BOOK OF ABSTRACTS

Proceedings of the First International Symposium on Risk Analysis and Safety of Complex Structures and Components
Preface

Dear Colleagues, Dear Friends,

It is with great pleasure that we welcome you to our beautiful city of Porto (Portugal) for the first edition of the International Symposium on Risk Analysis and Safety of Complex Structures and Components (IRAS 2019).

The ESIS Executive Committee decided to change the name of TC 12 in November 2016. The actual name of the ESIS TC12 is Risk Analysis and Safety of Large Structures and Components.

The tasks and objectives of the Technical Committee are the following: - consolidation of the European scientific community to solve scientific and technical safety problems; - development of perspective research directions, computational and experimental methods and technologies in the area of safety of engineering systems; - cooperative researches, held by specialists and scientists from various countries on behalf of reducing the rate of accident risks while operating dangerous objects and systems; - development of modelling the incident theory of large technical systems; - development of mechanical and mathematical models and risk-analysis technologies; - development of reliability and probabilistic approaches for the fatigue and fracture characterization of materials (metals, polymers, composites among others) and structures (metallic, composite, joints, etc); - elaboration of standards using methods of probabilistic risk-analysis of technical systems according to fracture mechanics criteria; - elaboration of standards using reliability and probabilistic models for the large structures and components according to local criteria; - elaboration of standards using risk models of complex hierarchical technical systems; - unification of approaches to safety analysis of large technical systems; - unification of analysis methods of information on technical condition of large technical systems; - creation of unified methods and the harmonization of national regulatory documents in the area of technical systems safety; - elaboration of special study courses, problem books and test books on fracture mechanics, fatigue, reliability theory, and risk-analysis of technical systems.

The First International Symposium on Risk Analysis and Safety of Complex Structures and Components (IRAS 2019) is organised by ESIS TC12 on Risk Analysis and Safety of Large Structures and Components (in-team TC12), which will take place in the Faculty of Engineering of the University of Porto, in the City of Porto, located at seaside in the northwest region of Portugal, in 1-2 July 2019. This Symposium is intended to be a forum of discussion of the recent advances in maintenance, safety, risk analysis, probabilistic assessment, life-cycle performance, fatigue, fracture, damage mechanics, numerical simulation of a wide range of infrastructures, such as, engineering technical systems, transportation systems, bridges, buildings, dams, railways, underground constructions, wind and transmission towers, offshore platforms, pipelines, naval vessels, oceanic structures, nuclear power plants, airplanes and
other types of structures including aerospace and automotive structures are considered. It is expected contributions from engineers, metallurgists, material scientists, among others, allowing a very multidisciplinary discussion.

The Organizing Committee of the IRAS 2019 deeply acknowledges all authors that contributed to the success of this event, with their exciting presentations. The members of the International Scientific Committee are also fully acknowledged for their support to the IRAS 2019 event. Special thanks are also addressed to the Thematic Sessions Organizers and Plenary Speakers for their dedication and knowledge and energy brought to this event. Sponsors are also fully acknowledged for their important contributions. Finally, chairmen sincerely thank the tireless efforts of Organizing Committee members as well as students and other FEUP and IC staff.

The first edition of the IRAS 2019 event, organized between 1st and 2nd of July 2019 at the Faculty of Engineering of the University of Porto, Portugal, gathers more than 100 participants from more than 20 nationalities demonstrating the vitality of this new event.

This book gathers the abstracts of the works presented in the colloquium. In general, the abstracts were organized into eighteenth chapters, according to the main topics of the thematic sessions foreseen in the programme of the conference.

The Organizing Committee of the IRAS 2019 deeply acknowledges all authors that contributed to the success of this event, with their exciting presentations. The members of the Advisory and Scientific Committees are also fully acknowledged for their support to the conference. Special thanks are also addressed to the Thematic Session Organizers, Plenary Speakers, Chairmen of the Sessions for their dedication, knowledge and energy brought to this event. Sponsors are also fully acknowledged for their important contributions. Finally, a word of appreciation for the Organizing Committee members as well as students and other FEUP/INEGI/IC staff for their tireless support.

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Keynote Lectures
Application of weakest link concept to fatigue and fracture assessment

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Keywords: Fatigue, Fracture, Probabilistic model, Microcrack distribution, Size effect.

ABSTRACT

Among many contributing factors, the load range, number of load cycles and specimen geometry (including configuration and size) are three major variables for fatigue failure. Most existing statistical fatigue models deal with only one or two of these three variables. According to the statistical distribution of microcracks with respect to their size and spatial location, a weakest-link probabilistic model for fatigue failure is established to incorporate the combined effect of load range, number of load cycles and specimen size. The model reveals a compound parameter of load range and number of load cycles reminiscent of the empirical formulae of fatigue stress-life curve and its correlation with another compound parameter of cumulative failure probability and specimen size. The test data are adopted to validate the model. A statistical model for cleavage fracture toughness of ferritic steels is proposed according to a new local approach model. The model suggests that there exists a unique correlation of the cumulative failure probability, fracture toughness and yield strength. This correlation is validated by the Euro fracture toughness dataset for1CT specimens at four different temperatures, which deviates from the Weibull statistical model with a modulus of four.
Dr. Guian Qian, Professor in the State Key Laboratory of Nonlinear Mechanics, Institute of Mechanics, Chinese Academy of Sciences, China. He obtained his PhD from the institute of mechanics, Chinese Academy of Sciences with the major of solid mechanics in 2009. Afterwards, he moved to PSI and was a postdoctoral fellow until 2012. From 2013.1 to 2018. 7, he was a scientist in the Laboratory for Nuclear Materials, Nuclear Energy and Safety Department, Paul Scherrer Institute. Thereafter, he moved back to Chinese Academy of Sciences. **His current research interest lies in the fatigue and fracture analysis of nuclear components and structures.** He made significant contribution to the nuclear safety assessment, especially in the pressurized thermal shock analysis of reactor pressure vessels and leak-before-break analysis of nuclear piping. He has published more than 60 peer reviewed papers, including more than 40 SCI-indexed papers in journals including Acta Materialia, International Journal of Solids and Structures, Engineering Fracture Mechanics, International Journal of Fatigue. He has been invited for several keynote talks in international conferences and symposiums, including the 11th International Workshop on the Integrity of Nuclear Components, 2014 International Symposium on Structural Integrity and Nuclear Materials Symposium in Chinese Materials Conference 2017. He is session organizer in ASME Pressure Vessels and Piping conferences (2015, 2016, 2017, 2018) and the 14th International Conference on Fracture Mechanics. He serves as reviewer for more than 20 international journals and several international funding.
Machine Learning and Structural Health Monitoring

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Keywords: Machine Learning; Structural Health Monitoring.

ABSTRACT

Machine learning (ML) is a key and increasingly pervasive technology in the 21st century. The author will present the view that it is going to impact the way people live and work in a significant way. This lecture starts with an overview of the key ML concepts and different types of ML algorithms. In general, machine learning algorithms simulate the way brain learns and solves an estimation/recognition problem. They usually require a learning phase to discover the patterns among the available data, similar to the humans. An expanded definition of ML is advanced as algorithms that can learn from examples and data and solve seemingly interactable learning and unteachable problems, referred to as ingenious artificial intelligence (AI). Next, recent and innovative applications of ML in various fields and projects currently being pursued by leading high-tech companies such as Google, IBM, Uber, Baidu, Facebook, Pinterest, and Tesla are reviewed. Then, machine learning algorithms developed by the author and his associates are briefly described with applications for health monitoring of structures. Finally, ideas are presented for improving ML algorithms and some future directions are delineated.
Hojjat Adeli received his Ph.D. from Stanford University in 1976 at the age of 26. He is currently an Emeritus Academy Professor at The Ohio State University where he held the Abba G. Lichtenstein Professorship for ten years. He is the Editor-in-Chief of the international journals *Computer-Aided Civil and Infrastructure Engineering* which he founded in 1986 and *Integrated Computer-Aided Engineering* which he founded in 1993. He has also served as the Editor-in-Chief of the *International Journal of Neural Systems* since 2005. He has authored over 600 research and scientific publications in various fields of computer science, engineering, applied mathematics, and medicine, including 16 ground-breaking high-technology books. He is the recipient of sixty awards and honors including an Honorary Doctorate and Honorary Professorship at several Asian and European Universities. In 2005, he was elected Distinguished Member, ASCE: “for wide-ranging, exceptional, and pioneering contributions to computing in civil engineering and extraordinary leadership in advancing the use of computing and information technologies in many engineering disciplines throughout the world.” He is a member of Academia Europaea, a corresponding member of the Spanish Royal Academy of Engineering, a foreign member of Lithuanian Academy of Sciences and Polish Academy of Science, and a Fellow of AAAS, IEEE, AIMBE, and American Neurological Association.
Overview of TUD-Stevin Laboratory fatigue research and recent results

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Keywords: joints, connections, HSS, OSD, Residual Stress; Fatigue crack initiation and propagation; XFEM.

ABSTRACT

Stevin laboratory is one of few University owned laboratories which have constant activity since 1970-ies. Specimens were tested in tailor made set-up on area of 800 m² and to 8 m height. They are exposed to monotonic and cyclic loading up to 10 MN.

The laboratory has made strong contribution in developing knowledge in various areas of bridge engineering, use of hollow sections in onshore and offshore environment, prediction methods for joints and connections made of rolled sections and casted joints, improving use of very high strength steels. Many of projects were developed for commercial applications creating innovation in structural engineering but majority of activity was focused on to educate students at various undergraduate and post-graduate levels.

The major contributions will be highlighted in the presentation focusing on bridge decks and connections of monopoles for onshore and offshore supporting towers for wind turbines.

Important contribution to design standards and engineering science in area of steel, steel-concrete composite, and composites based on FRP structures is well documented in hundreds of technical reports, conference and journal papers, BSc/MSc and PhD theses.

Many part of Eurocode 3 have been influenced by the contributions from Stevin laboratory research activity. One of examples, which is in focus of this paper, is related to orthotropic bridge deck with closed longitudinal stiffeners. EN 1993-1-9 2005 and EN 1993-2 2006, fatigue and steel bridges, respectively, are modified in the Dutch national Annex of EN 1993-2 (NEN-EN 1993-2+C1/NB 2011) which includes the latest knowledge about the fatigue strength of these joints.

Description of the welded joints and the relevant stress range, the fatigue calculation and the tolerances of the joint and weld geometry, the type of crack and crack growth, and fatigue design categories are included in the NAD. Standardization of these joints are relevant for estimation of remaining life time of existing and new orthotropic decks. This national Annex includes deck plate thicknesses as a function of the design life considering different type of surfacing and traffic intensity. For some of the critical regions the National Annex NEN-EN 1993-2+C1/NB gives an higher detail category. These values may only be used in combination with the specified execution requirements and NDT results.

All these issues which we experimentally justified will be shown in the presentation.

In addition to obvious needs for experimental research, numerical simulations is increasing use to predict fatigue behaviour of steel structures. Prediction of welded connections are challenging because of effects caused by welding process which causes changes in the parent material, material of weld and in HAZ.

Effects of the residual stresses due to welding on fatigue crack initiation and propagation is successfully estimated on a relatively small scale by using phantom nodes-based extended finite element method. A
user-defined fatigue damage initiation subroutine based on Smith, Watson, and Topper (SWT) damage model combined with non-linear isotropic/kinematic cyclic hardening model is implemented in Abaqus software package to predict fatigue crack initiation. Residual stresses influenced position of the crack see Figure 1 and reduction of crack initiation and the total fatigue life.

Fig.1 Effect of residual stresses on the crack initiation and propagation, comparison between experiments and FEA

En example from offshore applications, where parameters of corrosion fatigue crack growth rate for Q355J2 steel based on “Paris’ law” were evaluated using stress intensity factor (SIF), J-integrals (LEFM), J-integrals (EPFM), CTOD (EPFM) and CTOA (EPFM) approach will be discussed at the presentation. The residual stresses influence the corrosion fatigue crack growth rate. The exponent m of fatigue crack growth rate based on LEFM calculation is larger than it based on EPFM approach. The exponent m of fatigue crack growth rate based on LEFM calculation, obtained on the parent material considering residual stresses, tends to be smaller than obtained from experimental results of weld and HAZ material, while it is closer to the experimental results when EPFM approach is used.

Fig.2 Residual stress effects on fatigue crack propagation rate

REFERENCES
Milan Veljkovic received PhD at Lulea University in Sweden in 1996 and became full professor in Steel Structures at the same university in 2007. In 2015 he moved to Delft University of Technology, the Netherlands to become full professor in Steel and Composite Structures. In the last 15 years he has participated in 20+ research projects with a total budget more than 12 mil euros. He has published more than 200 journal and conference papers. Main cornerstones of his research are bolted connection, development of a concept for more than one life time of steel and steel/composite structures- development of technical aspects for the implementation of the circularity in construction. Since he has moved to TUD he has focused on prediction methods and behaviour of bridges and offshore structures exposed to fatigue loading. He has served as reviewer for dozens of international journals and research funding in Sweden, Norway, Czech Republic, Slovenia, Belgium and for a couple of funding schemes of EU. In last 10 years he has been involved in executive board of ECCS and in Technical Management Board. He is involved in activity of many technical committees and in the work on the second generation of Eurocodes, in the project team for connections. He received Sigge Thernwalls Stora Byggpris in 2015 for his contribution for development of education and research at LTU, Sweden.
From Reliability to Resilience: Advanced Challenges for Technical System Performances

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Keywords: Reliability; Resilience; Technical System Performances.

ABSTRACT

There are several trends of development of modern reliability theory and engineering. Some of them are subjects of everyday engineering activity, like: quality control of mass production or classical reliability. But most of these issues, such as: effectiveness, durability, resistance, survivability, safety or security are currently the subject of many scientific works concerning modeling and simulation of technical objects, case studies of complex systems operation and maintenance or concepts of man-machine-environment system assessment.

The aim of the presentation is to show how the performance requirements of technical objects were supplemented with: customer expectations (quality), abilities to prevent the loss of the object properties in operation time (reliability and maintainability), the effects of undesirable events and protection against them (safety and security) and the ability to restore performance (resilience).

The beginnings of reliability engineering are discussed. It allows to define the basic concepts of failure, unrepairable element reliability characteristics and reliability structure models. Thus, the problem of maintaining technical facilities is shown. Due to the rapid increase in information processing capabilities the concept of maintenance 4.0 have become "fashionable”.

Sources of interest of system resilience came from supply chains development. On SC example it is shown that the main goals of resilience analysis concern: identification of the set of events and event sequences that can cause damages, identification of the relevant set of initiating events which affect the system performance, identification of the set of events respective to event consequences that would cause the given end state of the system and identification and determination of events and observed outcomes dependencies (within the system and among the system).
Prof. Tomasz Nowakowski, Wroclaw University of Science and Technology, Wroclaw, Poland. Dean of Mechanical Engineering Faculty WUST, head of Department of Operation and Maintenance of Logistic, Transportation and Hydraulic Systems. Member of Transport Committee of Polish Academy of Science, chairman of Winter School on Reliability (the 47th edition in January 2019), chef editor of “Logistics and Transport” quarterly. Scientific and research interests concern problems of reliability, maintainability and safety of machines, then – complex technical systems; currently – resilience and vulnerability of transport and logistics systems. He is also interested in problems of computer aided systems for operation and maintenance management, knowledge based expert systems and information uncertainty analysis and modeling. Author of over 300 scientific publications in national and international papers and books. Prof. T. Nowakowski promoted 14 doctors, supervisor in the next 5 doctoral programs.
Advances in structural fatigue reliability design and assessment under uncertainty

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Keywords: Fatigue; Reliability; Uncertainty; Size effect; Notch; Defects; Life prediction.

\textbf{ABSTRACT}

In order to ensure the safety and reliability of power and energy systems, including gas/steam turbines, power plants, etc., failure mechanism and reliability assessment have becoming a recent development in integrity analysis of these systems/components. For many countries, currently facing a potential future mismatch from energy production and transformation, currently increasing interests are being paid on new techniques to discover and understand the lifing and reliability assessment of power and energy systems. Due to unexpected ageing related fatigue damaging, mechanical properties, microstructures and structural resistance of components often require stochastic considerations related to failure mechanism modelling and analysis. In addition, various sources of uncertainty/variability arising from a simplified representation of the actual physical process (often through semi-empirical or empirical models) and/or sparse information on manufacturing, material properties, and loading profiles contribute to stochastic behaviour under operation.

The aim of the presentation is to show how to improve structural fatigue reliability through the accurate modelling of failure mechanisms by introducing advanced mathematical approaches/tools, from the aspects of design and assessment in engineering practice. Particularly, through combining the deterministic and probabilistic modelling techniques, researches on failure mechanism and reliability are provided for new structures at the design stage and ensure the integrity in the construction at the fabrication phase. Specifically, an engineering case on power system failure under multi-sources of uncertainty/variability will be elaborated, which results from load variation in usages, material properties, geometry variations within tolerances, and other uncontrolled variations.

In this presentation, advanced methods and applications for theoretical, numerical, and experimental contributions that address these issues on failure mechanism and reliability analysis are introduced, including the influence of notch, size effects and defects on fatigue strength and life prediction, which attempts to prevent over-design and unnecessary inspection and provide the tools to enable a balance between safety and economy to be achieved.
Prof. Shun-Peng Zhu, University of Electronic Science and Technology of China (UESTC), who received his Ph.D degree in Mechanical Engineering from UESTC in 2011. From 2016 to 2018, he was an International Fellow in the Department of Mechanical Engineering at Politecnico di Milano, Italy and research associate in the Department of Mechanical Engineering at University of Maryland, United States from 2010 to 2011. His research which has been published in scholarly journals and edited volumes, over 100 peer-reviewed book chapters, journals and proceeding papers, explores the aspects: Fatigue assessment; Probabilistic Physics of Failure modeling; Structural reliability analysis; Multi-physics damage modelling and life prediction under uncertainty; Multi-scale uncertainty quantification and propagation; Probability-based life prediction/design for engineering components. Dr. Zhu also studies advanced numerical methods for uncertainty quantification in engineering. He received the 2nd prize of the National Defense Science and Technology Progress Award of Ministry of Industry and Information Technology of China in 2014, Hiwin Doctoral Dissertation Award in 2012, and Polimi International Fellowship in 2015, and “Most Cited Chinese Researchers” (Elsevier) in the field of Safety, Risk, Reliability and Quality in 2018. He serves as guest editor, editorial board member of several international journals and Springer book series, Organizing Committee Co-Chair of QR2MSE 2013, TPC Member of QR2MSE 2014-2018, ICMR 2015 and ICMFM XIX 2018.
Probabilistic fatigue & fracture approaches applied to materials and structures
A-IRAS2019-PFFA

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The Generalized Local Model (GLM): A probabilistic approach to ensure transferability in the practical design process

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Keywords: Failure probability, Generalized local model (GLM), practical design, Structural glass.

ABSTRACT

Proper test selection and experimental program planning along with unobjectionable probabilistic data assessment are required necessarily to achieve basic mechanical characterization of a material. In this work, the generalized local model (GLM) is proposed as a methodology providing a correct probabilistic material characterization, particularly, against fracture or fatigue, independently of the test performed and specimen size and shape being used in the experimental program.

Basically, the procedure consists of the following steps: First, the choice of a test, in which a suitable generalized parameter (GP) and corresponding failure criterion are selected as the adequate failure reference to allow failure to be probabilistically predicted. Second, definition of the experimental failure cumulative distribution function (EFCDF) from the test results, third, transformation of the latter to the so-called primary failure cdf (PFCDF), which represents the failure cdf of the material when subject to uniform distribution of the GP and fourth, possible checking of the suitability of the GP and failure criterion chosen by resorting to another test type.

In this way, a consistent methodology is proposed that guarantees transferability, i.e. reliable applicability of laboratory results assessment to calculate the global failure probability of components subject to whatever load, thus ensuring structural integrity in practical design.

