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FATIGUE DAMAGE OF THE HEEL JOINT OF WELDED ROOF TRUSS

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Summary*. The investigation of the welded roof truss behavior under the complex influence of static and cyclic loads is carried out. The truss is made of the shaped pipes and its size is 24000x2400 mm. The technique of computer simulation experiment by means of SolidWorks Simulation software is used. It is found that the maximum stresses are formed in the area of thermal impact from the weld in the truss heel joints. During the truss operation, these stresses initiate the emergence of fatigue cracks and their growth until the structure ultimate state. The fatigue curve for the investigated structure is constructed. It is determined that the design service life of the truss under operational load modes is going to be 52 years.*
Key words: *welded truss, stress-strain state, supporting ability.*

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Statement of the problem. Welded roof trusses are widely used in civil engineering due to the optimal combination of their cost, high technological effectiveness and ability to operate under various force factors. They are used in the construction of long-span building structures (production facilities, warehouses, sports complexes, exhibition halls, shopping centers, etc.). However, the precautions factor that limits the use of such building structures is the complexity of calculation of their lifespan under cyclic loads. Such loads are formed from suspended conveyor tracks and crane-beams. The initiation of fatigue cracks and their growth until the limit state occur under normal operating loads. Classical analytical calculations do not enable to predict the safe service life of welded roof trusses under cyclic loads with sufficient probability. Therefore, in order to ensure the guaranteed fatigue strength and reliability of the structure, the obtained results are adjusted in the direction of increasing its material consumption, which, in turn, results in the truss cost increase. The current state of computer technology development and the use of numerical calculation methods makes it possible to determine the origin of fatigue cracks and the dynamics of their growth during the structure operation with a high degree of probability with less complexity of design calculations. Computer simulation experiment, as the methodological approach for the investigation of welded trusses behavior under the action of cyclic loads is the most widely used today.

Analysis of available investigations and publications. According to the results of the analysis of previously carried out investigations of the stress-strain state (SSS) in welded trusses elements, it was found that in modern science and engineering practice a large number of applied software packages are used for this purpose (SP POFSK-Mirazh-PSMK, «Lira-W», SCAD, Cosmos Works, Design Space, PC SCAD and Mathcad, SP ANSYS Workbench 14.5, SolidWorks Simulation, etc. [1, 2, 4, 5]). Each of the used software packages has its own principles of SSS simulation in the welded trusses elements and the degree of approximation to real structure operation. The application of these software products makes it possible to reduce significantly the duration of the design documentation development and minimizes the impact of subjective factors on the calculations results.

Typically, these software packages are based on finite element analysis systems and make it possible to determine the parameters of SSS in the structural elements of welded trusses at the design stage. Based on this, the optimal cross-sectional dimensions of the rod elements and welds for their connection are selected, thus ensuring the design strength, rigidity, reliability and durability of the truss as a whole.

The described investigations are based on the results of computer simulation experiment carried out for welded roof truss using SolidWorks Simulation SP. This software package makes it possible to take into account the multi-parameter influence of design, technological and operational factors on the behavior of the structure during operation under cyclic loads.

The objective of the paper is to identify the places of primary origin of fatigue cracks and the nature of their propagation in 24000x2400 mm welded truss elements under the complex influence of static and cyclic loads which identify the operating mode of the investigated structure, and determine the safe life of the truss.

Statement of the problem (task). In order to achieve the stated goal, it is necessary to carry out computer simulation experiment using application suite SolidWorks Simulation for welded roof truss made of steel tubular rectangular rolled profile, with combined action of static and cyclic loads on the structure. The task of the investigation is to identify the design resource of this truss.

Results of the investigation.

The problems of crack resistance and durability of welded trusses are very important for structures that are subjected to cyclic loads. In industrial buildings roof trusses of roof cladding operate under such conditions. In addition to static loads (own weight, roof weight, snow in the winter) they also carry cyclic loads from temperature differences (climatic or technological), wind influence and loads from suspended technological means (conveyers, bridge cranes, crane-beams and telphers).

From this perspective 24-meter-long roof truss made of bent-welded profile pipes is chosen for the investigation (Fig. 1).

