PROCEEDINGS

4th International Congress of Serbian Society of Mechanics

Editors:
Stevan Maksimović
Tomislav Igić
Nataša Trišović

June 4-7, 2013, Vrnjačka Banja, Serbia

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PREFACE

These proceedings contains the papers presented at the Forth (29^{th} Yu) International Congress of Serbian Society of Mechanics held in Vrnjačka Banja during the period 4^{th} – 7^{th} June, 2013.

Theoretical and Applied Mechanics is a subject of great importance in the developing of science and technology. The aim of the Congress is to provide a forum to exhibit the progress in this field during the past years and a place to further the interaction between of modern theoretical and applied mechanics, as well as modern engineering sciences.

The papers, contributed by authors from all around the globe, have been separated into 7 sections which cover the main areas of interest: `Plenary Lectures`, Section A, Section B, Section C, Section D and two Mini-symposia.

We would like to express our gratitude to all members of the Scientific Committee and also to the participants for their engagement in organizing of the Congress, including the preparation of manuscripts to be published in the Journal Theoretical and Applied Mechanics, Scientific Technical Review and Journal of Serbian Society for Computational Mechanics.

It gives us great pleasure to express our deep appreciation for the great long-standing support that Prof. Dr. Nikola Hajdin, President of the Serbian Academy of Sciences and Arts, has given to the promotion of all aspects of theoretical and applied mechanics in Serbia.

Last, the Congress organizing committee wishes to acknowledge the collaboration of the Ministry of Education, Science and Technological Development of the Republic of Serbia, Serbian Academy of Sciences and Arts, Municipality Vrnjačka Banja and many supporting members of the Serbian Society of Mechanics.

S. MAKSIMOVIĆ & T. IGIĆ
June, 2013

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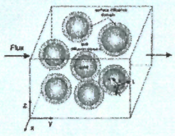

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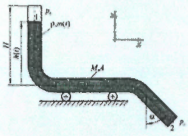

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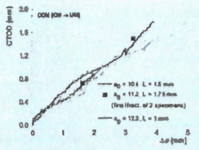

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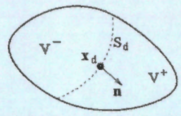

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ANALYSIS OF INFLUENCE CHOICE FATIGUE FAILURE CRITERIA TO ASSESS THE INTEGRITY OF WAGON STRUCTURE PARTS

Vladimir Milovanović [1], Gordana Jovičić[1], Miroslav Živković[1], Dragan Rakić[1], Aleksandar Dišić[1]

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Abstract: One of the most common phenomena in engineering practice that causes failure is fatigue. Carrying parts of wagon structure exposed to high-cycle fatigue. This paper presents an analysis of the load on the bottom part of the wagon underframe structure and fatigue failure analysis of the most critical zones based on S-N approach. For the analysis of the fatigue failure phenomenon Goodman's criterion and fatigue criterion based on the equivalent stress range were used. Integrity assessment of wagon structure parts was determined according to calculation of fatigue safety factor. Analysis of influence choice fatigue failure criteria to assess integrity of wagon structure parts was done.

Key words: Fatigue failure, Failure safety factor, Goodman's criterion, FEM

1. Introduction

Carrying parts of wagon structure loaded with a periodic stresses that oscillates between some limits are subjected to stresses called repeated, alternating, or fluctuating stresses. Often the wagon structure parts fail under the action of repeated or fluctuating stresses. The most common causes of these failures is that the stresses have been repeated a very large number of times. Hence, the failure is called a fatigue failure. A fatigue failure begins with a small crack [1] and fatigue failure is characterized by two distinct regions. The first one is due to the progressive development of the crack, while the second one is due to the sudden fracture.

In this paper an analysis of the load on the bottom part of the wagon underframe structure and fatigue failure analysis of the most critical zones based on S-N approach is presented [2]. Goodman's criterion and fatigue criterion based on the equivalent stress for analysis of the fatigue failure phenomenon range were used. According to calculation of fatigue safety factor integrity assessment of wagon structure parts was determined.