Requirements for application of the GLM are the weakest link principle and statistical independence among the results. Further, suitability in the choice of the GP and failure criterion is taken for granted as well as of the test, in which general character and sufficiency are presupposed.

The utility of the approach is highlighted by presenting an applied example related to characterization of structural glass.
A generalized model for static fatigue lifetime prediction of silica optical fibers

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Keywords: Lifetime prediction, Static fatigue, Model uncertainty, Optical fiber.

ABSTRACT

The mechanical reliability of silica-based optical fibers declines especially under the combination of applied stresses and severe chemical environment in service. It is of great concern to assess the mechanical reliability and lifetime based on the short-term accelerate testing and the relevant mechanism. The long-term lifetime prediction of optical fibers is sensitive to the form of kinetic model, yet no fair and common agreement has been reached on the best model. This study hence proposes a generalized lifetime model to search the best model in an expanded model space and hence can reduce model uncertainty. Following that, a procedure using the maximum likelihood estimation and the likelihood ratio test is conducted to determine the model structure. Furthermore, three sets of static fatigue lifetime data are used to illustrate the validity and superiority of the proposed framework. The result demonstrates that the proposed framework can reduce the uncertainty in model choice and is readily applicable to evaluation of static fatigue lifetime of optical fibers.

Introduction

The mechanical reliability and lifetime prediction of optical fibers is of great concern and has been a topic of research [1]. Several kinetics models have been proposed to predict the lifetime, including the empirical and mechanism based models. Empirical power law model is the most commonly used model due to its mathematical concision although it has no physical implications [2]. Wiederhorn [3] proposed a model in exponential form by assuming that the tensile stress at the crack tip reduced the activation free energy. A more rigorous model proposed by Lawn [4] considered both the breaking and forming processes of silicon-oxygen bonds during the fracture.

However, different models would give quite different results for data fitting and long-term lifetime prediction. Thus, the model uncertainty exists in long-term life prediction of optical fibers. Therefore, in this work, a generalized lifetime model is proposed to incorporate the characteristics of different models and a corresponding procedure is provided to simplify the proposed model for various conditions. An example is given to verify the validity of the method.

Generalized lifetime modeling approach

By merging the similar terms in the three lifetime model, a generalized lifetime model is proposed as follows,

\[ T = 2 \cdot K_{IC}^2 \cdot \exp(-n'_I \cdot \ln(S/S_i) - n'_2 \cdot (\sigma/S_i) - n'_3 \cdot (\sigma/S_i)^2)/\lambda/\gamma \cdot Y^2 \cdot n' \],

where \( A', n', n'_I, n'_2, n'_3 \) are fitting parameters, \( \sigma \) is the applied stress, \( S_i \) is the inert strength and \( K_{IC} \) is the critical stress intensity factor.

We use the likelihood ratio test to determine whether and how the generalized lifetime model can be simplified, and the log-likelihood ratio statistic is given by

\[ \Lambda = -2 \ln(L(\hat{\theta}_0)/L(\hat{\theta}_1)) \],

where \( \hat{\theta}_0 \) and \( \hat{\theta}_1 \) are MLE estimates under the null hypothesis \( H_0 \) (i.e., the simplified model) and the alternative hypothesis \( H_1 \) (i.e., the generalized model), respectively. The null hypothesis \( H_0 \) would be rejected if \( \Pr(\chi^2_{m} > A_0) \) is lower than a given significance level \( \gamma \).

Case study

A set of static fatigue experimental data of laser-drawn TO-8 clad optical fibers in [5] is utilized to illustrate the validity of the proposed generalized lifetime model and the model simplification approach. The fitting performances of the four models under each stress are plotted in Fig. 1.
Fig. 1. Predicted and experimental lifetimes of four models under different stresses.

It is quite clear that the simplified generalized lifetime model has the best fitting performance, especially under the lower stress levels. We use the maximum relative error $\delta_{\text{max}}$, the total average relative error $\delta_{\text{ave}}$, and the average relative error of the three lowest stresses $\delta_{\text{ave3}}$ to compare the four models, as shown in Table 1.

Table 1. The relative errors of different models

<table>
<thead>
<tr>
<th>Model</th>
<th>$\delta_{\text{max}}$</th>
<th>$\delta_{\text{ave}}$</th>
<th>$\delta_{\text{ave3}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power law lifetime model</td>
<td>525.4 %</td>
<td>132.5 %</td>
<td>214.4 %</td>
</tr>
<tr>
<td>Simple chemical lifetime model</td>
<td>271.7 %</td>
<td>78.9 %</td>
<td>120.9 %</td>
</tr>
<tr>
<td>Atomic lifetime model</td>
<td>492.3 %</td>
<td>219.1 %</td>
<td>263.4 %</td>
</tr>
<tr>
<td>Proposed lifetime model</td>
<td>189.8%</td>
<td>42.9%</td>
<td>18.0%</td>
</tr>
</tbody>
</table>

This paper presents a generalized lifetime model to investigate the static fatigue lifetime of optical fibers and reduce the uncertainty of model selection. The proposed model explores the model space by incorporating the forms of three basic models and therefore could better describe the experimental data with its flexibility in model structure. Besides, a procedure for the maximum likelihood estimation of model parameters is conducted to determine the model structure and to simplify the generalized model. By this method, we can find the best model and reduce the model uncertainty.

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Interdependencies between variables in fatigue analysis of a weight-optimised naval ship

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**Keywords:** Fatigue life; naval ships; hull monitoring; slamming

**ABSTRACT**

In the structural design and through-life management of naval ships, factors including the construction quality, lifetime loads, material properties, and mission requirements are sources of uncertainty [1, 2]. Modern warships are often constructed from aluminium alloys or high tensile steel, and their increasing range of operational roles indicates exposure to harsh seaway loads. These factors can lead to fatigue cracking, which can reduce operational availability.

In general, the primary sources of cyclic loads applied to a ship hull are wave action and impact loads such as slamming. Slamming can have a considerable influence on the fatigue life of ships when compared to accounting for the global wave induced stresses alone [3-5].

The objective of the present study is to improve understanding of the influence of variables in the fatigue analysis of a 56 m naval patrol boat constructed from marine-grade aluminium alloys. This work supports informed decision-making regarding the fatigue life and operational availability of weight-optimised naval ships.

The uncertainty associated with the occurrence of slamming and its impact on fatigue damage is investigated through analysis of strain data acquired from a hull monitoring system (HMS) that was implemented on a patrol boat. In addition, the results from Spectral Fatigue Analysis (SFA), a direct calculation method, are used to establish the significance of the ship speed, heading relative to the dominant wave direction, significant wave height, and wave period to the fatigue damage.

Analysis of the HMS data at two welded structural details indicates that the number of slams per hour and the fatigue damage is of moderate statistical association. However, the correlation between the ship speed and fatigue damage is not statistically significant. Prima facie, these observations are counter-intuitive as it would be expected that the stresses and in turn the fatigue damage increase with ship speed.

Based on SFA using linear hydrodynamic analysis, the positive correlation between the ship speed and fatigue damage is statistically significant.

These results lead to the proposal that voluntary speed reduction and/or involuntary speed reduction influences the fatigue damage incurred in the in-service ship. Voluntary speed reduction occurs when the operator reduces the speed of the ship due to severe slamming or large accelerations. Involuntary speed reduction is caused by the added resistance of the ship and changes to the propeller efficiency, due to waves and wind. Both voluntary and involuntary speed reduction depend on the significant wave height and the relative heading between the ship and waves [6, 7]. These factors are inherently captured in the measured data but not in the SFA. As such, it is suggested that use of long-term distributions of the significant wave height, wave period, and ship speed, which are assumed in numerical fatigue analysis,
may mask the interdependencies between the variables that affect the probability of the vessel experiencing slamming and the fatigue damage.

REFERENCES


Probabilistic assessment of structural safety of complex structures – Application to Terminal 2E at Roissy-CDG airport

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Keywords: Probabilistic analysis; Structural safety; Complex structure; Roissy.

ABSTRACT

Probabilistic analysis is used to assess the safety of structures by taking into account uncertainties that may affect structural performance in order to prevent the failure of structure, which can lead to injury or loss of life as well as financial losses. Terminal 2E at Roissy at Charles De Gaulle Airport is a large and complex structure consisting of three main parts: a main building, a boarding area and an isthmus connecting these two buildings. The boarding area, where the collapse occurred, has a length of 650 m and consists of 10 shells stiffened by curved steel girders (ties) braced to the two sides and held away from the shell by regular steel struts. Part of the terminal collapsed in 2004, after eleven months of its inauguration, and resulted in four casualties. The inadequate design of the terminal was the principle reason of its failure; the long term concrete creep caused excessive unpredicted deformations resulting in excessive forces in the struts that led to shear punching [1] and in redistribution of efforts and moments that led to the fracture of the terminal shell [2]. The reliability analysis of the terminal performed by Daou et al. [3] showed that the structure represented deficiencies and was prone to failure.

The purpose of this paper is to assess the structural safety of the terminal using probabilistic approach taking into consideration uncertainty on material properties and loads on the flexural moment and the long-term deflection. Therefore, a nonlinear finite element model of the terminal was carried out using Ansys. Subsequently, probabilistic analysis was performed by using a combination of Response Surface Method (RSM) and Monte Carlo Simulation (MCS). Then, the ratio of reinforcement required was calculated based on the results of the flexural moment values and compared to the existing reinforcement ratio and sensitivity analysis was performed. Moreover, shape optimization of the terminal shell, which is used to reduce bending and associated flexural stresses, was also performed to determine its optimal thickness.

FINITE ELEMENT MODEL

Nines arches including the collapsed ones were modelled using Ansys taking into consideration structure complexity, material nonlinearity, holes in the shell, asymmetry of the structure and loads applied (Fig. 1). The probabilistic analysis of the finite element model is performed by using a combination of RSM and MCS. The density (DENS), the compressive strength (Fc) and the modulus of elasticity of concrete (ECM), the temperature (TEMP) and the wind velocity (WIND) are the random variables considered in this study. The target reliability index is equal to 4.3 corresponding to \( P_f = 8.539 \times 10^{-6} \) [3].

RESULT AND DISCUSSION

Fig. 1. Ansys model of the terminal
Table 1. Values of the flexural moment and the long term deflection based on deterministic and probabilistic analyses

<table>
<thead>
<tr>
<th></th>
<th>Deterministic analysis</th>
<th>Probabilistic analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum value</td>
<td>Average value</td>
</tr>
<tr>
<td>Deflection (cm)</td>
<td>9.09</td>
<td>5.02</td>
</tr>
<tr>
<td>Moment (N.m)</td>
<td>153721</td>
<td>115500</td>
</tr>
</tbody>
</table>

Table 1 shows the values of the flexural moment and the long term deflection based on deterministic and probabilistic analyses. The probabilistic analysis shows that the values of deflection and moment exceed 63% and 25% of the values obtained by the deterministic analysis, respectively. According to EC2, the required reinforcement ratio based on deterministic analysis is 0.65, which is greater than the existing ratio. The long term deflection obtained by the deterministic analysis does not exceed the admissible value (12 cm) [3] while it reaches 14.8 cm according to the probabilistic analysis.

Based on the sensitivity analysis, Figure 2 shows the influence of the input variables on the moment value of the shell. The density of concrete (or the dead load) has the main effect on the value of moment but the modulus of concrete, the wind velocity and the temperature have also an effect on the moment value of the shell. Therefore, the poor quality of concrete and its weakness in addition to the rapid change in temperature affected the moment value and thus led to the failure.

Table 2. Values of the long term deflection (in cm) for different values of shell thickness

<table>
<thead>
<tr>
<th>Shell thickness (cm)</th>
<th>Deterministic analysis</th>
<th>Probabilistic analysis</th>
<th>Probability of failure P_f</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>minimum</td>
<td>maximum</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>10.10</td>
<td>5.63</td>
<td>17.24</td>
</tr>
<tr>
<td>30</td>
<td>9.09</td>
<td>4.73</td>
<td>15.23</td>
</tr>
<tr>
<td>35</td>
<td>8.54</td>
<td>4.39</td>
<td>14.11</td>
</tr>
<tr>
<td>40</td>
<td>8.11</td>
<td>4.02</td>
<td>13.59</td>
</tr>
</tbody>
</table>

The optimum shell thickness corresponds to the shell thickness value that provides the minimum reinforcement ratio and respects the target probability of failure. Therefore, the optimisation of the thickness shows that the problem is not in the shell thickness but in the design (shape) of the shell.

CONCLUSIONS

Based on the probabilistic analysis, the required reinforcement ratio is greater than the existing ratio and the long term deflection exceeds the admissible value. Therefore, the structure is not safe and present deficiencies in terms of moment and long term deflection. Moreover, probabilistic analysis gives more reliable and realistic results than deterministic analysis concerning the structural safety because it takes into consideration the uncertainty of material properties and loads. The optimisation of the thickness shows that the problem is not in the shell thickness but in the design (shape) of the shell.

REFERENCES

Probabilistic modelling of notch and size effect of components under fatigue loadings

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Keywords: highly stressed volume theories, size effect, notch effect, Weibull distribution, life prediction

ABSTRACT

Due to time-consuming and cost for full-scale testing of structures and component, normally smooth specimens with smaller size are tested for structural integrity assessment. The relationship between smooth specimens with smaller size and full-scale component can be established by characterizing the size and notch effect. Kloos [1] classified the influential factors of fatigue life into several aspects, i.e., (i) geometrical size effect attributed to stress inhomogeneity from different notch types, (ii) statistical size effect induced by the high probability of defects in larger specimens (fatigue strength of material decreases with the increase of sample size), (iii) production size effect generated by the production technology (like residual stress), and (iv) surface size effect caused by the surface technology (such as the roughness). Furthermore, under effect of stress concentration, fatigue cracks usually initiate at the inhomogeneity such as holes and notches, in which the structural geometry changes suddenly. Since high stress gradient exists in these components, fatigue crack initiation is conducive to structural failure through crack propagation. Therefore, it has separately triggered enormous research efforts to incorporate the stress concentration phenomenon (i.e., notch effect) and size effect in evaluating fatigue lifetime to ensure reliable life prediction for the engineering application. However, the current research work shows that a better method for coupling size effect and notch effect is lacking and highly expected.

As one of the mostly investigated methods in the evaluation of fatigue strength considering the statistical size effect and the geometrical size effect, the Highly Stress Volume (HSV) approach was first introduced by Kuguel [2], and then employed by Sonsino and Fischer [3], and others [4]. According to the concepts stated above it is assumed that the crack leading to fracture normally start in some point of the HSV. Therefore, the greater the HSV of the specimen in testing, the greater the probability of finding in it a more severe flaw or microcrack, which leads more easily to the failure [5]. The terminology $V_{n\%}$ is used to define the volume of material that is subjected to at least $n\%$ of maximum stress ($\sigma_{n\%} = n\% \times \sigma_{\text{max}}$). This volume of material is assumed to have an increased probability of fatigue crack initiation, i.e., the larger the critical volume, the higher the probability for crack initiation to start.

Furthermore, research has shown that fatigue life of a component usually relates with the size of highly stressed volume or surface at its stress concentration location [6], and there is a decreasing linear regression between the logarithm of the maximum tensile stress at the moment of failure and the logarithm of the HSV [5]. However, very little has been reported in literature on the application of the
HSV approach for analysis of fatigue life distribution. Therefore, in a review of data from [7], this paper found that, in specimens under different stress concentration factors, a proportional relation between the fatigue life and the size of the most highly stressed part with approximate stress state. Based on the HSV theory and the probability model of size effect [8], this study proposes a probabilistic model to account for the influence of size and notch effects on fatigue life. Moreover, the HSV approach only focuses on one of the highly stressed volume and surface, crack initiation actually occurs on the internal region and surface rim region of components. Therefore, a weight coefficient combining with probabilistic model is proposed to quantify the influence of the highly stressed volume and surface. Finally, based on the HSV theory, a proper transfer of fatigue life distribution from smooth specimens to largescale structures is established by probabilistic modelling of size and notch effect. By calibration and validation with experimental data of TC4 alloys [7], the experimental data for the notch specimens are almost within the estimated $P–S–N$ curve for 90% survival probability from smooth specimens, which indicates a good correlation between the predicted and experimental data.

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ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support of the National Natural Science Foundation of China (No. 11672070 and 11302044), Open Project Program of Key Laboratory of Aero-engine Thermal Environment and Structure (Nanjing University of Aeronautics and Astronautics), Ministry of Industry and Information Technology (No. CEPE2018007) and Fundamental Research Funds for the Central Universities (No. ZYGX2016J208) are acknowledged.
Probabilistic lifetime prediction of fatigue crack initiation of notched components using the generalized local model (GLM)

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Keywords: Fatigue, Fatigue crack initiation, Notched components, Probabilistic models.

ABSTRACT

The inherent scatter of experimental fatigue results, the specimen shape and scale effect, and the non-uniform distribution of the local stresses and strains due to the particular load acting on components are the main sources of uncertainty, which have to be indispensably taken into account, first, in the correct characterization of the material in the laboratory, and second, in its consideration for predicting the fatigue lifetime in the structural component design. The generalized local model (GLM), provide a possible solution to the reliable extrapolation of experimental data from conventional fatigue tests to predict lifetime of more complex components or even large engineering structures, such as bridges, ensuring transferability. The methodology also includes the fatigue data assessment with the software ProFatigue, based on the model of Castillo-Canteli, to define in a probabilistic way the S-N field. The methodology presumes an adequate choice of both reference parameter and failure criterion for crack initiation, the distribution of which in the component is determined by finite element calculation. This allows the global failure probability of the component to be determined.

The methodology proposed consists in the following steps: First, the reference or generalized parameter (GP) and the failure criterion are explicitly identified. Second, the testing type and the specimen geometry are defined, and the sample tested, according to the planned experimental program. Third, the primary failure cumulative distribution function (PFCDF) of the GP is derived from the experimental program for a given reference size. Fourth, the GP distribution present in the riveted joints under real loading is determined from FE calculations, and fifth, the global probability of failure is calculated for the non-uniform distribution of the generalized parameter (GP) all over the riveted joints taking into account the PFCDF.

The utility of this methodology is confirmed when applied to the probabilistic estimation of the initiation fatigue lifetime of structural riveted joints pertaining to structural members of the historical Fão Bridge in Portugal.
Statistical characterization of cleavage fracture toughness of ferritic steels at different temperatures

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Keywords: Statistical model, ferritic steels, cleavage fracture toughness, master curve behavior.

ABSTRACT

It is a conventional practice to adopt Weibull statistics with a modulus of 4 for characterizing the statistical distribution of cleavage fracture toughness of ferritic steels, albeit based on a rather weak physical justification. In this study, cleavage fracture toughness of ferritic steels is characterized according to a new local approach model. A master curve behavior correlating cumulative probability, fracture toughness and yield strength is proposed and validated by the Euro fracture toughness dataset for 1CT specimens at four different temperatures.

According to the new local approach model for brittle fracture, the cumulative failure probability is formulated as follows for a uniform spatial distribution of microcracks:

\[
P = 1 - \exp \left\{ \int_{V_{pi}} \ln [1 - p(V_0)] \frac{dV}{V_0} \right\}
\]

Here \( p(V_0) \) is the fracture probability of an elementary volume \( V_0 \) induced by an embedded microcrack under an arbitrary stress state. Based on a new local approach model, cleavage fracture toughness data of 1CT specimens at four different temperatures are synchronized onto a single master curve governed by the two compound parameters \( m \left[ \frac{\ln [1/(1-p)]}{\sigma_y} \right] / \sigma_y \) and \( B(K_{fc}/\sigma_y)^4 \). Finite element analysis reveals the non-linear relationship between \( V_{pi} \) and \( B(K_{fc}/\sigma_y)^4 \).
Fuzzy fatigue reliability analysis of structures with random input variables

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Keywords: Fatigue reliability; Fuzzy failure probability; Fuzzy state; Subset simulation.

