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FEATURES OF MODELING BOLTED JOINTS OF THIN-WALLED STEEL ELEMENTS IN DYNAMIC MONITORING TASKS

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The article considers the issue of modeling joints in thin-walled steel structures, which are actively used in construction, mechanical engineering and other branches of engineering. These structures are characterized by high efficiency and economy, however, their mechanical characteristics and features of the interaction of individual elements require detailed analysis to ensure reliability and durability. Bolted joints are one of the key methods of fixing elements of such structures, as they provide strength, ease of installation and the possibility of replacing components. The research focuses on the development and improvement of numerical models that describe the operation of bolted joints in real operating conditions. The use of numerical methods allows predicting the behavior of joints, assessing their strength and determining factors that affect the accuracy of calculations. Special attention is paid to the analysis of geometric parameters and material characteristics of the connected elements, as well as their impact on the effectiveness of structural solutions. A special place in the study is occupied by the issue of model verification, because the reliability of numerical methods must be confirmed by comparison with experimental data. The article considers the possibilities of using various computational complexes to assess the correctness of models, as well as analyze their compliance with real tests. An important aspect is the consideration of dynamic monitoring of the condition of joints, which allows ensuring the safety of structural operation and preventing potential emergency situations. The results of the study confirm the effectiveness of the applied models and methods, and also open up prospects for further improvement of approaches to design and optimization of structures. The results obtained can be used in practical engineering solutions, which will contribute to increasing the reliability of joints in difficult operating conditions.
Keywords: dynamic monitoring, bolted joints, vibration frequencies, metal structures.

Introduction. In modern construction and mechanical engineering, structures made of cold-rolled thin-walled profiles have been widely used, combining lightness, strength and efficiency in the use of materials. An important component of such structures are bolted joints, which ensure the strength and stability of the entire system. Despite their practical importance, bolted joints of such profiles remain insufficiently studied, especially with regard to their behavior under static and dynamic loads. Accurate prediction of their condition under operating conditions is a complex task that requires improvement of calculation models and monitoring methods.

The computational models used to analyze the strength and stability of bolted joints must accurately reflect their real stress-strain state. In addition, the consideration of dynamic characteristics, such as natural frequencies of oscillation, is a key aspect for creating an effective monitoring system that can predict possible damage and prevent emergency situations.

The relevance of the research is due to the need to increase the reliability of bolted connections of cold-rolled thin-walled profiles in critical structures. The use of numerical modeling together with laboratory experimental studies allows creating accurate numerical models that reflect real processes in structures.

Integration of calculation data with dynamic monitoring systems opens up new prospects in engineering diagnostics and forecasting of the technical condition of structures. In the conditions of increasing loads on construction and engineering facilities, the development of such methods is necessary to ensure their durability and safety.

The scientific literature presents a significant number of works devoted to the study of bolted joints, their analysis using numerical methods and laboratory experiments. In particular, modern works in the field of structural mechanics demonstrate the need to coordinate numerical calculations with experimental studies. Recent scientific developments [1] are focused on improving numerical analysis algorithms for more accurate prediction of the behavior of structures. Analytical calculation of bolted connections of metal structures is actively studied by modern scientists, depending on the chosen research direction [2-7]. However, the issue of practical application of the obtained models in dynamic monitoring systems remains insufficiently studied, which determines the need for further scientific research in this area.

The purpose of the study is to develop and improve a computational model of bolted connections of cold-rolled thin-walled profiles, which is consistent with experimental studies and provides accurate prediction of the state of the structure.

The research objectives are to analyze the stress-strain state of bolted joints based on numerical modeling in Scad Office and Abaqus, compare the results of numerical analysis with experimental data obtained during laboratory tests of structures under static loads, and assess the possibility of practical application of the obtained results in dynamic monitoring systems of critical facilities.

Creating a calculation model. The model (Fig. 1) was used for the study consisting of two transverse load-bearing C-shaped profiles (a) C+450x4, which are rigidly attached to the support posts (b). The support posts act as vertical columns of the structure. Between the transverse load-bearing profiles there are longitudinal C-shaped profiles (c) C+350x4, which are fixed using a connecting angle (d) and a bolted connection with a tightening torque of 95 N·m, in accordance with [9]. Open-section profiles of cold forming made of pre-galvanized strip steel S390GD-Z275MA [8].