2. **Fatigue failure criteria - Theoretical basis**

2.1. Fatigue endurance limit

The initial analysis of the fatigue life is performed using the S-N approach, assuming that there was no occurrence of initial flow and the known fatigue endurance limit S_e. The symbol for fatigue endurance limit is $S_e^{'}$. The fatigue endurance limit can be related to the tensile strength through the following equation [3]

$$S_e^{'} = \begin{cases} 0.504 S_{ut} & S_{ut} \le 1400 MPa \\ 700 MPa & S_{ut} > 1400 MPa \end{cases}, \tag{1}$$

where S_{ut} is the minimum tensile strength. The prime mark on $S_e^{'}$ refers to the fatigue endurance limit of the test specimen itself, while the symbol S_e represent the fatigue endurance limit of a structure part subject to any kind of loading. The fatigue endurance limit is affected by some factors such that

$$S_e = k_a k_b k_c S_e^{'}, \tag{2}$$

where k_a is the surface factor, k_b is the size factor, and k_c is the load factor.

2.2. Fluctuating stresses

In design problems, it is frequently necessary to determine the stress of parts corresponding to the situation when the stress fluctuates without passing through zero, Fig. 1.

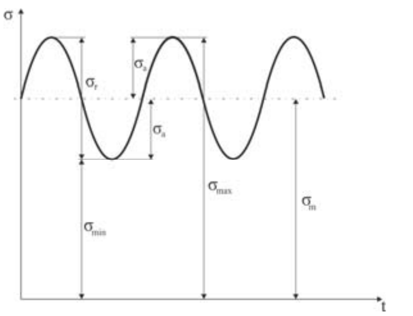

Figure 1. Fluctuating stress.

A fluctuating stress is a combination of static plus completely reversed stress. The components of the stresses are depicted in Fig. 1, where $\sigma_{\min}$ is minimum stress, $\sigma_{\max}$ is the maximum stress, σ_a is the stress amplitude, σ_m is the mean stress, σ_r is the stress range, and σ_s is the steady or static stress. The steady stress is not the same as the mean stress. It can have any value between $\sigma_{\min}$ and $\sigma_{\max}$

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} \quad and \quad \sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2}\,. \tag{3}$$

The stress ratios

$$R = \frac{\sigma_{min}}{\sigma_{max}} \quad and \quad A = \frac{\sigma_a}{\sigma_m}\,, \tag{4}$$

are used to describe the fluctuating stresses.

2.3. Criteria of failure

The numerical values of the calculated maximum principal stress on the structures, for the two types of loads, are one load cycle used to calculate the failure safety factor, using S-N analysis. For assessment of failure safety factor it is necessary, for the adopted boundary conditions of cyclic loading structures, to define the principal stresses in each integration point of finite element and the values of alternating stress and mean stress [4]. The reciprocal value of the failure safety factor is calculated using the modified Goodman criteria of failure:

$$\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_u} = \frac{1}{FSF_{GD}}\,, \tag{5}$$

similarly, the modified Goodman relation is

$$\frac{S_a}{S_e} + \frac{S_m}{S_u} = 1\,. \tag{6}$$

The meaning of these equations is illustrated in Fig. 2, using the modified Goodman theory as example. The safe-stress line through *A* is constructed parallel to the modified Goodman line. The safe-stress line is the locus of all sets of $\sigma_a - \sigma_m$ stresses having a failure safety factor FSF_{GD}, that is $S_m = FSF_{GD}\sigma_m$ and $S_a = FSF_{GD}\sigma_a$.

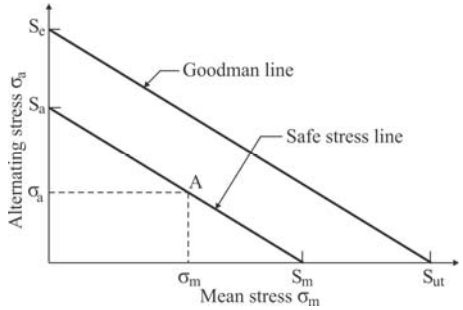

Figure 2. Constant-life fatigue diagram obtained from S-N approach and Goodman's criteria of failure.

