ISSN 2307–3489 (Print), ISSN 2307–6666 (Online)
Наука та прогрес транспорту, 2025, № 2 (110)

UDK 624.014.2.072.2:69

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Features of modern design of steel crane beams for industrial buildings

Purpose. The main purpose of the publication is to comprehensively compare the methods and approaches to the design of steel crane beams according to the current standards of China and Ukraine. The relevance of the work is due to the constant increase in the volume and types of cooperation between these two countries over the past decades. The subject matter is also related to the increasing use of high-strength steels in construction practice, which also have a number of additional improved performance characteristics. **Methodology.** To achieve this goal, we considered the design of a 6 m span steel simply supported crane beam at one of the modern energy enterprises in Ukraine. The load was assumed to come from an electric overhead crane with a lifting capacity of 25 tones. The selected cross-section was checked in accordance with the design requirements of the current standards of China and Ukraine, which together include about 20 items. Separate consideration was given to the design requirements for the arrangement of reinforcing stiffeners and ensuring local stability of the section elements. **Findings.** The comparative analysis of the existing approaches according to the standards of China and Ukraine has made it possible to establish that, in general, the Chinese standard imposes more stringent requirements both for the material to be used for the crane beam production and for design and construction solutions. At the same time, in terms of ensuring general and local stability, the Chinese standard uses a fundamentally different conceptual approach than the Ukrainian standard. However, the final solution has approximately the same level of bearing capacity. **Originality.** The comparative analysis of the requirements of the current Chinese and Ukrainian standards for the design of steel crane beams has made it possible to identify the strengths and weaknesses of each standard, as well as to outline the main fundamental differences between them. **Practical value.** The paper develops and proposes for practical implementation a design variant of a steel simply supported crane beam, which in terms of its bearing capacity meets the requirements of the current standards of China and Ukraine in the field of metal construction.

Keywords: steel crane beam; industrial building; overhead crane; Chinese standard; Ukrainian standard; experience exchange

Introduction

Industrial buildings have been and remain the main type of industrial facilities that are designed to ensure real technological processes in all types of economy [1]. Such buildings are created and operated in more than 10 sectors of modern industry (power engineering, mining, metallurgy, chemical production, mechanical engineering, metalworking, construction materials, wood processing, etc.), agriculture, and transport. The volume of construction of new and reconstruction of old industrial buildings is only increasing worldwide from year to year. Therefore, it is still an urgent issue to improve existing approaches to the development of constructive solutions for such buildings, the design of their structural elements and systems, as well as methods for the practical implementation of such approaches [20].

Modern industrial buildings are quite complex structural systems (Fig. 1), in which non-standard space-planning solutions, atypical structural schemes, building materials with improved characteristics, and the latest design methods are used to meet the most modern requirements of functional processes.

Recently, the main structural system of industrial buildings has been the frame system. It has a number of advantages compared to other structural systems, including the possibility of flexible layout and, if necessary, easy transformation of

doi: https://doi.org/10.15802/stp2025/332153

production space, high maintainability and ease of maintenance of structures and technological communications, as well as the ability to implement complex and non-standard structural solutions for load-bearing elements.

As for the material used to manufacture the load-bearing elements of the frame, steel is becoming increasingly common in global practice. This material has high strength characteristics (especially modern high-strength steel grades made using controlled rolling technology [16]) and at the same time makes it possible to create architecturally expressive and aesthetically pleasing structures (especially when using modern BIM technologies for their design).

All of this requires accurate and high-quality approaches to assess the stress-strain state of structures and their components, identify available reserves, and at the same time ensure the required level of reliability and durability of structures. Therefore, the issues of improving existing methods for designing building structures and developing new methods have been and remain relevant.

One of the most critical structural elements of industrial buildings is the crane beam. They serve as a kind of path along which overhead cranes, the main transport mechanism in industrial buildings, move. In order to cover the entire technological space of the building, overhead cranes are placed at a certain height, which is limited by the functional and technological parameters of production. At the same time, the crane beams themselves must also be raised above the floor level of the building, which is achieved through a special design of the frame columns.

From the point of view of operation, crane beams are in an extremely complex stress-strain state. They are subjected to spatial dynamic loads from the movement of overhead cranes, accompanied by a constant change in their intensity over time. However, despite this, engineers create such beams of a fairly simple geometric shape with minimal additional reinforcing elements.

Thus, the design of crane beams is a rather complex and responsible process that requires knowledge and understanding of both theoretical laws and practical experience. This is where international cooperation and partnerships between the world's leading countries come in handy. It involves the exchange of engineering and technical information and national heritage in the construction industry of individual countries.

Modern China has excellent historical traditions and is a highly developed technological country, so the use of the country's accumulated practical experience in the construction industry is invaluable to the entire world community. So let us look at a kind of symbiosis in the design of steel crane beams associated with the use of the national heritage of two countries – China and Ukraine. We will also try to evaluate this integrated approach in terms of its practical implementation and manufacturing costs. We will pay special attention to the national standards of these two world countries.

Purpose

In view of the above, the main purpose of this publication is a comprehensive analysis of existing approaches and methods of modern design of steel crane beams for industrial buildings with overhead cranes, based on the international experience of China and Ukraine.