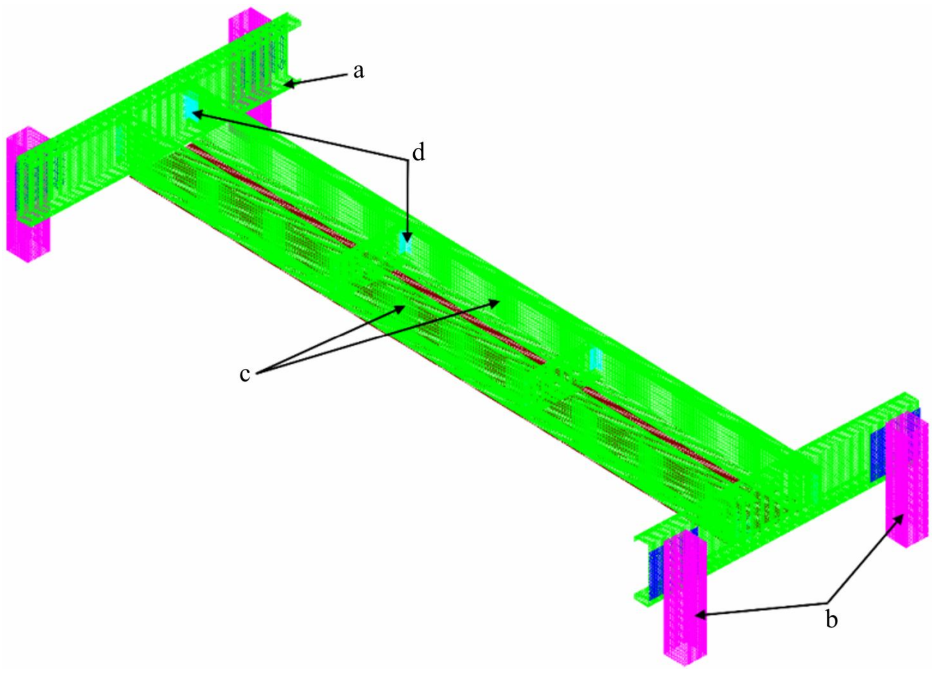

Fig. 1. Calculation model of the studied structure in the Scad office

The steel elements of the calculation model are simulated in the Scad Office software from 4-cornered finite element (FE) shells (44 type of finite element). The mesh step of the finite elements is taken as 5 mm. In the bolted zones around the holes, the mesh is thickened (Fig. 2).

The bolted connection is simulated by combining the aggregation of node displacements along projection axes of the holes of the adjacent elements along three projection axes. The welded connection of the support post with the plate is simulated by combining aggregation of node displacements along projection axes and rotational movements around axes of the nodes located in the weld zone.

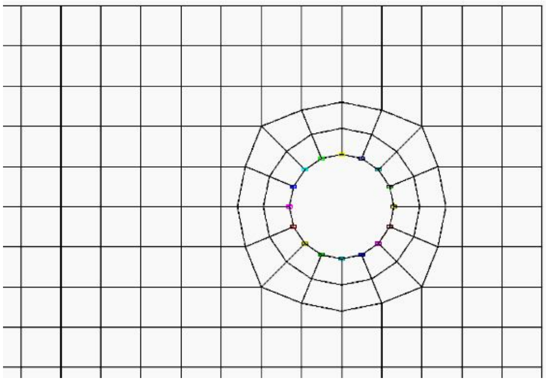

Fig. 2. Fragment of a connecting plate and profile with the aggregation of node displacements

Verification of the calculation model. To verify the calculation model of the structure created in the Scad Office software, there were compared the results of the static calculation of the model in the Abacus software [10], as well as the results of the static and dynamic calculations of the real structure in laboratory conditions.

As a static calculation, the load was applied to the secondary beams (Fig. 1 (c)). Comparison of the obtained results (Fig. 3) of the three tests showed the convergence of the obtained displacements. The maximum difference of the obtained displacements within the limits of plastic deformations was 3.51%.