ABSTRACT

As one of the most common mechanisms of mechanical structure fatigue failure, low cycle fatigue usually causes fatigue fracture of the structure. For low cycle fatigue, local strain is the most important parameter, so low cycle fatigue is also called strain fatigue[1]. Fatigue failure usually exhibits a stochastic behavior due to uncertainties in material performance parameters, load parameters, and structural geometries. Thus, fatigue reliability analysis is an important step to evaluate the safety level of structures.

In recent years, researchers have done a lot of work in the field of fatigue life prediction and fatigue reliability analysis. Yu et al. proposed a new energy-critical plane damage parameter for multiaxial fatigue life prediction of turbine blades[2]. Zhu et al. assessed the fatigue reliability of turbine discs under multisource uncertainties[3].

The structure life data can be expressed by Morrow correction equation based on Coffin-Manson equation

\[
\frac{\varepsilon}{2} = \frac{\sigma' - \sigma_m}{E} \left(2N_f\right)^b + \varepsilon' \left(2N_f\right)^c
\]

\[
\varepsilon = \varepsilon_{\text{max}} - \varepsilon_R = \frac{\sigma_{\text{max}} - \sigma_R}{E}, \sigma_m = \frac{\sigma_{\text{max}} + \sigma_R}{2}
\]

where \(\varepsilon\) is the total strain range; \(\sigma'\) is the fatigue strength coefficient; \(\sigma_{\text{max}}\) is the maximum stress; \(\sigma_R\) is the residual stress; \(\sigma_m\) is mean stress of stress cycle; \(E\) is the Young’s modulus; \(N_f\) is the number of cycles to failure; \(b\) is the fatigue strength exponent; \(\varepsilon'\) is the fatigue ductility coefficient; and \(c\) is the fatigue ductility exponent.

In low cycle fatigue, plastic deformation occurs locally in the structure, and residual stress exists in the plastic deformation region, so the stress needs to be corrected. The relationship between the residual stress \(\sigma_R\) and the maximum stress \(\sigma_{\text{max}}\) can be expressed by:

\[
2\sigma_{\text{max}}\sigma_R + E\sigma_{\text{max}}\left(\frac{\sigma_{\text{max}}}{K'}\right)^n = (\sigma_R)^2
\]

where \(K'\) and \(n'\) are the cyclic strength coefficient and cyclic strain hardening coefficient, respectively.

The parameters \(\varepsilon, \sigma_m, E, \sigma', \varepsilon', b\) and \(c\) can all be regarded as random variables for structural
fatigue reliability analysis, and the limit state function can be given as:

\[ g = 1 - \sum_{i=1}^{N_i} \frac{N_i}{N_i^f} (\Delta \varepsilon_i, \sigma_m, E, \sigma_f, \varepsilon_f, b, c) \]  

(4)

where, \( N_i \) is the number of loading cycles and \( N_i^f \) is the number of cycles to failure at the \( i \)th stress level.

However, with the increase of cycles, due to the existence of uncertainties, the boundary of the safe state and failed state is ambiguous. The following linear-type membership function can be used to calculate the fuzzy failure probability.

\[ \mu_f[g(x)] = \begin{cases} 
1 & g(x) \leq 0 \\
1 - \frac{g(x)}{a} & 0 < g(x) < a \\
0 & g(x) \geq a 
\end{cases} \]  

(5)

Then the fuzzy failure probability \( P_f \) can be expressed as,

\[ P_f = \int_{-\infty}^{\infty} \mu_f[g(x)] f(x, x_2, \ldots, x_n) dx \]  

(6)

With the inverse function \( u_i^{-1}(\lambda) \) of \( \mu_f[g(x)] \), Eq.(6) can be equivalently converted to:

\[ P_f = \int_0^1 P\{g(x) \leq u_i^{-1}(\lambda)\} d\lambda \]  

(7)

Uniformly divide the region \([0,1]\) into \( s \) discrete values, i.e., \( \lambda_j = 1 - \frac{j}{s} (j = 0, 1, \ldots, s) \), then, Eq.(7) can be derived as,

\[ P_f = \frac{1}{s} \left[ \frac{1}{2} P\{g(x) \leq u_i^{-1}(\lambda_0)\} + \sum_{j=1}^{s-1} P\{g(x) \leq u_i^{-1}(\lambda_j)\} + \frac{1}{2} P\{g(x) \leq u_i^{-1}(\lambda_s)\} \right] \]  

(8)

The above fuzzy fatigue failure probability \( P_f \) can be solved by the subset simulation method, the detailed procedure can be found in Feng et al.[4].

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A simulation-based fatigue-impact-aerodynamic multidisciplinary design optimization for vehicle wheel

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Keywords: time-varying load; fatigue performance; impact performance; aerodynamic performance; surrogate model.

ABSTRACT

The wheel is an important carrier in the operation of the vehicle. It is subjected to the time-varying load in actual work. In the lightweight design of the wheel, it is necessary to consider the influence of the change of wheel structure on the mechanical properties such as fatigue performance, impact performance and aerodynamic performance of the wheel. In this study, based on the finite element simulation analysis method, a multidisciplinary design optimization model considering the coupling of mechanism-material-performance is proposed for the wheel design. Different properties of wheel, including wheel quality, strength, stiffness, modal frequency, fatigue life, different angle impact and aerodynamic performance, are taken into consideration. Also, the related performance surrogate models are introduced to performance the multidisciplinary and multi-objective lightweight design of the wheel.
Probabilistic fatigue life evaluation for turbine disk with decomposed-coordinated surrogate modeling

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Keywords: probabilistic fatigue life; turbine disk; decomposed-coordinated strategy; neural network; surrogate model.

ABSTRACT

To improve the computational efficiency and precision of probabilistic fatigue life evaluation for turbine disk, a decomposed-coordinated neural network surrogate (DCNNS) model is developed. By integrating the proposed neural network surrogate and decomposed-coordinated strategy, the mathematical model of DCNNS is studied. The probabilistic fatigue life evaluation framework is introduced in respect of the DCNNS model. Moreover, the probabilistic fatigue life prediction for aircraft turbine disk is regarded as one case to evaluate the proposed method with respect to various uncertainties such as material property, load fluctuation and model variability. We obtain the distributional characteristics, reliability degree and sensitivity degree of fatigue failure cycle, which provides an effective guidance for the turbine disk life control. By comparing the direct Monte Carlo simulation, RSM, NNS, DCRSM and DCNNS, we observe that the DCNNS model holds high efficiency and accuracy for the probabilistic fatigue life evaluation of the turbine disk. The present effort offers a useful insight for predicting and evaluating structural fatigue failure from a probabilistic perspective.
Probabilistic Fatigue Reliability Assessment and Inspection Planning of Process Piping Using Dynamic Bayesian Networks

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Keywords: Reliability, Statistical methods, Crack growth, Finite element method, process piping.

ABSTRACT

As per the data collated by Health Safety and Executive, process piping is the most common source of hydrocarbon release on offshore oil and gas platforms in the North Sea. One of the dominant degradation mechanisms, deteriorating the structural integrity of process piping below the anticipated levels during its service life, is Vibration Induced Fatigue (VIF). The hydrocarbon release due to VIF jeopardizes the safety and cost millions of dollars each year in inspection, maintenance and replacement activities and lost production for oil and gas operators. Therefore, it is vital to develop methodology for framing inspection plans for topside piping subjected to VIF.

In this context, authors have tried to utilize fundamentals of the probability, reliability and statistical methods, using Dynamic Bayesian Networks (DBNs) for estimating the reliability of process piping. At first, the various sources of uncertainty such as physical variability, statistical uncertainty etc. in the crack growth process (Paris law, is used to model the crack growth) are identified and quantified with suitable distributions, and parameters obtained from literature. Then, a DBN is developed to perform probabilistic crack growth (PCG) analysis (by employing the BS7910 methodology) to obtain the distribution of the Remaining Fatigue Life (RFL).

The results of the DBN (in terms of Stress Intensity Factor) are validated against three different sources, namely experimental data (taken from the literature), finite element method (FEM) and Gaussian process regression.

Thereafter, statistical methods are used to obtain the reliability/PoF curves from the RFL distribution derived previously. The outcome of the obtained, reliability/PoF curves is a reliability index which is finally used to frame an inspection strategy for process piping. The advantage of using DBNs for inspection planning is that they offer ease in updating the results of the previous inspection (i.e. crack size obtained after inspection) into the PCG analysis and at the same time allow to see the effect of updating in the future inspection intervals.
A perspective on Fatigue Performance of Rail Profiles under Shuttle Loads

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Keywords: Rack structures; Z rail; Fatigue behaviour; S-N curves; Numerical models; Cold roll-forming.

ABSTRACT

Cold roll forming is a continuous process aiming a progressive bending of sheet steel using stations with rotating rolls, without changing material thickness [1]. Racking systems used today in logistic industries are normally made of thin-walled cold formed steel members. Cold roll forming processes introduce residual stresses in steel components and when combined with service loading stresses (e.g. due to the passage of shuttles in racking systems), these stresses may change the resulting stress range or average, affecting fatigue life of these components. FASTCOLD project purpose is to develop fatigue design rules for cold formed steel members. Design rules already exist for hot-rolled steel details in EN1993-1-9 [2]. However, for cold formed steel sections, they are missing on a European level (EN1993-1-9: Design of steel structures - Part 1-9: Fatigue does not present fatigue design rules or classification of cold-formed thin-walled details) [2]. Due to the lack of these fatigue design rules for cold rolled formed steel members, this paper aims at analysing the stresses induced by roll forming and propose a setup for testing representative rail profiles under fatigue loadings that could arise from shuttle moving loads.

Numerical simulations of cold-formed steel sections have been performed using COPRA FEA code. Relevant residual stresses have been computed and fatigue analysis performed for applied external loads. More importantly, an evaluation of residual stresses distribution across the thickness and along the surface of the strip width was performed [3]. The development and design of the simulation models (specification of machine parameters, rolls design, flower pattern, mesh definition, etc.) and the numerical simulation were performed using COPRA\textsuperscript{®} FEA RF finite element software. The roll forming numerical simulations were performed for a Z-section profile, in order to analyse the three-dimensional effects of this manufacturing process in this structure, as well as the residual stresses generated (see Fig. 1). Afterwards, a local stress-based approach was used to estimate fatigue life of these components when subjected to cyclic loading. The stress range calculated incorporated the stresses after the roll forming process and the stresses induced by external cyclic loading. A comparison of the maximum load that can be applied in order to achieve a fatigue endurance limit (according to [2], the limit is established for 5 million cycles) was performed (see Fig. 2). Numerical results showed that residual stresses across the thickness displayed some deviations between 2D theoretical solution (press-brake) and 3D roll-forming [3], due to the existence of three-dimensional effects that cannot be neglected (the bending occurs gradually, which can lead to defects such as edge waviness, bow and twist, depending on the design of the process and rolls). Fig. 1 reveals the smaller differences between the theoretical solution and the through the thickness residual stresses distribution of the Z-section profile. Fig. 2 shows the prediction of the S-N curves using local approaches to fatigue. Local stresses result from the superposition of residual stresses from cold-roll forming and the external loads, representative of shuttle loads. In addition to the numerical simulations, an experimental
setup has been developed and the first preliminary tests were performed within FASTCOLD project (see Fig. 3). Different load actuators and boundary conditions have been tested for a successful fatigue test.

![Fig. 1. Cold-roll forming of Z-Rail section simulation and analysis of thru thickness residual stresses.](image)

![Fig. 2. Z-rail fatigue simulation using local approaches to fatigue with superimposed residual and external load stresses.](image)

![Fig. 3. Experimental setup for fatigue testing of Z-rail profiles.](image)

**Acknowledgments**

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Uncertainty quantification in parameters of fatigue crack growth model for GH4169 superalloy based on Bayesian method

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Keywords: fatigue crack growth, uncertainty quantification, Bayes’ rule, Markov chain.

ABSTRACT

A recognized need for quantifying the uncertainty in experimental fatigue crack growth data, through the form of probabilistic distribution, has been soundly expressed. In order to satisfy the engineering demand, a Bayesian approach, where the Markov Chain Monte Carlo method is employed as a central algorithm, is introduced and demonstrated in the context of a nickel-based GH4169 superalloy. Rather than proposing a modified model, the scatter of data considered in this work is evaluated by establishing a stochastic distribution of model parameters. An initial motivation of this article is to determine the parameters without any knowledge about the material properties and the experimental conditions. Furthermore, the amount of available experimental data is far from abundant, thus emphasis is given to uncertainty quantification with relatively a small amount of data.

Model parameters are divided into two categories: parameters x that present the known conditions of the system and parameters θ that contain unknown settings. Appropriate choice of θ obtained by calibration is consistent with the physical data. In most cases, an error term is added to accounts for the discrepancy between the simulation model and the reality. However, it is negligible in this article because it is random, independent and identically distributed. In a realization of the proposed methodology, first a prior distribution is specified for the unknown parameters, using historical or expert information. Second, a simulation process is established that well represents the practical system. Then the posterior distribution for θ is characterized by Bayes’ rule, with the integration of possible observations. In realistic problems, the manipulator is difficult to be defined with deterministic formulations since it is often non-linear and high dimensional. A simple implementation of the Markov chain Monte Carlo method is employed in order to deal with the complicated system.

Experimental data involved in this work is derived from the fatigue crack growth tests of GH4169 superalloy, where compact tension specimens are employed. Possible potentials of the proposed model are then exhibited by a comparison with the probabilistic model based on the introduction of life distribution factor. The proposed methodology focus on the uncertainty evaluation on different stages of fatigue crack growth. Due to the category division of parameters, it turns out to be more capable in predicting as the amount of parameter increases.
Reliability analysis with imprecise probability distributions by using adaptive Kriging

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Keywords: Reliability; Adaptive Kriging; Optimization; Learning function.

ABSTRACT

In reliability analysis, the probability distributions of input variables always need to be known to describe the uncertainties. But due to the epistemic uncertainties, those distributions are difficult to be obtained precisely, which leads to the failure probability varying with distribution parameters.

To compute the failure probability efficiently, the adaptive Kriging model is popularized. It can update the Kriging model by adding new points with a learning function, which determine whether the points are selected to add or not are proposed by B. Echard [1]. The learning function $U(x)$ is given by:

$$
\hat{G}(x) - U(x)\sigma^2(x) = 0
$$

where $\hat{G}(x)$ is the estimate value and $\sigma^2(x)$ is the Kriging variance. $\mu_0(x)$ is usually taken as the estimated $\hat{G}(x)$ at point $x$ during calculation. So the function $U(x)$ is defined as:

$$
U(x) = \frac{\mu_0(x)}{\sigma^2(x)}
$$

The stopping condition of this learning method is $U_{min} \geq 2$.

However, for the failure probability with imprecise distribution parameters, Kriging model cannot be used directly because the input space varies with the distribution parameters. The performance functions corresponding to different distribution parameters have the same structure, but the failure boundaries are different. This also means that for imprecise probability distribution there are corresponding learning function $U$ at each distribution parameter which can be show as:

$$
U_i(x|\theta) = \frac{\mu_0(x|\theta)}{\sigma^2(x|\theta)} (i = 1, 2, 3, \ldots, N)
$$

To make the final surrogate model more accurate, the point that contributes most to the accuracy of the surrogate model need to be selected to update the Kriging model. For traditional failure probability solution, the Kriging model is updated each time according to the point with the minimum $U$ value. While in order to enable the established Kriging model to traverse the entire distribution parameter space, the point that contributes most to the accuracy of the surrogate model is from the minimum value of all $U_i$ which can be show as:

$$
x_{new} = \arg \min \{ \min_{i=1,2,3,\ldots,N} U_i \}
$$

Then, the new training sample points are selected through the following optimization process:
Find \( x \)

\[
\min \min U_i(\mathbf{x} | \theta) = \frac{\mu_i(\mathbf{x} | \theta)}{\sigma_i(\mathbf{x} | \theta)} (i = 1, 2, 3, \ldots, N) \tag{5}
\]

There is a cantilever beam with rectangular section. It is loaded uniformly. The limit state function is constructed as \( G(\omega, b, L) = L/325 - \omega bL^3 (8EI) \), where \( \omega, b, L, E, I \) are unit load, sectional dimension, length of the beam, elastic modulus, sectional moment of inertia respectively with \( E = 26GPa, I = b^4/12 \) and others are normal distributed random variables listed in Table 1. Assume that only the range of mean value of the variables can be obtain due to the epistemic uncertainty.

**Table 1.** The distributional parameters of random variables.

<table>
<thead>
<tr>
<th>Random variable</th>
<th>( \omega )</th>
<th>( L )</th>
<th>( b )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean value</td>
<td>( \theta_1 ) (N/m²)</td>
<td>( \theta_2 ) (m)</td>
<td>( \theta_3 ) (mm)</td>
</tr>
<tr>
<td>Distribution parameter range</td>
<td>[900, 1100]</td>
<td>[5, 7]</td>
<td>[220, 280]</td>
</tr>
<tr>
<td>Variation coefficient</td>
<td>0.1</td>
<td>0.15</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Then the failure probabilities when the distribution parameters have different values are calculated by MCS, Adaptive Kriging method respectively. The results are listed in Table 2.

**Table 2.** The estimated values of failure probability.

<table>
<thead>
<tr>
<th>Method</th>
<th>MCS</th>
<th>AK-S</th>
<th>AK-M</th>
<th>AK-N</th>
</tr>
</thead>
<tbody>
<tr>
<td>[900, 5, 220]</td>
<td>0.01896</td>
<td>0.01897</td>
<td>0.02194</td>
<td>0.01921</td>
</tr>
<tr>
<td>[920, 5.2, 226]</td>
<td>0.01932</td>
<td>0.01938</td>
<td>0.02096</td>
<td>0.01940</td>
</tr>
<tr>
<td>[940, 5.4, 232]</td>
<td>0.01968</td>
<td>0.01968</td>
<td>0.02060</td>
<td>0.01974</td>
</tr>
<tr>
<td>[960, 5.6, 238]</td>
<td>0.02023</td>
<td>0.02023</td>
<td>0.02062</td>
<td>0.02027</td>
</tr>
<tr>
<td>[980, 5.8, 244]</td>
<td>0.02077</td>
<td>0.02080</td>
<td>0.02101</td>
<td>0.02083</td>
</tr>
<tr>
<td>[1000, 6, 250]</td>
<td>0.02131</td>
<td>0.02130</td>
<td>0.02130</td>
<td>0.02132</td>
</tr>
<tr>
<td>[1020, 6.2, 256]</td>
<td>0.02193</td>
<td>0.02197</td>
<td>0.02177</td>
<td>0.02197</td>
</tr>
<tr>
<td>[1040, 6.4, 262]</td>
<td>0.02269</td>
<td>0.02272</td>
<td>0.02216</td>
<td>0.02273</td>
</tr>
<tr>
<td>[1060, 6.6, 268]</td>
<td>0.02351</td>
<td>0.02356</td>
<td>0.02242</td>
<td>0.02363</td>
</tr>
<tr>
<td>[1080, 6.8, 274]</td>
<td>0.02464</td>
<td>0.02471</td>
<td>0.02269</td>
<td>0.02466</td>
</tr>
<tr>
<td>[1100, 7, 280]</td>
<td>0.02559</td>
<td>0.02559</td>
<td>0.02271</td>
<td>0.02568</td>
</tr>
<tr>
<td>( N_{\text{call}} )</td>
<td>10⁵</td>
<td>390</td>
<td>15+20</td>
<td>15+41</td>
</tr>
</tbody>
</table>

As revealed in Table 2, the results of the MCS are regarded as the exact solution, the final Kriging model updated by AK-N is more accurate than AK-M. Comparing with AK-S, the number of calls to the performance function of AK-N is significantly reduced and there are little errors at the edge of the distribution parameter range which can be accepted.

