in particular demand. Such systems have been known since ancient times and gained a special flourishing during the Middle Ages, when their operation and force transmission scheme gradually began to become clear to architects (Fig. 1).

They allow you to cover quite large spans, creating a completely free interior space without additional intermediate supports. However, the «price» for this is the need to arrange special spacers, which often significantly increase the cost and complexity of the object [2, 19]. Therefore, arch systems are currently used mainly for light industrial and warehouse buildings (Fig. 2). To reduce the loads and, accordingly, the bracing forces, the coating of such systems does not contain insulation, which is unacceptable for public buildings. Therefore, the question arises of developing a simple arch system that is also suitable for providing the required temperature and humidity conditions for human habitation.

Purpose

In view of the above, the main purpose of this publication is to analyse possible constructive options for a small span load-bearing arch system for a public building.

Methodology

A food and non-food store in one of the districts of the Lviv region of Ukraine was chosen as a base object for consideration. The general view of the facility is shown in Fig. 2, *a*, and the model of its constructive solution in Fig. 2, *б*.

The building has a rectangular shape of the main part with dimensions of 50.77x17.6 m. In terms of architectural and planning solutions, it meets the requirements of current Ukrainian standards [6, 7]. Its main parameters are shown in Table 1. The complex frame consists of thin-walled pleated arch profiles of trough-shaped cross-section and rigid steel structures (arches, purlins, bracing). The folded arch structures are made up of U-shaped bent profiles manufactured by Wedgor metal building systems (USA). The profiles and their cross-sectional proportions are of the MARVELLE type. The profiles (SCAT) are manufactured by Sunward-Ukraine LLC using equipment and under licence from Sunward Corporation. SCAT profiles are installed on top of a rigid frame. The arches of the frame are spaced at an interval that is a multiple of the width of the SCAT profiles along the building.

The structural scheme is based on arched load-bearing elements in the form of circular arches with a span of 17.5 m and a sweep angle of 90º. The spacing of the arches is 3.43 m and was chosen in accordance with the natural and climatic conditions of the construction site, as specified in the Ukrainian standard [5]. The arches are connected by longitudinal purlins made of closed bent-welded profiles. There are five purlins along the span between the arches. Along the length of the building, there are transverse bracing blocks and vertical walls that serve as diaphragms. The braced lattice is made of diamond-shaped corners and a square tube profile according to standards [9, 10, 12]. The spin frame structures are made of shaped tubes. The spacers are connected to the posts by means of assembly welding.

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Table 1

Technical characteristics of supermarket

Characteristic	Value
Land area	0.2209 ha
Building area	1393.7 m^2
Number of floors	1
Total area	1242.1 m^2
Construction volume	8884.7 m^3
Number of workplaces	35 people
Fire resistance class	III
Rentable area	1236.9 m^2
Projected area	1158.9 m^2
Trading floor area	817.9 m^2

a

b

Fig. 1. Arch systems:
a – ancient buildings; *b* – modern buildings
(for materials on the site https://www.google.com/imgres?imgurl=https%3A%2F%2Fspbsmk)

The load and impact absorption, structural integrity and rigidity of the frame are ensured by the integrated operation of the arch-type folded structures (SCAT) and the rigid reinforcement frame. The joint operation of the SCAT and the rigid frame is ensured by fastening the SCAT profiles along the entire length of the upper arch boom and additional fasteners on the purlins. Fastening to the

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upper arch booms is provided using M8 bolts of strength class 8.8. The adjacent profiles are each attached to the upper arch booms with a 250 mm spacing.

The consequence class of the building in accordance with the standard [11] is CC2, and the category of responsibility of the structure in accordance with the standard [4] is A. The seismicity of the construction area according to the standard [3] is 6 points, which does not require additional structural anti-seismic measures. Therefore, only traditional natural and climatic loads were considered as the main loads in the analysis of the facility operation.

The steel structures of the building were designed in accordance with the requirements of the standard [8], and the total deformations were limited to the requirements of the standard [9].

The analysis of the steel frame of the building also took into account the requirements of the Chinese standard [18, 19], which in general were somewhat stricter than the requirements of the national standards of Ukraine.

The analysis was carried out with the aid of one of the most widely used numerical methods of structural mechanics in the world – the finite element method [14, 20]. Its practical implementation was envisaged on the basis of the SCAD design and computing complex, Ukraine [15].