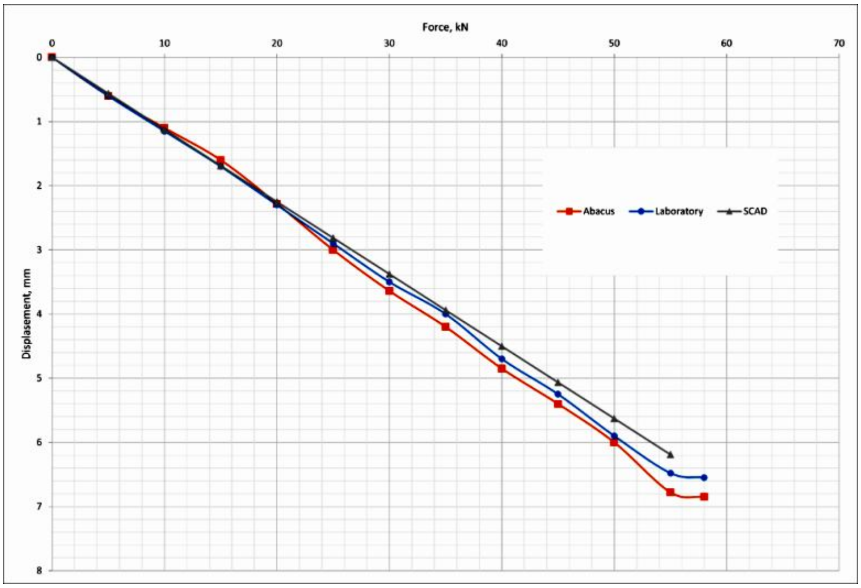

Fig. 3. Comparison of static test results

As a dynamic calculation, there was performed a modal analysis of the structure under the action of its own weight. A comparison of the results given in Table 1 showed the convergence of the initial natural frequencies of oscillations of the structure obtained in Scad Office with the spectrogram of the structure obtained in laboratory conditions.

Based on the verified shell model in the Scad office, there was conducted a comparative study of the possibility of using rod elements (Fig. 4) and various variants of a combined structural scheme containing both rod and shell finite elements.

The rod model used type 5 finite element members. The bolted connections of the members are provided with hinged joints, and the wooden decking is modeled with elastic ties (type 55 finite element) of equivalent stiffness.

Table 1

Comparison of the oscillation frequencies

Form No., measurement axis	Oscillation frequency, Hz		δ, %
	Scad Office	Laboratory conditions	
1, *Z*	8.117	8.3	2.25
2, *X*	14.216	14	1.52
7, *Z*	25.692	25.71	0.07

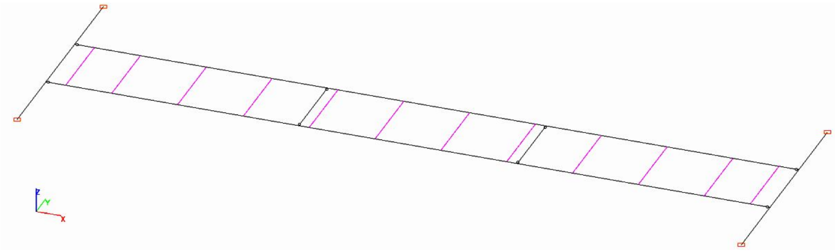

Fig. 4. Rod model of the structure

In the combined model (Fig. 5), both shell and rod finite elements with elastic connections were used. The supports, main beams and supporting sections of the secondary beams (the behavior of which was studied) were modeled by analogy with the shell scheme. The main part of the secondary beams is modeled by rod elements. The rod and shell finite elements are connected to each other by a completely rigid body (100 type of finite element).

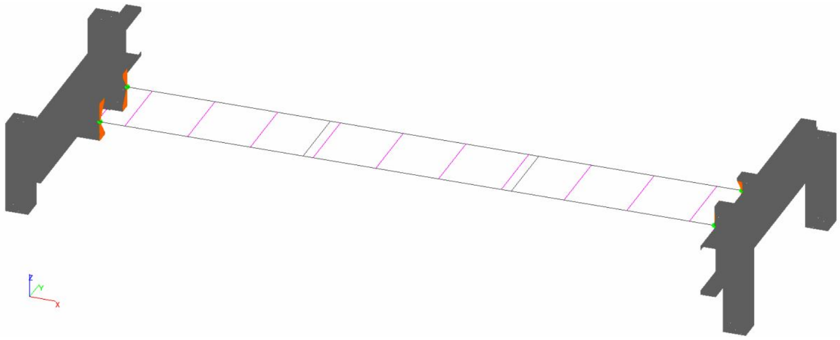

Fig. 5. Combined model of structure

The obtained results (Table 2) showed that the vibration frequencies of the rod structure gave results close to the shell model (2.9% difference in the frequency of the first vibration mode, 12.32% difference in the 7th vibration mode). But the modal analysis of such a model does not capture all the vibration frequencies obtained in the shell model. For example, in the frequency range of the first 100 Hz in the shell model, 62 vibration modes were obtained, while in the rod model - only 6 modes of natural vibrations of the structure.