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**ACKNOWLEDGMENTS**

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Application of Probabilistic Leak-Before-Break for WWER-1000 Unit

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Keywords: Leak-Before-Break; Probabilistic analysis; Henry-Fauske flow model; crack morphology; WWER-1000.

ABSTRACT

Leak-Before-Break (LBB) is a term that has been used for decades in reference to a methodology that means, that a leak will be discovered prior to a fracture occurring in service. For Ukrainian's WWERs only deterministic LBB concept was applied for Main Circulating Piping (MCP), Emergency Core Cooling System (ECCS) passive pipelines and Pressurizer piping. As we can see, only piping of the first circuit are selected, as they have large dimensions, and are of the main concern for the Reactor safety. A set of calculations were conducted for Normal Operating(NO) conditions, Safety Shutdown Earthquake (SSE) and several emergency situations like: shaft jamming of a reactor cooling pump and break of the piping’s connected to the considered ones (a set of LOCA events). Material properties were used as minimal guaranteed by the PNAE, and safety coefficient according to operation conditions were applied, also a safety coefficient of 2 for critical through wall crack together with safety coefficient of 10 for leak rate (LR) detection ($38 \text{ l/min}$ is a well-known LR criterion) were applied. To support these activities, a series of burst experiments for WWER piping (straight pipe, bend and nozzle) were conducted [1,2]. As a result, LBB concept was successfully applied for all Ukrainian's WWERs.

The main idea of current paper is to extend deterministic LBB analysis to probabilistic evaluation, and to investigate the correctness of Leak Rate safety coefficient value of “10”. To achieve these aims, we have used real material data for MCP steel, found in the piping documents on Zaporizhzhya NPP. Experimental data for fracture toughness is taken from [3], we used data only for piping specimens. Median curve was fitted using least square method, and the standard deviation for normal distribution is obtained. Critical temperature of brittleness (CTB) is calculated based on Charpy impact experimental data, and methodology taken from PNAE G-7-002-86 (1989. Based on static and dynamic calculations, the most loaded places were selected, where the cracks were postulated. Crack opening area was calculated according to originally developed procedure [4], which accounts for membrane and linear stress components thought the wall thickness. Typically, for LBB concept Henry-Fauske flow model[5] is used with modified parameters accounting for crack morphology [6]. A flow model is an important part of analysis, since different crack types have a great differences in friction ($\mu_L, \mu_G$), bend protrusion ($n_L$) and flow length ($K_G, K_{GL}$) parameters.

Monte-Carlo simulations were performed with number of samples $10^6$. First Ultimate, Yield Strength as well as Fracture toughness distributions were generated. For a Normal operation conditions FAD was established and critical crack lengths for axial and circumferential crack were iteratively calculated. Then, crack opening area (COA) as well as crack opening displacement (COD) were calculate, followed by leak rate estimations, according to modified Henry-Fauske model for different crack types (Corrosion fatigue, IGSCC, PWSCC). Some results of these calculations are presented in Fig. 1. As we can see from Fig. 1, accounting for crack morphology strongly affects the results scatter, and it is more significant then mechanical properties scatter. Comparing the mechanical properties influence we can see, that Fracture toughness has bigger influence. Considering Fig. 1 we can see, that transition from criterion $38 \text{ l/min}$ to $3.8 \text{ l/min}$ reduce the probability of failure of around an order of magnitude.
Fig. 1. Probabilistic analysis in $K_{IC}$-$\sigma_u$ space, IGSCC cracks, NO, with crack morphology stochastic parameters.

A probabilistic Leak-Before-Break analysis for WWER-1000 unit was performed based on the Failure Assessment Diagram (FAD), treating strength and crack morphology parameters as stochastic values. In order to perform probabilistic calculations, Critical temperature of brittleness and Yield (Ultimate) Stress were fitted by normal distribution, based on experimental data taken from the manufacture documentation found at the Ukrainian NPP. The statistical behavior of the leak rate and critical crack length for different defect orientation was examined treating crack morphology parameters as a normally distributed random variables. The failure probability was calculated using Monte-Carlo simulation, with and without the safety factor of 10. Calculations with safety factor proved to be very conservative, thus a reduction of conservatism is possible for LBB concept. Analysis of the resulting statistical data allowed to fit them with normal distribution for the critical crack length and Weibull distribution for the leak rate, parameters for these distributions for several types of crack were estimated. It was proven, then crack morphology parameters highly affects the leak rate, the leak rate distribution becomes more scattered. Among the mechanical characteristic, a Fracture toughness has more influence rather than Ultimate of Yield strength. For future work a Leak Rate model should be improved, as Henry-Fauske model has a drawback in two-phase physics, because the leak rate characteristics should be treated accurately for nuclear safety.

REFERENCES

**Probabilistic Leak-Before-Break analysis of a nuclear piping considering intergranular stress corrosion cracking**

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**Keywords:** Fracture mechanics, nuclear piping, Leak-Before-Break, intergranular stress corrosion cracking, welding residual stress.

**ABSTRACT**

Cracks due to intergranular stress corrosion cracking (IGSCC) have been observed recently in the nuclear piping in a boiling water reactor (BWR). These cracks may propagate due to the welding residual stress, thus posing a threat for the integrity of a nuclear power plant.

According to the United States Code of Federal Regulations 10CFR50 Appendix A General Design Criterion 4 (GDC-4), primary piping systems for nuclear power plants should exhibit an extremely low probability of rupture. In order to demonstrate the low probability, the probabilistic fracture mechanics (PFM) code PRO-LOCA, which has been developed in PATRIDGE I (Probabilistic Analysis as a Regulatory Tool for Risk-Informed Decision Guidance - Phase I) and is under development in PATRIDGE II in the framework of an international cooperative program, is used in this analysis.

This paper aims to perform a probabilistic Leak-Before-Break (LBB) analysis for a nuclear piping considering IGSCC. Nonlinear fracture mechanics method is used to model circumferential cracks in a piping for calculating critical crack size and crack opening displacement. A large number of deterministic simulations are performed to assess the failure probability. For each individual simulation, a leak-rate evaluation and a stability assessment are performed.

The leak and rupture probabilities of nuclear piping systems are predicted taking into account the whole sequence of crack initiation, crack growth until leakage and instability of the through-wall crack. A series of probabilities of surface crack initiation, through-wall crack development and different sizes of crack opening areas corresponding to different leak flow rates are calculated. Based on the sensitivity analyses, it is found that the piping temperature, the leakage detection limit, and mitigation are major factors in the resulting failure probabilities.
Reliability Modeling and Analysis for the FBGs based on Copula Function by Considering Multi-Performance Parameters Degeneration

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Keywords: Reliability, multi-performance parameter degradation, Copula functions.

ABSTRACT

Under secular alternating load, the multiple performance parameters of the FBGs, such as sensitivity, repeatability, consistency, linearity, etc. degrade simultaneously, and the degradation quantities are correlated. The current researches mainly focus on studying the reliability modeling methods for the FBGs from the perspective of single performance parameter degradation, and it may be unreasonable and one-sided. Thus this paper proposes a reliability modeling and analysis method for the FBGs by considering multi-performance parameter degradation. According to theory of multi-performance degradation failure, a reliability calculation model for multi-performance degradation is set up, where some stochastic processes, including Wiener, Gamma, and Inverse Gaussian, are adopted to fit the degradation data of performance parameters, and Copula functions are then utilized to model the dependent degradation failure. Finally, the reliability calculation model was verified by finite element simulation methods and experiments. This study can better reveal the FBGs’ performance degradation law, and can get a more accurate result compared with the traditional method which considers only single performance parameter degradation.
Probabilistic modeling and simulation of multiple surface crack propagation for Q&T rotor steel

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Keywords: fatigue, life prediction, crack propagation, crack coalescence, failure probability

ABSTRACT

In a LCF regime, fatigue failure of metals is usually dominated by multiple surface crack propagation and coalescence. However, fatigue has also been observed to initiate from subsurface sites. When this happens, it may result much longer fatigue lives for comparable stresses or strains [1]. Specifically, its final failure is characterized by linking several neighboring cracks to form a critical crack [2]. This process often shows a stochastic nature on crack propagation and coalescence. According to this, a probabilistic procedure for modeling multiple surface crack propagation and coalescence is established by incorporating Monte Carlo simulation with experimental measurements. Particularly, surface crack density and length distribution were measured from LCF replica tests of KSA30 steel. Through probabilistic modeling of crack growth, the procedure calculates the probability of coalescence of any neighboring cracks with allowance for their interaction and the local plastic deformation at the crack tips. Using this procedure, it estimates the remaining usage life of engineering components from the initial state to critical cracks by propagation and coalescence of dispersed defects.

Competing failure modes originated from microstructural defects that randomly switch crack nucleation between surface and subsurface regions with the failures being mutually exclusive. Whether a specimen/component would fail from surface-initiated or interior-initiated fatigue crack is often not predictable before the test. Why there is a change in crack initiation mode from surface to interior, is yet to be fully resolved. Based on previous studies and their shortcomings[3][4][5][6][7], we studied and proposed a method to combine the location and size of cracks to determine whether the crack belongs to a surface crack in this paper. The probability of the appearance of surface crack with different value of average crack length (m) and crack density (Λ) is given in Fig. 1.

For the fracture process of materials, one of the main features is the multistage character. In general, the life of an engineering component includes the process of crack initiation to the appearance of a critical crack. During this process, the propagation of a crack is not only the growth of itself but also the coalescence of neighboring cracks. The number of cracks from initiation to the critical length has shown uncertainty because of shapes and dimensions of the specimen, loadings, experimental factors and so on [8][9][10]. Based on the distribution of crack location and size, we proposed probability models of crack coalescence. The results are shown in Fig. 2. For the first case, the probability when a critical crack appears by coalescence is mainly determined by the sum of two crack lengths, which can be used as a reference for fatigue life prediction. The largest crack is an important factor in predicting fatigue life while crack coalescence is the main reason lead to final fracture. Results show that a probability model considering crack growth rate provides a reasonable prediction for fatigue failure analysis.
Fig. 1 Probability of the appearance of surface crack

Fig. 2 The probability when a critical crack appears by crack coalescence (a) and the probability of crack coalescence based on Tomkins’s model

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**Isodamage curve-based fatigue damage accumulation model considering the exhaustion of static toughness**

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**Keywords:** damage accumulation, isodamage curve, fatigue, life prediction

**ABSTRACT**

Engineering structures operated under harsh environments normally bear high temperature, high pressure and high-intensity loadings. Furthermore, owing to the different working conditions like starting-up, acceleration, braking, and closing down, the critical parts of structures need to bear a series of complex alternating cyclic loading, namely, variable amplitude loadings. Fatigue damage accumulation by cyclic stress usually cause the fracture failure of engineering structures. Consequently, the phenomenon of weakening fatigue strength and fatigue failure under cyclic loading should be highly valued. Various methods for damage accumulation modelling have been developed under different loading conditions, while it is insufficient for design and manufacturing technology due to the degradation of material physical properties. To ensure that engineering structural integrity, the ever-increasing requirement on theories for safety design and service life lead to the rapid development on methods for fatigue damage accumulation and life prediction [1-2].

Until now, various refinements and extensions on the theories of fatigue damage accumulation have been proposed [3-5]. However, an effective method for predicting fatigue life under variable amplitude loadings is still lacking and highly expected. Note that conventional damage accumulation model usually gives satisfactory predictions for tests under two-level loadings, but not for multi-level loading and random loading conditions.

Experimental results show that evolution curves of the component’s fatigue damage converge to one point due to degradation of material physical properties, which is deemed to be exhaustion of static toughness according to the Ye’s research [6]. In general, isodamage curve presents the evolution process of components’ fatigue damage in the form of hyperbolic curve, which characterizes fatigue damage accumulation better than the isodamage line in the low stress range. Nevertheless, existing isdamage curve theory couldn’t take into account the degradation of material physical properties. In this work, a new non-linear fatigue damage accumulation model based on the exhaustion of static toughness is proposed, which is derived by taking into account fatigue damage evolution under different load levels, and a computational process is established based on the assumption, which indicates that isodamage curves converge to one point due to exhaustion of static toughness. Experimental data of three metals [7-8] are utilized for model validation, and indicates that the proposed model has shown better accuracy than Batsoulas’ model [1] and Lin’s model [5] under two-level loadings. Apropos of the application of proposed model under multi-level loading and random loading, substantial further investigations are expected.
REFERENCES


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Decomposed-coordinated surrogate modelling strategy for the probabilistic analysis of aeroengine turbine blisk system

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Keywords: Probabilistic analysis; Quadratic polynomial model, Kriging model; Monte Carlo simulation, aeroengine turbine blisk system.

ABSTRACT

Performing probabilistic analyses on a complex structure is challenging with a high computational burden, owing to the many components and multiple disciplines involved, with high nonlinearity and many hyperparameters. Despite the advancements in surrogate models, they are still insufficient to accurately model compound functions with many sub-layers and sub-functions. In this study, we propose the decomposed coordinated surrogate model method (DCSMM) to improve the modeling accuracy and efficiency of compound functions. This improvement will enable performing expensive probabilistic analyses, which typically involve thousands of Monte Carlo simulation runs, efficiently. This type of analysis would be too computationally expensive to perform when using full-scaled models. The proposed DCSMM uses the decomposition and coordination strategy, and combines it with surrogate modeling methods. In this work, we will establish the mathematical model of the DCSMM with quadratic polynomial (QP) and Kriging model, and develop QP-DCSMM (the DCSMM based on QP), K-DCSMM (the DCSMM based on Kriging) and M-DCSMM (the DCSMM based on the mixture of QP and Kriging). The approximation accuracy and simulation performance (including computational precision and efficiency) of the DCSMM will be demonstrated with an analytical model and a turbine blisk multi-failure mode of an aeroengine as an engineering case study. The proposed DCSMM will be demonstrated to be effective in modeling the high-nonlinearity between output response and input variables, in addition to being robust. These benefits become even more prominent as we increase the number of Monte Carlo simulation runs. Overall, this study will show a high-efficiency and high-precision approximation method for complex compound functions and complex structures. This contribution will further enrich the theory and application of probabilistic statistical analysis as well. This paper also offers useful insights into engineering optimization and reliability design pertaining to multimodel mechanical systems.
Vibrations, fatigue and fracture problems in safety of engineering structures
B-IRAS2019-VFFSPSES

Organized by:
Grzegorz Lesiuk, Wroclaw University of Science and Technology, Poland
José A. F. O. Correia, Faculty of Engineering, University of Porto, Portugal
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Remaining useful life prediction for bivariate deteriorating systems with dynamic environments

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Keywords: Degradation, Bayesian dynamic model, Kalman filtering method, Copulas theory, microwave component.

ABSTRACT

Degradation modeling and remaining useful life (RUL) prediction for the equipment with various dependent deteriorating features and dynamic operational environments can be a challenging task. The key to addressing this problem is how to consider two kinds of dependencies simultaneously under dynamic operational condition, i.e. the dependence among multiple degradation processes and the dependence among the RUL distributions of different features.

A novel bivariate degradation modeling and RUL prediction method based on Bayesian dynamic model and time-varying copulas is proposed, which could take account into the dependence both in the degradation model and RUL distributions. Bayesian dynamic model is adopted to describe the degradation processes of multiple features, where covariance matrix is applied to describe the coupling effect in the evolution process. Then, a covariate item is added in the Bayesian dynamic model aiming at the influence of dynamic operational environments. Next, the Kalman filtering method is used for the model updating and recursive prediction. Combing with the corresponding failure thresholds, the failure distribution for each feature could be calculated. Finally, the time-varying Copulas theory is selected to characterize the statistical dependence among the failure distributions of multiple features and calculate the joint RUL distribution of the product.

An engineering case study on a microwave component is conducted to demonstrate the effectiveness of the proposed method. The results illustrate that the proposed method is quite effective in degradation modeling and RUL prediction of a product with s-dependent deteriorating features under dynamic environments.
Nonlinear probabilistic analysis for compressor blade flutter using least-squares support vector regression

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Keywords: compressor blade flutter; support vector regression; surrogate model; nonlinear probabilistic analysis; reliability.

ABSTRACT

Compressor blade flutter seriously affects the reliability and stability of aircraft engine. Nonlinear probabilistic analysis of compressor blade flutter can effectively quantify the risk and improve aeroelastic stability. To improve the computational efficiency of nonlinear probabilistic analysis, a least-squares support vector regression (LSSVR) was proposed. The mathematical model of LSSVR was established and the corresponding framework of nonlinear probabilistic analysis was introduced. The probabilistic analysis of NASA Rotor 37 was regarded as one case to evaluate the proposed LSSVR considering the nonlinear characteristics and coupling effects of stochastic variables. Compared with Monte Carlo simulation and response surface method (RSM), the LSSVR possesses the highest computational efficiency while keeping acceptable computational precision in the nonlinear probabilistic analysis of compressor blade flutter. The presented efforts are promising to provide an effective approach for precise control of compressor blade flutter from a probabilistic perspective.
Impact damage identification in high-pressure composite vessels using the modal analysis

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Keywords: impact damage, modal analysis, random loading, composite pressure vessels.

ABSTRACT

Due to their advantages, composite pressure vessels (CPV) are increasingly used in industrial applications. The need of gases storage under high pressure and the reduction in weight of pressure equipment and/or vehicles makes the composite pressure vessels attractive in various applications, even though CPV cost is several times higher than its metal equivalent. Both for reasons of unit cost and safety, it is desirable to be able to assess the condition and suitability of the tank for further operation in the event of occurrence, or suspicion of occurrence, of damage. Typical causes of damage may be a fall of the tank or a collision with various objects, resulting in an impact load.

In this study, the tested tanks were subjected to an impact load of different energy, simulating a random loading. The tanks were tested using a relatively inexpensive and non-invasive modal analysis method. On the tanks, at selected points (Fig. 1), measurements were made on which the forms of modal vibrations of the tested tanks for selected lines (I - VII) were determined. In the case of tanks after mechanical impact, possible disturbances in the form of vibrations determined for selected frequencies were analyzed. The relationship between these disorders and the energy of the stroke was then sought through analysis.

On the basis of the results of the tests it was tried to show whether the applied method allows to detect the place of damage to the tank. In addition, it was examined whether it was possible to distinguish, on the basis of the methodology used, between impact loads with different energy values.

Fig. 1. Arrangement of measuring points on tanks after impact loading.
Assessment of the risk of fatigue damage in biaxial stress state

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Keywords: fatigue life, biaxial loading, notch.

ABSTRACT

The paper contains the biaxial fatigue test results of specimens with round cross-sections, made of 10HNAP steel. Shape and dimensions of the test specimens are presented in Fig. 1. The tests under cyclic bending with torsion [1] were carried out for the following ratios of normal to shear stresses amplitudes $\sigma_a/\tau_a = 0.5, 1$ and $2$ considering a loading frequency was 26.5 Hz. Nominal stresses were chosen for the equivalent stress amplitude according to the Huber-Mises hypothesis equal to 360 MPa.

Cantilever specimens were subjected to bending and torsion loading for different nominal normal stresses, $\sigma_a = 99, 180$ and 272 MPa, as well as nominal shear stresses, $\tau_a = 136, 180$ and 199 MPa, to the crack initiation. The tests were performed in the high-cycle fatigue regime for the stress ratio, $R$, equal to -1, and phase shift between bending and torsion equal to $\phi = 0^\circ$ and $90^\circ$. Lifetimes calculated according to several selected criteria were compared with the experimental results.

REFERENCES

Fracture analysis of rigid PUR elastomers commonly used in suspension system

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Keywords: Fracture, Fatigue, PUR material, Energy approach, Suspension system.

