UNIVERSITY OF EAST SARAJEVO

FACULTY OF MECHANICAL ENGINEERING

7th INTERNATIONAL SCIENTIFIC CONFERENCE

COMETa 2024

„Conference on Mechanical Engineering Technologies and Applications“

PROCEEDINGS

14th-16th November East Sarajevo, RS, B&H

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University of East Sarajevo
Faculty of Mechanical Engineering
Conference on Mechanical Engineering Technologies and Applications

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East Sarajevo, B&H, RS
14th – 16th November, 2024

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PREFACE

Mechanical engineering, as one of the basic engineering disciplines, represents the key to understanding and improving many aspects of modern society. From the development of energy-efficient systems, through advanced materials and production technologies, to robotics and automation, mechanical engineering is at the very heart of innovation, which drives the global economy and contributes to a better quality of life. Contemporary trends in mechanical engineering, such as the application of artificial intelligence, additive technology, digital transformation, minimizing the impact of industrial processes on the environment, etc. widely open new horizons and opportunities for our profession. Through mutual cooperation, interdisciplinary approaches and the integration of new technologies, we can find solutions that will shape the future of industry and society. Today, our profession faces numerous challenges, which are the result of accelerated technological development. They are at the same time extremely complex, but also very inspiring and require not only technical expertise, but also creativity, cooperation and a constant desire for new scientific achievements. Therefore, we must be able to recognize and implement new approaches, methodologies and technologies. Moreover, only a holistic approach in the application of knowledge in various engineering fields, and especially in the field of mechanical engineering, is a safe way into the future. Finally, in today's world, which is rapidly changing under the influence of global economic, environmental and social factors, it is important that all of us, who deal with the field of mechanical engineering from various aspects, do not forget our responsibility. In this context, engineering ethics, quality of work and continuous education play a crucial role.

Although the scientific research process is crucial for economic progress, we must not forget the importance of educating new generations of mechanical engineers. The conference COMETa 2024 is precisely an extraordinary opportunity to further encourage young researchers and students to actively engage in scientific activities through the development of their ideas. In this sense, academic institutions have a great responsibility to provide quality education and research programs to future generations.

Recognizing the importance of the broad field of mechanical engineering for the overall industrial development of society, the work of the conference will take place through 5 sections. The program is focused on the following thematic areas:

Manufacturing technologies and advanced materials,
Applied mechanics and mechatronics,
Machine design, simulation and modeling,
Product development and mechanical systems,
Energy and thermotechnic,
Renewable energy and environmental,
Maintenance and technical diagnostics,
Quality, management and organization.

Also, as part of the conference program, one round table and two workshops will be held, whose topics relate to the generation of ideas and proposals for future project activities that must inevitably be based on innovation, quality, and upcoming machine technologies, which is actually in accordance with the Development strategy of science and technology of the Republic of Srpska for the period 2023-2029, in which education, science, technology, research, innovation, and digitization are recognized as key prerequisites for achieving a sustainable economy.

Many experts, researchers, university professors, businessmen and students from various fields of mechanical engineering have registered to participate in this edition of conference COMETa 2024. The topics that will be discussed by the scientific and professional public will certainly contribute to the acquisition of new knowledge and open up a lot of space for future innovations. 77 papers will be published in the Conference proceedings, including 3 plenary lectures. The fact that numerous participants from abroad have been registered for the conference COMETa 2024 this year is especially pleasing.

Namely, 262 authors come from 16 countries. The review team is composed of 53 colleagues from the country and abroad. This is certainly the result of strenuous activities that were aimed at raising the international reputation and visibility of the conference in the regional, but also in the wider academic and scientific research area, which will be one of our primary goals in the future.