Table 2

Comparison of oscillation frequencies of shell and rod models of the structure

Form No., measurement axis	Oscillation frequency, Hz		δ, %
	Shell model	Rod model	
1, *Z*	8.117	7.882	2.9
2, *X*	14.216	not caught	-
7, *Z*	25.692	28.856	12.32

Studies of the combined design scheme (Table 3) showed that combining shell and rod elements in the model did not bring the results obtained in the rod scheme closer to those obtained in the shell scheme. And the difference in the frequency of the first mode of oscillations increased almost 7 times.

Table 3

Comparison of oscillation frequencies of shell and combined structural models

Form No., measurement axis	Oscillation frequency, Hz		δ, %
	Shell model	Combined model	
1, Z	8.117	6.57	19.43
2, X	14.216	not caught	-
7, Z	25.692	25.09	9.64

Conclusion. The study showed that the computational model of the structure of thin-walled steel elements, created in the Scad Office software using 4-angular FE shells (44 finite elements), adequately describes the real structure in modal analysis problems. Verification of the model by comparing static and dynamic calculations with the results of laboratory tests confirmed the high accuracy of the modeling, since the maximum discrepancy of the obtained displacements was 3.51%.

The mesh thickening of the finite elements in the bolted joints and the use of aggregation of node displacements ensured a correct representation of the mechanical behavior of the structure. In addition, the modal analysis of the structure simulated in Scad Office showed good agreement with the experimentally obtained spectral characteristics of vibrations. This confirms the possibility of effective use of such a model for predicting the dynamic response of similar structures.

The results of the comparative analysis of the rod, shell and combined structural showed that the rod model provides approximate oscillation frequencies to the shell model, but significantly limits the number of natural oscillation modes. Attempts to combine rod and shell elements in the model did not lead to an improvement in the accuracy of calculations, but on the contrary - increased the discrepancies in the determined oscillation frequencies. This indicates that combining these elements in a single model does not make much sense. Given the results obtained, for further research it is advisable to consider the shell and rod models separately, depending on the requirements for the accuracy of calculations and the physical characteristics of the analyzed structures.

REFERENCES

1. Vabishchevych M.O., Dedov O.P., Savchuk D.O. The current state of the problem of numerical investigation of metal structure refusal based on dynamic monitoring // Strength of Materials and Theory of Structures: Scientific-and-technical collected articles. – K.: KNUBA, 2024. – Issue. – P. 52-57. https://doi.org/10.32347/2410-2547.2024.112.52-57
2. Y. Maggi, R. Gonçalves, R. Leon and L. Ribeiro, "Parametric analysis of steel bolted end plate connections using finite element modeling", in Journal of Constructional Steel Research, Vol. 61(5). Elsevier, 2005, pp. 689-708.
3. F. Liu, M. Shan, L. Zhao and J. Zhang, "Probabilistic bolt load distribution analysis of composite single-lap multi-bolt joints considering random bolt-hole clearances and tightening torques", in Composite Structures, Vol. 194 (15). Elsevier, 2018, pp. 12-20.
4. M.D. Elliott, L.H. Teh and A. Ahmed, "Behaviour and strength of bolted connections failing in shear", in Journal of Constructional Steel Research, Vol. 153. Elsevier, 2019, pp. 320-329.
5. B. Farahmand, Fracture mechanics of metals, composites, welds, and bolted joints: application of LEFM, EPFM, and FMDM theory. Springer, 2001.
6. T.S. Kim, J.H. Yoo and C.W. Roeder, "Experimental investigation on strength and curling influence of bolted connections in thin-walled carbon steel", in Thin-Walled Structures, Vol. 9. Elsevier, 2015, pp. 1-12.
7. C. Yu and M. Panyanouvong, "Bearing strength of cold-formed steel bolted connections with a gap", in Thin-Walled Structures, Vol. 67. Elsevier, 2013, pp. 110-115.
8. EN 1991-1-1:2002 Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings. 2002.
9. DSTU EN 15048-1:2017. Non-preloaded structural bolting assemblies. Part 1: General technical requirements. Kyiv: SE "UkrNDNC", 2017.
10. Vabishchevych M.O., Dedov O.P., Diachenko O.S., Lytvyn O.V. Research of the design of a T-shaped node of cold-rolled profiles, the connection of which is made by a plate using a bolt connection // Strength of Materials and Theory of Structures: Scientific and technical collected articles – K.: KNUBA, 2025. – Issue 114. – P. 62-75. https://doi.org/10.32347/2410-2547.2025.114.62-75

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ОСОБЛИВОСТІ МОДЕЛЮВАННЯ БОЛТОВИХ З'ЄДНАНЬ ТОНКОСТІННИХ СТАЛЕВИХ ЕЛЕМЕНТІВ У ЗАДАЧАХ ДИНАМІЧНОГО МОНІТОРИНГУ

