Вісник Тернопільського національного технічного університету
https://doi.org/10.33108/visnyk_tntu
Scientific Journal of the Ternopil National Technical University
2025, № 2 (118) https://doi.org/10.33108/visnyk_tntu2025.02
ISSN 2522-4433. Web: ***visnyk.tntu.edu.ua***

UDC 621.177; 621.314

DEFORMATION BEHAVIOR SIMULATION OF A SUB-RAFTER WELDED TRUSS

Yaroslav Kovalchuk; Natalya Shynhera; Makar Shynhera

Ternopil Ivan Puluj National Technical University, Ternopil, Ukraine

Abstract. *The deflection of a welded sub-rafter truss under external static loads applied to the nodes of the upper chord was investigated. Experimental force testing and computer simulation experiments were conducted on a physical model of the truss with dimensions of 2000x400 mm. Based on the study results, numerical and graphical data sets were obtained regarding the deflection of the investigated truss under external loads ranging from 2.5 kN to 45 kN. The results from the computer simulation closely matched those from the experimental force testing, with a 94.2% correlation, indicating linear deformation behavior. Furthermore, computer modeling was used to study the truss's deformation behavior under higher loads, identifying the locations of maximum stress concentration. The study also determined the load limits that induce the structure's ultimate state. The methodology and findings are recommended for designing such trusses to ensure high accuracy in results, thus providing the necessary durability of welded sub-rafter trusses throughout their service life.*

Key words: *welded truss, experimental testing, computer simulation experiment, deformation behavior of the structure, load-bearing capacity, truss stability loss.*

https://doi.org/10.33108/visnyk_tntu2025.02.109 *Received 03.04.2025*

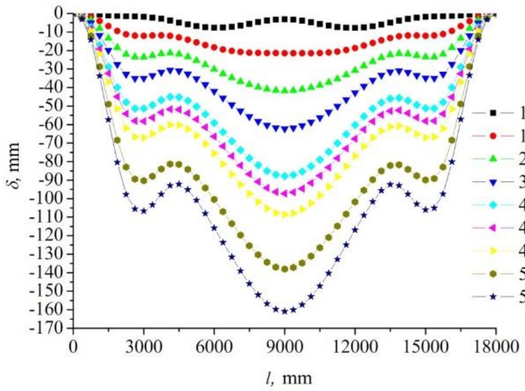
1. INTRODUCTION

The design of complex metal structures in buildings, including welded trusses, is now conducted through applied software applications that utilize algorithmic methodologies based on the finite element method. This engineering approach is referred to as a computer modeling experiment, which presents numerous advantages when compared to traditional computational engineering methods. Primarily, it offers significantly enhanced productivity in design activities and the capacity to consider a complex interplay of various influencing factors, including constructive, technological, operational, and emergency considerations. However, it is important to note that a computer modeling experiment does not eliminate the potential impact of subjective factors on the resulting design outcomes. This influence results from the introduction of sufficient input information for modeling, specifically the structural scheme of the truss, its support and loading configurations, the actual properties of structural materials, weld parameters, and the operating conditions of force and temperature. Additionally, it is imperative to accurately select the parameters of the finite element model, which will serve as the algorithmic foundation for the computer calculation. The degree of reliability of the derived calculation results is determined by verifying the outcomes of computer modeling, that is, by comparing them with the results of full-scale force experiments conducted on a real structure post-manufacture and loading. However, for full-scale truss structures, force experiments are typically not conducted due to the high costs associated with samples, the substantial dimensions, and the requirements for testing equipment. Nevertheless, verification of the results of computer simulation alongside full-scale experiments can be accomplished through the analysis of the results obtained from studying the physical model of the truss.

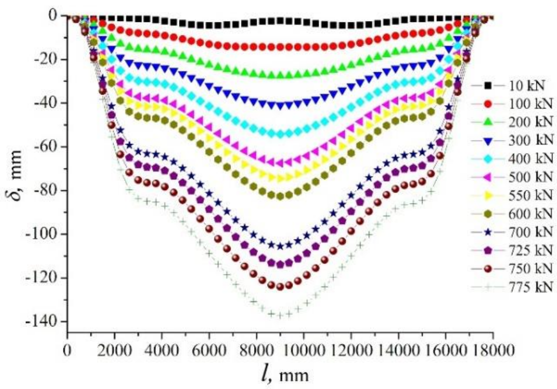
Corresponding author: Yaroslav Kovalchuk; e-mail: yarkv@i.ua