We are sure that the work at the conference COMETa 2024 will be fruitful and that each of you, after its end, will leave with new ideas, knowledge and contacts that will contribute to your further professional development. This is an opportunity not only to learn from each other, but also to build the foundations for future research projects and industrial innovations together. In addition, we believe that in the coming days we will have the chance to get to know each other better, discuss common challenges and establish new forms of cooperation. In this sense, we would like to point out that all your proposals and suggestions are more than welcome and will be carefully considered by the Organizing and Scientific Committee in order to improve the organization of the next conferences.

Finally, on behalf of the Organizing and Scientific Committee of the conference COMETa 2024, we express our great gratitude to all authors, reviewers, universities and faculties, business entities, and national and international institutions and organizations that supported the organization of the conference. Special thanks go to the Ministry of Scientific and Technological Development and Higher Education of the Repubilc of Srpska, the City of East Sarajevo, the Municipalities of East New Sarajevo, East Ilidža and Pale, without whose help the organization and work of the conference certainly could not be at the level that its status deserves.

East Sarajevo, November 13th, 2024.

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IMPROVED STRUCTURAL FATIGUE ANALYSIS USING FEM: DEVELOPMENT OF API SCRIPTS FOR STRESS RANGE CALCULATION

Aleksandar Bodić[1], Snežana Vulović[2], Milan Bojović[3], Jelena Živković[4], Miroslav Živković[5]

Abstract: This paper presents an improved procedure for performing structural fatigue analysis using the finite element method (FEM). Numerical analyses were conducted for two typical structural load cases using Femap with NX Nastran software. To automate the fatigue stress range calculations, two custom API scripts were developed. The fatigue stress range was determined as the difference between the stress responses of the two load cases. First API script calculates the stress range based on the principal stresses, while second script uses the Von Mises equivalent stress criterion. The resulting stress ranges from both methods were compared, and their deviations were analysed. By automating the otherwise time-intensive task of calculating stress range vectors, these API scripts significantly reduce the required engineering time and probability of error. The results of the fatigue analysis confirm that these API tools can effectively improve the process and save engineering time.

Key words: API, Fatigue analysis, Finite element method, Principal stresses, Von Mises stress

1 INTRODUCTION

Assessment of the fatigue life of steel structures is a very important issue in the field of design and maintenance. This is especially important for large structures that are exposed to various environmental conditions, and their eventual failure can have huge

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consequences (cranes, bridges, etc.). For this reason, fatigue life prediction is a common and very important step in the structural design process [1]. Fatigue strength evaluation of structure is commonly considered for characteristic number of working cycles and according to specific standard. For these purposes, it is necessary to determine the stress range for defined load cases to which the structure is subjected. One of the most popular numerical methods for analyzing the behaviour of complex structures is finite element method (FEM) [2, 3]. There are many papers in the literature whose focus is the fatigue analysis of different types of structures using FEM [4, 5, 6]. For example, the application of FEM for fatigue analysis of pressure vessel is considered in [7, 8]. FEM fatigue analysis of crane is considered in [9]. Different methods for determining the stress range used in fatigue calculations of offshore transport equipment based on FEM are investigated in [10]. FEM fatigue analysis of pipelines due to slug flow are considered in [11]. Fatigue analysis of welded joints using FEM is investigated in [12, 13]. Therefore, it can be concluded that the application of FEM in the fatigue analysis of various types of structures is very widespread recently.

Using FEM, it is possible to perform a numerical analysis of the structure for two characteristic load cases, and then, based on the obtained stress fields, determine the stress range field in structure. Manually calculating the stress range field takes a lot of engineering time. For this reason, it is necessary to automate this process by developing API scripts [14].

This paper presents an improved procedure for performing structural fatigue analysis using the finite element method (FEM). Two custom API scripts were created to automate the process of calculating the stress range in the structure. The first script calculates the stress range using principal stress theory, while the second calculates the stress range based on the von Mises equivalent stress theory. The scripts were tested on the lower shell model for two typical load cases for that structure.

In the second chapter, the theoretical basis for calculating the stress range using principal stress theory and von Mises equivalent stress theory is given.

In the third chapter, the Lower Shell model on which the scripts were tested is presented and a procedure for numerical fatigue analysis for two characteristic load cases is given.