Findings

First of all, we analysed the main structural variant of the arch, which was proposed during the development of the design documentation. It is a welded double-T section (height H = 450 mm, width W = 100 mm, steel C345), the lower flange is reinforced with sheet metal (Fig. 3, *a*).

According to the results of the analysis, the cross-sectional efficiency coefficient was obtained to be 0.66 (Fig. 4). This leaves a certain reserve for the use of the bearing capacity. The mass of one arch is 1377 kg. It was also found that the reinforcement of the lower flange with an additional sheet is necessary to ensure the standard flexibility. In turn, the analysis revealed that the purlins have a utilisation factor of 1.33.

The envelope diagrams of the internal force distribution were obtained from the analysis: N – longitudinal force, Q – transverse force, M – bending moment (Fig. 5).

To improve the situation, the following changes to the frame structures are recommended, namely:

– reducing the height of the arch section by 110 mm, which for the final version is 340 mm;

– increasing the width of the flanges by 20 mm, which for the final version is 120 mm – this makes it possible to remove the lower reinforcing sheet;

– increasing the cross-section of the square tube purlins from 200x200x6 to 200x200x8.

The resulting final cross-section with all the proposed design improvements is shown in Fig. 3, *б*. In this case, the efficiency coefficient is 0.88, and the mass of the arch has decreased to 945 kg, which is 432 kg less than in the original version.

The analysis also considered additional design options:

– rolled I-beam section, I-beam 30U (steel C345);

– cold-formed welded rectangular section, rectangular square profile 350x152x8 (steel C345);

– hot-rolled round tube 325x8 (steel S255).

It is worth noting that the rolled I-beam section 30U turned out to be similar in terms of performance to the final design, but this section cannot be bent. At the same time, the use of rectilinear fragments contradicts the architectural expressiveness of the project.

It should also be emphasised that in order to increase the load-bearing capacity, this analysis used high-strength steels of the C345 class, which have proven themselves quite effectively both from a theoretical and practical point of view. An assessment of the feasibility and effectiveness of their use for a number of building structures in Ukraine is presented in [18].

The comparison of the considered options is summarised in Table 2. The cost of the profiles is given in the national currency of Ukraine at the prices of the beginning of 2025.

The supporting unit of the arch is shown in Fig. 6.

The envelope diagrams of the internal force distribution for the final arch variant are given in Fig. 7: N – longitudinal force, Q – transverse force, M – bending moment.

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a

b

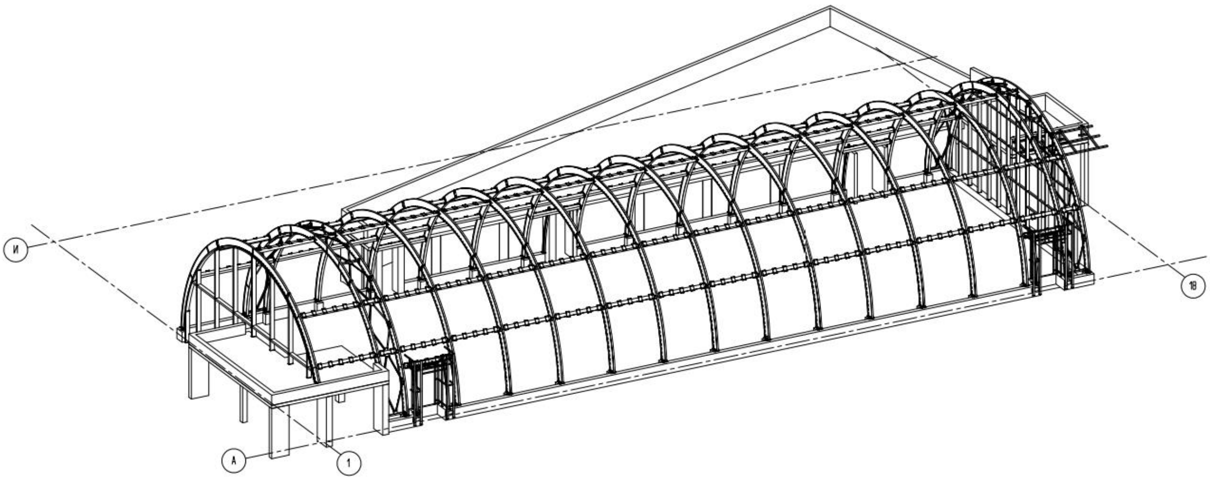

Fig. 2. Supermarket:
a – general view (for materials on the site https://guide.in.ua/business/622596/атб-маркет-солонка);
b – structure scheme

