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ТРАНСПОРТНЕ БУДІВНИЦТВО

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RATIONAL DESIGN OF SHORT-SPAN INDUSTRIAL BUILDING ROOF FOR RECONSTRUCTION CONDITIONS

Purpose. Recently, the demand for reuse of industrial buildings that have not been in operation for some time has been increasing in Ukraine. Herewith, quite often the design of their roof requires the complete replacement and renovation by using modern roofing materials to meet the requirements of new government standards. Therefore, the choice and justification of the rational design of steel roof on the example of a short-span industrial building (18-24 m span), which is planned to be returned to exploitation after idle time, is the main goal of this publication. The object of the analysis is an unheated building equipped with bridge cranes of a small capacity (up to 10 tons). **Methodology.** To achieve this purpose, the comparison of structural variants of a roof steel collar tie was performed. Such variants include two types of collar tie cross-section – a lattice truss and a solid I-girder. The first type was analyzed for four possible types of section of elements – double angles, a roll-welded square profile, an electric-welded round tube and a rolled round tube. The second type was analyzed for two possible types of section – rolled I-section made of normal strength steel and fabricated sections of thin-gage high-strength steel. The design variants were compared on the basis of a numerical analysis of their work using the finite element method based on the software complex SCAD for Windows. **Findings.** According to the research results it should be stated that for the conditions of the city of Dnipro the most cost-effective variant of the steel collar tie cross section for the short-span industrial building is the truss made of electric-welded round tubes. Also the construction of collar tie made of roll-welded square profiles or fabricated section of thin-gage high-strength steel is considered quite effective. **Originality.** The research presented in the publication allows estimating the possibility and economic efficiency of usage for various types of cross-sections for the collar tie of a steel non-insulated roof of the industrial building for the reconstruction conditions in the Dnipro-city. **Practical value.** A practical estimation of mass and cost parameters for steel collar ties of various types has been carried out, and the methodology for conducting such estimation has been substantiated.

Keywords: industrial building; collar tie; girder; truss; software complex SCAD for Windows; finite element method

Introduction

Currently, in Ukraine one of the key problems in the field of exploitation of the industrial enterprise structures is the level of their technical condition. This is especially true for such buildings, which for some time were not in operation, but were, so to speak, «on their own». During such an idle period some structures degraded, maybe went to ruins, and the other remained in a semi-usable state of operation. However, attempts to return such structures to operation are increasingly observed in practice, because it is often a cheaper option than the construction of a completely new object.

As a rule, such reuse of building structures is accompanied by their full or partial renewal, depending on their technical condition, and the building itself is redesigned to the requirements of new

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modern design standards and potentially new equipment to be installed. Most often it is the roof that requires renovation, because, on the one hand, it is in the most unfavorable conditions during idle time, and on the other hand, the roof itself often limits the dimensions for the installation of new equipment in the building.

It should also be noted that the demand for short-span buildings, such as storage buildings, has been particularly active recently. This is due to their relatively low cost, as well as the desire to use them in the future for production processes in the small business.

Purpose

Taking into account the foregoing, the main purpose of the study conducted by the authors is to choose and justify the rational design of steel roof on the example of a short-span industrial building (18-24 m span), which is planned to be returned to exploitation after idle time. The object of the analysis is an unheated building equipped with bridge cranes of a small capacity (up to 10 tons).

To achieve this, it was necessary first to analyze the existing and approved roof design variants, suitable for use in such buildings, then to compare these variants, taking into account both their carrying capacity and the estimated cost, and to choose the best variant that can be proposed for practical implementation.

Methodology

Given the nature of the industrial building in question, the design of its roof should provide for the use of bearing collar ties, which include a system of purlins and steel profiled flooring. This roof type is proved itself good in practice and is considered to be the main one for modern non-heated industrial buildings [10].

It is also worth noting that abroad the short-span industrial buildings, which are quite popular, have a similar roof design solution [13].

