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FATIGUE FAILURE OF GUSSET PLATES NODES OF WELDED TRUSS

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Summary. *The fatigue failure modeling of welded rectangular truss 4954 x 1596 mm size with gusset plates joints under external cyclic loading was studied in the paper. The sample is made of steel shaped tubes with various cross section areas. Loading and support schemes that identify the operating mode for this type of structure were selected. According to the results of computer simulation experiment in ANSYS Workbench 19.1 the stress value of welded truss nodes and the fatigue sensitivity curve were obtained. The results obtained in the paper can be applied both in the design of new trusses to prevent the destruction of structures in service.*
Key words: *welded truss, truss nodes, fatigue failure.*

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Statement of the problem. The influence of cycle loadings on the welded trusses caused by exploitational influences leads to the initiation of the fatigue cracks located in the heat affected zone of the weld bead. The cracks growth and their maximum length contributes to the limit state achievement and failure. To find the failure degree of welded trusses being under the cycle force effects, it is necessary to find the dependence between the stress-strain state (SSS) parameters in the area of the weld joint and its fracture.

Analysis of the latest investigations and publications. Researching of the fatigue failure nodes of welded trusses was carried out using:

- full-scale experiment [1–3]
- semi-scale force experiment [4, 5]
- computer modeling experiment [2, 3, 6]

The cumulative influence of structural, technological and operation indicators are taken into account the most completely using the computer modeling experiment.

But according to the analysis of results obtained by the other researchers, it was found, that:

- there were investigated the nodes themselves, but not the truss in whole;
- there were no taken into account such effects as:

a) the changes of physical-mechanical properties of the weld joint surrounding area;
b) residual stresses caused by the thermal deformations;

- the welded nodes were investigated using the method of finite elements and using the shell elements of the «SHELL» – type.

The objective. To determine the level of fatigue failure of the welded truss with gusset plates nodes under the external concentrated cycle loading of the central joint of the upper layer.

Method of investigation. To solve the problem in question the software complex ANSYS WORKBENCH 19.1 for the welded construction truss of 4954 x 1596 mm size was used (Figure 1).

Statement of the task. To find the fatigue cracks initiation location and the intensity of their propagation depending on the value of the force effect and the geometric parameters of the structural nodes of the welded truss.

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The investigation was carried out for the welded rectangular truss with the gusset plate nodes. The truss elements are made of shaped tubes of different sizes (Table 1) made of ВСт3пс steel. Gusset plates are made of the cast sheet steel of 5 mm thickness as trapezoidal shape. Weld beads are made by semi-automatic arc welding in the CO_2 environment using the wire electrode Sv08G2C.

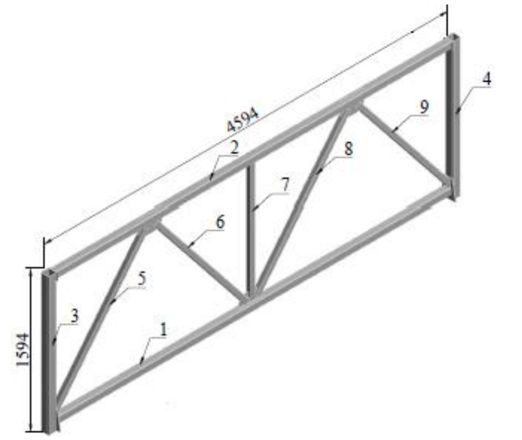


Figure 1. Constructional scheme of welded truss

Table 1

Types of cross section areas and the elements length of welded truss

Element number	Shaped tube, mm	Length, mm
1	80x4	4830
2	80x4	4840
3	100x6	1186
4	100x6	1186
5	60x4	1870
6	60x4	1910
7	60x4	1465
8	60x4	1910
9	60x4	1870

The truss support is made at the base nodes of the bottom chord and the cycle loading P is applied on the central node of the top chord (Figure 2). The loading mode and the cycle parameters are presented on Table 2. Such conditions are almost similar to those of the exploitation mode of the truss, on which the structures with under-crane roads for the bridge lifting crane are mounted.