At the end, the results are shown, and conclusions were drawn about the conducted analyses.

2 STRESS RANGE DEFINITION USING FEM

In this chapter, the theoretical basis for calculating the stress range for 2D and 3D finite elements are given. The stress range is calculated in two ways: the first is based on the principal stress theory, while the second is based on the von Mises stress theory. The equations given in this chapter were used to create API programs for calculating the stress range.

2.1 Stress range calculation according to principal stresses theory

The calculation of the structural principal stress range is determined by the difference between the first and second characteristic load case for which the fatigue analysis is considered:

$$\Delta\boldsymbol{\sigma} = \boldsymbol{\sigma}_{case1} - \boldsymbol{\sigma}_{case2} \tag{1}$$

where $\boldsymbol{\sigma}_{case1}$ represents stress tensor due to Load Case 1 and $\boldsymbol{\sigma}_{case2}$ represents stress tensor due to Load Case 2.

For plate elements, principal stress ranges can be calculated as [2]:

$$\Delta\sigma_1 = \frac{\Delta\sigma_{xx} + \Delta\sigma_{yy}}{2} + \sqrt{\left(\frac{\Delta\sigma_{xx} - \Delta\sigma_{yy}}{2}\right)^2 + \Delta\sigma_{xy}{}^2} \tag{2}$$

$$\Delta\sigma_2 = \frac{\Delta\sigma_{xx} + \Delta\sigma_{yy}}{2} - \sqrt{\left(\frac{\Delta\sigma_{xx} - \Delta\sigma_{yy}}{2}\right)^2 + \Delta\sigma_{xy}{}^2} \tag{3}$$

where $\Delta\sigma_{xx}$, $\Delta\sigma_{yy}$ and $\Delta\sigma_{xy}$ represent the difference of *x* normal stress, *y* normal stress and *xy* shear stress, respectively between load cases 1 and 2:

$$\begin{aligned} \Delta\sigma_{xx} &= \sigma_{xx(case1)} - \sigma_{xx(case2)} \\ \Delta\sigma_{yy} &= \sigma_{yy(case1)} - \sigma_{yy(case2)} \\ \Delta\sigma_{xy} &= \sigma_{xy(case1)} - \sigma_{xy(case2)} \end{aligned} \tag{4}$$

For 3D elements, principal stress range scan be calculated as [2]:

$$\Delta\sigma_1 = \frac{\Delta I_1}{3} + \frac{2}{3}\left(\sqrt{\Delta I_1^2 - 3\Delta I_2}\right)\cos\phi \tag{5}$$

$$\Delta\sigma_2 = \frac{\Delta I_1}{3} + \frac{2}{3}\left(\sqrt{\Delta I_1^2 - 3\Delta I_2}\right)\cos\left(\phi - \frac{2\pi}{3}\right) \tag{6}$$

$$\Delta\sigma_3 = \frac{\Delta I_1}{3} + \frac{2}{3}\left(\sqrt{\Delta I_1^2 - 3\Delta I_2}\right)\cos\left(\phi - \frac{4\pi}{3}\right) \tag{7}$$

where I_1, I_2 and I_3 represent first, second and third stress invariant, which can be expressed with following equations [2]:

$$\begin{aligned} \Delta I_1 &= \Delta\sigma_{xx} + \Delta\sigma_{yy} + \Delta\sigma_{zz} \\ \Delta I_2 &= \Delta\sigma_{xx}\Delta\sigma_{yy} + \Delta\sigma_{yy}\Delta\sigma_{zz} + \Delta\sigma_{zz}\Delta\sigma_{xx} - \Delta\sigma_{xy}^2 - \Delta\sigma_{yz}^2 - \Delta\sigma_{zx}^2 \\ \Delta I_3 &= \Delta\sigma_{xx}\Delta\sigma_{yy}\Delta\sigma_{zz} - \Delta\sigma_{xx}\Delta\sigma_{yz}^2 - \Delta\sigma_{yy}\Delta\sigma_{zx}^2 - \Delta\sigma_{zz}\Delta\sigma_{xy}^2 + 2\Delta\sigma_{xy}\Delta\sigma_{yz}\Delta\sigma_{zx} \end{aligned} \tag{8}$$