3. Integrity assessment of wagon structure parts – Example

According to exposed theoretical basis, integrity assessment of wagon structure parts was determined according to calculation of fatigue safety factor.

The wagon is designed for the transportation of containers and Swap Bodies (SBs). The underframe of wagon is adapted for the containers transportation. The existing underframe is reconstructed, strengthened and enhanced to completely fulfill the request of TSI standard. The bottom side of underframe is made of steel plates and rolled steel profiles, as a welded construction.

Eighty percent of all wagons, which were used in transport, have failure or initial cracks Fig. 3. According to this fact, it was necessary to determine the reason for the appearance of the cracks according to calculated fatigue safety factor. The observed cracks appear on the welded joints or near the welded joints [5].

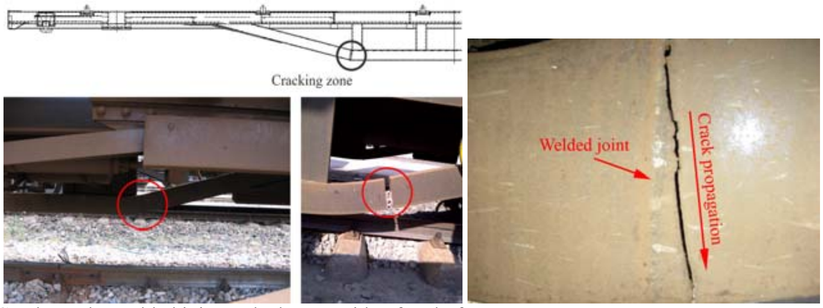

Figure 3. Crack nearby welded joint at the bottom side of underframe.

3.1. Fatigue load case

According to standards UIC 592-4 [6], all vertical load cases (from SBs and from containers) are analyzed. For the analysis of fatigue load case the most unfavorable load case (vertical load – 2xSB – Group 20, 21, mass 31t) was used. Fatigue load case, acceleration in Z direction, is specified by TSI standard [7], and British Standard (BS EN 12663:2000) [8]. Limit values for static test to verify fatigue strength, determined for minimum number of two million constant amplitude cycles, using Eurocode 3 [9]. For the most conventional wagon designs, the loading defined in Table 16 of BS EN 12663:2000 is considered as sufficient to represent the full effective combination of fatigue load cycles. Source of fatigue loading is determined according to TSI standard, Annex CC. The dynamic load used in design is in range of ±30% of vertical static load. According to this load case, numerical calculated stresses were used for fatigue failure analysis of the most critical zones based on S-N approach.

3.2. Analysis of obtained results

Analysis was performed using the finite element software package PAK [10]. According to the construction type, shell elements of the appropriate thickness and 3D eight node elements are used for creating the finite element mesh. The structure is modeled in details with 54,735 elements and 56,620 nodes. The element length is approximately 40 mm [5].

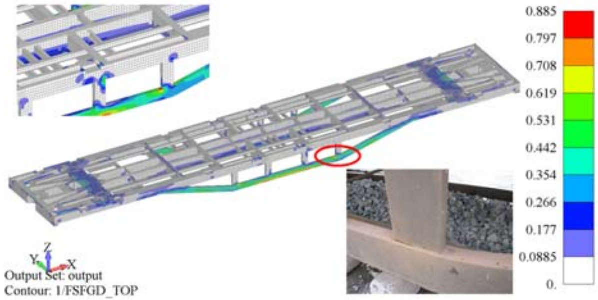

Figure 4. Failure safety factor field obtained by Goodman's criterion (principal stresses).

Fields of reciprocal value of failure safety factor obtained by Goodman's criterion and fatigue criterion based on the equivalent stress range are presented on Fig. 4 and Fig. 5 respectively. Fig. 4 and Fig. 5 show the fields of reciprocal value of failure safety factor for the fatigue strengths at 2 million cycles, for the case if the whole wagon was made of the parent material.