2. ANALYSES OF RECENT PUBLICATIONS

A rectangular welded truss is a conventional metallic structure utilized predominantly as a rafter in industrial and public edifices characterized by considerable inter-support spans. This aspect fundamentally influences the design and load-bearing scheme of the structure. Predominantly, the main load types encountered under such conditions are static loads applied to the nodes of the upper chord. However, this truss configuration, whether in a planar or spatial arrangement, may also function as a supporting element subjected to cyclic loads, as observed in applications such as bridge girders, overhead conveyors, crane structures, and power line supports. Consequently, a number of investigations have been conducted regarding this specific truss configuration. For instance, the study referenced as work [1] examined the effect of the height of the angular profile on the deformation behavior of a rectangular welded truss measuring 18000x3600 mm, employing a computational modeling approach within the ANSYS Workbench 14.5 framework (see Fig. 1).



a



b

Figure 1. Deflections along the lower chords of 18000 × 3600 mm trusses made of different angular profiles: *a* – 80x80x10 mm; *b* – 120x120x10 mm

The locations of maximum stresses have been identified, as well as the magnitude of the load on the truss at which at which the limit state of the structure is formed. However, due to the significant size of the studied truss and the lack of appropriate equipment, a physical strength experiment was not conducted, and consequently, the verification of the calculated results was not performed.

In the work [2], a combination of computer modeling experiments in the SolidWorks environment and real thermal experiments for a physical model of a 2000x400 welded truss was carried out regarding its deformation under increased temperature without applying external loads to the structure. In these studies, the verification of the results obtained from computer modeling was performed. The coincidence of the values of thermal deformations was found to be 95.8…98.7%.

The study of the strength of welded trusses under static loads was conducted in works [3–5]. Special emphasis was placed on the formation of damages that determine the strength of the welded truss as a whole, at its nodes under both static [6–10] and cyclic [11–16] loads.

As a continuation of the studies performed and taking into account the technological feasibility of a force experiment for a physical model of a 2000×400 welded truss regarding its deformation under the action of a static load on the nodes of the upper girders, it is advisable to computer simulate the deflection of the truss in the middle of the lower girders and assess the degree of coincidence of the results obtained by physical and computer simulation.

The objective of this work is to determine the parameters of the stress-strain state (SSS) in the elements of a physical model of a 2000×400 welded truss under its loading using the method of computer simulation experiment, to perform a full-scale force experiment for this truss within its elastic deformations, and to verify the results obtained.

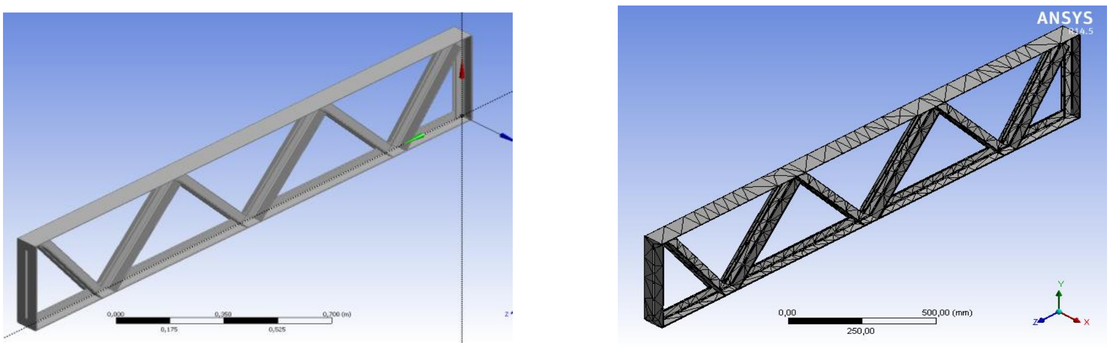
To achieve this goal, it is necessary to perform a computer simulation experiment for a physical model of a truss up to the destruction of the structure, to form numerical and graphical information arrays on the parameters of the NDT in the truss elements, in particular, the deflection of the middle of the lower belt, to make a full-scale sample of the physical model of the truss, to perform a full-scale force experiment for loads within the elastic deformation of the structure, to determine the deflection of the truss in the middle of the lower belt for discrete values of the applied loads, to analyse the experimental findings and their verification.