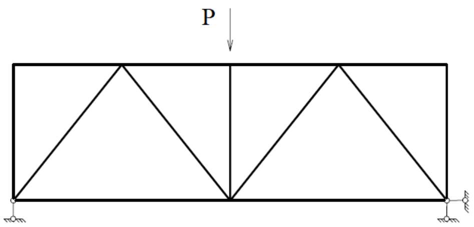
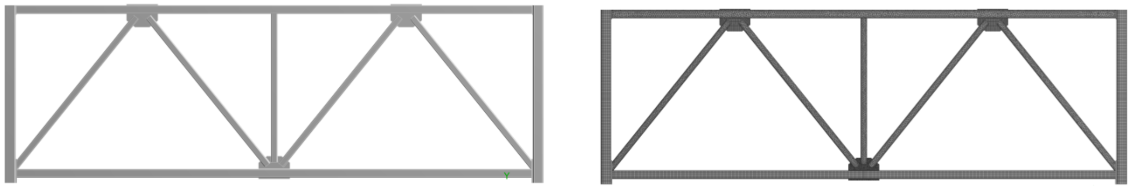


Figure 2. Support and loading scheme

To find the parameters of the fatigue failure of the welded trusses under the cycle loadings the geometric (Figure 3, a) and discrete models (Figure 3, b) were created.



a *b*

Figure 3. Models of welded truss
a – geometrical model of welded truss; *b* – finite element model of welded truss

To create the finite-element mesh of the geometric model of the welded truss the group of finite-elements of the SOLID 226 type was used (Figure 4) [7]. This finite element consists of 20 nodes, every of which consists of 6 degrees of freedom. This is the finite element, which was chosen as it supports all types of geometric figures of the determined elements, as well as makes possible to take into account the heat effect and to find the residual stresses after them.

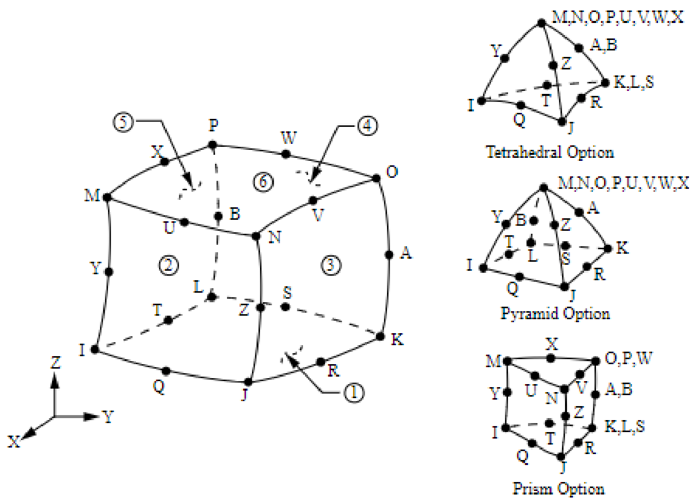


Figure 4. Finite element Solid 226

To calculate the truss under the cycle loadings in the installed module Static Structural the Fatigue Tool was used. The type of analysis for finding the fatigue failure is that of Stress Life, which is based on the empiric fatigue curves. To correct the average cycle stresses the Gerber theory for the plastic materials has been chosen, which takes into account the material force characteristics (1). The fatigue strength factor is $K_f=1$.

$$\frac{\sigma_{Alternating}}{S_{Endurance\_limit}} + \left(\frac{\sigma_{Mean}}{S_{Ultimate\_strength}}\right)^2 = 1 \quad (1)$$

where $\sigma_{Alternating} = (\sigma_{\max} - \sigma_{\min})/2$, $\sigma_{Mean} = (\sigma_{\max} + \sigma_{\min})/2$, $S_{Endurance\_limit}$ – is the steel endurance limit, $S_{Ultimate\_strength}$ – is the steel ultimate strength limit.