У статті розглядається питання моделювання з'єднань у тонкостінних сталевих конструкціях, які активно використовуються в будівництві, машинобудуванні та інших галузях машинобудування. Ці конструкції характеризуються високою ефективністю та економічністю, проте їх механічні характеристики та особливості взаємодії окремих елементів потребують детального аналізу для забезпечення надійності та довговічності. Болтові з'єднання є одним з ключових методів кріплення елементів таких конструкцій, оскільки вони забезпечують міцність, легкість монтажу та можливість заміни компонентів. Дослідження зосереджено на розробці та вдосконаленні числових моделей, що описують роботу

болтових з'єднань у реальних умовах експлуатації. Використання числових методів дозволяє прогнозувати поведінку з'єднань, оцінювати їх міцність та визначати фактори, що впливають на точність розрахунків. Особлива увага приділяється аналізу геометричних параметрів та матеріальних характеристик з'єднуваних елементів, а також їх впливу на ефективність конструктивних рішень. Особливе місце в дослідженні займає питання верифікації моделей, оскільки надійність числових методів повинна бути підтверджена порівнянням з експериментальними даними. У статті розглядаються можливості використання різних обчислювальних комплексів для оцінки коректності моделей, а також аналізу їх відповідності реальним випробуванням. Важливим аспектом є врахування динамічного моніторингу стану з'єднань, що дозволяє забезпечити безпеку експлуатації конструкцій та запобігти потенційним аварійним ситуаціям. Результати дослідження підтверджують ефективність застосованих моделей та методів, а також відкривають перспективи для подальшого вдосконалення підходів до проектування та оптимізації конструкцій. Отримані результати можуть бути використані в практичних інженерних рішеннях, що сприятиме підвищенню надійності з'єднань у складних умовах експлуатації.
Ключові слова: динамічний моніторинг, болтові з'єднання, частоти коливань, металеві конструкції.

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FEATURES OF MODELING BOLTED JOINTS OF THIN-WALLED STEEL ELEMENTS IN DYNAMIC MONITORING TASKS.

The article considers the issue of modeling joints in thin-walled steel structures, which are actively used in construction, mechanical engineering and other branches of engineering. These structures are characterized by high efficiency and economy, however, their mechanical characteristics and features of the interaction of individual elements require detailed analysis to ensure reliability and durability. Bolted joints are one of the key methods of fixing elements of such structures, as they provide strength, ease of installation and the possibility of replacing components. The research focuses on the development and improvement of numerical models that describe the operation of bolted joints in real operating conditions. The use of numerical methods allows predicting the behavior of joints, assessing their strength and determining factors that affect the accuracy of calculations. Special attention is paid to the analysis of geometric parameters and material characteristics of the connected elements, as well as their impact on the effectiveness of structural solutions. A special place in the study is occupied by the issue of model verification, because the reliability of numerical methods must be confirmed by comparison with experimental data. The article considers the possibilities of using various computational complexes to assess the correctness of models, as well as analyze their compliance with real tests. An important aspect is the consideration of dynamic monitoring of the condition of joints, which allows ensuring the safety of structural operation and preventing potential emergency situations. The results of the study confirm the effectiveness of the applied models and methods, and also open up prospects for further improvement of approaches to design and optimization of structures. The results obtained can be used in practical engineering solutions, which will contribute to increasing the reliability of joints in difficult operating conditions.
Keywords: dynamic monitoring, bolted joints, vibration frequencies, metal structures.

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Вабіщевич М.О., Дєдов О.П., Савчук Д.О., Кара І.Д. **Особливості моделювання болтових з'єднань тонкостінних сталевих елементів у задачах динамічного моніторингу** // Опір матеріалів і теорія споруд: наук.-техн. збірник. – К.: КНУБА, 2025. – Вип. 115. – С. 63-68.– Англ.
Стаття присвячена розробці та верифікації числових моделей болтових з'єднань у тонкостінних сталевих конструкціях, з метою підвищення їх надійності, ефективності та безпеки в реальних умовах експлуатації..
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Vabishchevych M.O., Dedov O.P., Savchuk D.O., Kara I.D. **Features of modeling bolted joints of thin-walled steel elements in dynamic monitoring tasks** // Strength of Materials and Theory of Structures: Scientific-and-technical collected articles. – K.: KNUBA, 2025. – Issue 115. – P. 63-68.
The article is devoted to the development and verification of numerical models of bolted connections in thin-walled steel structures, with the aim of increasing their reliability, efficiency and safety in real operating conditions.
Fig. 5. Ref. 10.

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