3. RESEARCH FINDINGS

The study of the deformation behaviour of a welded truss under static loads is carried out by a computer simulation experiment using the ANSYS Workbench 14.5 application software package, which is algorithmically based on the finite element method. The following mathematical model is used for the solution of this task:

– The CAD geometric model along with the specified load is a formalized physical model (Fig. 2, a);

– The finite element mesh is a mathematical representation of the CAD geometric model; it is a computational model (Fig. 2, b).



a *b*

Figure 2. Truss with dimensions of 2000x400 mm. a – CAD – geometric model;
b – CAE – finite element mesh model

A full-scale force experiment was performed on a test bench (Fig. 3).

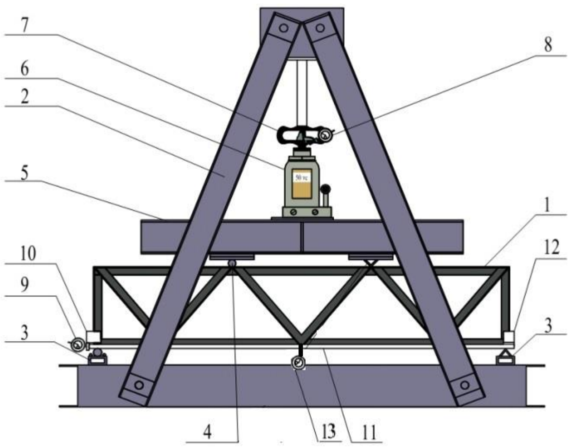


Figure 3. Test bench for determining the deflection at the midpoint of the lower chord of a 2000x400 mm truss under various loads through experimental testing

To conduct field experiments, the physical model sample of the truss 1 is installed in the frame structure 2 with a base on supports 3. The forces on the upper chord joints of the truss are transmitted through the compression elements 4, placed on the crossbeam 5. Discrete load values are created by the power unit 6, and their magnitude is determined by the dynamometer 7 with a measuring device 8. The dial indicator 9, mounted in the clamp 10 on the left support joint of the truss, provides information about the elongation of the lower chord due to the movement of the rod 11, fixed by the clamp 12 in the right support joint of the truss. The dial indicator 13 is fixed on the lower beam of the frame structure 2, and its operating rod is brought into contact with the lower chord of the truss 1.

Based on the results of the computer modeling experiment, graphs of deflection along the lower chord of the truss under the action of static discrete loads were obtained (Fig. 4).

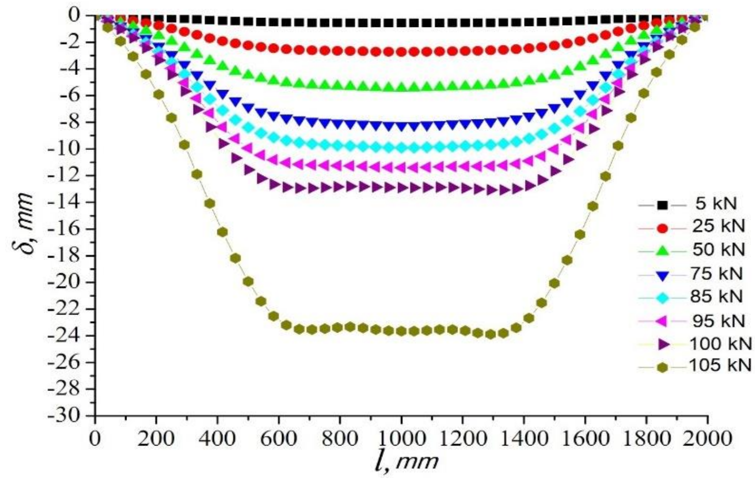


Figure 4. Deflection of the 2000x400 mm truss along the lower chord under various loads based on the results of a computer simulation experiment

In the same manner, stress diagrams along the lower chord of the 2000x400 truss under the action of static discrete loads were obtained (Fig. 5).

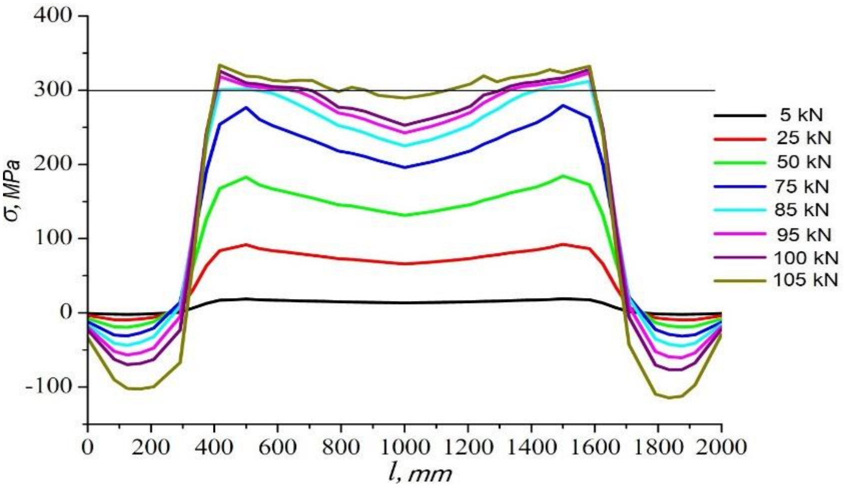


Figure 5. Stress diagram along the lower chord of the 2000x400 mm truss under various loads based on the results of a computer simulation experiment