Methodology

The design of steel crane beams for industrial buildings, like the design of any other steel structures, should be based on standards. In Ukraine, the current standard governing the design of steel structures in general and crane beams in particular is DBN B.2.6–198:2014 [8]. This standard covers not only the design provisions but also provides the basic requirements for the construction of such beams. Therefore, it is a basic document in this aspect.

The applied loads from cranes are determined in accordance with another standard in force in Ukraine – DBN B.1.2–2:2006 [4]. This standard has undergone two changes, the last of which was introduced into design practice in 2023 [5]. It has somewhat streamlined the definition of crane loads for bridge cranes with a lifting capacity of up to 50 tonnes inclusive. Also, when designing crane beams, the standard DSTU B B.1.2–3:2006 [7] is used, which regulates the deformed state of crane beams.

doi: https://doi.org/10.15802/stp2025/332153

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a

b

Fig. 1. Constructive «interior» of the current production environment:
a – Interpipe Steel, Dnipro (Ukraine); *b* – Zhejiang Zhanggong Technology Co., Ltd., Dongyang (China)
(for materials on the site https://zhang-gong.en.alibaba.com/index.html?spm=a2700.shop_index.88.17.597f4ee8ntOw2m)

An additional source to rely on when designing crane beams is the standard SNiP II–23–81*, which has been cancelled in Ukraine. Despite its status, this standard provides a more classical methodology for assessing the endurance of structures such as crane beams that are subjected to cyclic dynamic loads.

In China, the main regulatory document governing the design of steel structures is GB 50017–2017 [11]. The determination of loads from overhead cranes is regulated by GB/T 22437.1–2018 [13] and GB/T 22437.5–2021 [14], which are essentially adapted versions of ISO 8686–1:2012(E) [18] and ISO 8686–5:2017(E) [19], respectively. Thus, China's own regulatory framework provides a design process for steel crane beams for industrial buildings.

doi: https://doi.org/10.15802/stp2025/332153

The object of research is the crane beams of the repair shop of a transformer substation of one of the energy enterprises of Ukraine. According to the current classification of construction facilities in Ukraine, presented in the DSTU 8855:2019 standard [8], energy enterprises are classified as consequence class CC3. This is the most complex and most responsible class, for which the highest values of the responsibility coefficient are set according to the DBN B.1.2–14:2018 [6] – $\gamma_n = 1.25$ (for calculations for the first group of limit states) and $\gamma_n = 1.00$ (for calculations for the second group of limit states).

The basic design of the shop is shown in Fig. 2. The shop is made of reinforced concrete according to a wall structural scheme. The crane beams are placed on special horizontal brackets connected to the walls through embedded parts. The span of the crane beams is L = 6 m, their structural scheme is simply supported, and their design scheme is pivoting support on both sides.

An electric bridge crane with a lifting capacity of 25 tonnes is envisaged as the main tool for technological production operations. Its general view along with the layout is shown in Fig. 3. The main technical characteristics of the crane are presented in Table 1.

Table 1

Technical characteristics of bridge crane

Characteristic	Value
Crane type	CXTD25t x 20m Hol:22m
Span (Spa)	20.000 m
Load (SWL)	25 000 kg
Crane group	FEM A3
Crane speed	25 m/min
Crane weight	12 040 kg
Crane type	CXTD25t x 20m Hol:22m
Buffer type	D2240
Wheel base (Wb)	4 966 mm
Crane rail in calculation	60*40
Wheel groove	74 mm
Crane travel limit switch	2-step

Table 2 shows the quantitative values of horizontal and vertical forces on the wheels of a bridge crane according to the data of the crane equipment developer. The chart of load distribution on the crane wheels is shown in Fig. 4.

Findings

To determine the forces from a bridge crane that will occur in a crane beam, Ukrainian design practice provides for the use of influence lines. This approach is due to the fact that the bridge crane creates a moving load on the crane beam and the question arises of determining the most disadvantageous position of the crane.

In the case of crane beam design, there can generally be two such positions – separately for determining the largest bending moment and separately for determining the largest transverse force.

In the first case, the position of the bridge crane is determined by Winkler's rule, which is formulated as follows: the maximum possible bending moment in a simply supported beam loaded with a system of interconnected moving loads occurs if the equivalent of this system of loads and the load closest to it are equidistant from the beam's centre. The maximum bending moment occurs in this case in the section located under this load.

For the case under consideration, the equalising force of all forces should be located at a distance of X_0 m from the left support of the crane beam:

$$X_0 = \frac{\sum M_0}{R} = \frac{846,59}{321} = 2.64\ m,$$

where $\sum M_0$ – the total moment of vertical loads on the crane wheels relative to the left support wheel; R – resultant of vertical loads on the crane wheels.

The dynamic loads on the wheels of the bridge crane were taken into account in these expressions (Table 2); since the crane was manufactured in Germany, the loads were calculated in accordance with the standards of this country DIN 4132 [10] and DIN 15018–1 [9].

The calculation scheme for determining the maximum bending moment is shown in Fig. 5, *a* (the critical load is marked in red).

In the second case, the position of the bridge crane is assumed to be as close as possible to the left support of the crane beam. This will generate the maximum transverse force. The calculation

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scheme for this case is shown in Fig. 5, *b* (the critical load is marked in red).

The calculated values of the internal forces, taking into account the load reliability factors for the crane beam (heavy crane operation is assumed), are significant:

– vertical bending moment
M_V = 37 646 kN·cm;

– horizontal bending moment
M_H = 4 323 kN·cm;

– vertical transverse force
Q_V = 306 kN;

– horizontal transverse force
Q_H = 40 kN;

– longitudinal force
$N = 0.015 \cdot Q_V \cdot g$ = 45 kN.