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a *b*

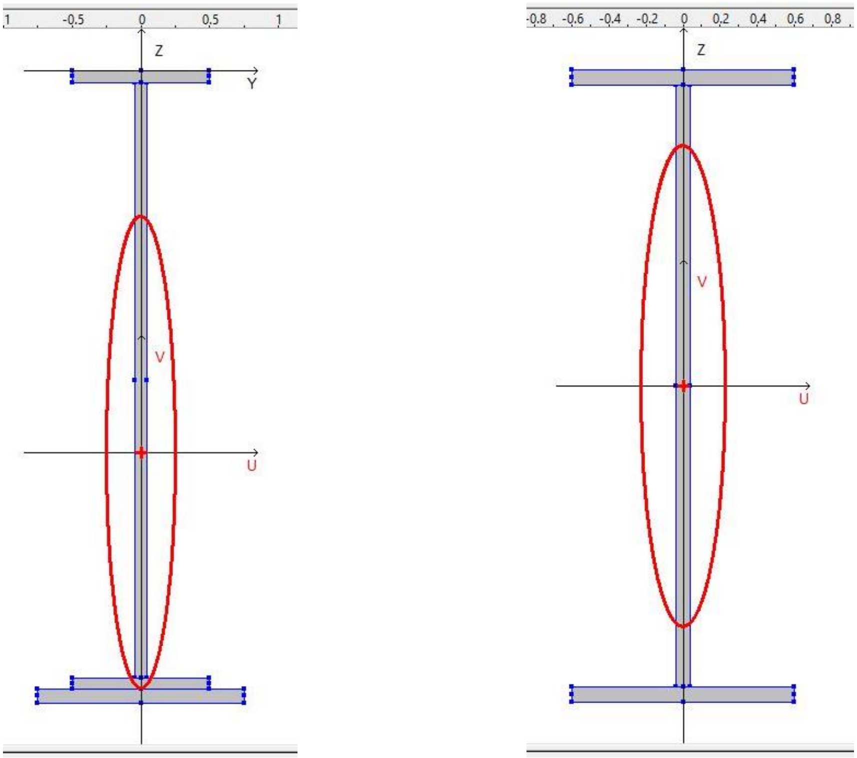

Fig. 3. Arch cross-sections:
a – initial variant; *b* – plan

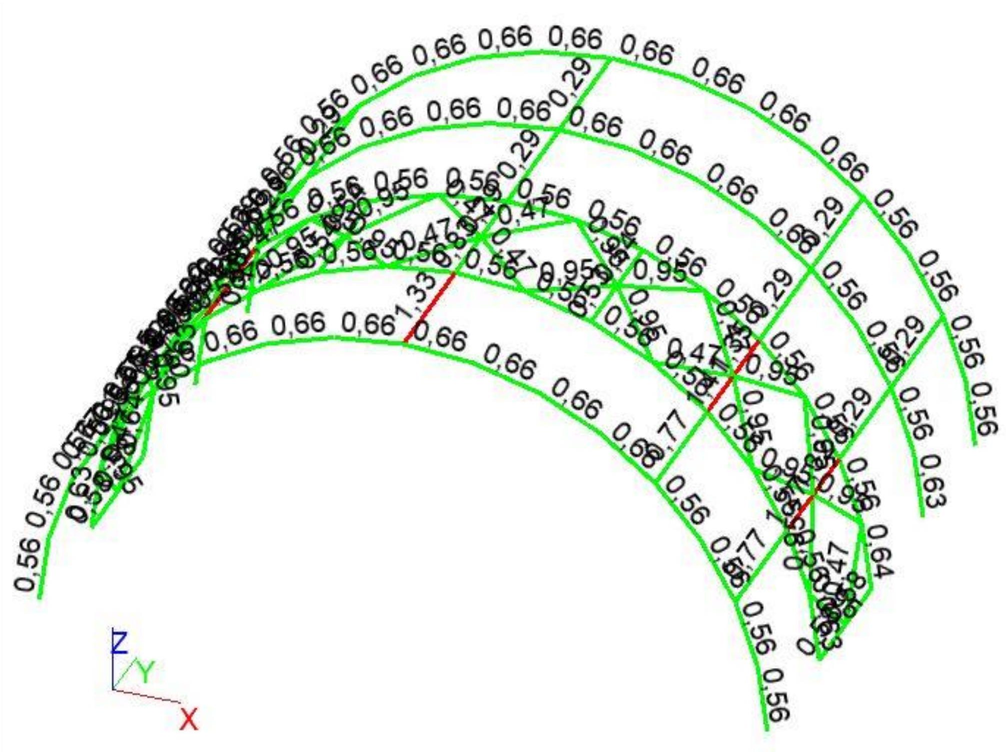

Fig. 4. Effectiveness coefficient in cross-section of the initial variant

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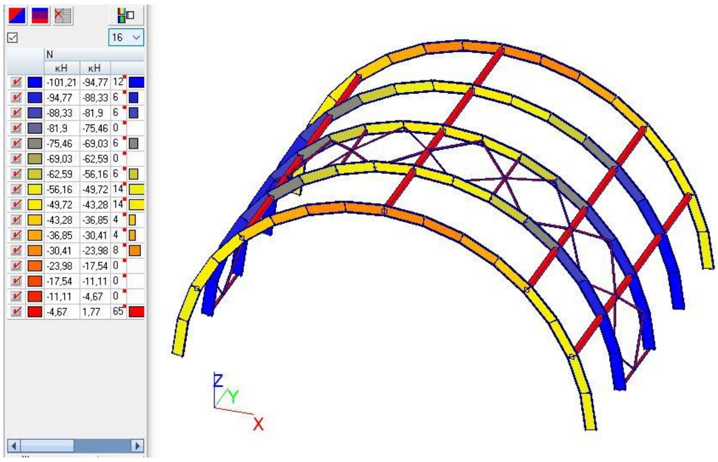