Fig. 4 shows that the maximum deflection of the truss occurs at the midpoint of the lower chord. When comparing the deflection diagrams of the 18000x3600 truss (Fig. 1) and the 2000x400 truss (Fig. 4), their graphical similarity is evident, indicating that the parameters of physical modeling were correctly chosen during the research.

According to the stress diagram along the lower chord of the 2000x400 truss (Fig. 5), it is evident that under loading, the maximum stresses are formed in the vicinity of the extreme nodes on the lower chord. These areas determine the truss's stability. In Fig. 5, a horizontal line is drawn at the stress level of 300 MPa, which is the limit for welded joints and areas affected by thermal influence. These stresses correspond to a load of 80 kN on the truss.

The visualisation of deformation and stress distribution for a welded truss 2000x400 obtained by a computer simulation experiment at the level of the structural limit state is shown in Fig. 6.

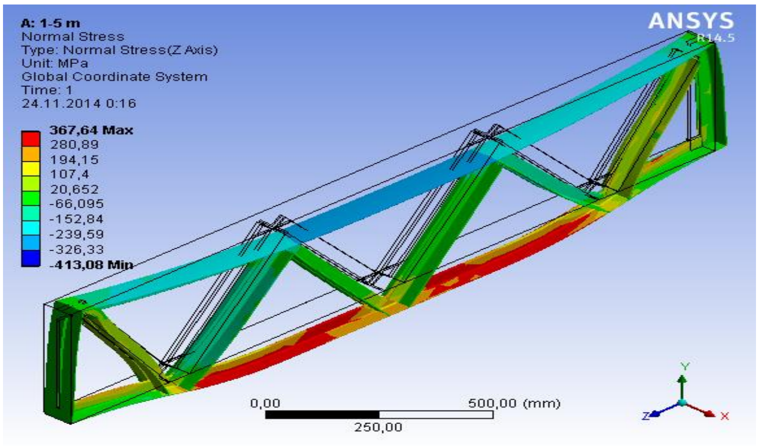


Figure 6. Visualization of deformation and stress distribution for the 2000x400 mm welded truss, obtained through computer simulation at the structure's ultimate limit state

This visualisation (Fig. 6) confirms the graphical dependence of the stress distribution along the lower chord (Fig. 5), namely the formation of maximum stresses between the extreme nodes.

The numerical base obtained from the results of computer modelling and full-scale experiments is summarised in Table 1.

Table 1

Maximum strsses and deflections in the center of a 2000x400 mm welded truss under load

Load P, кN	5	15	25	35	50	75	85	95	100	105
Sress σ, MPa	18,8	-	92,4	-	184	279	315	347	367	397
Deflection of the lower chord, δ_1	0,55	-	2,72	-	5,43	8,24	9,91	11,41	12,90	23,65
Deflection of the lower chord, δ_2	0,53	1,56	2,59	3,61	5,13	7,73	-	-	-	-
Ration C between δ_1 and δ_2	0,963	-	0,952	-	0,945	0,938	-	-	-	-

The table shows:
δ_1 – deflection of the lower chord according to the results of a computer simulation experiment;
δ_2 – deflection of the lower chord according to the results of a full-scale experiment.

Ratio C between δ_1 and δ_2 are determined as

$$C = \delta_1/\delta_2.$$

Based on the obtained data arrays, deflection diagrams of the lower chord of the 2000x400 welded truss were built (Fig. 7).