Based on these values, using the accumulated experience in the design of crane beams, the minimum required cross-section of the I-beam type was determined – Fig. 6, *a*. The cross-section was assumed to be composite welded steel sheets, taking into account the DSTU 8540:2015 standard [2]. Vertical stiffeners were placed in the longitudinal direction at 1 m intervals. In addition, to ensure the overall stability of the beam, it is planned to brace its upper compressed flange in plane – the installation of a braking beam (Fig. 6, *b*).

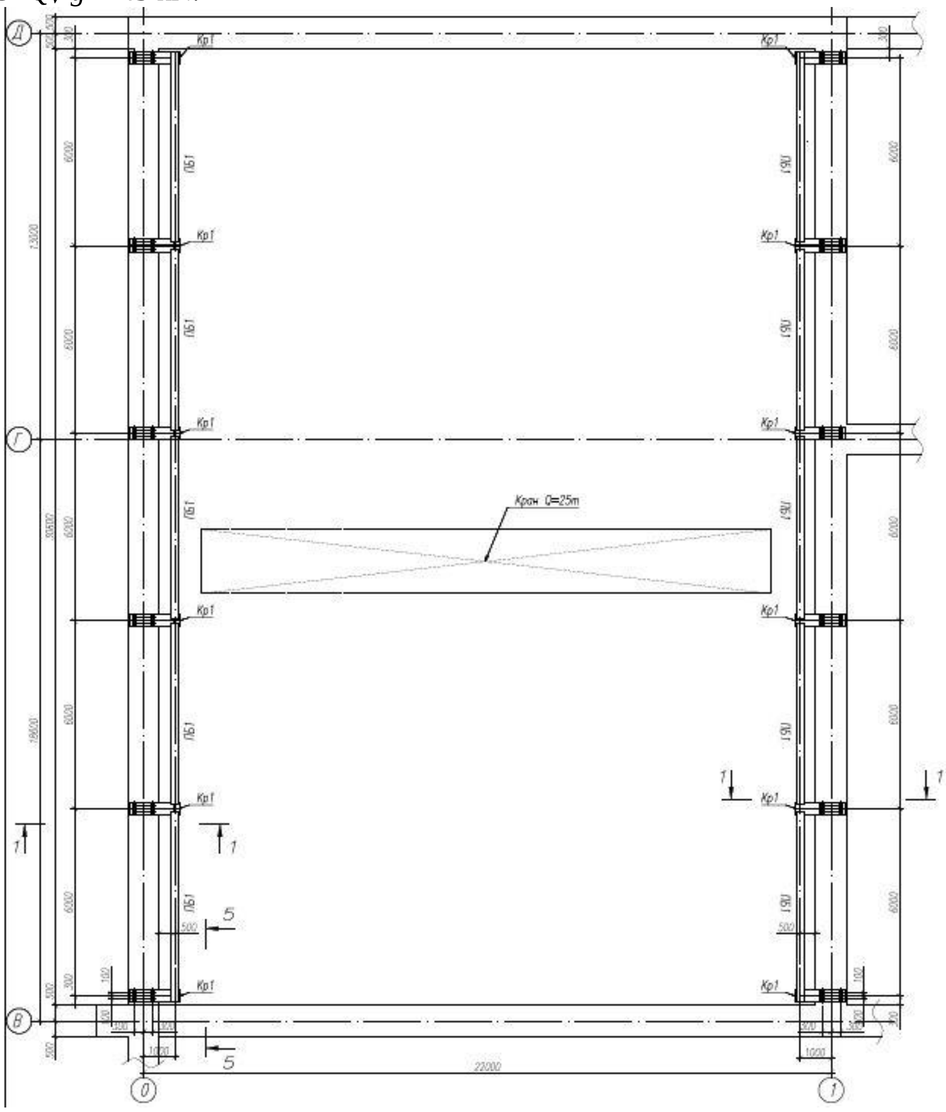

Fig. 2. Repair shop plan

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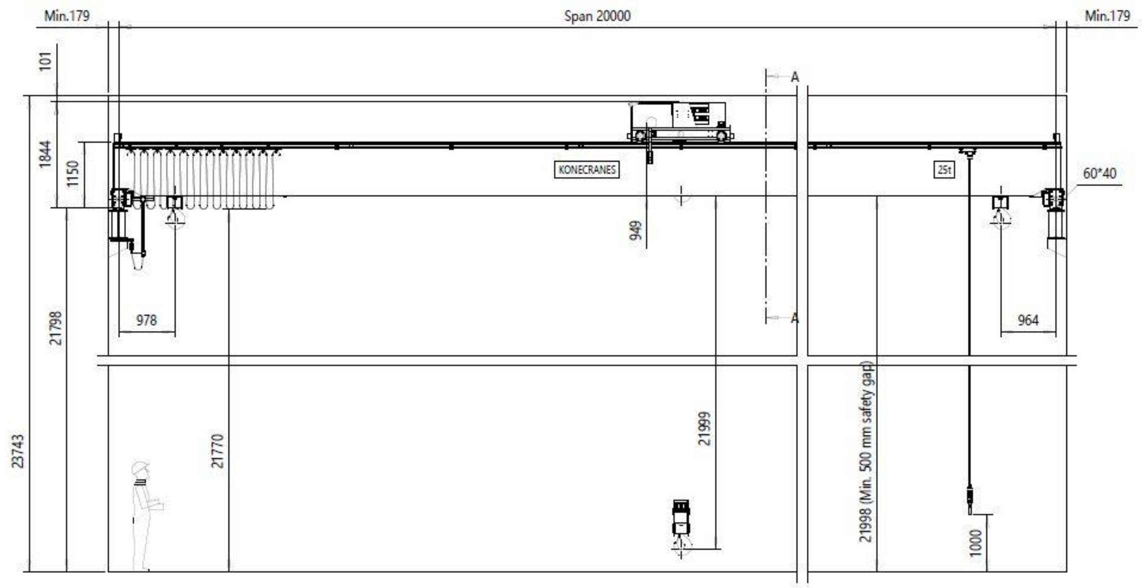
a