The main issue, when designing such short-span roofs, is the choice of type of collar tie. For this purpose, straight-axis collar ties (trusses or beams) may be used, as other types of bearing structures, such as arches or frames, are more suitable for significant spans. The slope of the upper chord of the collar ties in accordance with the standard requirements [6] shall be not less than 20% (11°), which is due to the need of preventing the water flow through the profiled sheet joints to the building. In case of installation of such roofs on the 10 – 20% (5.5 – 11°) slopes there are must be provided the sealing of joints between the flooring sheets. However, as the experience of operation shows, firstly, such works are technologically costly, and secondly, over time, sealing requires periodic renewal. Therefore, the practice of such roofs with small slopes is mostly abandoned.

Taking into account the above limitations, a triangular truss with a triangular lattice with additional posts, as the most economical one, was accepted as a lattice truss during the studies. At the same time, four types of sections of the elements of such a truss were analyzed, which are now used in metal structures and available on the Ukrainian steel market: – angles (according to GOST 8), roll-welded square profiles (according to GOST [3]), electric-welded round tubes (according to GOST [1]) and rolled round tubes (according to GOST [4]). For the first two types of cross-sections, C255 grade steel was used, which is the minimum allowable for structures of group 1 according to the standard [7]. For the last two types of round tube cross-sections, C245 grade steel was used according to this standard.

As a solid girder, we considered two types of beams – rolled I-section girder (according to GOST [2]) and a plate girder made of high-strength steel of C325 grade, which is becoming more and more popular at the modern market of Ukraine. To ensure the desired slope, the girder had an asymmetrical design.

Roof loads were determined according to the current standards in Ukraine [5]. Since, at a given angle of inclination of 11° the wind load is upward due to the negative aerodynamic coefficient, we took into account only the proper weight of the roof together with the collar tie and snow load.

To specify the research, we considered the object – the industrial storage building, located in the city of Dnipro at the address of Panikakhi street 1, which for a long time (almost 15 years) was not in operation (Fig. 1). According to the data of its survey, carried out by a specialized organization, the roof design should be completely replaced by

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a new one, since its technical condition was assessed as the state of failure.

One of the peculiarities of the building under consideration was a varying span, which for its main part was 24 m, and for final sections decreased to 18 m. Therefore, in order to provide the required slope of the roof, it was necessary to develop a design of a universal collar tie that would provide the required slope of the roof without changing the type of the collar tie itself.

For conducting variant calculations we used an extremely popular and approved numerical method of building mechanics – the method of finite elements [12, 14, 15] based on the well-known domestic software complex SCAD for Windows [11]. The constructed calculation models for the considered collar tie design variants are shown in Fig. 2 – 5. The trusses and the rolled girder were modelled by rod finite element of universal type, and the plate girder was modeled by plate four-node finite elements of isoparametric type. All calculations were performed in geometrically and physically linear settings. This approach avoids issues of estimating the convergence of results peculiar for finite elements of other types [9].

Findings

According to the calculation results for truss-type collar ties the sections of the elements were selected for each of the four constructive types. Herewith, upon selection the cross sections were adjusted according to the rules of unification. Also, according to the unification results, a universal truss for 18 and 24 m spans was formed, which consisted of the largest profiles. These data are presented in Table 1.

For the I-section collar ties the profile 70B1 was selected. For the collar ties in the form of fabricated sections the 1.3 m high profile was chosen for the elements thickness of 4 mm and 1.0 m high profile – for the elements thickness of 6 mm. Herewith the condition of stiffness was the determining condition.

Based on the results of calculations, a summary table was drawn up, which takes into account the total costs for the profiles of the collar ties of each type. Data are taken as averaged generalizations at the rolled metal market in the city of Dnipro for November-December 2018. However, this analysis allows us to reveal a general picture.