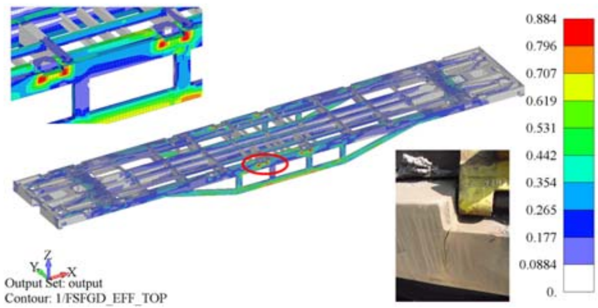

Figure 5. Failure safety factor field obtained by fatigue criterion based on the equivalent stress range.

According to Eurocode 3 and technology of welding it is necessary to determine category type of welds, and then to assess the integrity of the observed part of the construction. With the previously displayed figures, we can clearly see critical zones with cracks, with small values of fatigue safety factor. In order to make the best observed structural assessment of the failure safety factor, it is necessary to define every welded joint of wagon and observe each individually. Welded joint of two plates which close rolled steel profile of bottom side of underframe was considered, Fig. 6.

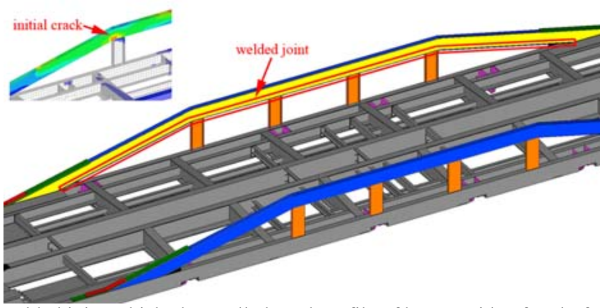

Figure 6. Welded joint which close rolled steel profile of bottom side of underframe and crack location.

A review of types of welds in accordance with the Eurocode-3, Section 1.9 and based on the documentation on the technology of welding, observed type of welded joint belongs into the category 71 type of welds. This type of weld is given in [9]. In accordance with these facts, at the place of mentioned welded joint, calculate failure safety factor is scaled and diagram reciprocal value of failure safety factor versus normalized distance along welded joint is given on Fig 7.
According to calculation results at the place of weld, Fig. 7, reciprocal value of failure safety factor for the fatigue strengths at 2 million cycles is higher than 1 for the Goodman's criterion and fatigue criterion based on the equivalent stress range. On the basis of these facts, it can be concluded that the observed cracks (Fig. 3) on wagon type Sgmns are caused by service (fatigue) load.

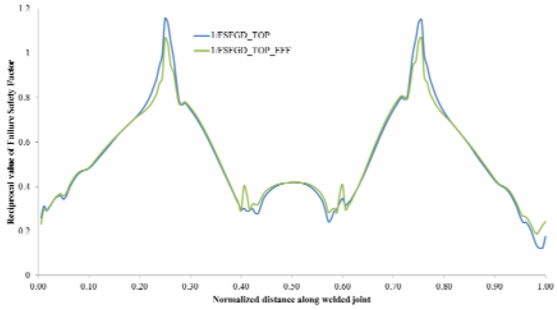

Figure 7. Distribution of reciprocal value of failure safety factor along welded joint.

4. Conclusions

The paper presented the S-N approach to fatigue failure analysis of welded joints that integrates well with finite element modeling. Goodman's criterion and fatigue criterion based on the equivalent stress range were used for the analysis of the fatigue failure. Calculation of fatigue safety factor was determined to assess the integrity of wagon structure parts according to the most commonly used European standards. According to failure safety factors obtained by Goodman's criterion and fatigue criterion based on the equivalent stress range it should be noticed that both methods give good results. The both criteria give us adequate identification causes of cracking on the underframe of wagon. The results and their well matching prove reliability of both fatigue failure criteria and that they can be used for integrity assessment of wagon structure parts.

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