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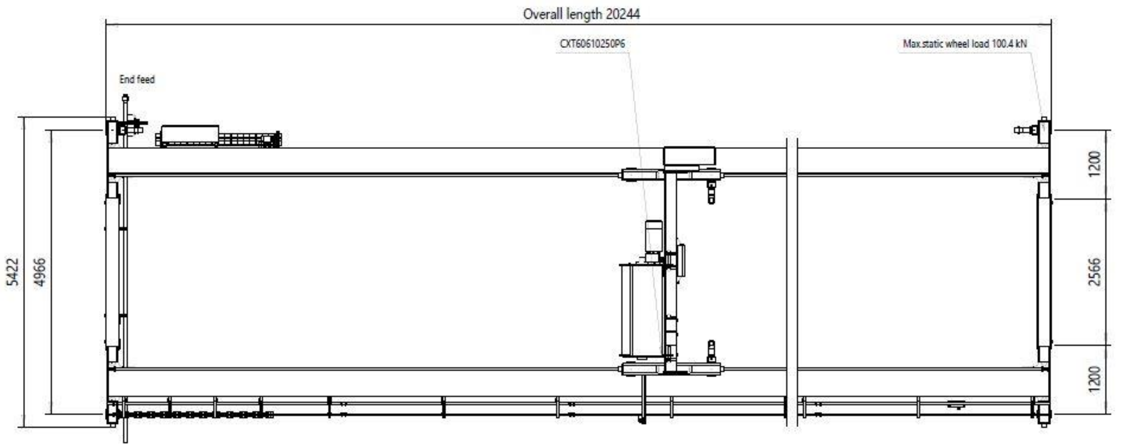

Fig. 3. Bridge crane layout:
a – frontal view; *b* – plan

Table 2

Wheel loads of bridge crane

Wheel	NR1	NR2	NR3	NR4	NR5	NR6	NR7	NR8
Vertical wheel loads								
Rmax Stc	100.4 kN	64.0 kN	–	–	53.3 kN	84.8 kN	–	–
Rmin Stc	–	–	20.7 kN	10.1 kN	–	–	8.8 kN	18.9 kN
Rmax Dyn	106.3 kN	68.0 kN	–	–	56.8 kN	89.9 kN	–	–
Rmin Dyn	–	–	22.3 kN	11.2 kN	–	–	9.8 kN	20.4 kN
Horizontal wheel loads								
HSNR= kN	11.7	16.6	2.2	3.2	–3.7	1.2	–0.7	0.2