Fig. 1. Object of the research – short-span industrial storage building

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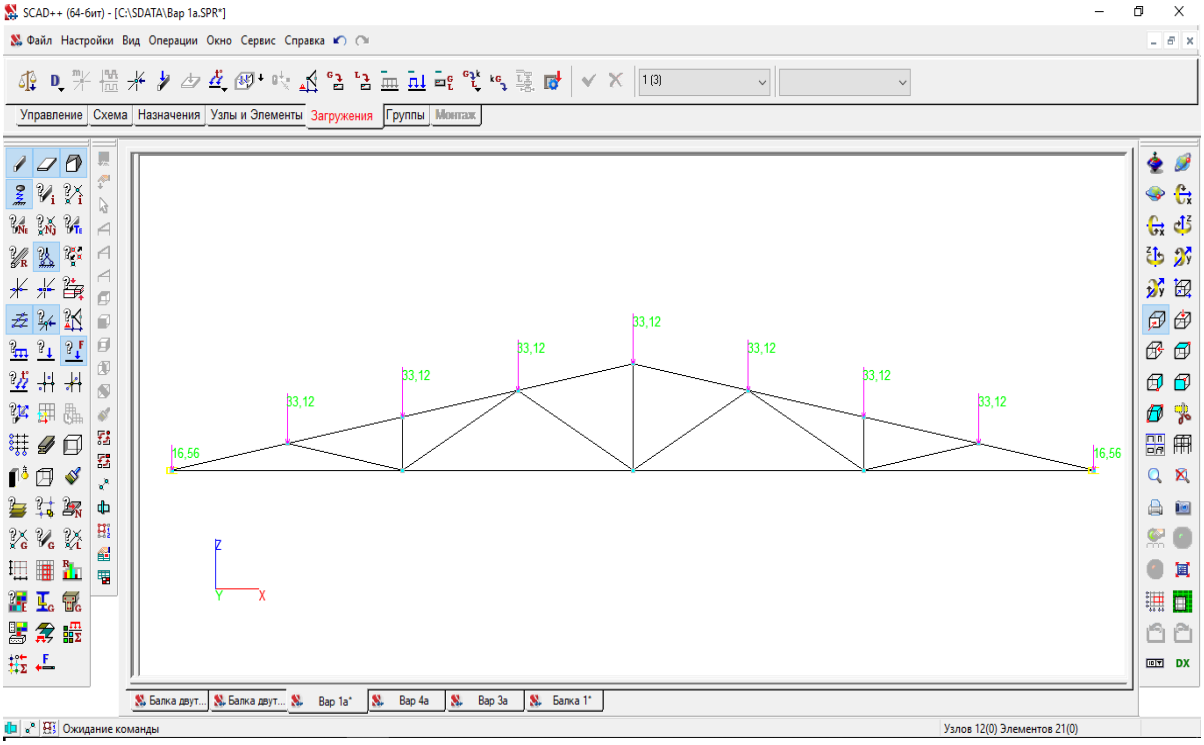