ABSTRACT

Polyurethane (PUR) material is a commonly used material, as a rubber replacement, in suspension system of vehicles (Fig. 1). The knowledge about static and cyclic behavior of this materials with consideration of the manufacturing discontinuities or fatigue cracks is limited. In the paper, the experimental results of the fatigue and fracture tests have been presented. The main attention was paid to fracture and tearing resistance of polyurethane elastomers in terms of two different hardness configurations: 80 ShA and 90 ShA. The impact of material hardness on the fracture resistance is reflected in experimental results. It has been shown, that the 80 ShA and 90 ShA materials demonstrate completely different behavior under high stress concentration condition - see the results for the cracked DENT (Double Edge Notch Tension) specimens. From the perspective of usefulness of fracture mechanics, the energy approach seems to be crucial in the context of the real operating conditions of the bushing in suspension system of vehicles subjected to cyclic loading. For this purpose the fatigue, fatigue crack growth rate test was performed in order to predict fatigue lifetime of PUR components.

Fig. 1. Typical PUR components in vehicle suspension system (on the left), damaged PUR bushing after uniaxial fatigue tests (on the right).
ACKNOWLEDGEMENTS

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An equivalent stress transformation method for efficient fatigue life estimation under variable amplitude loading

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Keywords: variable amplitude loading; fatigue crack propagation; closure model; loading sequence effects; equivalent stress; aluminium alloy

ABSTRACT

In this paper, an equivalent stress transformation approach considering the nonlinear interaction effects is proposed to calculate the fatigue crack growth efficiently under variable amplitude loading. Since the computational cost of the traditional cycle-by-cycle method for the fatigue life prediction is relatively expensive, it is necessary to develop the substituted approach to increase the computing efficiency. In this investigation, the crack closure concept is employed to account for the loading dependence effects. A plastic-state-based crack closure model is reviewed herein to describe the loading sequence effects in the fatigue crack growth process. Then a stress transformation equation is derived to turn the effective stress ranges into an equivalent constant amplitude loading, which can not only largely improve the computational efficiency but also consider the interaction effects appropriately. Furthermore, a simulation study is performed to investigate the efficiency of the proposed transformation approach. The overall loading sequence and any part of the population are assumed to have the same statistical properties, and different loading samples are intercepted from the original sequence to calculate the equivalent constant amplitude loading. It is noted that the computational cost is decreased significantly with the error less than 3%. In addition, large amounts of experimental data under the variable amplitude loading are also employed to validate this method, and the satisfactory results are observed. Meanwhile, the fatigue reliability prediction model is used to validate the availability of the equivalent stress transformation method. It is concluded that this method can applied for structure safety evaluation.

It is validated by simulations under tension-tension random load sequence. In addition, the testing data of 7075-T6 aluminum alloy and 2024-T6 aluminum alloy are also used to demonstrate the method’s accuracy. The results show that the proposed method greatly enhances the fatigue life estimation efficiency and takes the loading sequence effects into account at the same time. Several conclusions can be drawn as follows.

—The plastic-based crack closure model is employed to deal with the loading effects. With this model, the raw loading spectrum can be turned into the effective loading spectrum. Then the equivalent transformation method is utilized to derive a constant amplitude loading from the effective loads sequence. Different from other approaches in which the load-dependent empirical coefficients are used to account for the loading interaction effect, our proposed method is derived based on the physical mechanism. Thus the modified equivalent stress transformation method is demonstrated that it is not only time-saving but also can depict the interaction effects well.

—In this paper, the modified equivalent stress transformation method has been validated by simulations and testing data. In the simulation, the loading sequence is generated from the two-dimensional normal distribution, and different loading samples are intercepted from the original sequence to calculate the equivalent constant amplitude loading. The computational cost decreases significantly and
the relative error is less than 2%. Additionally, the testing data of specific materials under repeated block loading is used to validate the method’s accuracy. Compared with the Xiang’s model, the modified equivalent stress transformation method has better agreements with the experimental data without tuning any loading dependent coefficients. It is illustrated that the proposed approach has a great applicability for life prediction under practical fatigue loading spectra.

In brief, the current study only has been validated in Al2024-T3 and Al7075-T6 under different types of block loading conditions. Further investigations are still need to extend to complex non-stationary loading spectra and other material systems.

ACKNOWLEDGMENTS

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Mechanical properties of porous ceramics with various porosities and pore sizes

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Keywords: fatigue reliability; orthotropic bridge deck; weigh-in-motion.

ABSTRACT

In this study the compressive strength of porous ceramic samples is investigated numerically by the method of movable cellular automata. As a result of modelling, we identified the influence of porosity on the derived mechanical characteristics.

The movable cellular automaton method (MCA) [1,2] is based on the concept of discrete particles. A material consist of a certain number of finite-size elementary objects (automata) interacting with one another and capable of moving in space, thus modelling real deformation processes. The motion of a particle is described by the Newton–Euler equations.

A porous structure of ceramic samples was generated by randomly removing automata from a dense packed system of cells arranged according to the crystallographic hexagonal system.

The structural properties of porous structure were determined using the Monte Carlo methods. These properties include pore size distribution, pore volume in [ml/g] and area in [m2/g].

Numerical investigations of the influence of the porosity and pore size on the mechanical response of samples were performed. Exemplary results of compressive strength for samples with Young’s modulus 330 [GPa], density 3.01 [g/cm3] and Poisson’s ratio equal 0.1 are given in Table 1.

<table>
<thead>
<tr>
<th>Percentage of Porosity</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength [GPa]</td>
<td>441.643</td>
<td>268.047</td>
<td>142.611</td>
<td>69.9895</td>
<td>20.4432</td>
<td>3.06638</td>
</tr>
</tbody>
</table>
References


**Sensitivity of reliability-based fatigue analysis to crack shape development in cracked pipeline**

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**Keywords:** Fracture; Pipeline; X80 Steel; Shape Factor; Importance Sampling.

**ABSTRACT**

An accurate prediction of crack shape development during fatigue propagation plays a key role in structural reliability assessment. To predict crack shape, aspect ratio variability (a/c; a: crack depth, c: half crack length) is widely used and different correlations to estimate this later exist in literature. In this paper, reliability index of a pipeline with axially surface crack is evaluated. Initial aspect ratio was varied. Tow dimensional crack growth models based on Paris Law coupled to liner elastic fracture mechanics were used. The objective is to clarify the effect of initial aspect ratio and it variability during propagation on the life time prediction of cracked pipeline. Based on Importance sampling, reliability index is plotted against number of load cycle. Results show an important role of initial aspect ratio and crack growth model in reliability index estimation. Calculation of different sensitivity factors illustrates the effect of uncertainty and correlation of Paris law parameters on the predicted life time of the pipeline.
Life reliability based multidisciplinary design optimization of centrifugal impeller

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Keywords: reliability, design optimization, aerodynamic, heat transfer, centrifugal impeller.

ABSTRACT

A life reliability based multidisciplinary design optimization method considering aerodynamic, heat transfer, strength and its uncertainties is developed in this work. The parametric model of the centrifugal impeller is created by the non-uniform rational B-spline; the multidisciplinary analysis of the centrifugal impeller is implemented by analyzing the aerodynamic, heat transfer, strength in turn with coupling information transferring; the main design parameters that influence the centrifugal impeller aerodynamic efficiency and life are analyzed by design of experiment. A total of seven parameters are chosen as design variables, the optimization of the centrifugal impeller taking life reliability as constraints and isentropic efficiency, total pressure ratio as objectives is carried out on basis of a surrogate model. After optimization, the entropy efficiency and total pressure ratio of the centrifugal impeller are increased by 3.4% and 6.2%, respectively, and the maximum Mises stress is reduced by 10.3%, while satisfying the life reliability constraint. The improvement of centrifugal impeller performance proves the effectiveness of the developed method.
Simulation analysis of traveling-wave vibration of a compressor spool

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Keywords: spool; traveling-wave; vibration; finite element method.

ABSTRACT

Based on Block Lanczos method, the traveling wave resonance characteristics of a compressor stage 14-16 spool are studied. Firstly, the three-dimensional solid model of the 14-16 spool is established by UG software; then, the model is imported into ANSA software for pre-processing and meshing; finally, the meshed file is imported into ANSYS software to calculate the static and dynamic frequencies, and the vibration frequencies of the main array in the spool concerned are screened by normalization method. According to the traveling wave resonance theory of the spool, the vibration characteristics of the compressor disk are analyzed, which provides an important reference for the vibration safety inspection and structural optimization design of the compressor disk.
A Research on Dynamic Characteristics of a Geared Rotor System with Rotor Crack on the Shaft

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Keywords: geared rotor system, dynamic model, rotor crack, breathing behavior, operation safety.

ABSTRACT

Rotor crack is a common fault for Geared Rotor System (GRS), which usually have a significant effect on the overall safety and reliability of mechanical system. Due to the effect of gear meshing, Rotor crack fault occurs in GRS may shows more complicated vibration features compared with other rotating machinery. Thus, a GRS dynamic model is presented to analyze the effect of breathing crack on dynamic characteristics. Firstly, a nonlinear gear dynamic model considering time-varying mesh stiffness, gear transmission error, gyroscopic effect and other factors is established. Based on energy release rate theory and stress intensity factor theory, the stiffness matrix of a Timoshenko beam element is derived to account for the breathing behavior of rotor crack. Finally, the vibration response characteristics of GRS with rotor crack fault was simulated by Newmark-β numerical integral method. The differences between GRS and single shaft rotor system was researched. The results show that the most significant effect of crack on GRS is the amplitude modulation. Moreover, the amplitude of rotational frequency and second harmonic increased significantly; An obvious sideband will appear near meshing frequency. The results can serve as the theoretical fundamentals for rotor crack detection and guarantee the operation safety of GRS.
Three-dimensional Dynamic Simulation of Stress Intensity for Perforating Gun Burr and Bulge Gun Based on LS-DYNA

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Keywords: Stress intensity; ALE method; dynamic simulation; Perforating gun burr.

ABSTRACT

Perforation is a complex dynamic process. On the perforation site, the sticking accident usually occurs due to the bulging and excessive burr eversion of the perforating gun. In order to make clear the dynamic stress distribution law of the perforating gun and accurately analyze the bulging degree and the burr eversion height, the perforating charge-perforating gun (containing the scallop)-casing 3D finite element model was established with the assembly of 7”×12.65mm TP140 casing and 5”×11.00mm 32CrMo4 perforating gun as an example by using LS-DYNA software. Results showed that the perforation gun produced 4.3mm high eversive burr, and the inner wall of the casing produced 0.9mm high eversive burr. The accumulative burr height in the casing was 5.2mm. If the gap was close to or less than 5.2mm, it was easy to have the sticking accident. The average perforation diameter of the perforating gun was 18.7mm, and the average perforation diameter of the casing was 7.7mm. There was a difference of 11mm between them, which indicated that a lot of energy was consumed for penetrating through the scallop of the perforating gun, and attention should be paid to the wall thickness of the scallop in design. In the 125 mm wide belt with perforations connecting with each other in the perforating gun, the minimum stress reached 774MPa. The stresses on the whole belt all exceeded its yield strength. Under the effect of high detonation pressure, it would bulge outward, which was the so-called bulging. Considering the effect of burr and bulging of the perforating gun and the superposition of detonation waves between charges could provide a useful reference for the optimal design of the safety of perforating gun. It could also provide ideas for subsequent mechanical analysis of casing under the perforation impact.
Open Issues in PTS Assessment of WWER RPVs

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Keywords: Pressurized Thermal Shock (PTS); Fracture Toughness (FT); Linear Elastic Fracture Mechanics (LEFM); Elastic-Plastic Fracture Mechanics (EPFM).

ABSTRACT

As a rule, assessment of integrity of RPV is based on calculations of their resistance against fast (brittle fracture). Ukraine is the only WWER country which has practice of RPV brittle fracture assessment under PTS with using three different modern approaches (normatives, methodologies, codes): national Ukrainian (MT-D.0.03.391-09[1]), Czech (VERLIFE[2]) and Russian (MRKR-SKhR-2004[3]). Besides at WWER design stage the USSR’s rules PNAE-G-7-002-86[4] was used for RPV lifetime justification in terms of resistance against brittle fracture.

The crack initiation criterion, all along the crack front of the ferritic material is based on the following expression:

\[ K_I \leq K_{IC} \]  

Here: \( K_I \) is the stress intensity factor (SIF) of postulated or existing defect in RPV wall; \( K_{IC} \) is the Fracture Toughness(FT) of RPV metal.

Analysing modern codes based on our practical experience of RPV lifetime extension the several issues were observed. Thus, current paper devoted to description of them and possible ways of their solutions.

According to criterion (1) the problems are divided onto two groups related to:

• Computational fracture mechanics;
• Determination of fracture characteristics of metal of RPV beltline zone.

In integrity assessment of RPV WWER units both linear elastic fracture mechanics (LEFM) and elastic-plastic fracture mechanics (EPFM) are used. EPFM analysis is considered to be a refined analysis, but its mindless use can significantly reduce the RPV resource. The problem is in J-integral calculations, generally a modify version should be used, which accounts for residual stresses, non-monotonic loading and incremental theory of plasticity. Compared to other designs, for example French PWR, plasticity correction factor for LEFM is not allowed, but this approach can reduce uncertainties inherent EPFM. Another issue is crack insertion in the residual stress field, instantaneous and progressive nodes release technics can be used, the first one is more conservative, and plastic wake is avoided. Residual crack stress field distribution is also a problem, a conservative way to include weld residual stresses is to apply an additional pressure corresponding to the residual stress amplitude. Two types of cracks are assessed surface crack (more dangerous for LEFM) and sub-cladding crack (more dangerous for EPFM), in second case often a cladding integrity assessment is required. Thus, we need to calculate fracture mechanics parameters on the bi-metal interface, but convergence can’t be achieved there, so we must extend our crack inside the cladding.

Characterization of RPV beltline zone metal related to the following:

• Fracture Toughness curve;
• Parameter of cladding integrity.
• Critical temperature of brittleness (CTB – analogue of PWRs DTBTT); Fracture toughness curves of the WWER-1000 RPV steel and its welds are specified by the four different documents, that used in Ukraine to RPV brittle strength assessment: PNAE-G-7-002-86[4] (USSRs), MT-D.0.03.391-09[1], VERLIFE[2] and MRKR-SKhR-2004[3]. So, the strange situation we
have – for the one and the same material we have for different curves, that were used for RPV brittle fracture assessment. Nevertheless, that MT-D.0.03.391-09 [1] and MRKR-SKhR-2004 [3] FT curves are probabilistic ones – they are used for deterministic brittle fracture assessment. In addition, it is important to mention about so called upper shelf of FT curves specified by MT-D.0.03.391-09 [1], VERLIFE [2] and MRKR-SKhR-2004 [3] at 200 MPa√m level, but at the same time – it is well known that within LEFM there is no such limitations, moreover there a lot data in the literature for RPV metal FT values exceed this shelf. Due to this issue in some case the unfulfillment of brittle fracture criteria was received and Utility was forced to implement the mitigation actions for the corresponding PTS scenario, unnecessary actions.

In Ukraine cladding integrity assessment is performed according to the VERLIFE’s criterion only, with 150 kJ/m2 cladding toughness. It should be noted, that austenitic cladding: is much more plastic in comparison with ferritic RPV steel; characterized ductile type of failure, especially at elevated temperatures; has significantly bigger FT than ferritic steels. As a result, cladding integrity criterion not met for nozzle region of all prolonged Ukrainian WWER-1000 RPVs and as a corrective actions NPP’s were oblique to implement the ultrasonic inspection of cladding – again, unnecessary action.

The paper presents critical analysis of the currently existing methods of PTS calculations (namely EPFM aspects), CTB prediction and examples of methodological misconceptions with impact demonstration on RPV lifetime. Practical recommendations for further development of normative documents that specifies CTB are formulated (which include the chemical factor).

According to the RPV brittle fracture criterion the open issues are divided onto two groups related to computational aspects of Fracture Mechanics, and Fracture Toughness definitions.

As for the computational part:

• Estimations within EPFM have shown that the J-integral inherent absence of convergence in case of reloading and at the Bi-metallic interface.

• Modelling of WRS needs to be justificated within EPFM, before they are considered as the part of good-practice methodology of RPV integrity assessment.

• Currently best-practice is postulating of WRS as additional force/pressure. Based on the current “state of the art” RPV cladding integrity assessment is not related to the good practice.

As for the Fracture Toughness part:

• The PNAE G-7-002-86 FT curves for WWER-1000 RPVs are lower envelope of corresponding data. Modern WWER codes have more conservative FT curves which is unreasonable from the practical point of view.

• Artificially created upper shelf of FT curve must be excluded at all as it contradicts to the FT nature.

• Currently, MC approach is inapplicable for the WWER-1000 RPV integrity assessment.

• CTB shift ideology must be improved (in terms of initial CTB and data scatter accounting) or replaced on the usage of actual CBT data and its scatter (obtained directly from Charpy V-notched impact tests).

• Chemical factor must be included in the radiation embrittlement assessment as for deterministic RPV brittle strength assessment as well as for probabilistic ones.

• VERLIFE’s radiation embrittlement chemical factor for probabilistic RPV brittle fracture assessment contradicts with the results of welds SS of WWER-1000 RPV and cannot be used in the practice.

REFERENCES

Analysis of selected dynamic properties of the composite hydraulic microhose

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Keywords: simulation, experiment, vibrations, PDE

ABSTRACT

The composite hydraulic microhose was analysed. In particular, the attention was driven on forced flexural vibrations of the object and on the deformation of the element in the axial direction depending on the method of its loading [1]. The research object was Polyflex 2020N-013V30 hydraulic microhose made by Parker Hannifin, consisting of an aramid braid embedded in an thermoplastic matrix. External excitation was carried out using an electrodynamic vibration exciter placed in the 3/8 length of the hose. Visualization tests were carried out with the aid of a fast camera to identify the frequency and form of the element’s own vibrations.

Experimental tests were also carried out in which the tested microhose was loaded stepwise in conditions similar to the hydraulic impact. In the first series of tests, the object was loaded with a flow (with mean values of 0.6, 1, 1.4 l/min) and pressure (with mean values of 60; 100; 150 bar), and in the second series the object was loaded with pressure alone.

![Graph](graph.png)
By using a micrometric indicator, axial deformations of the loaded microhose were observed. At the same time, changes in the deformation were recorded with a camera. This allowed to obtain a graph of changes in the length as a function of time for different loading methods [2]. It has been shown that increasing the flow through the element leads to its extension, whereas increasing the medium pressure causes shortening of the hose (Fig. 1).

It was observed that the maximum elongation of the microhose occurs after the load has ceased, and its value depends on the flow rate in the system [3]. However, the pressure affects the change in the length of the hose observed during the load. The higher the pressure, the smaller the elongation. In extreme cases of high pressure and low flow rate, a shortening of the object was noted [4]. Elongations (caused by flow rate) take place more slowly than shortenings (caused by pressure).

REFERENCES

The experiment and modeling for sealing strength degradation evaluation of lithium-ion pouch cell

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Keywords: pouch cell; strength degradation; CZM; ADT.

ABSTRACT

The battery pack is the key part of the power components in an electric vehicle. In a variety of power batteries, compared with traditional shell batteries, the pouch cell which is packaged by aluminum-plastic compounding film, is becoming a mainstream because of its higher energy density and lower weight and flexible shape design. When it comes to the probability of gas production in a pouch cell, the increasing internal gas pressure will cause strength degradation of the sealing area. This process significantly decides the safety and remaining useful life (USL) of a pouch cell. This paper is devoted to evaluate the strength degradation of sealing adhesive area through experiments and modeling. The model is developed based on cohesive zone model (CZM) and accelerated degradation test (ADT).