a



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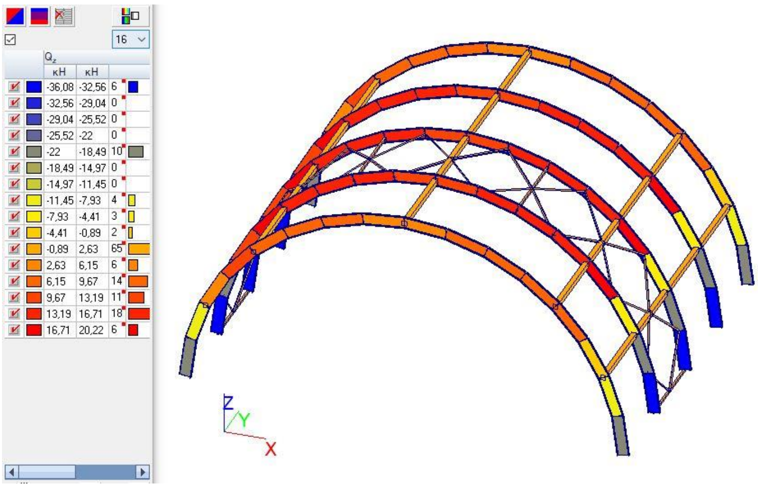

c

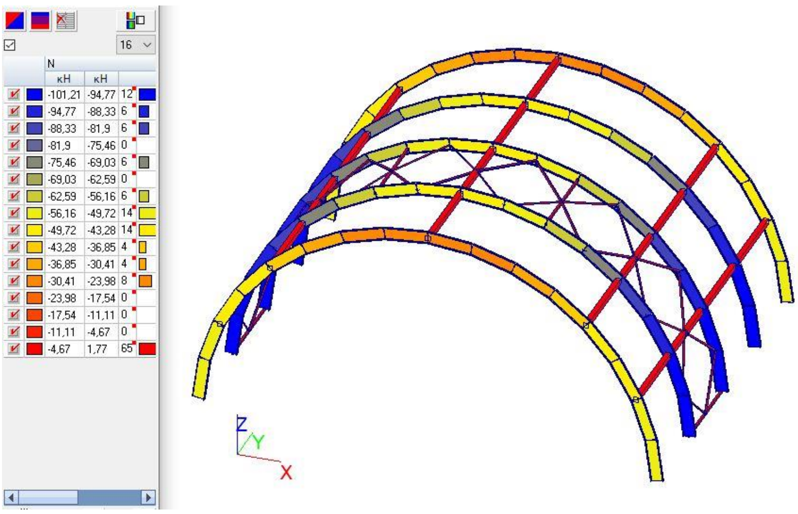

Fig. 5. Design factors in cross-section of the initial variant:
a – envelope diagram of N; *b* – envelope diagram of Qz; *c* – envelope diagram of My