doi: https://doi.org/10.15802/stp2025/332153

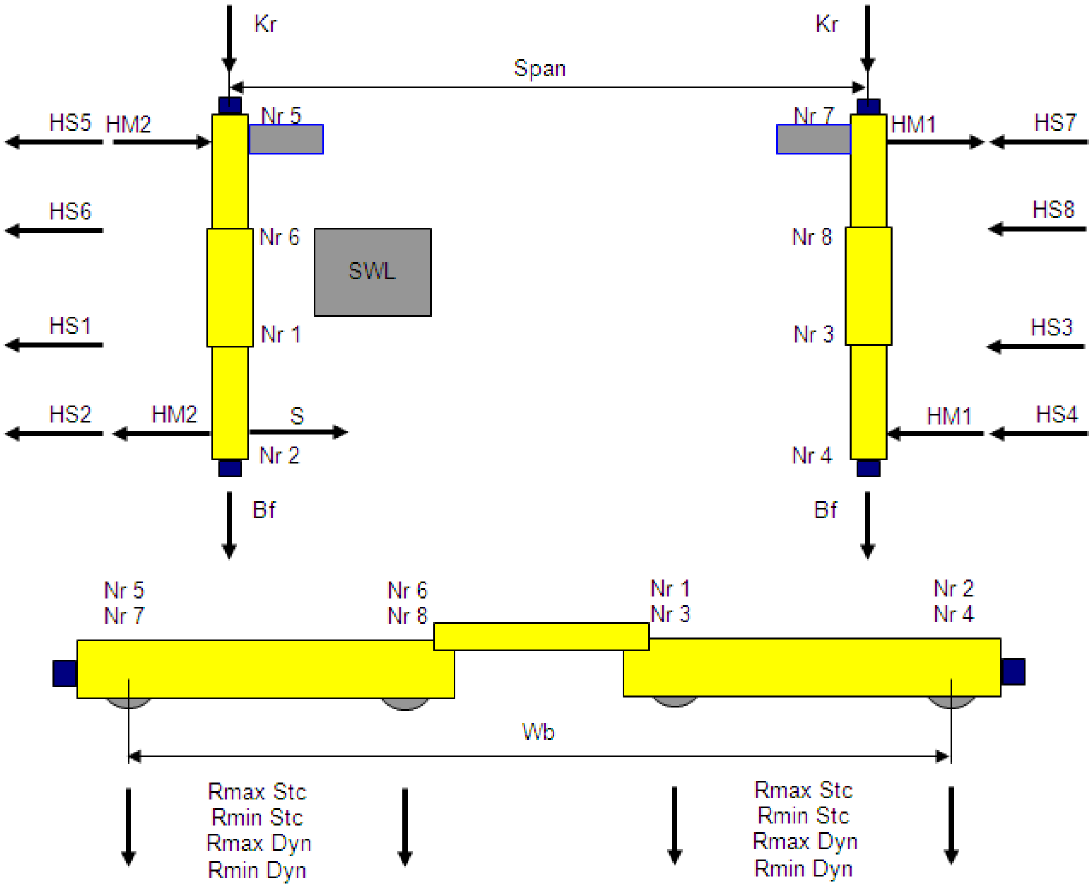

Fig. 4. Load scheme of bridge crane:
a – frontal view; *b* – plan

At the next stage, the determined structural solution of the crane beam was subjected to a comprehensive analysis for compliance with the requirements of the standards of China and Ukraine. The results of this analysis are summarised in Table 3. It presents the main conditions and determines the degree of compliance with these conditions through the efficiency factor *K*.

The steel used for the manufacture of the beam cross-section was of class C355 (calculated resistance R_y = 350 MPa), and for the manufacture of the transverse stiffeners – class C235 (calculated resistance R_y = 220 MPa). The use of high-strength steel grades is quite effective in modern conditions and can significantly improve a number of building structure indicators [16, 17].

According to the Chinese standards GB/T 700–2006 [15] and GB/T 19879–2023 [12], Q345GJ (design resistance R_y = 345 MPa) and Q235GJ (design resistance R_y = 215 MPa) steels should be used, respectively. In our opinion, the use of Q355NH and Q235NH steels with improved corrosion resistance can be justified in this case, since the production process of the shop involves the presence of an aggressive environment.

It should be noted that according to the Chinese standard GB 50017–2017 [11], all elements of a crane beam belong to different design classes. The class is calculated taking into account a special correction factor, which for the case under consideration is equal to:

– for section elements $\varepsilon_k = \sqrt{\dfrac{235}{355}} = 0.66$;

– for stiffeners $\varepsilon_k = \sqrt{\dfrac{235}{235}} = 1.00$.

For the entire crane beam structure, the design class is S1. Accordingly, certain corrections should be made to the design expressions on the one hand, and on the other hand, the calculation should be supplemented with new items. A summary of this is presented in Table 4. The last column shows the value of the efficiency coefficient by analogy with Table 3.

doi: https://doi.org/10.15802/stp2025/332153

The main features of this approach are as follows:

– the difference in the values of the calculated steel resistance in compression and bending does not exceed 3 %;

– the calculation takes into account plastic deformations. However, for structural elements that are designed for endurance, this requirement is advisory;

– local stresses for cranes with increased lifting capacities should be checked with an additional multiplying factor of 1.35;

– the overall stability should be checked only in full expression, taking into account the longitudinal bending stability factor;

– the requirement to install vertical stiffeners is less stringent, as compared to the Ukrainian standard, in terms of the number of vertical stiffeners, which is approximately twice as much;

– the analysis of local stability considers the possibility of torsion of the compressed part of the beam section;

– fundamentally different calculation expressions for determining the critical stresses of loss of local stability, which, compared to the Ukrainian standard, are approximately 2–2.5 times lower. This partially negates the requirement to install stiffeners;

– the minimum overhang of the stiffener must be 15 mm greater than that required by the Ukrainian standard, but the thickness of the stiffener can be about 2.5 times less.