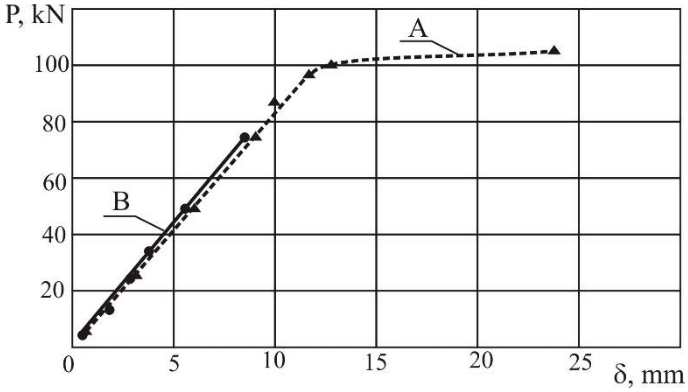


Figure 7. Deflection diagram of the lower chord of the 2000x400 mm welded truss based on the results of the computer simulation (A) and full-scale force experiments (B)

According to Fig. 7, there is a visually noticeable satisfactory match of the deflection values of the truss determined by computer simulation and full-scale force experiments. The numerical values of the ratio C between δ_1 and δ_2 are defined above and presented in Table 1. For low loads, a match of 0.963 was obtained, and for loads approaching the ultimate state of the structure, – C=0.938.

The limit state of the 2000×400 mm truss made of a 40×40×4 mm angle profile, according to the results of a computer simulation experiment, was formed under a load of Pmax= 80 kN, while plastic deformation of the structure, according to the calculations, occurred at forces of 85 kN.

4. CONCLUSSIONS

The paper proposes a methodological approach aimed at increasing the reliability of the results of a computer simulation experiment when analysing the deformation behaviour of welded trusses under the influence of loads. The main goal of this approach was to generate input data that would correspond to the actual operating conditions of structures of this type. Based on the research results, an input information array was formed, which includes indicators of the stress-strain state of a welded truss in its various locations and in a wide range of loads. A satisfactory agreement between the results of computer modelling and full-scale experiments of at least 93.8% was obtained.

The obtained research results can be used for modeling the behavior of welded trusses using modern applied software packages. The application of these software tools will allow for the consideration of the complex influence of design, technological, and operational factors in the process of designing welded trusses, ensuring optimal strength, reliability, and durability of the structure under various operating conditions.

References

1. Kovalchuk Y., Shynhera N. (2017) The influence of height of angular profile of rods on rectangular welded truss deformation. Scientific Journal of TNTU, vol. 88, no. 4, pp. 82–87. https://doi.org/10.33108/visnyk_tntu2017.04.082
2. Kovalchuk Y., Kovalchuk Y., Shynhera N. (2022) Welded truss deformation under thermal influence. Scientific Journal of TNTU, vol. 105, no. 1, pp. 13–18. https://doi.org/10.33108/visnyk_tntu2022.01.013
3. Zhang Zhaobo, et al. "Deflection Estimation of Truss Structures Using Inverse Finite Element Method." Sensors 23.3 (2023): 1716. https://doi.org/10.3390/s23031716
4. Tiainen T., Mela K., Jokinen T., Heinisuo M. The effect of steel grade on weight and cost of warren-type welded tubular trusses. Proc. Inst. Civ. Eng. Struct. Build. 2017, 170, 855–873. https://doi.org/10.1680/jstbu.16.00112
5. Lan X., Huang Y., Chan T.-M., Young B. (2018) Static strength of stainless steel K- and N-joints at elevated temperatures. Thin-Walled Struct, 122, pp. 501–509. https://doi.org/10.1016/j.tws.2017.10.009
6. Efendi A. W. (2024) Behavior of welded joints on the roof truss of KOJK Office using LISA V.8 FEA – Journal of Metallurgical Engineering and Processing Technology, vol. 5, no. 1, August, P-ISSN: 2723-6854, E-ISSN: 2798-1037, pp. 24–41. https://doi.org/10.31315/jmept.v5i1.12020
7. Majko J., Saga M., Sagova Z., Handrik M., Kopas P., Jakubovicova L. (2022) Numerical analysis and optimization of large dimensioned structures considering stress concentrations in welded joint. MATEC Web of Conferences, 357, 02002. https://doi.org/10.1051/matecconf/202235702002
8. Shao Y., He S., Zhang H., Wang Q. (2017) Behavior of tubular T-joints after exposure to elevated temperature. Ocean Eng., 129, 57–67. https://doi.org/10.1016/j.oceaneng.2016.11.017
9. Azari Dodaran N., Ahmadi H., Lotfollahi-Yaghin M. A. (2018) Static strength of axially loaded tubular KT-joints at elevated temperatures: Study of geometrical effects and parametric formulation. Mar. Struct., 61, 282–308. https://doi.org/10.1016/j.marstruc.2018.06.009
10. Larsen Mikkel Lovenskjold, et al. "Fatigue life estimation of the weld joint in K-node of the offshore jacket structure using stochastic finite element analysis". Marine Structures 78 (2021): 103020. https://doi.org/10.1016/j.marstruc.2021.103020
11. Suo Y., Yang W., Chen P. (2018) Study on Hysteresis Model of Welding Material in Unstiffened Welded Joints of Steel Tubular Truss Structure. Appl. Sci., 8, 1701. https://doi.org/10.3390/app8091701
12. Larsen Mikkel Lovenskjold, et al. "Fatigue life estimation of the weld joint in K-node of the offshore jacket structure using stochastic finite element analysis". Marine Structures, 78 (2021): 103020. https://doi.org/10.1016/j.marstruc.2021.103020
13. Kaminski Marcin and Rafal Blonski. "Analytical and numerical reliability analysis of certain Pratt steel truss". Applied Sciences, 12.6 (2022): 2901. https://doi.org/10.3390/app12062901
14. Khademi F. Enhancing Load Rating of Railway Truss Bridges through a Hybrid Structural Analysis and Instrumentation Procedure. Ph.D. Thesis, Illinois Institute of Technology, Chicago, ON, USA, 2017.
15. Tong G., Zhongxiang L., Jie L., Dazhang H. (2016) Diagnosis and Mitigation of Fatigue Damage in Longitudinal Diaphragms of Cable-Stayed Bridges. Journal of Bridge Engineering.
16. Hobbacher A. F., (2016) Recommendations for Fatigue Design of Welded Joints and Components IIW Collection, Springer International Publishing. https://doi.org/10.1007/978-3-319-23757-2
17. Li T., Lie S.T., Shao Y. B. (2017) Fatigue and fracture strength of circular hollow section TT-joint. J. Constr. Steel Res, 129, pp. 101–110. https://doi.org/10.1016/j.jcsr.2016.11.001