Fig. 2. Finite-element model of 24m span truss

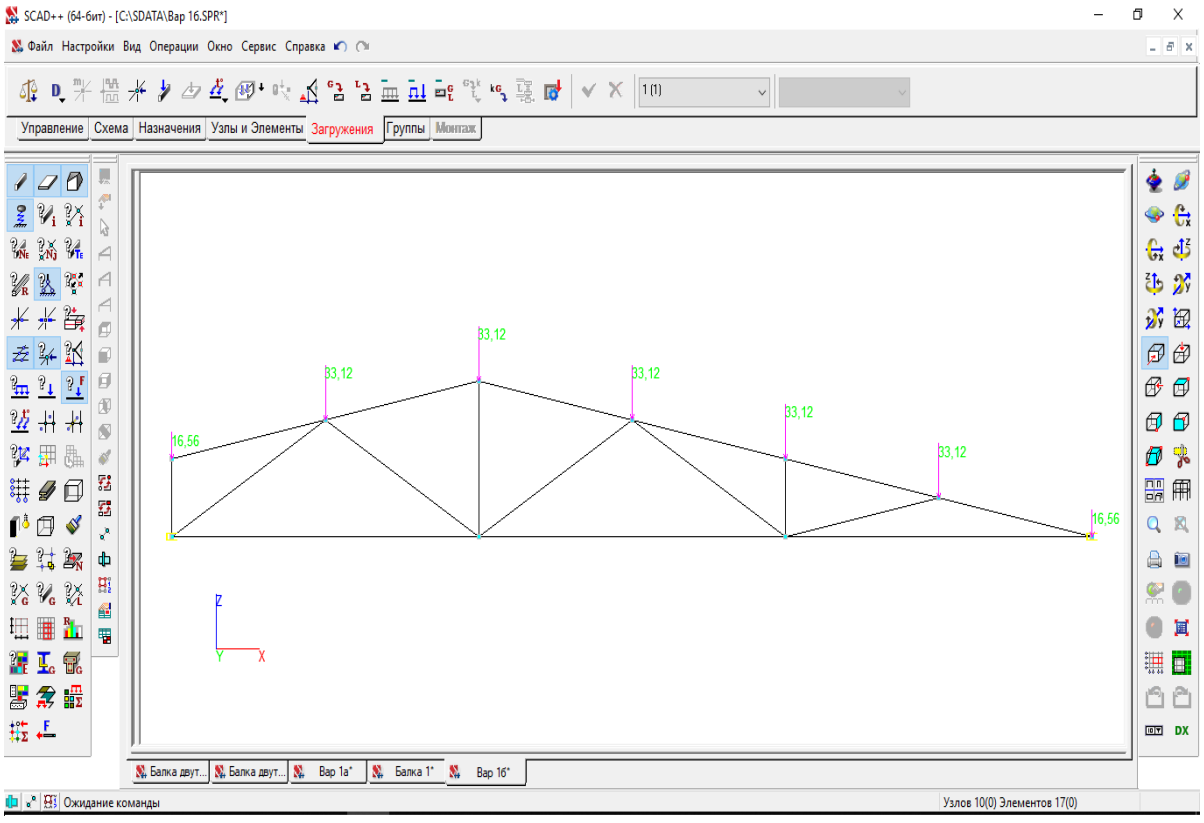

Fig. 3. Finite-element model of the shortened 18 m span truss

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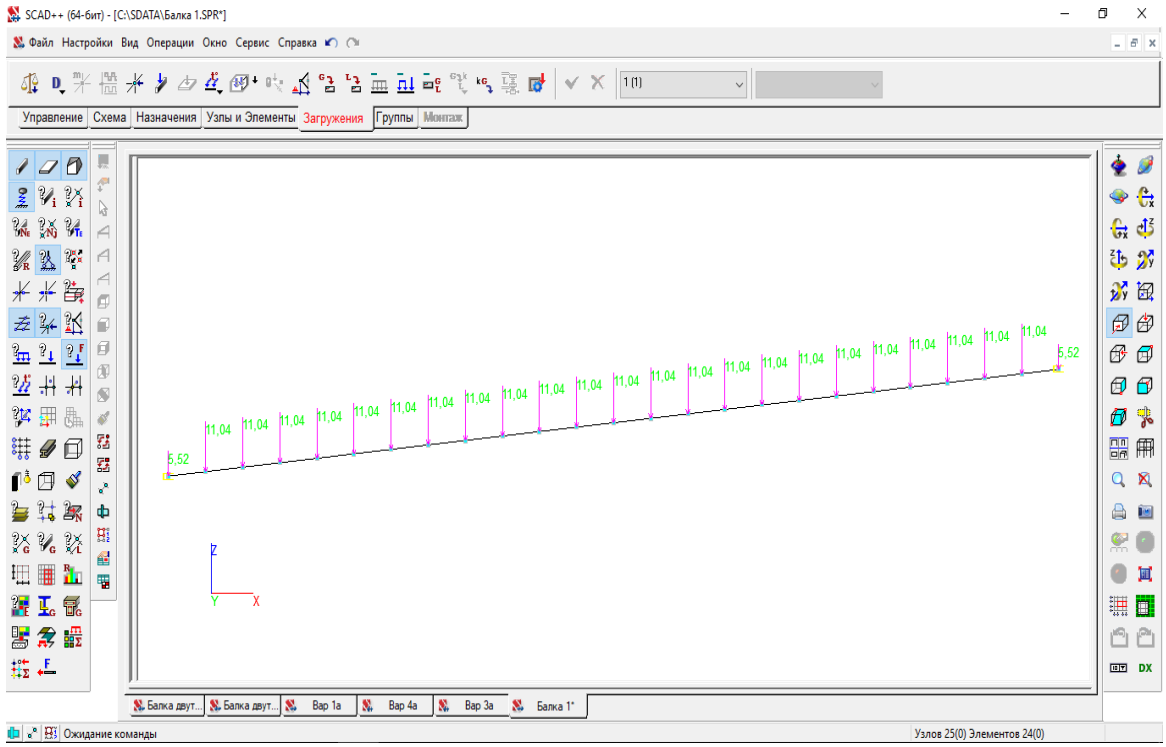