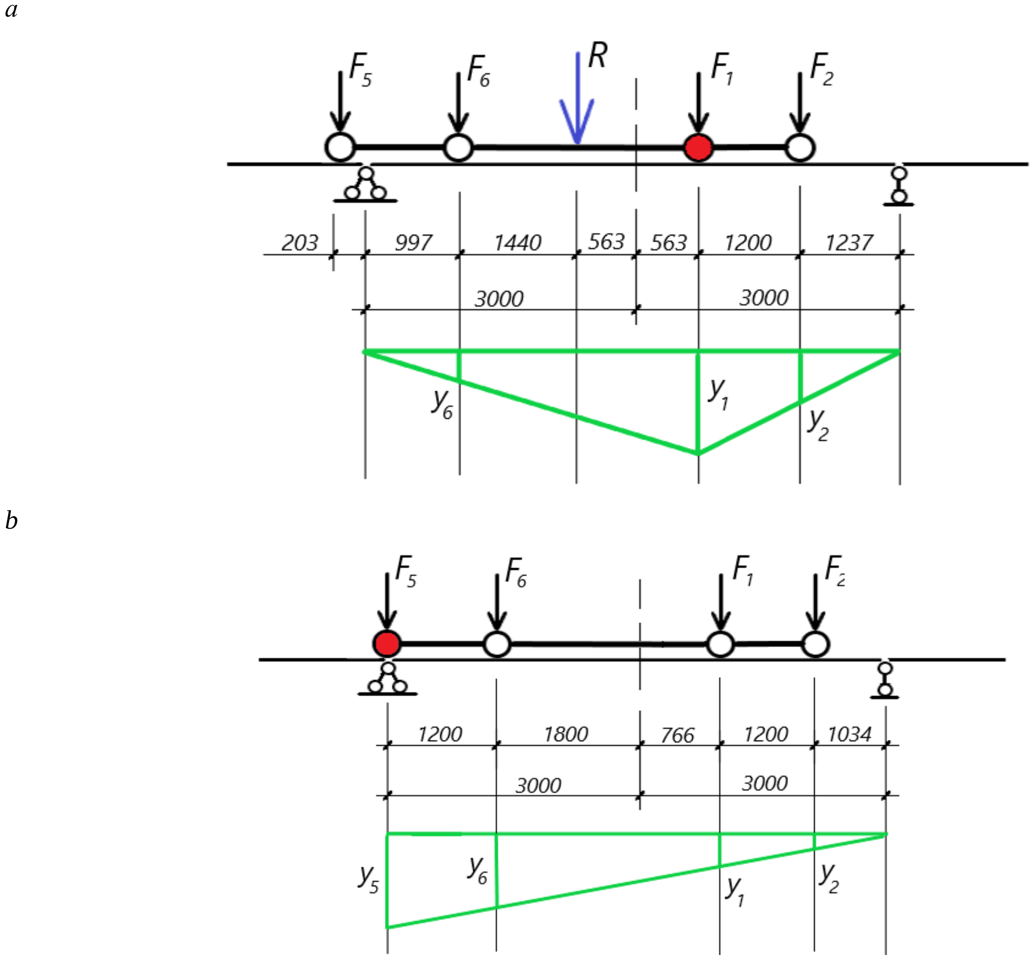

Fig. 5. Calculation scheme of crane beam:
a – for maximum bending moment; *b* – for maximum shear force

doi: https://doi.org/10.15802/stp2025/332153

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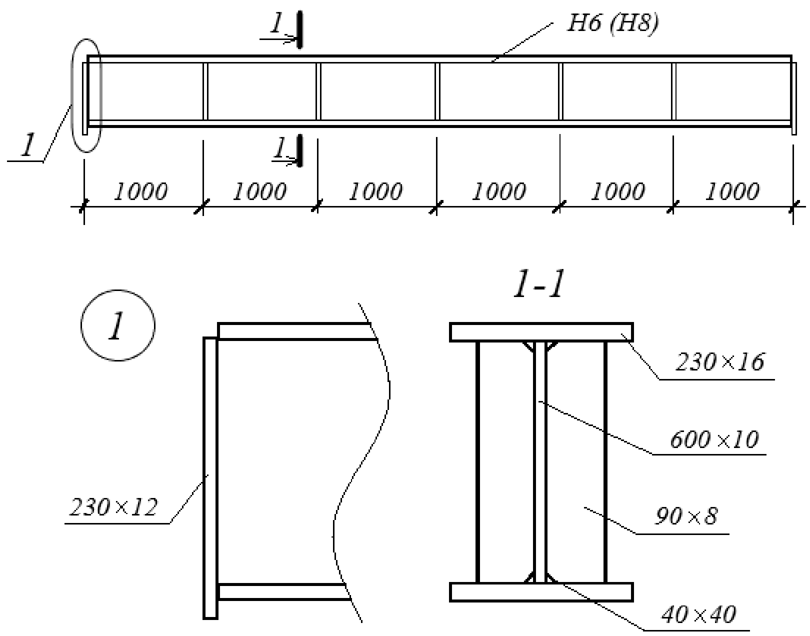

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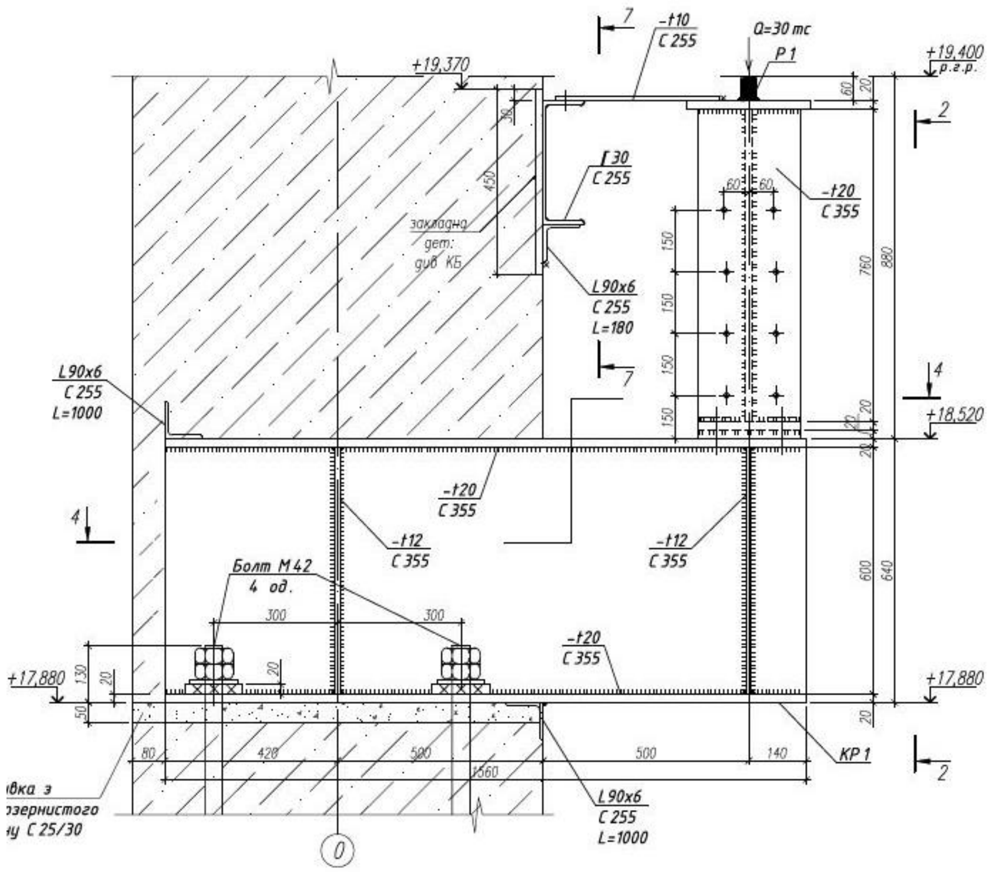