УДК 621.177; 621.314

МОДЕЛЮВАННЯ ДЕФОРМАЦІЙНОЇ ПОВЕДІНКИ ПІДКРОКВЯНОЇ ЗВАРНОЇ ФЕРМИ

Ярослав Ковальчук; Наталія Шингера; Макар Шингера

Тернопільський національний технічний університет імені Івана Пулюя, Тернопіль, Україна

Резюме. *Досліджено прогин зварної підкроквяної ферми при дії на вузли верхнього пояса зовнішніх статичних навантажень. Натурний силовий та комп'ютерний моделюючий експерименти виконано на фізичній моделі прямокутної підкроквяної зварної ферми з розмірами 2000x400 мм, виготовленої з кутникового профілю 40x40x4 мм зі сталі ВСт3пс. Конструкцію фізичної моделі* *розроблено з дотриманням класичних принципів теорії подібності. Схема базування й навантажування фізичної моделі відповідає умовам експлуатації підкроквяної ферми. За результатами натурного силового та комп'ютерного моделюючого експериментів отримано чисельну та графічну інформаційні бази про величину прогину досліджуваної конструкції при її зовнішньому навантажуванні від 2,5 кН до 45 кН. Виявлено, що при таких навантаженнях прогин досліджуваної конструкції є в лінійній залежності з прикладеними до ферми зусиллями. При цьому результати, отримані комп'ютерним моделюючим експериментом, співпадають з результатами прямого силового експерименту на рівні 94,2%. Крім того, комп'ютерним моделюючим експериментом досліджено деформаційну поведінку фізичної моделі ферми за межами лінійного діапазону її деформування й визначено напруження вздовж нижнього пояса. Виявлено, що максимальні напруження локалізуються у приопорних вузлах на нижньому поясові ферми. Визначено граничні навантаження на ферму, що зумовлюють формування граничного стану конструкції. Використану методику комп'ютерного моделювання параметрів напружено-деформівного стану підкроквяної зварної ферми, прийняті при моделюванні параметри скінченно-елементної моделі та отримані результати досліджень доцільно застосовувати для визначення конструктивних параметрів елементів фермових конструкцій при їх проєктуванні. Це забезпечить високу достовірність отриманих результатів, а, отже, потрібну тримкість зварних підкроквяних ферм упродовж їх експлуатації.*

Ключові слова: *зварна ферма, натурний експеримент, комп'ютерний моделюючий експеримент, деформаційна поведінка конструкції, несуча здатність, втрата тримкості ферм.*

https://doi.org/10.33108/visnyk_tntu2025.02.109 *Отримано 03.04.2025*