Fig. 4. Finite-element model of rolled girder

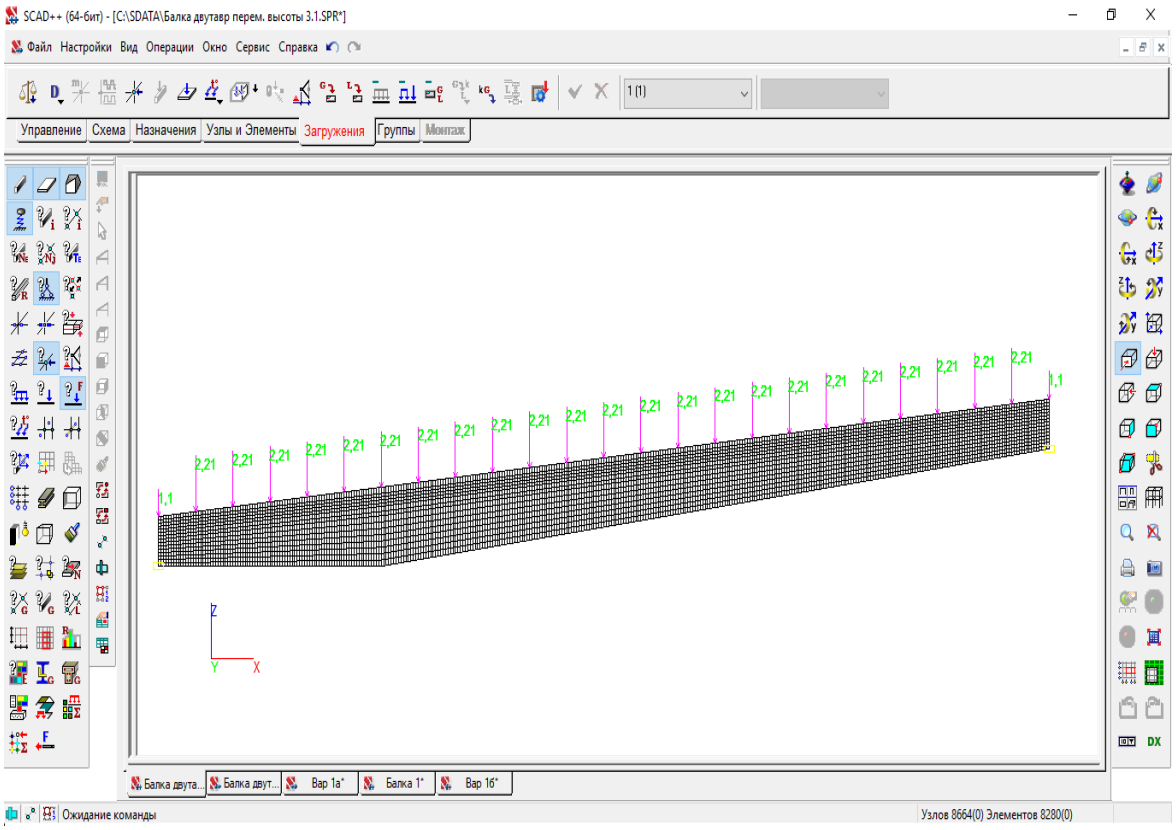

Fig. 5. Finite-element model of plate girder

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Table 1

Cross-sections of universal trusses with 18-24 m span

Truss element	Truss element cross-section made of			
	double angles	roll-welded square	electric-welded round tubes	rolled round tubes
upper chord	125x8	120×7	193.7x5	194x5
lower chord	90x7	110x6	159x5.5	133x6.5
posts	50x3	80x5	70x4	68x3
diagonal web elements	90x7	80x5	102x4	102x4