Fig. 6. Cross section of crane beam:
a – structure scheme; *b* – support unit

doi: https://doi.org/10.15802/stp2025/332153

Table 3

Regulatory conditions for steel crane beam

Condition	K-value
$\frac{M_{\text{В}}}{W_{\text{В}} \cdot R_y} + \frac{M_{\Gamma}}{W_{\Gamma} \cdot R_y}$	0.83
$\frac{Q_{\text{В}}}{0.58 \cdot A_w \cdot R_y} + \frac{Q_{\Gamma}}{0.58 \cdot A_f \cdot R_y}$	0.28
$\frac{0.87}{R_y} \cdot \sqrt{\left(\frac{M_{\text{В}}}{W_{\text{В}}} + \frac{\sum \gamma_f \cdot F_1}{4 \cdot l \cdot t_w}\right)^2 - \left(\frac{M_{\text{В}}}{W_{\text{В}}} + \frac{\sum \gamma_f \cdot F_1}{4 \cdot l \cdot t_w}\right) \cdot \frac{\sum \gamma_f \cdot F_1}{l \cdot t_w} + \left(\frac{\sum \gamma_f \cdot F_1}{l \cdot t_w}\right)^2 + \left(\frac{Q_{\text{В}}}{t_w \cdot h_w} + \frac{0.3 \cdot \sum \gamma_f \cdot F_1}{l \cdot t_w}\right)^2}$	0.45
$\frac{1}{R_y} \cdot \left(\frac{M_{\text{В}}}{W_{\text{В}}} + \frac{\sum \gamma_f \cdot F_1}{4 \cdot l \cdot t_w}\right)$	0.43
$\frac{1}{R_y} \cdot \left(\frac{\sum \gamma_f \cdot F_1}{l \cdot t_w} + \frac{2 \cdot t_w \cdot \left(1.5 \cdot \sum \gamma_f \cdot F_1 + 0.75 \cdot Q_r \cdot h_r\right)}{I_r + 0.33 \cdot b_f \cdot t_f^3}\right)$	0.28
$\frac{1}{0.58 \cdot R_y} \cdot \left(\frac{Q_{\text{В}}}{t_w \cdot h_w} + \frac{0.3 \cdot \sum \gamma_f \cdot F_1}{l \cdot t_w} + \frac{t_w \cdot \left(1.5 \cdot \sum \gamma_f \cdot F_1 + 0.75 \cdot Q_r \cdot h_r\right)}{2 \cdot \left(l_r + 0.33 \cdot b_f \cdot t_f^3\right)}\right)$	0.39
$\dfrac{\frac{l_f}{b_f} \cdot \sqrt{\frac{R_y}{E}}}{0.35 + 0.0032 \cdot \frac{b_f}{t_f} + \left(0.75 - 0.02 \cdot \frac{b_f}{t_f}\right) \cdot \frac{b_f}{h_w + t_f}}$	0.32
$\frac{b_f}{2 \cdot t_f} \cdot \sqrt{\frac{R_y}{E}} \cdot \frac{1}{\lambda_f}$	0.56
$\frac{h_w}{t_w} \cdot \sqrt{\frac{R_y}{E}} \cdot \frac{1}{\lambda_w}$	0.99
$\sqrt{\left(\frac{M_{\text{В}} + \frac{\sum \gamma_f \cdot F_1}{4 \cdot l \cdot t_w}}{W_{\text{В}} \cdot \sigma_{cr}}\right)^2 + \left(\frac{Q_{\text{В}}}{t_w \cdot h_w \cdot \tau_{cr}}\right)^2}$	0.29
$\frac{M_{\text{В}}}{\sum \gamma_f \cdot W_{\text{В}} \cdot \beta \cdot R_y}$	0.80
$\frac{5 \cdot \delta \cdot M_{\text{В}} \cdot L}{48 \cdot \sum \gamma_f \cdot E \cdot \text{I}_{\text{В}}}$	0.42

doi: https://doi.org/10.15802/stp2025/332153

Continuation of Table 3

Condition	K-value
$\frac{Q_В}{\varphi \cdot b_s \cdot t_s \cdot R_y}$	0.25
$\frac{b_s}{2 \cdot t_f} \cdot \sqrt{\frac{R_y}{E}} \cdot \frac{1}{\lambda_s}$	0.68
$\frac{b_h}{t_h} \cdot \sqrt{\frac{R_y}{E}} \cdot \frac{1}{\lambda_h}$	0.87