Analogous to equation (4) for plate elements, members $\Delta\sigma_{xx}, \Delta\sigma_{yy}, \Delta\sigma_{zz}, \Delta\sigma_{xy}, \Delta\sigma_{yz}$ and $\Delta\sigma_{zx}$ in equation (8) represent difference of *x*, *y* and *z* normal stresses, and *xy*, *yz* and *zx* shear stresses, respectively between load cases 1 and 2:

$$\begin{aligned} \Delta\sigma_{xx} &= \sigma_{xx(case1)} - \sigma_{xx(case2)} \\ \Delta\sigma_{yy} &= \sigma_{yy(case1)} - \sigma_{yy(case2)} \\ \Delta\sigma_{zz} &= \sigma_{zz(case1)} - \sigma_{zz(case2)} \\ \Delta\sigma_{xy} &= \sigma_{xy(case1)} - \sigma_{xy(case2)} \\ \Delta\sigma_{yz} &= \sigma_{yz(case1)} - \sigma_{yz(case2)} \\ \Delta\sigma_{zx} &= \sigma_{zx(case1)} - \sigma_{zx(case2)} \end{aligned} \tag{9}$$

Angle ϕ in equations (5), (6) and (7) is defined using following equation [2]:

$$\phi = \frac{1}{3}\cos^{-1}\left(\frac{2\Delta I_1^3 - 9\Delta I_1 \Delta I_2 + 27\Delta I_3}{2\left(\Delta I_1^2 - 3\Delta I_2\right)^{3/2}}\right) \tag{10}$$

The maximum structural principal stress range for plate elements is obtained from following equation:

$$\Delta\sigma = \max\begin{vmatrix}\Delta\sigma_1 \\ \Delta\sigma_2\end{vmatrix} \tag{11}$$

The maximum structural principal stress range for 3D elements is obtained from following equation:

$$\Delta\sigma = \max\begin{vmatrix}\Delta\sigma_1 \\ \Delta\sigma_2 \\ \Delta\sigma_3\end{vmatrix} \tag{12}$$

2.2 Stress range calculation according to von Mises stress theory

Stress range according to von Mises stress theory is determined based on the difference between the first and second characteristic load case for which fatigue analysis is considered, as defined in equation (1).

For plate elements stress range using von Mises stress theory is defined using following expression [2]:

$$\Delta\sigma = \sqrt{\Delta\sigma_{xx}^2 + \Delta\sigma_{yy}^2 - \Delta\sigma_{xx}\Delta\sigma_{yy} + 3\Delta\sigma_{xy}^2} \tag{13}$$

while for 3D elements is defined as [2]:

$$\Delta\sigma = \frac{1}{\sqrt{2}}\sqrt{\left(\Delta\sigma_{xx} - \Delta\sigma_{yy}\right)^2 + \left(\Delta\sigma_{yy} - \Delta\sigma_{zz}\right)^2 + \left(\Delta\sigma_{zz} - \Delta\sigma_{xx}\right)^2 + 3\left(\Delta\sigma_{xy}^2 + \Delta\sigma_{yz}^2 + \Delta\sigma_{zx}^2\right)} \tag{14}$$

where the terms $\Delta\sigma_{xx}$, $\Delta\sigma_{yy}$, $\Delta\sigma_{zz}$, $\Delta\sigma_{xy}$, $\Delta\sigma_{yz}$ and $\Delta\sigma_{zx}$ are defined in the previous chapter and are calculated by equation (9).