To investigate the process of separation in adhesive area while the internal gas pressure increasing, experiments were carried out on in-situ tensile test system in T-type peeling, using strip specimens cut out from sealing side, shown in Fig. 1 (a) and (b). In the experiments, the load-displacement relationship was obtained by controlling the adhesive area separating in quasi-static process. The exponential CZM was used to describe the mathematical relation, expressed as Eq. (1). And the test average curve and model curve of load-displacement relationship are shown as Fig. 1 (c). The point \((\lambda, \tau_{\text{max}})\) at which the load reaches its maximum value represents critical failure point. The area integral of model curve indicates fracture energy \(G_c\).

\[
\tau = \frac{G_c}{\lambda} \lambda \exp\left(-\frac{\lambda}{\lambda_c}\right) = \frac{254.26}{2.08} \lambda \exp\left(-\frac{\lambda}{2.08}\right) f(\lambda)
\]

(1)

Fig. 1. (a) The illustration of specimen; (b) In-situ tensile test system; (c) Comparison of model curve and test result.

Considering constant loading effect and adding a duration of ADT in the above experiments, new curves were obtained to deduce a modified model. Test results are shown in Fig. 2 (a), and Eq. (2) gives the relationship of degradation rate with constant load level and its duration. Eq. (3) gives the modified...
The sealing strength degradation is evaluated by the reduction of maximum cohesive strength. This modified model is validated well by the test data under different load level and duration, as an example shown in Fig. 2 (b).

\[ V = C \tau_0 = 0.4127 \tau_0 \]  

\[ r(t, \tau_0, \lambda) = \begin{cases} G \frac{\lambda}{\lambda_0} e^{\frac{t}{\lambda_0}}, & 0 \leq \lambda \leq f^{-1}(\tau_0) \\ \tau_0, & f^{-1}(\tau_0) < \lambda \leq f^{-1}(\tau_0) + C \tau_f \\ \frac{G}{\lambda_0} \left( \frac{\lambda - C \tau_f}{\lambda_0} e^{\frac{t}{\lambda_0}} \right), & \lambda > f^{-1}(\tau_0) + C \tau_f \end{cases} \]  

\[ (3) \]

**Fig. 2.** (a) Load-displacement curves with ADT process; (b) Comparison of modified CZM curve and test result.

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Damage mechanisms and crack propagation analysis in very high cycle fatigue of polycrystalline nickel-based superalloy

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Keywords: Very high cycle fatigue; Fracture mechanism; Finite element method; Stress intensity factor.

ABSTRACT

Damage mechanisms and crack propagation analysis in very high cycle fatigue of Ni-based GH4169 superalloys are investigated from room temperature to 400°C. All fatigue cracks are initiated from the edge of the surface of the plate specimens. At room temperature, loading frequency has no significant effect on fatigue life of GH4169 superalloy, the cracks are dominated by the mode I crack which caused by the stress concentration at the surface slip of the plate specimens. With the increase of fatigue life, the influence of temperature on the crack initiation process of GH4169 superalloy is weakened. The small crack propagation is dominated by the mixed mode crack at 400°C, and the finite element method (FEM) is used to quantitatively analyze the different crack propagation modes based on actual fatigue fracture characteristics after experiment. Furthermore, the mode I, II and III stress intensity factors (SIFs) of mixed mode cracks are calculated separately, the trend of stress intensity factor (SIF) during the mixed mode crack propagation is also investigated by the FEM. The mixity of SIFs of three modes is complex at early stage of growth, the mixed mode crack deflects during propagation and becomes perpendicular to the loading direction regardless of the initial orientation of the crack.
Structural Integrity of Renewable Energy and Oceanic Structures
C-IRAS2019-REOS

Organized by:

Dimitrios Pavlou, University of Stavanger, Norway
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Fatigue strength of corroded steel joints in marine environments


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Keywords: corrosion fatigue; steel joints, girth welds; S-N curve

ABSTRACT

Corrosion is one of the main structural degradation processes that affect integrity. Fractures due to cyclic stress in corrosive media are designated as corrosion fatigue (CF) which is a type of environmental assisted cracking. Recent failures of key structures such as Silver Bridge in 1967, Mianus River Bridge in 1990, Minnesota Bridge in 2007, etc., emphasize the importance of more accurate simulation of CF strength of structural joints (i.e. constructional details) in different corrosive environments. Recent fatigue failure of wind turbine in Taikoyama wind farm also highlights the significance of accurate prediction of fatigue strength [1]. The long-term integrity of the support structure of offshore wind-turbines is generally governed by fatigue limit state. The fatigue strength of girth welds located closer to splash zone area of the support structure is generally questionable. The pitting corrosion are commonly available for these welds as the coating in splash zone area disappears few years after the installation [2]. Though the CF strengths have been investigated in both the scale of material and structural components/joints, generalized formula has not been proposed/developed. Therefore, the main objective of this paper is to derive a formula to determine the fatigue strength of corroded structural joints.

Fatigue Strength Curve for Corroded Material

In the presence of corrosion, disorganized atoms are in motion along a gliding plane with less activation energy than in the absence of corrosion. This phenomenon may reasonably be expected, even below the fatigue limit. This means that there is no safe stress level at which the fatigue life is infinite [3]. Previous experimental fatigue lives show that the difference between fatigue strengths in corrosive and non-corrosive environments in the low-cycle fatigue (LCF) region is very low, compared to the high-cycle fatigue (HCF) and very-high-cycle fatigue (VHCF) regions [4,5]. The difference is significantly large in the HCF and VHCF regions. Hence the S-N curve formulae for corroded metals has been proposed in author’s previous paper [6] and summarized below.

\[
\log(\sigma_{a,cor}) = (b - c) \log(N_f) + \log(\sigma_f) + c \log(N_{f,LCF}) \text{ where } c = \frac{\log(\sigma_\infty)}{\log(N_{f,FL}/N_{f,LCF})} \tag{1}
\]

where \(\sigma_{a,cor}\) is fatigue strength of corroded material, which corresponds to the number of cycles to fatigue failure, \(N_f\). The \(\sigma_f\) is the fatigue strength coefficient and \(b\) is Basquin’s exponent. The \(\sigma_\infty\) is endurance limit (i.e. fatigue limit for high-cycle fatigue) and \(\sigma_{a,cor}\) is endurance limit for corroded material, which corresponds to a specified number of cycles, \(N_{f,FL}\). The \(N_{f,LCF}\) is the number of cycles to fatigue failure of uncorroded materials when stress amplitude is yield strength \(\sigma_y\). The proposed fatigue strength formulae for corroded materials were verified by comparing the experimental fatigue lives of corroded specimens of different materials.
Proposed Fatigue Strength Curve for Corroded Constructional Details

The above corroded material fatigue strength curve was further improved to develop a S-N curve for corroded detail categories. Only the full-scale girders with rivets and girth welds details are considered in this paper. The non-linear corrosion wastage model is considered, and loss of corrosion wastage becomes constant after certain age of the structure. Then the rate of corrosion becomes ideally zero. The corrosion fatigue endurance $\sigma_{\infty, cor}$ should be determined corresponding to this age by limited number of tests in the VHCF region. The case of unable to perform VHCF tests, ratio $\sigma_{\infty, cor}/\sigma_\infty$ can be conservatively taken as 0.6 [7]. The developed S-N curve is verified by comparing several full-scale fatigue tests of corroded riveted plate girders as shown in Fig. 1. Fig. 2 shows the similar verification with the fatigue testing results of full-scale girth welded pipes tested under variable amplitude loading. Both figures show a good comparison of proposed fatigue strength curves for corroded riveted and girth-welded details.

REFERENCES

Structural safety assessment of a rubble-mound breakwater with an incorporated Hybrid Wave Energy Converter

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Keywords: Physical Modelling, Wave Energy, Harbours, Safety, Risk of Overtopping, Stability.

ABSTRACT

Seaports are important infrastructures capable of sheltering ships, innermost facilities and equipment from severe wave conditions, thus allowing port activities to be carried out safely. These activities imply a considerable energy demand, which encompasses a large ecological footprint and negative environmental impacts, including air, noise and water pollution. Moreover, the pollutants that are emitted due to port activities and berthed ships can have a negative effect on the health of local communities. To tackle these impacts, port authorities have set their sights on fostering more sustainable approaches to their harbour activities, ranging from pre-emptive measures [1] to the use of shoreside power derived from the national electricity grids [2]. A promising approach, however, involves the deployment of wave energy converters (WECs) to serve as sources of clean, sustainable and independent energy.

Within this scope, the SE@PORTS project (OCEANERA-NET) intends to assess the current status of wave energy conversion technologies, suitable of being integrated into port breakwaters, and develop a hybrid solution capable of harnessing the energy available due to the breakwaters’ high exposure to ocean waves. Fulfilment of this goal must also ensure adequate sheltering conditions within the harbour basin or, ideally, improve them. By combining different WEC concepts in the hybrid technology, it is expected that their individual strengths and weaknesses will be bolstered and mitigated, respectively.

This work analyses the stability of the armour layer and toe berm of the rubble mound structure that was designed for the extension of the north breakwater of the Port of Leixões, with and without the hybrid WEC integrated. The impact of the hybrid WEC on the functional performance of the structure concerning overtopping is also assessed. The developed hybrid WEC combines an Overtopping device, based on the Sea-wave Slot-cone Generator (SSG) concept [3], with an Oscillating Water Column [4] and its geometry has been optimized using the WOPSim 3.11 [5] and ANSYS® Fluent v15.0 [6] numerical models. The experimental study was performed in the wave basin of the Hydraulics Laboratory of the Hydraulics, Water Resources and Environment Division (SHRHA) at the Faculty of Engineering of the University of Porto (FEUP), and involved the reproduction of the planned extension of the breakwater with the aforementioned hybrid WEC solution on a geometric scale of 1/50. The rubble mound breakwater was tested with and without the hybrid WEC as to enable a comparison between both options regarding structural stability, safety and risk of overtopping. The seabed bathymetry in front of the breakwater was reproduced and extreme irregular waves were generated to test and analyse the integrity of the structure. The following combinations of significant wave heights and peak wave periods were considered consecutively for the Mean Low-Water Springs (MLWS) and Mean High-Water Springs (MHWS): MLWS – 6 m, 13 s; 7.7 m, 16 s; 8.0 m, 16 s; MHWS – 6.0 m, 13 s; 7.7 m, 16 s; 9.1 m, 16 s.
The stability of the breakwater’s armour layer and toe berm was analysed by means of orthogonal photographs of the structure taken between tests, allowing for the accounting of the number of blocks displaced during the tests. The results were then compared and the effect of the WEC’s integration into the breakwater quantified, whilst a qualitative assessment of the changes in the structure’s response to severe wave climate due to the inclusion of the device was made. The damage number is defined as,

\[ N_{od} = \frac{N_{dis}}{W/D_n} \]  

where \( N_{dis} \) represents the number of units displaced out of the armour layer or toe berm, \( W \) the width of the reference section and \( D_n \) the nominal diameter of the blocks. Considering that Antifer blocks were used in this study, \( D_n \) was calculated as the equivalent cube length. Fig. 1 shows the toe berm’s cumulative damage number evolution for the two water levels tested (MLWS and MHWS). The armour layer’s \( N_{od} \) is not presented since no block movement was observed during the tests. The results suggest that the stability of the toe berm is affected by the hybrid WEC, although within acceptable safety levels.

Since the study carried out points towards a decrease in the structural stability of the breakwater, the incorporation of the hybrid WEC should be considered when designing its armour layer and toe berm. On the other hand, overtopping discharges were considerably reduced by the hybrid WEC, leading to safer conditions inside the port and potentially fewer downtime periods during severe wave conditions.

REFERENCES


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Fatigue assessments of a jacket-type offshore structure based on static and dynamic analysis: A comparative study


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Keywords: Fatigue; static analysis; dynamic analysis; offshore structure; Jacket.

ABSTRACT

Offshore structures are mainly associated to oil and gas industry given that globally, nearly one third of the oil and gas extracted worldwide comes from offshore sources. This figure is likely to continue to rise over the coming decades because of abundant deposits of oil and gas still present in the oceans, as such, the exploration of these hydrocarbons, production and storage remains essential [1].

To ensure that the structure will fulfil its function, the design of fatigue is crucial to ensure an adequate service life, since it is responsible for more than 80% of the structural failures, most of them catastrophic and without warning [2], case in point is the Alexander L. Kielland oil drilling rig, in 1980. After a sharp crack was reported, the structure capsized into the sea completely, killing more than 120 people, which stands to this day as the worst disaster in Norwegian waters since World War II [3].

Due to importance of the subject, this study aims to analyse the fatigue cumulative damage and dynamic behaviour of a case study Jacket-type offshore platform. Since fatigue occurs due to the presence of cyclic loading, leading to a range of stresses, environmental actions, namely wave loading, becomes of extreme relevance for the estimation of fatigue damage and remaining fatigue life. By using the sea load history provided from wave measurements taken in the North Sea in the form of a wave data scatter diagram wave particle kinematics can be calculated and the wave loading obtained.

In this study, a comparative study between a standardized fatigue damage evaluation due to a static linear-elastic analysis is conducted according to DNVGL recommended practice [4], where S-N curves for tubular elements under sea environment with catholic protection are opted for elements completely submerged and the S-N curve with free corrosion for tubular members in the splash zone, since there are no anodes in this region, which, along with hot-stop stresses, and a quasi-static or simplified dynamic linear-elastic analysis, fatigue life calculation is conducted.

For this work, a model offshore platform illustrated in Figure 1, situated in a region with a water depth of 75m and a total height of 103.5m, off the west coast of Norway is presented. Build in S355 structural steel with 4 main tubular vertical elements, and laterally supported by diamond bracings at four different elevations, with cans and stubs for increased stiffness in the joints have been considered, presents a footing at mud level of 41.5 x 41.5 m².

Relating to the simplified dynamic analysis, a model analysis was conducted, and the 3 main modes of vibration were determined with 0.441Hz, 0.445Hz and 0.519Hz for the first, second and third mode of vibration, respectively, determined. In order to perform a quasi-static analysis a dynamic amplification
factor was calculated according to DNVGL-RP-C104 [5]. Lastly the results from both analyses were compared and the ratio between the static and dynamic responses are compared for each wave and wave propagation directions, and a maximum value above the threshold of 1.1 for the DAF, as imposed by DNV practice recommendations [5] thus invalidating a simplified dynamic approach.

Fig. 1. Offshore Jacket-type platform model case study, a) SESAM model; b) element cross-section distribution.

Fig. 2. Fatigue life for both analysis for the critical joints of the offshore platform.

REFERENCES

Experimental and Theoretical Study on the Mechanical Characteristics of Perforated Casings

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Keywords: Perforated casing; Mechanical characteristics; Well integrity.

ABSTRACT

Due to the perforated holes on casings after perforating, the strength of perforated casings will be decreased and the well integrity will be influenced during sequential well services. To get the residual strength of perforated casings, experimental and theoretical study were completed. The samples of perforated casings were obtained from conventional oil field casings perforated in simulation well according to oilfield perforating practice, and the stress concentration coefficients around perforated holes were measured and confirmed by experiments and finite element analysis. Taking the perforated holes as semi-elliptical surface cracks on casings, the formula for calculating stress intensity factors and revised coefficients of perforated holes were derived. Then, both strength safety and stress intensity factors were applied to evaluate the safety of perforated casings. Thus, the safety analysis method for perforated casings is improved and more considerate. Considering the similarity of compressed rod and pipe, the formula for calculating the residual collapse strength of thin walled casings were developed, taking account the stress concentration of perforated holes. The experimental and theoretical study shows that: the stress concentration coefficients around perforated holes were about 1.3 and the residual strength will be decreased more when both stress concentration and stress intensity factors are took into consideration. Taking the mostly used perforating parameter as an example, the collapse strength of a perforated casing with 16 perforations/m and 90°helix may be decreased 12%. Based on the results of the experimental and theoretical study of this paper, the working parameters were decided and guidelines were developed to ensure the safety of perforated casing and well integrity.
Forces on bottom-fixed offshore substructures based on different wave theories


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Keywords: Offshore; Jacket; Morrison; Wave theory.

ABSTRACT

Due to past events, renewable energy, mainly hydroelectric and wind power have gained a considerable increase in support amongst the years. Country’s with a high dependency on fossil and nuclear energy production have had their mindset altered in the wake of either environmental disasters or market fluctuations, for this reason, wind power in particular, has had an exponential increase in the last decades from the initial large scale offshore wind farm off the coast of Copenhagen to the latest 16.7 GW of future projects for new wind capacity financed in 2018 [1], a trend that will certainly continue to rise if the European wind energy goals are taken it consideration.

With this in mind, the risk and damage assessment of both future and present structures must be carefully considered, and the service life of these structures evaluated. As a pre-study to future fatigue damage and residual life studies either from normalised [2] or more scientific methodologies, a thorough understanding of the loads offshore structures are subjected to is required.

In this paper, a brief overview of linear and non-linear wave theories is conducted in order to account for the non-linearity of the loading nature [3] where wave particle kinematics according to several regular wave theories aligned with a deterministic model using wave measurements recorded in the Norwegian sector of the North Sea, gathered with the use of recorders and in compliance with the Norsok standard [4] are determined. A pre-selection of waves according to the measured scatter diagram is made and only waves with a probability of occurring once every 100 years are taken. Afterwards, and once the wave particle velocity and acceleration are obtained according to Airy’s linear for both finite and infinite water depth as well as Stokes more advanced non-linear 5th order theory, forces using Morrison equation are determined according to [4,5] for a uniform geometric in depth and for a specific case study of a jacket-type offshore platform, are the results compared.

Even though based on the same premises that waves can be presented by regular profiles, with a two-dimensional flow, with a unidirectional propagation and an idyllic horizontal sea bed, some present better results depending on the “water depth” under consideration, placing them into different ranges of applicability [6]. Since it presents a regular wave profile, the equation governing the wave profile can be written as any other sinusoidal wave. In order to achieve wave particle acceleration and velocity, a potential function is used as is presented in Eq. (1) for finite depth, and later simplifying by extending water depth, d, to an infinite value.

\[ \Phi = \frac{g\xi}{w} \frac{\cosh(k(z+d))}{\cosh(kd)} \cos(wt - kx) \] (1)
For Stokes 5th order theory a similar the velocity potential takes on a similar shape, whilst represented with the use of a Fourier’s series with different perturbation parameters, $a$ and $b$, dependent on wave height [7].

By developing a software tool that calculates the wave particle velocity and acceleration, which is represented in Fig. 1 for a significant wave height of 14.5m a period of 13.63s, the Morrison equivalent forces on the structure can be obtained as represented in Fig. 2 by using the values presented in Table 1 for added mass and drag coefficient, as well as marine growth for both constant and case study geometrical values.

### Table 1. Morrison equivalent constants for several depth intervals.

<table>
<thead>
<tr>
<th>Depth [m]</th>
<th>$C_A$</th>
<th>$C_D$</th>
<th>Marine growth [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$-115.67 \leq z &lt; -42$</td>
<td>2.2</td>
<td>0.88</td>
<td>50</td>
</tr>
<tr>
<td>$-42 \leq z &lt; -6.3$</td>
<td>2.2</td>
<td>0.88</td>
<td>100</td>
</tr>
<tr>
<td>$-6.3 \leq z &lt; 0$</td>
<td>2.0</td>
<td>0.8</td>
<td>100</td>
</tr>
<tr>
<td>$z \geq 0$</td>
<td>2.0</td>
<td>0.65</td>
<td>0</td>
</tr>
</tbody>
</table>

**Fig. 1.** Wave particle kinematics: a) velocity field; b) acceleration field.

**REFERENCES**

Quality Control of a Pos Tensioned Concrete Tower Wind Turbine Assembly

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Keywords: Wind turbines; Assembly; Quality; Inspection.

ABSTRACT

More than 30 years ago, Enercon created a unique technology patent in the form of gearless WEC technology. Ever since then, our engineers and specialists have been working continuously to further develop the products and manufacturing processes. We guarantee our customers maximum agility and excellent solutions which make good economic sense and comply with market requirements.