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Table 2

Effectiveness of designing variants

Section	Efficiency factor	Weight, kg	Cost, UAH
Welded I-beam section	0.88	945	40 163
Rolled I-beam section	0.90	974	41 395
Rectangular square section	0.98	1576	66 980
Hot-rolled round tube	0.86	1669	70 933

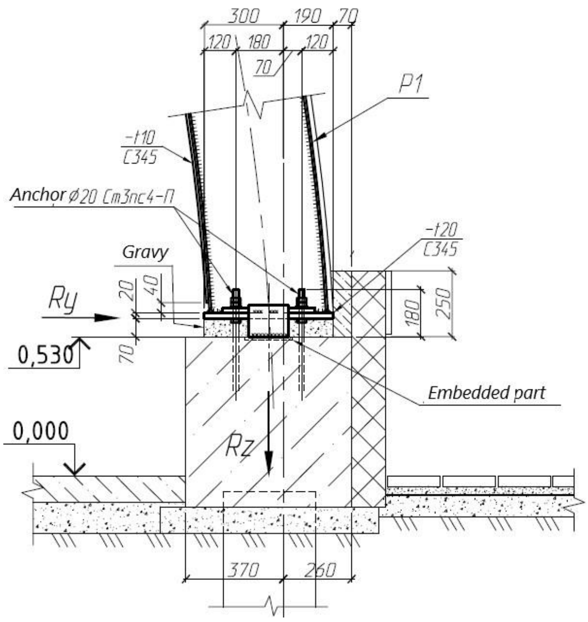

Fig. 6. Supporting unit of the arch section

Originality and practical value

Thus, this publication presents the results of a comprehensive automated analysis of an arch-type steel load-bearing frame for a food and non-food store in Ukraine. At the same time, the possibility of using an arched load-bearing element for the case of an insulated roof is substantiated and the effectiveness of using it is quantified.

In practical terms, the possible cross-sections of a steel arch bearing element – welded I-beam, hot-rolled I-beam, cold-bent welded rectangular, hot-rolled round tube – are considered, and the most efficient profile is identified as a welded I-beam section. The article also shows the capabilities of modern automated analysis using the SCAD design and computer system developed by Ukrainian specialists.

Conclusions

The comprehensive comparative automated analysis of possible types of cross-sections for a steel arch bearing element for an insulated roof of a modern city building allows us to state the following:

1. The arched element is quite architecturally expressive and at the same time an economically feasible design solution in this case.
2. For small spans of about 20 m, it is quite effective to use a welded I-beam section, which in terms of weight and cost can be almost twice as rational as existing analogues.
3. Such an architectural and structural solution also does not require the development of massive foundations, since the distribution forces are quite insignificant.

The final design solution of the steel bearing arch presented here meets the minimum requirements of Ukrainian standards.

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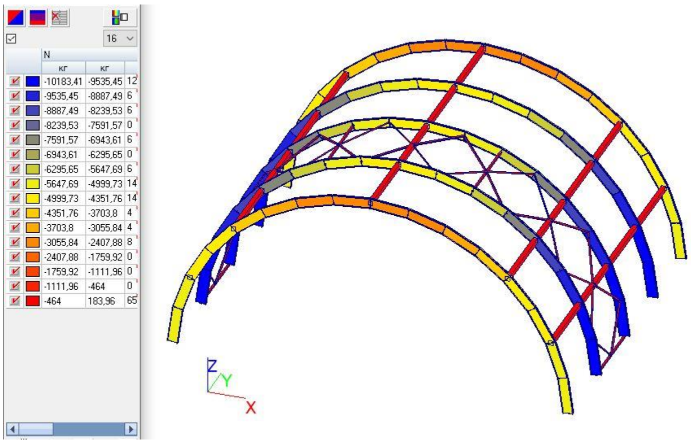
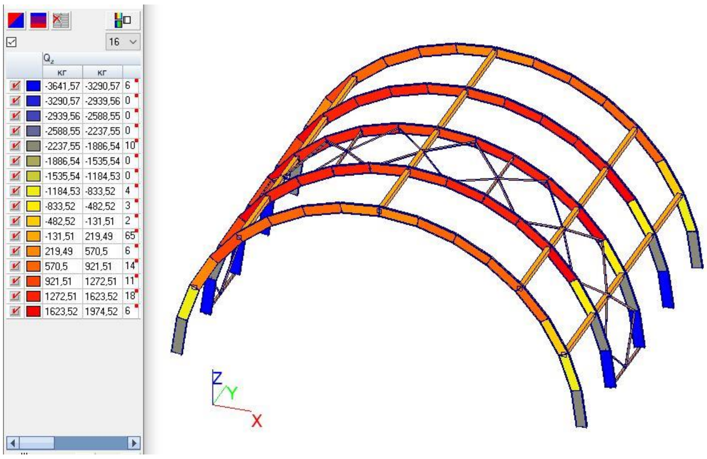
a