Table 2

Weight and cost of constructive variants for roof collar ties

No.	Collar tie cross section	Weight, t	Cost per 1 t, UAH	Cost, UAH
1.	Truss of double angles	1.63	22 912	37 350
2.	Truss of roll-welded square profile	1.33	22 150	29 460
3.	Truss of electric-welded round tubes	1.35	18 975	25 620
4.	Truss of rolled round tubes	1.28	28 250	36 160
5.	Girder of rolled I-section	3.10	19 400	60 140
6.	Girder of fabricated I-section (4 mm)	1.58	19 670	31 080
7.	Girder of fabricated I-section (6 mm)	2.08	19 670	40 915

From the data in the table it is clearly seen that the smallest weight for the considered industrial building roof reconstruction conditions has a collar tie in the form of the truss of rolled round tubes. A slightly larger weight, but not much, has a collar tie in the form of trusses of roll-welded square profile and electric-welded round tubes. The largest weight has a collar tie of rolled I-section. The welded collar tie of thin-gage high-strength steel takes an intermediate position.

Taking into account the market value of each type of cross-section, the lowest cost has the collar tie in the form of the truss of electric-welded tubes. In the second place there is the collar tie of roll-welded square profile, the cost of which is 15% higher. The third is ranked the collar tie in the form of welded fabricated I-section of thin-gage (4 mm thick) high-strength steel. Its value is higher by almost 18%. The most uneconomical is the collar tie made of rolled I-section, the cost of which is more than 2 times higher than that of the collar tie in the form of the truss of electric-welded tubes.

Originality and practical value

The research presented in the publication allows estimating the possibility and economic efficiency of usage for various types of cross-sections for the collar tie of a steel non-insulated roof of the industrial building. At the same time, the study outlined the case of reconstruction of the short-span (18-24 m) building, which is quite common nowadays, with the complete roof replacement.

The results obtained are valid for the conditions of Dnipro, but according to a similar methodology the degree of efficiency of reconstruction and rebuilding of steel roofs of industrial build-

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ings can be determined in practice for other regions of Ukraine as well.

Also, it should be noted that the conducted study allow us to outline the range of the most rational constructive solutions of bearing collar ties for short-span industrial buildings.

Conclusions

Based on the material outlined in the publication, the following conclusions can be drawn:

1. For the reconstruction conditions of a steel roof of a short-span (18-24 m) industrial building, the use of the truss of electric-welded round tubes is the most cost effective as a bearing collar tie.

2. In the second place, according to the degree of economic efficiency, there is the use of the truss of roll-welded square profiles, the cost of which is 15% higher than the previous variant. Taking into account the higher technological efficiency of the implementation of node connections for such trusses, under certain conditions this type of collar tie can be considered the most rational.

3. Also noteworthy is the collar tie in the form of fabricated I-section of small thickness (4 mm) of high-strength steel, the cost of which is 18% higher than the first constructive variant. Therefore, this section can also be considered as competing with the main recommended variant (truss of electric-welded round tubes), taking into account its high manufacturability.

4. The least effective of all considered variants is the collar tie made of rolled I-section. Its weight and value are more than 2 times higher than the main recommended variant (truss of electric-welded round tubes).

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РАЦІОНАЛЬНА КОНСТРУКЦІЯ ПОКРИТТЯ МАЛОПРОГОНОВОЇ ПРОМИСЛОВОЇ БУДІВЛІ ДЛЯ УМОВ РЕКОНСТРУКЦІЇ