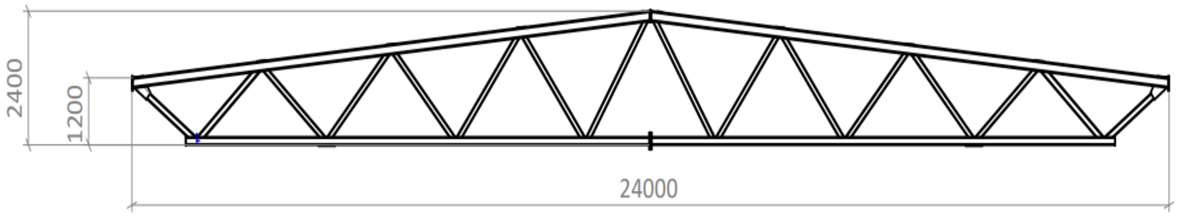

Figure 1. Structural design of welded truss

The upper chord of the truss is made of 180x180x6 mm shaped pipe, the lower belt is made of 140x140x5 mm shaped pipe, the support braces are made of 120x120x5 mm pipe, the non-supporting braces are made of 100x100x5 mm pipe. The truss is obtained in compliance with all regulatory requirements for the design and technology of its manufacture.

All welds are made by semi-automatic DC arc welding by wire electrode with 2 mm diameter Sv-08G2S in CO_2 medium in compliance with standardized technologies. The operating current of welding is 270 A. The weld leg is taken on the smallest thickness of the connecting elements, i.e. 5 mm.

The characteristics of mechanical properties of VSt3ps steel in tension were obtained in the previous authors' investigations according to the results of a series of natural experiments for statistical sampling [3], i.e. ultimate strength (sampling mean) for the base material $\overline{\sigma_{в}}$ = 380 MPa, for the weld $\overline{\sigma_{в}}$ = 283 MPa, sampling mean values of the yield strength

$\overline{\sigma_T}$ = 273 MPa, the ultimate strength $\overline{\sigma_в}$ = 360 MPa. These indicators are introduced as an input information base in computer simulation experiment.

The scheme of basing and loading of the investigated truss is developed (Fig. 2).

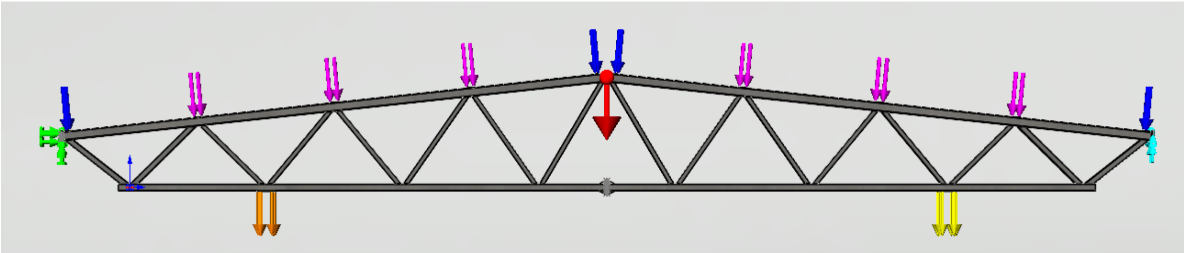

Figure 2. Scheme of basing and loading of welded truss

The length of the truss on both sides is limited by vertical flanges (Fig. 3), by means of which it is based on the inner surface of the building frame columns with the support on the lower part of the flanges and is fixed in the design position by threaded elements through flanges holes.

Based on design and operational factors, the parameters of force effect on the truss are determined. The total static component per truss is P_{cmam}=378 kN. The amplitude of the cyclic component is $\Delta P_{цикл}$=32 kN. The cycle period is T=7 s (Fig. 4). The operating mode is two-shift.

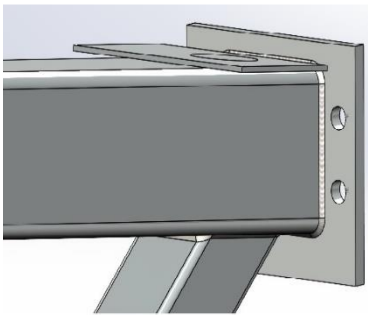

Figure 3. The design of mounting flange

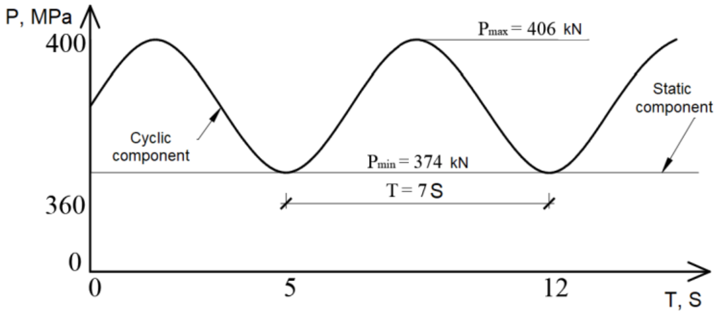

Figure 4. The mode of complex force effect on the investiggated welded truss

At the first stage of the investigation the places of formation of maximum stresses in the truss under the action of static loads (Fig. 5), i.e. in the fastening units, are determined by the method of computer stimulation experiment in SolidWorks Simulation environment. In addition to the visualization of the truss behavior under loading, numerical values of local maximum stresses at 160 MPa under operational forces are obtained (Fig. 6). Therefore, the structure deformation occurs within the limits of base material elasticity.