To identify the stresses in nodes, in the welded joints in particular, the force component was used according to the Mises criterion of the equivalent stresses (2):

$$\sigma_{eq} = \sqrt{(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{xz}^2)} \qquad (2)$$

where σ_x – are normal stresses along the axis X of the finite element, correspondingly, σ_y – along the axis *y*, σ_z – along the axis *z*, τ_{xy} – are the tangent stresses towards the *xy* of the finite element, τ_{yz} – towards *yz*, τ_{yz} – towards *yz*.

Results of investigation. According to the results of computer modeling experiment the SSS parameters in the welded truss elements and in the welded joints have been obtained (Figure 5). To identify the fatigue failure of the welded truss, there were found the places, in which the maximum stresses are concentrated and, thus, the fatigue cracks are initiated. According to the obtained distribution, the maximum stresses are revealed in the central node of the bottom chord, that is, in the heat affected zone of the weld bead (Figure 5, a, 1, I) from the side X – global coordinate system. Thus, the initiation of the first fatigue crack occurs at the beginning of the welded joint in the place of the central post connection to the gusset (Figure 5, a, 2, II). Besides, it was found, that the stresses concentration in the places (Figure 5 a, 1, I) occurs on the welded joints borders at the surface of the central post perpendicular to its axis.

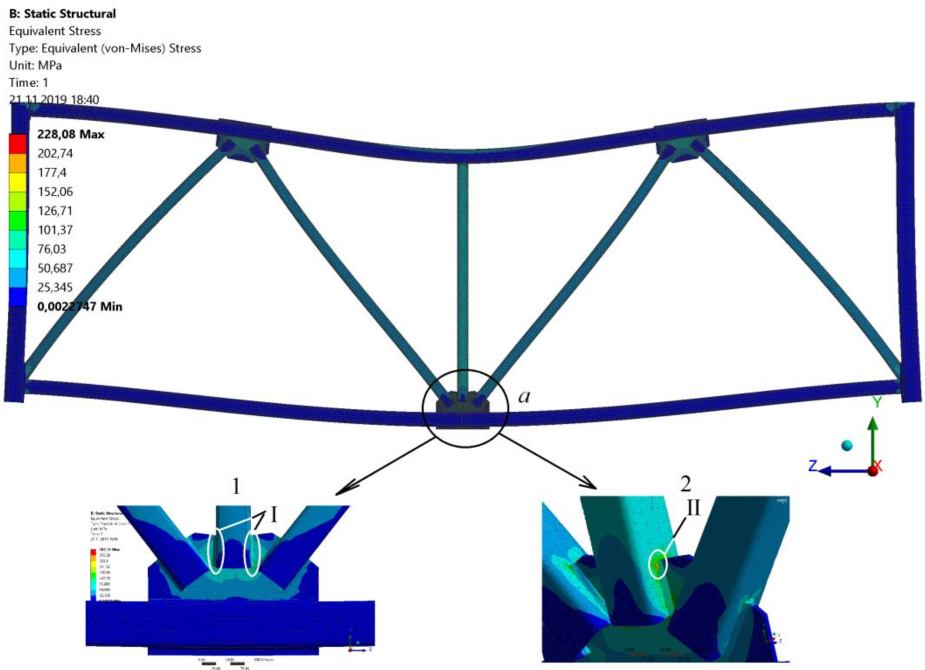


Figure 5. Fatigue failure location

The number of cycles up till the fatigue crack initiation and till the limit state have been found (Table 2).

Table2

Fatigue failure indicators of welded truss

Loading, kN		Cycle ratio, r	Frequency of loading, ν Hz	Fatigue failure during operation	
				Before fatigue crack	Before limit state
P_{max}	P_{min}			Number of cycles	Number of cycles
50	10	0,2	0,1	457488	938940
40	10	0,25	0,1	959073	1542600
30	10	0,3	0,1	1625886	2943700
20	10	0,5	0,1	3495522	6695700

It was found, that for the maximum loading mode P=50kN the maximum crack length is 117,2 mm. According to the results of computer modeling experiment the fatigue sensitivity curve has been built (Figure 6) [7].