2.3 API scripts for calculating stress range

Two API scripts were created for calculating the stress range: one based on the principal stress theory, and the other based on the von Mises equivalent stress theory. Both scripts calculate stress ranges based on the difference of the two characteristic load cases for which the fatigue analysis is considered. Figure *1* shows the algorithms based on which the API scripts were developed.

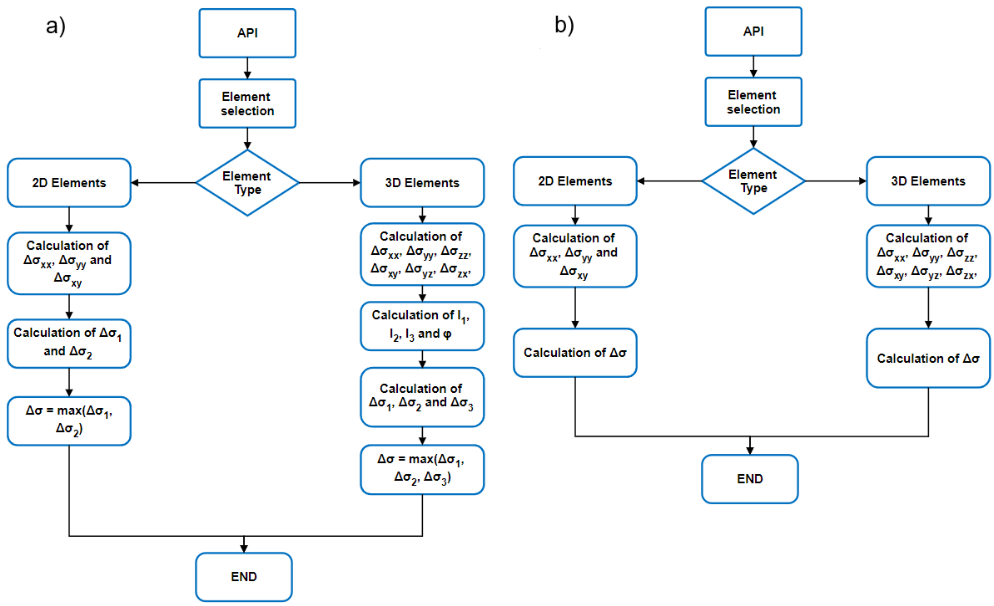

Figure 1. *Algorithm for stress range calculation using a) principal stress and b) von Mises equivalent stress*

The API script for calculating the stress range according to the theory of principal stresses is developed according to the algorithm shown in Figure *1*a. After starting the API script, the elements for which the stress range is calculated are first selected. The API then calculates the required variables based on the element type. If the 2D element is selected, the differences of the normal stresses in the *x* and *y* directions, as well as the *xy* shear stress, are calculated first according to equation (4). After that, it calculates the ranges of principal stresses using equations (2) and (3) and the maximum stress range in the element according to equation (11). If the 3D element is selected, API calculates the differences of the remaining normal and shear stresses, three stress invariants and the principal angle according to equations (9), (8) and (10). After that, similarly as for 2D elements, it calculates the principal stress ranges using equations (5) , (6) and (7) and the maximum stress range in the element using equation (12).

The algorithm shown in Figure *1*b refers to an API that calculates the stress range according to the von Mises equivalent stress theory. By running the API script, the elements in which the stress range is calculated are selected, and then, based on the element type, the equivalent stress range is calculated according to equation (13) for 2D elements or equation (14) for 3D elements.

3 FATIGUE ANALYSIS OF LOWER SHELL MODEL

FE model of Lower Shell (Figure *2*) is created within Femap software [15]. Model is created using 2D 4-noded plate elements and 3D hexahedral elements and consists of 225364 elements and 227850 nodes.