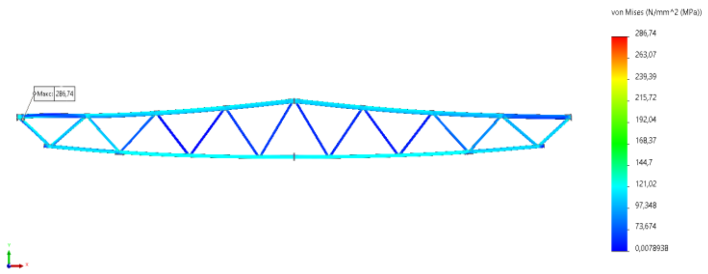

Figure 5. Identification of the place of maximum stresses formation in the truss

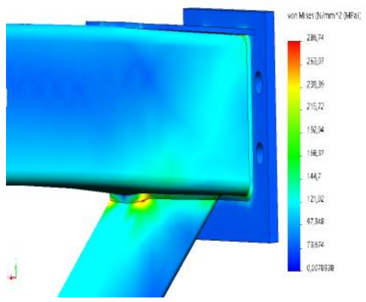

Figure 6. Localization of stresses in the welded joint

A detailed investigation of the distribution of stresses and strains at their maximum localization, i.e. in the area of thermal influence around the weld is carried out. Visualization of the distribution of residual stresses (Fig. 7) and residual plastic deformation is obtained (Fig. 8).

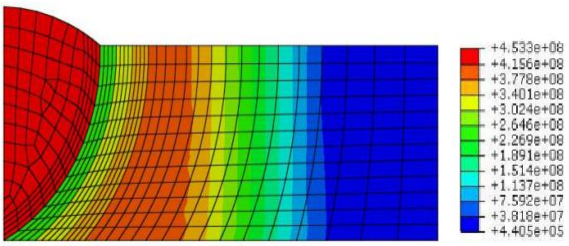

Figure 7. Distribution of residual stresses

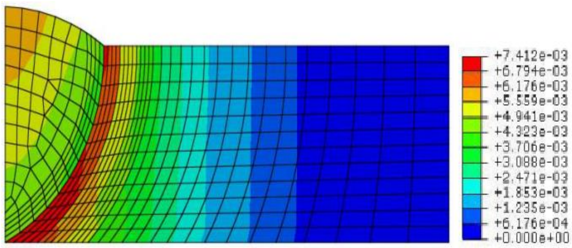

Figure 8. Distribution of residual plastic deformation

According to the obtained results, the process of fatigue crack initiation and propagation along the boundary of the front and flank welds and the base material is simulated (Fig. 9).

The stresses in the vicinity of the crack tip (Fig. 10) and their influence on the dynamics of the structure fatigue damage are determined. The fatigue curve for the investigated area (thermal impact area) in the welded roof truss is constructed according to the obtained numerical values of SSS parameters in the area of fatigue failure, values of mechanical characteristics of the main material and weld material, taking into account the dynamics of the structure fatigue damage (Fig. 11).

The fatigue curve determines the dependence of the number of load cycles to the structure fracture (abscissa axis in Fig. 11) depending on the magnitude of the force impact on the truss. The value of the total external load forms the stresses magnitude in the investigated section of the truss (ordinate axis in Fig. 11). According to the obtained fatigue curve, it is possible to determine the design resource during truss operation under various force factors, both in terms of load and frequency of its application.