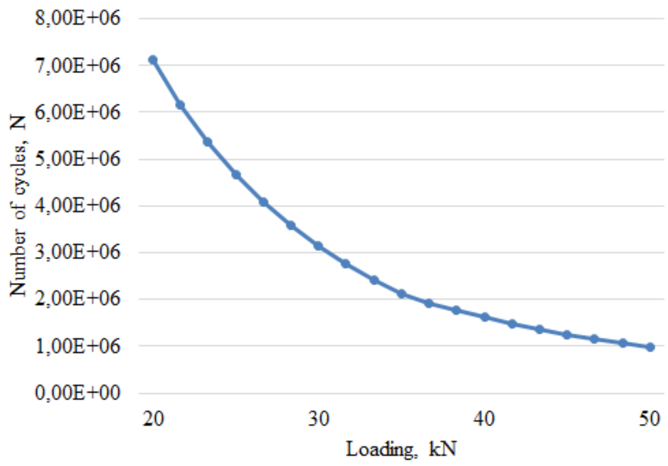


Figure 6. Fatigue sensitivity curve

The obtained fatigue sensitivity curve demonstrates the intensity of the fatigue failure for different values of the external loadings and makes possible to determine the level of fatigue failure of the welded truss both at the stage of its design and during its operation.

Conclusions. According to the results of researching it was revealed, that the fatigue crack, which specifies the structure strenght loss during its operation, is initiated in the cenral node of the bottom chord at the beginning of the weld bead connecting the post and the gusset. The welded truss failure level was revealed while connecting the parameters of the force effect and stresses distribution in the nodes. The obtained results are worth being used both while designing of new trusses and preventing the structures failure being in operation.

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ВТОМНА ПОШКОДЖУВАНІСТЬ ФАСОНКОВИХ ВУЗЛІВ ЗВАРНОЇ ФЕРМИ

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Резюме. *Із використанням комп’ютерного моделювання у програмному комплексі ANSYS Workbench 19.1 виконано дослідження втомної пошкоджуваності зварної прямокутної ферми 4954 х 1596 мм при дії зосередженого циклічного навантаження на центральний вузол верхнього пояса. Конструктивно зварна ферма виготовлена з профільних труб різноманітних розмірів зі сталі ВСт3пс. Вузлові з’єднання ферми виконані через фасонку. Вузлові фасонки виготовлені з прокатної листової сталі товщиною 5 мм у вигляді трапецій, які встановлені у попередньо виконані вирізи у поясах ферми. Зварні з’єднання виконано напівавтоматичним дуговим зварюванням у середовищі СО2 з використанням дротового електрода Св08Г2С, катет зварного шва 5 мм. Обрана схема навантажування та базування ідентифікує експлуатаційний режим для такого типу фермової конструкції, а саме для підкроквяних ферм, до яких прикріплені підкроквяні шляхи мостових підвісних механізмів. За результатами виконання комп’ютерного моделюючого експерименту в середовищі ANSYS Workbench 19.1 отримано рівень напружень та їх розподіл в елементах та вузлах зварної ферми. Виявлено місця з найбільшими напруженнями, у яких будуть зароджуватися втомні тріщини, а саме у навколошовній зоні термічного впливу з’єднання фасонки із центральною стійкою у центральному вузлі нижнього пояса зварної ферми. Також отримано показники втомної пошкоджуваності в числовому вигляді кількості циклів до зародження втомної тріщини та до настання граничного стану конструкції. Визначено, що для режиму з максимальним навантаженням Р=50кН критична довжина тріщини становить 117,2 мм. На базі отриманих числових показників побудовано криву втомної чутливості, яка візуалізує інтенсивність втомної пошкоджуваності залежно від величини прикладеного зовнішнього навантаження. Отримані результати дають можливість визначати рівень втомної пошкоджуваності зварних ферм як на стадії проектування, так і впродовж їх експлуатації.*

Ключові слова: *зварна ферма, вузли ферми, втомна пошкоджуваність.*

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