Innovations are fundamental to success here. We want to be the first to establish new ideas on the market and new standards in the industry. The expertise of our employees and their interdisciplinary working partnerships form are the essence of our technological excellence.

Every day we work to live up to our claim to perform as technology leader. We are leading the way in developing new technologies and taking an active and responsible role in shaping the future of energy generation and supply from renewables.

For that we aim to develop and produce the highest-quality wind energy converter on the market. We do not define ourselves primarily in terms of the purchase price, but instead offer turbines with the lowest running costs per unit generated. Content and well-qualified employees are essential for long-term success. That is why we make huge investments in training and advanced training and measures to promote healthy workplaces. The successful further development of our high-tech products relies on us working together. Hybrid towers for ENERCON wind energy converters comprise individual precast concrete elements and steel sections that form the top end of the tower. Concrete segments with large diameters are produced in two or three shells so that they can also be transported to locations which are complex to reach. After all segments and sections have been assembled, the bottom steel section, the concrete segments and the foundation are joined together and tensioned to form one unit by means of prestressing tendons.

The precast concrete segments are produced under strict quality control measures at one of the exclusive ENERCON concrete tower plants. The high level of manufacturing precision is guaranteed through the use of special steel moulds with very low tolerances.

To guarantee optimum quality, the properties of the high-strength concrete are also tested by specialized material testing.

Detailed procedure instructions, work procedure instructions and reports are provided for each production and installation area. This ensures that each individual work step can be completely retraced, as well as the materials and tools used.
In table 1 and 2 it is possible check an example of the reports that must be followed and fulfilled by the responsible for the assembly, these reports are checked, approved and inserted by the quality responsible in an internal system available to all project involved persons.

**Table 1.** Reports that must be followed to have a good final result.

<table>
<thead>
<tr>
<th>Report</th>
<th>Approved and available in the system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project preparation reports</td>
<td>Yes</td>
</tr>
<tr>
<td>Technicians documentation (trainings)</td>
<td>Yes</td>
</tr>
<tr>
<td>Equipment documentation (inspection, maintenance)</td>
<td>Yes</td>
</tr>
<tr>
<td>Components quality acceptance reports</td>
<td>Yes</td>
</tr>
<tr>
<td>Technical information and technical instructions</td>
<td>Yes</td>
</tr>
<tr>
<td>Technical quality reports</td>
<td>Yes</td>
</tr>
<tr>
<td>Final inspection reports (internal control)</td>
<td>Yes</td>
</tr>
<tr>
<td>Final acceptance report (external control)</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Table 2.** Technical quality reports that must be fulfilled by the assembly responsible.

<table>
<thead>
<tr>
<th>Report</th>
<th>Approved and inserted in the system</th>
<th>Non conformities detected</th>
<th>Non conformities solved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction site approval</td>
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<td>Yes/No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Earth resistance measurement site approval</td>
<td>Yes</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Material received approval</td>
<td>Yes</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Construction journal - Daily status</td>
<td>Yes</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Test reports - Grout samples</td>
<td>Yes</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Gap measurements concrete segments</td>
<td>Yes</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Horizontal measurement concrete tower</td>
<td>Yes</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Vertical measurements concrete tower</td>
<td>Yes</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Prestressing tendons assembly list</td>
<td>Yes</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Final inspection concrete tower assembly</td>
<td>Yes</td>
<td>Yes/No</td>
<td>Yes/No</td>
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<tr>
<td>Prestressing tendons assembly list</td>
<td>Yes</td>
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<tr>
<td>Pos tensioning prestressing cables protocol</td>
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<td>Yes/No</td>
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<tr>
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<td>Yes/No</td>
<td>Yes/No</td>
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<tr>
<td>Injection Protocol</td>
<td>Yes</td>
<td>Yes/No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Final Result</td>
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<td>OK</td>
<td>OK</td>
</tr>
</tbody>
</table>

Like all other components, tubular steel towers, machine house, generator, rotor and blades are subject to strict ENERCON quality standards. The high quality and labour safety standards that are partially clearly stricter than the Health & Safety inspectorate’s and liability insurance association’s requirements are also outstanding.
Labour safety and environment protection measures are also ground breaking and clearly above the standard in the branch. ENERCON only accepts highest quality standards for all components. A pioneering quality assurance system in which all production and installation steps are monitored and documented is the quality guarantee.

REFERENCES


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My big THANK YOU!
Structural Integrity of Lightweight Structures –
experimental, theoretical and numerical approach
D-IRAS2019-SILS

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Structural resistance of lightweight stiffened panels submitted to buckling

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Keywords: Lightweight stiffened panels; Remaining strength; Collapse modes; Finite element analysis; Nonlinear analyses.

ABSTRACT

Vessels are constantly subjected to stresses induced by the operating conditions. These loadings affect the structure of the ship, subjecting it to stresses that may, in some cases, lead to large deformations, structural instability, or even collapse [1-3].

Moreover, a limit state is conventionally defined by the condition in which a specific structural member, or even the entire structure, fails to fulfil the function for which it was designed. From a structural designer point of view, four types of limit states are considered for steel structures [4], namely:

- SLS – serviceability limit state
- ULS – ultimate limit state
- FLS – fatigue limit state
- ALS – accidental limit state

In practice, the ultimate limit state concept implies that the designer considers the post-buckling behaviour of the various components and the interaction between them.

The primary goal of the study herein presented was to evaluate the remaining strength of a stiffened panel belonging to a ship's deck that suffered some deformations during service (Fig. 1) [5].

Fig. 1. Large landing craft (LLC) under study. Panel with concavities uniformly distributed between the reinforcements.

For this purpose, some representative panels of the ship were modelled, aiming to simulate a range of typical deformations, from the ones found on board, as is, through to some extreme cases of deformations
that could lead to structural collapse. After shaping the stiffened panels, compressive in-plane loading was applied, simulating longitudinal bending of the hull in a sagging condition.

In order to assess the maximum theoretical bending loading induced in the ship due to sagging, a trochoid wave of the same length as the vessel was considered (56.54 m). The ship was then divided into twenty sections of equal length, and the weight and buoyancy were determined, in every section, as well as the distributed loading curve. For buoyancy, the immersed volume was calculated according to the height of the wave considered, \( H \), which was equal to 4.564 m \( (H = 0.607(L)^{0.5}) \) [6], and the weight corresponded to a maximum equivalent load of 900 ton, which was distributed along the length of the ship, having into account the superstructure’s arrangement and the available ship’s width. Therefore, transverse load curve, \( V(x) \), and bending moment distribution, \( M(x) \), were determined.

A maximum bending moment of 35 MN.m was estimated to be applied amidships of the vessel, and the neutral axis location was determined 1.309 metres above the baseline of the ship. Additionally, the moment of inertia of the section of each structural profile allowed to calculate a moment of inertia of the master’s midship cross-section equal to 0.49 m⁴, resulting in an extreme induced stress of 25.5 MPa at the reinforced panel under study.

In addition, non-linear structural analyses were carried out using the Finite Element Method (FEM) and ANSYS software. It was found that the existence of large deformations between reinforcements led to the loss of strength of the original stiffened panel and the local deformations occurring near the reinforcements do not affect the strength of the panel significantly. The case with a higher loss of strength was the one relative to the collapse of a longitudinal reinforcement profile of the deck panel. Additionally, the main types of buckling found in the panel were the local buckling of plating between stiffeners and the lateral-torsional buckling of the smaller stiffeners.

Despite the moderate loss of strength found on some of the stiffened panels studied, it was possible to conclude that this loss of strength does not compromise the normal safe operation of the ship, even in extreme load.

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ACKNOWLEDGMENTS

The authors would like to thank the Portuguese Foundation for Science and Technology through project ref. UID/EMS/00667/2019.
The real strain of the measured object is transferred to FBG through the bonding layer and the packaging layer in turn, thus good strain transfer efficiency is the key for FBGs to measure strain accurately. The strain transfer efficiency of FBGs packaged by carbon fiber is related to the material properties, geometric size and curing technics of the bonding layer. While the material properties and geometric size of the bonding layer will degrade on secular cyclical loading and vibration force, even breaking, thus the strain transfer efficiency has a sharp cut-off characteristic. The existing researches focus on the static characteristics analysis of strain transfer efficiency, while few studies have been done on the dynamic or cut-off characteristic analysis, so a study on the dynamic strain transfer laws as well as reliability assessments based on dynamic strain transfer laws are performed for FBGs packaged by carbon fiber in this paper. Firstly, as the measured object under sinusoidal load for example, dynamic strain transfer model for FBGs packaged by carbon fiber was established through theoretical analysis, the influencing parameters were determined, and the dynamic strain transfer laws are studied. Then, the influences of dynamic strain transfer parameters were analyzed by using the finite element simulation method and the results of the theoretical analysis and simulations were verified by experiments. Finally, the reliability of the FBGs packaged by carbon fiber is calculated, and the reliability assessment method is proposed on the basis of dynamic strain transfer model. This study can be used to correct the measurement errors for FBGs, and also can act as a reference for FBGs’ packaging and bonding technics.
STRUCTURAL INTEGRITY ASSESSMENT OF WOODEN TRUSSES STRENGTHENED WITH CFRP COMPOSITE PATCHES

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Keywords: Wooden Trusses, Full Scale Test, Numerical Analysis, CFRP patches, Finite Element Model.

ABSTRACT

The paper presents a mechanical investigation of the wooden trusses. All experimental works were supported by FEM (Finite Element Model) analysis performed in ABAQUS environment. The experimental tests were focused on the trusses behaviour with and without additional CFRP strengthening layer. The different configurations of CFRP patches were considered. The experimental campaign resulted in the estimation of behaviour in an elastic range and nonlinearity influence until the rupture. One of the main goals of the researchers is a comparison of failure mechanisms depending on the reinforcement properties and the assembly methods. The next aim was an estimation of the reinforcement influence on the behaviour of the girder during operating conditions (in elastic range). The basic laboratory tests taking into account the rheological behaviour were performed.

Fig. 1. The numerical model of wooden trusses (left) and laboratory tested specimen (right).
Topology Optimization for Additive Manufactured Self-supporting Hollow Fan Blade Structure Assisted by Surrogate Model

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Keywords: Topology optimization, additive manufacturing, overhang angle, surrogate model, hollow fan blade.

ABSTRACT

Nowadays, hollow fan blade is widely adopted by the most sophisticated turbofan engine due to its ability to reduce mass and increase blade damping level. However, the conventional design for hollow fan blade is inevitably restricted by the ability of manufacturing, contributing to a limitation of design freedom. In this work, the feasibility of deploying topology optimization and additive manufacturing (AM) on hollow fan blade structure is investigated.

It is widely recognized that the application of topology optimization on AM greatly expands the design region to more complex geometry of the structures. However, AM-specific constraints are not included in the existing topology optimization algorithms. In this work, the overhang angle restriction and the minimum feature size restriction is embedded in the conventional bi-directional evolutionary structural optimization (BESO) framework involving compliance and mass minimization to obtain support-free and printable 3D structures. The constraint values dependent on the manufacturing process are gained from numerical simulation software ANSYS Additive Suite. To ensure the analysis efficiency of the optimization process, surrogate model is adopted to construct a multi-fidelity model by relating state function to design parameters. A postprocessor executing 3D boundary smoothing is also added to ensure the printability.

Topology optimization on an AM hollow fan blade is carried out to demonstrate the feasibility and benefit of the proposed method. Enlarged design freedom can be realized by the proposed method, which is promising to exploit the superiority of AM to one step further.
A review of structural health monitoring methods for composite materials

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Keywords: Critical infrastructures, Structural Health Monitoring, Composite materials.

ABSTRACT

Health monitoring techniques with regard to structural assessment has the attention of researchers worldwide owing to their potential in providing crucial information regarding structural damage and the reassurance of expected performance of critical infrastructures during service. These must operate with optimal system performance and against natural hazards. Such systems utilize state of the art sensing networks. The still high costs linked to the application of SHM does dictate that they are mainly incorporated to structures of high value. It can be expected that composite materials are increasingly utilized in such applications. The main difficulty posed by their use is that their failure mechanisms are much more complex.

From this perspective, health monitoring systems and operational safety evaluation techniques of energy generating critical infrastructures were systematically investigated with regard to current status, advantages, disadvantages, and the future development trend of existing systems and techniques sensing, data acquisition and transmission, overall operation and maintenance.
Design of CFRP-steel hybrid structure pipeline for concrete pumping under ultrahigh pressure

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Keywords: CFRP; Concrete pumping pipe; Connection structure; Filament winding patterns; Strengthening.

ABSTRACT

The pipeline is the main channel for concrete pumping in construction, and the lightweight, safe structure and long service life pipeline is very important for concrete pump trucks. For the existing double-layer metal pipes, the inner metal will get cracking and shedding probably because of the unavoidable gap between inner and outer layer. Besides, the lightweight and safety is difficult for double-layer metal pipes. This paper presents the design and experimental study on hybrid structure of carbon fiber reinforced polymer (CFRP) filament-winded strengthening circular long steel pipe. The design of filament-winded CFRP contains three layers: the inner layer for stress sharing of brittle steel tube, the middle layer for connecting to ductile steel flanges and the outer layer for explosion-proof and protection. With the hybrid structure distributed stress calculation, the design guideline of inner and outer layer CFRP is presented. Based on the design of the connection structure between pipe flange and CFRP with finite element analysis, this paper conducted an optimization of the filament winding patterns using special winding control program. The experiment result shows the new hybrid structure pipeline can bear the pressure of 17 MPa and the axial loading of 210 kN, and the working needs of concrete pumping can be satisfied. The result of actual test indicates that the hybrid structure pipeline reduces 43% mass compared with the traditional double-layer steel pipe and also the service life is 50% increased so as to the explosion-proof safety performance of concrete pump trucks is obviously improved.

Circumferential stress of the lining of the hybrid structure:

\[
\sigma_s = \frac{p r (t_s - d)}{(1 + \frac{E_t f}{E_s (t_s - d)})} - \frac{p a E_t f}{a E + (t_s - d)} \leq \sigma_s
\]

Fig. 1. The curves of the relation among lining circumferential stress, wearing depth and (a) thickness of CFRP or (b) prestress of CFRP
Based on the hybrid structure distributed stress calculation (as shown in Fig. 1), the CFRP thickness of stress-sharing layer should be designed to be at least 1.5mm, and the thickness of carbon fiber layer for outer explosion-proof and protection is 1.5mm, and the CFRP layer with the pre-stress of 35MPa is reasonable.

Fig. 2. The structure of flanges
Fig. 3. The patterns simulation of filament winding on pins
Fig. 4. The samples of the CFRP-steel pipes
Fig. 5. CFRP-steel pipe tested on the booms of concrete pumping truck

The connecting structure between pipe flange and CFRP can bear the inner pressure of 17 MPa and the axial loading of 210 kN. The weight of a 3 meters straight pipe less than 32 kg, which reduced 43% mass compared with double-layer metal pipe. The service life of the CFRP-steel pipes is increased by about 50% because of higher hardness and the absence of the gap between lining and outer layer.

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ACKNOWLEDGMENTS
This project went on and lasted for nearly 3 years. During this time, thanks for the support from the State Key Laboratory of Construction Machinery and Zoomlion Company in fund investment, equipment and staffing arrangements. Thank Dr. Ling Fu and Dr. Xiaoteng Wang for their great help in this project. Finally, thank the team members for their hard working and persistence.
Structural repairs in composite material infrastructure components in the energy industry

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Keywords: Structural repairs, composites, energy infrastructure, quality reassurance.

ABSTRACT

Polymer composites have sustained rapid development for many decades and found ever-increasing applications as engineering components and structures in various the fields of aviation, aerospace, and energy. Their physical and mechanical properties and attributes can be degraded to varying degrees when they are being manufactured and in service. It is critically important to identify potential damage so the problem can be rectified by repairing to avoid any catastrophic disasters. High quality repair of polymer composite components and structures has technological and economic significance because it can prolong their service life without sacrificing their performances and safety requirements. When a metallic or composite structure sustains damage in service a number of repair levels must be employed owing to the severity. If the damage has weakened the structure through delamination or fibre fracture and disbonding in the case of a composite, the repair will involve rehabilitation so as to restore the original mechanical properties. The following article investigates the optimal repair configurations along with the most appropriate repair methodology for both substrates.
Mode-I Interlaminar Fracture Toughness Investigation of Glass Mat Thermoplastics and Continuous Fibre Reinforced Thermoplastic Laminates

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Keywords: Structural Integrity, Fracture, Debonding, Fiber Reinforced Thermoplastics, Glass Mat Thermoplastics, Continuous Fiber Reinforced Thermoplastic, Laminates, Bonding, Hybrid Materials, Compression Moulding, Lightweight, Testing.

ABSTRACT

This paper is to present cohesive properties of combination of Glass Matt Thermoplastics (GMT) consisting respectively of 30 % wt. or 50 % wt. glass fiber and polypropylene (PP), as well as Continuous Fiber Reinforced Thermoplastic (CFRP) laminates - 30 % wt. glass fiber and PP. The investigation is conducted with reference to ASTM D5528 norm to determine the opening Mode I fracture toughness, \( G_{IC} \), of above-mentioned materials. This characterization contributes to better understanding of cohesive behavior of new hybrid materials and enables to create numerical model of cohesive zone model that provide reliable studies of strength and structural integrity of lightweight components, especially those hybrid multi-materials ones.

References


Fatigue Behaviour of Bolted Connections Applied in Racking Structures. Experimental and Numerical study

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Keywords: rack structures; bolted joints; fatigue behaviour; preload; S-N curves; numerical models.

ABSTRACT

Rack structures made of cold-formed steel have been used in industrial sectors, supporting and guiding S/R machines, which raises fatigue concerns. EC3 \cite{1} has no reference to fatigue design of cold-formed thin-walled sections. For that reason, the FASTCOLD project was proposed aiming at providing fatigue design rules to be include in EC3, including bolted joints that are often used to connect rack members. This work presents an overview of the work performed as regards the fatigue characterization of bolted joints made of thin steel plates.

Metal steel plates 2mm thick made of S350GD steel grade, connected with M12 bolts (class 8.8, DIN933; Washer DIN125; and Nut DIN934) were tested experimentally, covering the following conditions:

- Single bolted joints, snug tight bolts (30% preload), punched holes, stress ratio, R=0.1 (ref. series);
- Single bolted joints, preloaded bolts, punched holes, stress ratio, R=0.1;
- Single bolted joints, snug tight bolts, punched holes, reduced net section, stress ratio, R=0.1;
- Single bolted joints, snug tight bolts, punched holes, stress ratio, R=0.3;
- Single bolted joints, snug tight bolts, punched holes, stress ratio, R=0.5;
- Multiple bolted joints, snug tight bolts, punched holes, stress ratio, R=0.1;
- Multiple bolted joints, snug tight bolts, drilled holes, stress ratio, R=0.1;

S-N curves were obtained in accordance with ASTM E739 standard \cite{2}. Numerical simulations, using ANSYS R18.2 were carried out in order to predict the fatigue strength. For this purpose, the Ramberg-Osgood’s cyclic curve available in the literature for the S355 steel grade was considered \cite{3}. In addition, the fatigue strain-life relation available in the literature for the same material was used in the context of local strain approach. \(\frac{1}{4}\) of the joints was modelled using standard surface-to-surface contact conditions, with the augmented Lagrangian algorithm and a constant friction coefficient, extracted from literature for zinc coated steel \cite{4}, were taken into account.

Figure 1 shows that S-N results show in general an average slope around 8 instead of 3 as suggested by EC3. This discrepancy may be due to the higher importance that cracks initiation plays in the bolted joints fatigue behaviour. The preload effect increases the fatigue strength as expected. Also, for lower loads, the failure occurred along the gross cross-section due to the clamping effect. Changing the R-ratio effect, but maintaining the maximum load, the fracture tends to move away from the centre. Reducing the net section (reduction of 10mm) caused an increase in fatigue strength, which is an unexpected result. Multiple bolted connections presented higher strength than single connections. However, specimens with drilled holes resulted in worse results than punched holes due to a low quality of drilled holes. The EC3 class 90
S-N curve results in safe predictions for fatigue lives above $2 \times 10^5$ cycles. For fatigue lives above $1 \times 10^6$ cycles the EC3 is excessively conservative due to the significantly different slopes.