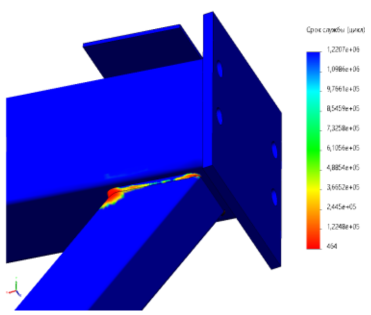

Figure 9. Stress in the joint under cyclic loads

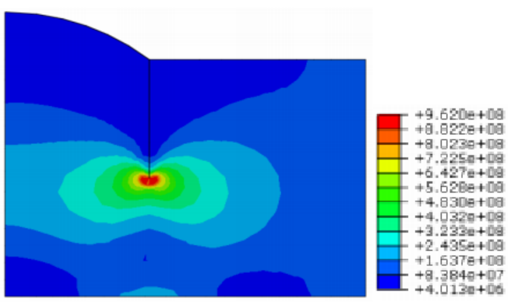

Figure 10. Stress around the crack tip

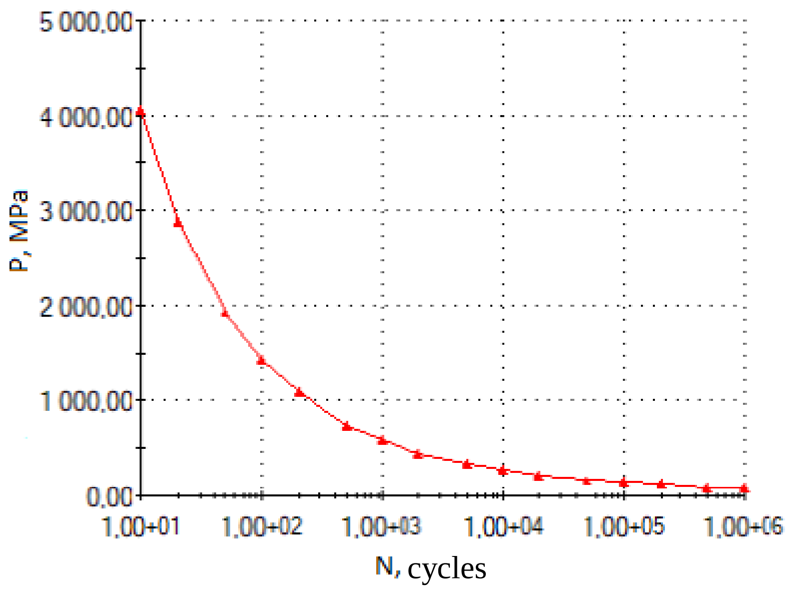

Figure 11. Fatigue curve for the area of the weld thermal impact in the outermost joints of the truss

Based on the operating modes of loading for the investigated truss, mentioned above, the guaranteed design life of the truss, constituting 52 years is determined according to the fatigue curve (Fig. 11). The influence of force factors changes or the roof truss operation mode on the structure service life can be easily defined by simple analytical calculations according to the fatigue curve constructed in this paper (Fig. 11).

Conclusions. The investigation of fatigue damage of the heel joint of welded roof truss is carried out by means of computer simulation in SolidWorks software package. Locations of maximum stresses in the elements of welded roof truss are identified. The process of fatigue crack initiation and propagation up to the structure failure is investigated. The fatigue curve for the roof truss is obtained. This curve makes it possible to determine the allowed time of the truss safe operation at different values of force and load modes. According to the calculation results, the structure fatigue life can be increased by local strengthening of the truss heel joint. The described simulation technique can be used for design calculations of construction trusses and checkup calculations of operating structures and prevention of the limit state occurrence under cyclic loads action.

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ВТОМНЕ ПОШКОДЖЕННЯ ОПОРНОГО ВУЗЛА ЗВАРНОЇ КРОКВЯНОЇ ФЕРМИ

Ярослав Ковальчук; Наталія Шингера; Ярослав Швед; Василь Ворончак

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Резюме. *Досліджено поведінку зварної кроквяної ферми 24000x2400 мм з профільних труб при комплексному впливові на неї статичного і циклічного навантажень. Конструкцію ферми взято з проектної документації виробничого приміщення, призначеного для роботи з підвісним конвеєром технологічної лінії. Вибрано схеми базування й навантажування ферми, які відповідають умовам роботи досліджуваної конструкції. Експлуатація несучих конструкцій за таких умов без попередніх досліджень є небезпечною, оскільки пошкодження формуються і накопичуються за нормативних циклічних навантажень, а руйнування настає раптово при досягненні втомної тріщини критичних розмірів. Для попередження руйнування конструкції й визначення допустимого терміну експлуатації ферми виконано дослідження з використанням методики комп'ютерного моделюючого експерименту за допомогою програмного комплексу SolidWorks Simulation. Виявлено, що максимальні напруження формуються на ділянці термічного впливу від зварного шва в опорних вузлах ферми. Саме в цих місцях відбувається зародження втомних тріщин і їх поширення аж до настання граничного стану конструкції. При дослідженнях враховано комплексний вплив конструктивних, технологічних і експлуатаційних чинників на формування параметрів напружено-деформівного стану до зародження втомної тріщини й упродовж її поширення. При комп'ютерному моделюванні використано фактичні характеристики міцності основного матеріалу, ділянок зварного шва і термічного впливу, які отримані авторами в попередніх дослідженнях. За отриманими результатами побудовано криву втоми для опорного вузла зварної кроквяної ферми. Дано рекомендації щодо умов експлуатації ферми та можливості використання отриманих результатів для подальших досліджень. Визначено, що проектний ресурс роботи ферми при експлуатаційних режимах навантажування становитиме 52 роки.*

Ключові слова*: зварна ферма, напружено-деформівний стан, тримкість.*

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