Table 4

Additional conditions according to the Chinese standard

Condition	K-value
$\frac{M_В}{1.05 \cdot W_В \cdot R_y} + \frac{M_Г}{1.20 \cdot W_Г \cdot R_y}$	0.74
$\frac{1}{R_y} \cdot \frac{1.35 \cdot \sum \gamma_f \cdot F_1}{l \cdot t_w}$	0.25
$\left(\frac{M_В}{W_В \cdot \sigma_{cr}}\right)^2 + \left(\frac{Q_В}{t_w \cdot h_w \cdot \tau_{cr}}\right)^2 + \frac{\sum \gamma_f \cdot F_1}{l \cdot t_w \cdot \sigma_{c,cr}}$	0.47
$\frac{M_В}{\varphi_b \cdot W_В \cdot R_y} + \frac{M_Г}{1.20 \cdot W_Г \cdot R_y}$	0.37

Value symbols: *A* – area; *I* – moment of inertia; *W* – moment of resistance; *b* – width; *h* – height; *l* – width of the local stress zone; *t* – thickness; *β* – endurance factor; *γ* – reliability factor; *δ* – strain factor; *λ* – slenderness; *σ* – normal stresses; *τ* – tangential stresses; *φ* – stability factor
Index symbols: *b* – beam; *c* – local value; *f* – beam flange; *h* – intermediate stiffener; *r* – crane rail; *s* – support stiffener; *w* – beam wall; *cr* – critical value

Originality and practical value

Thus, this publication provides a comprehensive comparison of the requirements for the design of steel crane beams for industrial buildings with bridge cranes in accordance with the current standards of China and Ukraine. The main differences in the design methodology and their possible consequences are outlined, and recommendations for their elimination are provided.

In practical terms, a structural solution for a steel simply supported crane beam with a span of 6 m for a 25-tonne capacity bridge crane has been developed. This solution covers the requirements of both Chinese and Ukrainian standards in this area. The paper also quantifies the level of compliance of the design solution with the requirements of the standards.

Conclusions

A comprehensive comparative analysis of methods and approaches to the calculation of steel crane beams (using the example of a 6 m span beam for a 25 tonne crane), laid down in the cur-

doi: https://doi.org/10.15802/stp2025/332153

rent standards of China and Ukraine, allows us to state:

1. The design solution must meet a total of about 20 design conditions of the standards.

2. Structural requirements in both standards are limited to the requirements for bracing the upper compressed flange of the beam in the horizontal direction and the selection of the dimensions of the supporting stiffeners.

3. The Chinese standard generally provides for stricter requirements for the design of steel crane beams.

The final design solution of the steel crane beam shown here meets the minimum requirements of the Chinese and Ukrainian standards.

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Особливості сучасного проєктування сталевих підкранових балок виробничих будівель

Мета. Ця публікація спрямована на комплексне зіставлення методик та підходів до проєктування сталевих підкранових балок за чинними стандартами Китаю та України. Актуальність роботи обумовлена постійним нарощування обсягів та різновидів співпраці між цими двома країнами протягом останніх десятиріч. Також тематика роботи пов'язана з усе більш широким упровадженням в будівельну практику сталей підвищеної міцності, які мають низку додаткових покращених експлуатаційних характеристик. **Методика.** Розглянуто проєкт сталевої розрізної підкранової балки прогоном 6 м одного із сучасних енергетичних підприємств України. Навантаження було передбачено від електричного мостового крана вантажопідйомністю 25 т. Перевірку підібраного перерізу проведено відповідно до розрахункових вимог чинних стандартів Китаю та України, які в сукупності налічують близько 20 позицій. Окремо враховано наведені в стандартах конструкційні вимоги щодо влаштування кріпильних ребер жорсткості та забезпечення місцевої стійкості елементів перерізу. **Результати.** Проведений порівняльний аналіз чинних підходів за стандартами Китаю та України дозволив установити, що в цілому стандарт Китаю висуває більш жорсткі вимоги як для матеріалу, з якого виготовляють підкранові балки, так і до розрахунково-конструкційних рішень. При цьому в частині забезпечення загальної і місцевої стійкості в стандарті Китаю використано принципово інший концептуальний підхід, ніж у стандарті України. Проте остаточне рішення має приблизно однаковий рівень несної здатності. **Наукова новизна.** Проведений порівняльний аналіз вимог чинних стандартів Китаю та України в частині проєктування сталевих підкранових балок дозволив виявити слабкі та сильні сторони кожного із стандартів, а також окреслити основні принципові розбіжності між ними. **Практична значимість.** Розроблено та запропоновано до практичної реалізації конструкційний варіант сталевої розрізної підкранової балки, яка за своїми показниками несної здатності в сукупності відповідає вимогам чинних стандартів Китаю та України в галузі металобудівництва.

Ключові слова: сталева підкранова балка; виробнича будівля; мостовий кран; стандарт Китаю; стандарт України; обмін досвідом

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Надійшла до редколегії: 29.01.2025
Прийнята до друку: 09.06.2025

doi: https://doi.org/10.15802/stp2025/332153