Мета. Останнім часом в Україні зростає попит на повторне використання промислових будівель, які протягом певного часу не перебували в експлуатації. При цьому досить часто конструкція їх покрівлі потребує повної заміни й оновлення із сучасних покрівельних матеріалів з урахуванням вимог нових державних норм. Тому вибір та обґрунтування раціональної конструкції сталевого покриття на прикладі малопрогонової промислової будівлі (прогін 18–24 м) для повернення її до експлуатації після простою є основною метою цієї публікації. Об'єкт аналізу – неопалювана будівля, обладнана мостовими кранами незначної вантажопідйомності (до 10 т). **Методика.** Для досягнення поставленої мети виконано зіставлення конструктивних варіантів несного сталевого ригеля покрівлі. Розглянуто два типи перерізу ригеля: наскрізний – у вигляді ферми й суцільний – у вигляді двотаврової балки. Перший тип проаналізовано для чотирьох можливих типів перерізу елементів – подвійні кутики, гнутозварний квадратний профіль, електрозварна кругла труба й прокатна кругла труба. Другий тип досліджено для двох можливих типів перерізу – прокатний двотавровий профіль зі сталі звичайної міцності і зварний профіль із тонкостінної сталі підвищеної міцності. Зіставлення конструктивних варіантів виконано на основі чисельного аналізу їх роботи методом скінченних елементів на базі проектно-обчислювального комплексу SCAD for Windows. **Результати.** Проведене дослідження дає змогу констатувати, що для умов м. Дніпро найбільш економічно ефективним варіантом перерізу сталевого ригеля промислової будівлі невеликих прогонів є ферма з електрозварних круглих труб. Також досить ефективною слід вважати конструкцію ригеля, виконану з ферм із гнутозварними квадратними профілями або зварного двотаврового типу з тонкостінної сталі підвищеної міцності. **Наукова новизна.** Описане в публікації дослідження дозволяє оцінити можливість, а також економічну ефективність використання різних типів перерізів для ригелів сталевої неутепленої покрівлі промислової будівлі з метою реконструкції в м. Дніпро. **Практична значимість.** Виконано практичну оцінку масових і кошторисних показників для сталевих ригелів різних типів, а також обґрунтовано методику проведення подібної оцінки.

Ключові слова: промислова будівля; ригель; балка; ферма; проектно-обчислювальний комплекс SCAD for Windows; метод скінченних елементів

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РАЦИОНАЛЬНАЯ КОНСТРУКЦИЯ ПОКРЫТИЯ МАЛОПРОЛЕТНОГО ПРОМЫШЛЕННОГО ЗДАНИЯ ДЛЯ УСЛОВИЙ РЕКОНСТРУКЦИИ

Цель. В последнее время в Украине возрастает спрос на повторное использование промышленных зданий, которые на протяжении определенного времени не находились в эксплуатации. При этом довольно часто конструкция их покрытия требует полной замены и обновления из современных кровельных материалов

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с учетом требований новых государственных норм. Поэтому выбор и обоснование рациональной конструкции стального покрытия на примере малопролетного промышленного здания (пролет 18–24 м) для возврата в эксплуатацию после простоя является основной целью публикации. Объект анализа – неотапливаемое здание, оборудованное мостовыми кранами незначительной грузоподъемности (до 10 т). **Методика.** Для достижения поставленной цели было выполнено сопоставление конструктивных вариантов несущего стального ригеля покрытия. В качестве таких вариантов рассмотрено два типа сечения ригеля – сквозной в виде фермы и сплошной в виде двутавровой балки. Первый тип проанализирован для четырех возможных типов сечения элементов – двойные уголки, гнутосварной квадратный профиль, электросварная круглая труба и прокатная круглая труба. Второй тип исследован для двух возможных типов сечения – прокатный двутавровый профиль из стали обычной прочности и сварной профиль из тонкостенной стали повышенной прочности. Сопоставление конструктивных вариантов выполнено на основе численного анализа их работы методом конечных элементов на базе проектно-вычислительного комплекса SCAD for Windows. **Результаты.** Проведенное исследование даёт возможность констатировать, что для условий г. Днипро наиболее экономически эффективным вариантом сечения стального ригеля промышленного здания небольших пролетов является ферма из электросварных круглых труб. Также достаточно эффективной следует считать конструкцию ригеля, выполненную из ферм с гнутосварными квадратными профилями или сварного двутаврового типа из тонкостенной стали повышенной прочности. **Научная новизна.** Представленные в публикации исследования позволяют оценить возможность и экономическую эффективность использования различных типов сечений в качестве ригеля стального неутепленного покрытия промышленного здания для условий реконструкции в г. Днипро. **Практическая значимость.** Выполнена практическая оценка массовых и стоимостных показателей для стальных ригелей различных типов, а также обоснована методика проведения подобной оценки.

Ключевые слова: промышленное здание; ригель; балка; ферма; проектно-вычислительный комплекс SCAD for Windows; метод конечных элементов

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