b



c

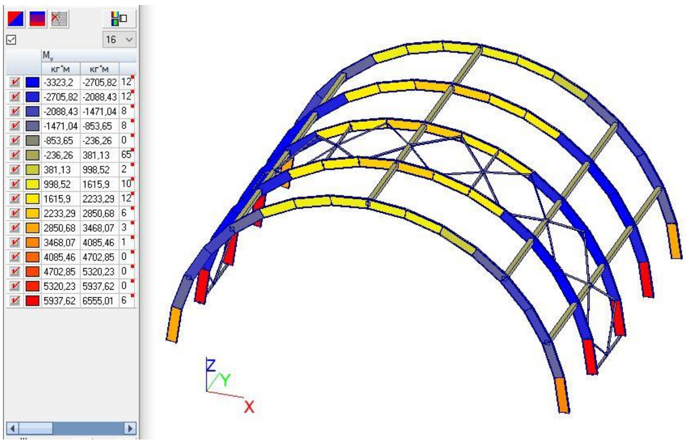


Fig. 7. Design factors in cross-section of the final variant:
a – envelope diagram of N; *b* – envelope diagram of Qz; *c* – envelope diagram of My

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Сучасні конструкції аркових несних систем громадських будівель

Мета. Основною метою публікації є порівняльний аналіз конструкційних варіантів несної аркової системи для громадських будівель з утепленим покриттям. Актуальність роботи пов’язана із сучасною тенденцією до створення громадських будівель різних типів без внутрішніх проміжних опор. Також тематика роботи обумовлена прагненням застосувати для цього відомі аркові системи, які дозволяють суттєво підвищити архітектурно-естетичні показники будівлі. **Методика.** Для досягнення цієї мети було розглянуто проєкт магазину продовольчих та непродовольчих товарів, розташований у Львівській області України. Основу його несного каркаса становлять циркульні сталеві арки прогоном 17,5 м і кутом розгортки 90 º. У ході аналізу виконано зіставлення різних типів поперечних перерізів арки – двотавр зварний та прокатний, труба прямокутна зварна та кругла безшовна. Для досліджень застосовано метод скінченних елементів на базі проєктно-обчислювального комплексу SCAD (Україна). **Результати.** Проведений порівняльний аналіз дозволив визначити геометрію найбільш раціонального конструкційного рішення для заданих умов у вигляді двотаврового зварного перерізу. Усі інші розглянуті типи поперечних перерізів мають нижчий рівень ефективності та технологічності виготовлення. Також додатково виявлено основні «слабкі» місця такого прерізу та надано рекомендації щодо їх усунення. **Наукова новизна.** Проведений порівняльний аналіз дозволив оцінити можливість застосування аркової несної системи як несного елемента безопорного каркаса громадської торговельної будівлі з утепленою конструкцію покрівлі. **Практична значимість.** Розроблено та запропоновано до практичної реалізації конструкційне рішення сталевої арки невеликого прогону у вигляді зварного двотавра, матеріаломісткість якої менша приблизно в 1,5 раза за можливі аналоги. Також отримано характер розподілу коефіцієнта ефективності використання матеріалу для заданих умов будівництва.

Ключові слова: сталева арка; несний каркас будівлі; зварний двотавр; громадська будівля; магазин продовольчих та непродовольчих товарів

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