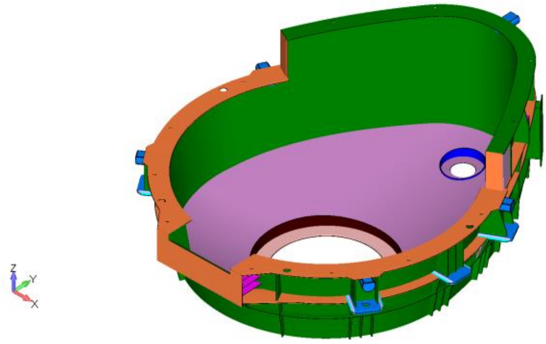

Figure 2. *FE model of lower shell*

Numerical analysis is performed for two load cases. The first load case corresponds to a regular melting operation. The Lower Shell is standing on a platform loaded with 100% payload. The second load case represents the discharge of the Lower Shell. The Lower Shell is inclined at 25 degrees from the horizontal to the tapping side and contains 30% of the load.For purpose of calculating stress range field both API scripts were used. Stress range field obtained using API scripts is shown in Figure *3* and Figure *4*.

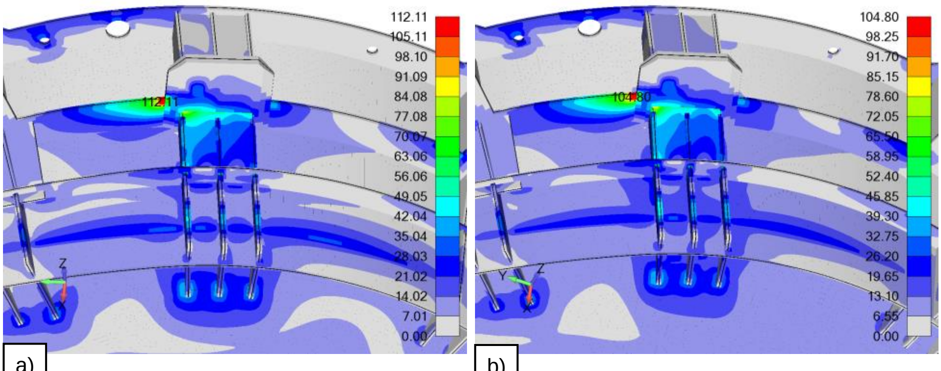

Figure 3. *Stress range field obtained using API based on a) principal stress theory and b) von Mises stress theory*

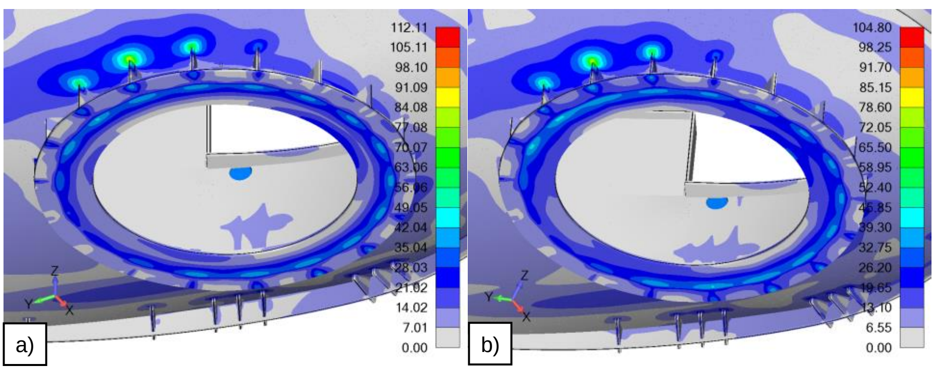

Figure 4. *Stress range field obtained using API based on a) principal stress theory and b) von Mises stress theory*

By visually comparing results in Figure *3* and Figure *4*, it can be seen that the stress range field matches for both methods. Also, the maximum values of the stress range for both methods match, with a smaller deviation. It can be concluded that the stress range determination process can be effectively automated using the created API scripts.

4 CONCLUSION

This paper presents an enhanced methodology for conducting structural fatigue analysis using the finite element method. Numerical simulations were performed for two standard structural loading scenarios, utilizing Femap with NX Nastran software. To streamline the fatigue stress range calculations, two custom API scripts were created: one based on principal stress theory and other based on von Mises stress theory. The fatigue stress range was calculated using both API scripts as the difference between the stress responses of the two load cases.

By comparing the results from principal stresses and von Mises stress criteria, it can be concluded that both scripts give similar solutions. For the conducted FEA analysis for lover shell divergence between max values of fatigue stress between two approaches was 6.7%. The results obtained by the principal stress theory are slightly higher than the results obtained by the von Mises equivalent stress theory, which puts the construction on the side of safety.

Also, it can be concluded that API usage for these purposes offer flexibility in fatigue assessment while reducing engineering effort and time.

The automation of these calculations not only ensures more efficient analysis but also enables handling of complex models with greater ease. Overall, these tools improve the fatigue analysis workflow and provide accurate, consistent results, demonstrating their practical value in structural engineering applications.

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REFERENCES

[1] W. Eichlseder, “Fatigue analysis by local stress concept based on finite element results,” *Computers and Structures,* vol. 80, no. 27-30, pp. 2109-2113, 2002.

[2] K. Bathe, Finite Element Procedures, Massachusetts: Massachusetts Institute of Technoogy: Prentice Hall, 1996.

[3] M. Kojić, R. Slavković, M. Živković and N. Grujović, Finite element method 1, Kragujevac: Faculty of Mechanical Engineering, University of Kragujevac,, 2010.

[4] J. Pereira R. Junior, R. Rodriguez and S. dos S. Hoefel, “FATIGUE ANALYSIS USING THE FINITE ELEMENT METHOD,” in *Proceedings of the XLII Ibero-Latin-American Congress on Computational Methods in Engineering and III Pan-American Congress on Computational Mechanics*, Rio de Janeiro, Brazil, 2021.

[5] Indian Register of Shipping, Guidelines on Spectral Fatigue Analysis of Ship Structures, 2020.

[6] C. Han, X. Qu, Y. Ma and D. Shi, “Experimental and Numerical Study of Fatigue Damage Assessment under Combined High and Low Cycle Loading,” *Shock and Vibration,* vol. 2018, pp. 1-12, 2018.

[7] K. Tamboli, “Fatigue Analysis of Pressure Vessel by FEA Techniques,” *International Journal of Engineering Trends and Technology (IJETT),* vol. 13, no. 1, pp. 25-28, 2014.

[8] P. Kadarno, D. Park, N. Mahardika, I. Irianto and A. Nugroho, “Fatigue Evaluation of Pressure Vessel using Finite Element Analysis based on ASME BPVC Sec. VIII Division 2,” *Journal of Physics: Conference Series,* vol. 1198, no. 4, pp. 1-12, 2019.

[9] R. Buczkowski and B. Żyliński, “FINITE ELEMENT FATIGUE ANALYSIS OF UNSUPPORTED CRANE,” *POLISH MARITIME RESEARCH,* vol. 28, no. 1, pp. 127-135, 2021.

[10] Project Report, “Fatigue analysis of offshore transport equipment,” Aalborg University Esbjerg Denmark, 2021.

[11] A. Mohmmed, H. Al-Kayiem, M. Nasif and Z. Mohammed, “Finite Element Analysis of Fatigue in Pipelines Due To Slug Flow,” *Advanced Materials Research,* vol. 845, pp. 271-276, 2014.

[12] M. AYGÜL, Fatigue Analysis of Welded Structures Using the Finite Element Method, Gothenburg, Sweden : CHALMERS UNIVERSITY OF TECHNOLOGY, 2012.

[13] W. Shin, K.-H. Chang and S. Muzaffer, “Fatigue analysis of cruciform welded joint with weld penetration defects,” *Engineering Failure Analysis,* vol. 120, p. art. no. 105111, 2021.

[14] Siemens Digital Industries Software Inc, FEMAP API Reference, 2021.

[15] Siemens PLM Software Inc., FEMAP User Guide Version 11.2, 2015.