Normal stresses and strains were evaluated numerically in the bolt holes (diametrical position), and it was verified that the average stress is almost null for a stabilized hysteresis loop (see Figure 1). Using a strain-life approach [3], S-N curves were predicted. It was verified that the predicted slopes of the SN curves are in agreement with experimental results (black circles). As the punching process may generate tensile residual stresses around the hole, that would cause a reduction of fatigue strength (black triangles). Assuming positive residual stresses at bolt holes vicinity leads to a discrepancy of results (conservative), but that may be associated to differences of material fatigue properties from literature and this study, and also due to the fatigue crack propagation disregard.

Fig. 1. S-N curves and failure modes: STB - Snug Tight Bolt; PB - Preloaded Bolt; S – Single; M – Multiple; PH - Punched Hole; DH - Drilled Hole; R - Stress Ratio; RS - Reduced Section. Numerical Models: A-Single/B-Multiple (Normal Stress XX); Stabilized stress-strain hysteresis loop.

Acknowledgments

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Lifelines and Infrastructures Safety Evaluation
E-IRAS2019-LISE

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Typical Damage in Steel Storage Tanks in Operation

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Keywords: steel storage tanks in operation; damage; design; maintenance.

ABSTRACT

The safe and long service life of structures could be assured only when adequate design and construction are combined with a proper and regular maintenance. The principal objective of this paper is to identify the most common failures that may occur in above ground cylindrical steel storage tanks in operation, to suggest better design decisions, possible solutions for repair and provide guidelines for appropriate care and maintenance of this type of structures.

Vertical cylindrical steel storage tanks are responsible facilities. During nearly all of their operational life they are filled to their maximum allowable level, respectively design stresses are constantly at the limit of the load-bearing capacity. Moreover, these structures often contain toxic, flammable and expensive products and therefore should be treated with caution and responsibility. However, some tank owners still believe that once built a facility can be exploited for a long time without proper maintenance. Evidence for the latter is provided by Chang and Lin [3]. They review 242 accidents of storage tanks that occurred in industrial facilities in the period 1960-2004. Almost half of the reported cases (46%) were caused by human errors including poor operation and maintenance, equipment failure, crack, leak and rupture, etc., i.e. could have been avoided.

Fortunately, documents regulating the terms, time periods and scope of the audit necessary for steel tanks were developed in the late 20th and early 21st century. In the Russian Federation were published the documents РД08-95-95 [14], РД 153-112-017-97 [15], CTO 0030-2004 [16], in the United States of America – a number of editions of standard API Std. 653, whose latest version is 5th edition [2]. Under their influence, scientific research on the topic initiated in other countries as well. The usage of those documents has its practical implementation. In 2018 a group of specialists was assigned the task to conduct a site inspection and provide a statement for the operational condition of 7 new and 13 steel storage tanks in service, owned by Bulgarian State agency “State reserve and war-time stocks”. The facilities contain different oil products – petrol, diesel and mixed fuel stored at ambient temperature and atmospheric pressure. The anchorage conditions vary. Some of the examined storage tanks were built in the 1970s, others – in the period 2009 - 2014. The audit was carried out in accordance with the Agency’s internal directive and standards API 650 [1], API 653 [2], EN 1993-4-2 [4], EN 14015 [5].

Based on this representative study and the practical design experience of the authors, this paper classifies the most frequently reported damage in different elements of tanks in operation – foundations, anchorage (if present), annular plates, tank bottom, shell, roof (fixed or floating), attached accessories and systems. Illustrative examples are presented, along with explanations for the critical aspects of adequate maintenance. Finally, some conclusions are drawn in the form of guidelines for failure prevention and if the damage already exists - possible ways for restoration of the facility to its proper operational state.

Based on the expertise of the authors, the most important measures that would increase the safety of all vertical steel tanks are:

a) Steel tanks should be inspected regularly, as prescribed by a relevant legislative document;
b) All observed faults or damage should be described in a log and repaired as soon as possible;
c) A high degree of soil compaction should be prescribed for the soil and/or crushed stone below the bottom of the tank;
d) Quick and easy drainage of rainwater from the roof and the tank shell should be ensured. The connection joints of steel elements should be designed in a manner that does not allow water retention;
e) All repairs should not deteriorate the condition of the tank;
f) When applying the corrosion-resistant coating, the technological requirements for maximum humidity, minimum temperature and the degree of cleaning of the surfaces have to be met.

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ACKNOWLEDGMENTS

The authors would like to express their gratitude to the Research, Consultancy and Design Centre (RCDC) of UACEG Sofia for the financial support provided.
**RISK BASED ANALYSIS OF PRESSURE VESSEL INTEGRITY AND LIFE**

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**Keywords:** Risk analysis, Structural Integrity, Fatigue, Fracture Mechanics, xFEM, Pressure vessel.

**ABSTRACT**

Risk based analysis of pressure vessel integrity and life has been performed by applying the new concept based on application of risk matrix to assess risk level according to probability and consequence of failure. Pressure vessel integrity has been assessed by using the Failure Assessment Diagramme (FAD), i.e. the ratio of linear elastic fracture mechanics parameter, $K_I$, and its critical value, $K_{Ic}$, in relation with the ratio of applied stress and its critical value. Probability of failure is then taken according to the position of the point in the FAD, corresponding to the pressure vessel data (material, loading, geometry, including a crack). Pressure vessel life has been assessed by applying the extended Finite Element Method (xFEM) to obtain number of cycles vs. fatigue crack growth. Probability of failure is then taken as the ratio of the number of cycles for a given crack length and the number of cycles for the critical crack length. This procedure is applied to one example, the oil rig pipe, both new and old (exploited), which was previously analysed by using the classical fracture mechanics approach. All data available is used in the risk matrix to estimate the risk for both integrity and life of new and old oil rig pipe. Results of fracture mechanics and fatigue testing are shown in Fig. 1 and 2, respectively. Risk analysis indicates higher risk of using the old pipe, i.e. shift of low to moderate risk. Such an analysis is useful for managers to make decision about further use of damaged pipes, based on data provided by engineers.

![Fig. 1. J-Δa Curves: a) new pipe; b) old pipe.](image-url)
Fig. 2. $\frac{da}{dN}$-$\Delta K$ curves: a) new pipe; b) old pipe.
A Study of Combustion Characteristics of Finishing Materials of Wall Construction for Fire Safety of the Annex Building to Nuclear Power Plants

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Keywords: Combustion; Finishing materials, Fire safety; Nuclear power plant

ABSTRACT

Fires occurred from buildings including annex to nuclear power plants can bring unexpected enormous life losses and property damages. Therefore, the fire resistance of the structural elements such as columns and beams should be maintained through the whole life of the structures. Especially, not only to reduce the fire severity within a fire cell but to help the people who are living, unknown users in the building, evacuate to a safety area from fires, the application of non-combustible construction materials are required. In this paper, to evaluate the non-combustible performance of gypsum wall boards, those are very famous construction materials not only to provide the fire resistance to the structures but also to limit smoke generation in a fire condition, the comparison of building regulations and the related fire test standards between Korea and the United States are executed. To compare the non-combustible performance of finishing wall construction materials in aspects of building regulations, the Korean fire rated building regulations [1] and the IBC [2], the NFPA 5000 [3], and Reg. Guide [4] of the USA were scrutinized. The table 1 shows the main contents of requirements for the finishing materials.

<table>
<thead>
<tr>
<th>Classifications</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building law, regulation</td>
<td>Finishing materials should be used to prevent a fire and these should be satisfied with a non-combustible performance defined in the Ministry of Land and Transportation.</td>
</tr>
<tr>
<td>REG.1.189</td>
<td>4.1.1 Combustibility of Building Components and Features According to GDC 3 in Appendix A to 10 CFR Part 50, noncombustible and heat-resistant materials must be used wherever practical throughout the unit. Interior wall and structural components, thermal insulation materials, radiation shielding materials, and soundproofing should be noncombustible.</td>
</tr>
<tr>
<td>IBC</td>
<td>703.5 Noncombustibility tests The tests indicated in Section 703.5.1 and 703.5.2 shall serve as criteria acceptance of building materials as set forth in Sections 602.2, 602.3 and 602.4 in Type I, II, III and IV construction. The term &quot;noncombustible&quot; does not apply to the flame spread characteristics of interior finish or trim materials. A material shall not be classified as a noncombustible building construction material if it is subject to an increase in combustibility or flame spread beyond the limitation here in established through the effects of age, moisture or other atmospheric conditions.</td>
</tr>
</tbody>
</table>
NFPA 5000

7.1.4.1.1 A material that complies with any one of the following shall be considered a noncombustible material:

(1) The material, in the form in which it is used, and under the conditions anticipated, will not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat.

(2) The material is reported as passing ASTM E 136, Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750 Degrees C.

In order to compare the non-combustible performance of fishing materials, gypsum boards were tested at the FILK and UL Chicago with the same products, respectively. The test results from the FILK were satisfied with the requirement of building regulation in Korea and the test results from the UL were shown in the Table 2 and Table 3.

Table 2. Test results of Gypsum board from ASTM E84

<table>
<thead>
<tr>
<th>Description</th>
<th>CFS(Calculated Flame Spread)</th>
<th>FSI(Flame Spread Index)</th>
<th>CSD(Calculated Smoke Developed)</th>
<th>SDI(Smoke Developed Index)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular gypsum board(9.5mm)</td>
<td>0.00</td>
<td>0</td>
<td>0.00</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 3. Test results of Gypsum board from NFPA 259

<table>
<thead>
<tr>
<th>Description</th>
<th>Heat of Combustion (Btu/lb)</th>
<th>% Ash(Residue)</th>
<th>Ash (Residue) Heat of Combustion (Btu/lb)</th>
<th>Calculated Potential Heat(Btu/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular gypsum board(9.5mm)</td>
<td>-288.53</td>
<td>79.1</td>
<td>0.77</td>
<td>-289.3</td>
</tr>
</tbody>
</table>

To make a guideline for the fire safety of finishing materials which can be applied to annex buildings to nuclear power plant, regulations, building codes were surveyed and conventional finishing materials were tested in the Korea and USA. Even though there were a different definition, requirements of non-combustible performance of finishing materials, gypsum boards showed a similar non-combustible performance and it seems to play a key role to prevent the spread of the fire and life loss in a fire.

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Evaluation of impact toughness of gas pipeline steels under operation using electrochemical method

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Keywords: pipeline steel; hydrogen assisted degradation; electrochemical analysis; brittle fracture resistance.

ABSTRACT

Natural gas transmission pipelines are an important component of worldwide energy supply. However, many gas pipelines are near the end of their design life. Long-term operation of pipelines leads not only to an appearance of macro defects but also to in-bulk damaging of pipeline steels at nano- and microscales [1, 2]. Hydrogen embrittlement, degradation of mechanical properties associated to a safe serviceability of the pipelines, stress corrosion cracking are the main problems for long-term operated pipeline steels [1–4]. A sharp decrease in characteristics of brittle fracture resistance of pipeline steels under long-time operation increases significantly a failure risk. Deterioration of pipelines under operation calls for effective methods for current condition evaluation.

The paper aimed to the development of a non-destructive electrochemical method for an evaluation of in-service degradation of impact toughness of pipelines steels under operation. The low-carbon low-alloyed ferrite-pearlite pipeline steels of gas transit pipelines were studied. The mechanical properties and the electrochemical corrosion behaviour of the 17H1S (equivalent to API 5L X52), API 5L X52, API 5L X60 and API 5L X70 pipeline steels in different states – as-received and after long-term operation (25–53 years) were experimentally investigated.

It was revealed that mechanical and electrochemical properties of the investigated pipeline steels were deteriorated due to long-term operation. Long-term service of transit pipelines caused a significant decrease in characteristics of brittle fracture resistance, namely impact toughness and fracture toughness. Impact toughness was considered as mechanical parameter of in-service material degradation.

Corrosion and electrochemical characteristics of the studied pipelines steels, measured in the NS4 test solution simulated soil environment and in the test solution simulated aqueous condensate in gas transit pipelines, were significantly deteriorated due to long-term service. Electrochemical characteristics of a metal being influenced by its structure and stress state have to be changed due to in-service degradation. Therefore, not only corrosion degradation of steel, but also degradation of in-bulk material mechanical properties could be estimated by changes in electrochemical characteristics both in the laboratory and in the field. Trends in changes in some electrochemical characteristics of the steels caused by their in-service degradation were analyzed. Different sensitivity of electrochemical characteristics of the studied steels to in-service degradation was revealed. Relative changes in corrosion potential and Tafel constant values were insignificant, however corrosion current density and polarization resistance were enough sensitive to pipeline steels degradation and could be informative parameters of change in a metal state under long-term operation.

An acceptable correlation between relative changes in electrochemical (polarization resistance Rp of a pipeline steel in a test solution simulated aqueous condensate in gas transit pipelines) and mechanical
(impact toughness KCV) characteristics of pipeline steels caused by their in-service degradation was revealed (Fig. 1). The dependence is the basis of non-destructive electrochemical method for in-service assessment of degradation degree of the low-carbon low-alloyed ferrite-pearlite pipeline steels. The method enables an evaluation of in-bulk material properties changes, namely impact toughness, by measurements of changes in its electrochemical characteristics. Having initial properties of the material (for example, impact toughness of the as-received pipeline steel according to certificate or impact toughness of the steel of the reserved pipe), its actual properties can be predicted.

**Fig. 1.** Correlation between relative changes in impact toughness \( \frac{K_{CV_{\text{deg}}}}{K_{CV_{\text{in}}}} \) and polarisation resistance \( \frac{R_{\text{p.deg}}}{R_{\text{p.in}}} \) for the low-carbon low-alloyed ferrite-pearlite 17H1S and API X52 pipeline steels after operation, and prediction of the relation \( \frac{K_{CV_{\text{deg}}}}{K_{CV_{\text{in}}}} \).

Summary. In-service degradation of the pipeline steels caused a deterioration of their mechanical properties and corrosion resistance. Corrosion resistance degradation of the steels correlated with degradation of their brittle fracture resistance. One of the most sensitive parameter to in-bulk material degradation was polarisation resistance. Impact toughness changes of pipeline steels caused by degradation under operation can be evaluated by measurements of changes in polarisation resistance. Having initial properties of the material, its actual properties can be predicted.

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A new design of chiral auxetic reactor pressure vessels in nuclear power plant

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\textbf{Keywords:} reactor pressure vessel, pressurized thermal shock, isotropic, additive manufacturing, auxetic.

\textbf{ABSTRACT}

Reactor pressure vessels (RPVs) of nuclear power plants are the most important component and its integrity determines the lifetime of the nuclear power plant. RPV is exposed to neutron irradiation, which causes embrittlement of the ferritic steel and makes the material susceptible to brittle fracture. A potential scenario for a pressurized water reactor is that its RPV has to withstand a pressurized thermal shock (PTS), which is characterized by severe cooling of the core together with or followed by repressurization, if not avoided by safety valves. During the PTS transient, a high thermal gradient formed in the RPV wall and thus PTS transients lead to high tensile circumferential and axial stresses. If the stresses are high enough they may initiate existing cracks in the embrittled RPV material, which may result in crack propagation and in the worst case in a failure of the RPV. Therefore integrity assessment of a RPV requires that there is sufficient safety margin for a RPV subjected to thermal stresses. The existing RPV is made of steel with positive Poisson’s ratio. This paper aims to design new RPVs made of auxetic materials with negative Poisson’s ratio. The advantage of the new RPV is demonstrated in the capacity of bearing stresses. Auxetic structures can expand its volume when stretched, enhanced and improved properties conventional materials such as higher shearing modulus, increased indentation resistance, good absorption properties (acoustic absorption), and higher fracture toughness, thus offering unique features for RPV application.
Method of maintaining the required level of risk, reliability and security of engineering infrastructure through the use of the reconfiguration mechanism

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Keywords: security, reliability, risk, usefulness control system, functional configuration, functional configuration, risk analysis, engineering infrastructure.

ABSTRACT

The article presents the concept of maintaining the required level of the engineering infrastructure (IT) usefulness through the use of a reconfiguration mechanism in relation to the usefulness of the safeguard subsystem and the hazard subsystem. Basic IT elements have been emphasized and characterized from the point of view of controlling its current level of usefulness (reliability and security). A model of engineering infrastructure was proposed for maintaining the required level of usefulness. Desired current IT usefulness is obtained by generating appropriate functional and IT security configurations from a set of allowable solutions. The proposed concept of ensuring reliability and security, taking into consideration the impact of not only various types of risk factors, but also changes in the conditions of the working/operating environment of both IT, its basic domain systems, and the information system, is the authors' own proposition.
FUZZY-BASED GRAPHICAL MATRIX MODEL FOR ASSESSING POWER PLANT SCHEME TOWARDS LOW COMMUNITY IMPACT

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Keywords: Multi-criteria decision making; Energy power plant; Group decision making; Fuzzy-set theory; Graph theory.

ABSTRACT

The seamless power supply is one key necessitates in community’s everyday life. Therefore, minimization of the negative impact of power plant operations on public health and society at large is highly desirable. These facts highlight the urgent need to understand the importance of the energy transition concept including the selection of the types, location and purposes of the power plants which thus an important consideration among the decision makers from a societal perspective. This research proposes a novel method to quantify and define the renewable energy scheme among various sub-system components and their importance respectively, based on expert perspectives. The proposed method, named as Fuzzy Graphical Matrix Method (FGMM), is a hybrid method that extends the Graph Theory and Matrix Approach (GTMA) and combines with Analytic Network Process (ANP), and Fuzzy logic theory. The FGMM addresses the main issue in a complex network of renewable energy important components analysis, which is judged in multi-expert decision making circumstances. Numerical experiments for evaluating 10 power plants with regards to their overall impacts criteria (as an indicator) on the local communities were carried out to demonstrate the applicability of, and to validate, FGMM.

The proposed approach identifies and measures critical performance indicators when comparing alternative energy power plants. Compared to conventional method, the FGMM approach effectively captures the dynamics of various expert perceptions within the assessment processes which provides more estimation accuracy, sensitive exploration, and efficiency in multi criteria decision making problem with multiple expert judgments under fuzzy environment. This research contributes to the evaluation of decision-making that is associated with power plant governance, including protection planning, and managing the vulnerability of power plant, as well as to increase the resilience of both power plant systems and the communities that rely on them.
Theoretical and Simulated Study on the Collapse Strength of Curved Casing in Horizontal or Directional Wells

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Keywords: Collapse strength; Curved casing; Cross-sectional ovalization; Wellbore curvature; Lame theory; Distortion energy theory.

ABSTRACT

Casing bends to be in accordance with the wellbore curvature in horizontal wells or directional wells. The collapse strength of curved casing will reduce correspondingly which may cause well failure if neglecting it. The formulae of collapse strength of curved casing considering cross-sectional ovalization or not are deduced using Lame theory and distortion energy theory. The collapse strengths with wellbore curvature for four casings are compared. Some conclusions are drawn from the analysis. The axial stress of casing changes nearly linearly with wellbore curvature. Collapse strength of casing decreases nonlinearly with increasing wellbore curvature. For 5 1/2”×10.54mm P110 casing, the difference between the two cases increases from 13.43MPa to 46.57MPa when wellbore curvature increases from 2°/30m to 12°/30m. For 4 1/2”×9.65mm TP140V casing, the difference between the two cases increases from 17.61MPa to 64.21MPa when wellbore curvature increases from 2°/30m to 12°/30m. In general, the collapse strength is smaller when considering the cross-sectional ovalization. With the increase of wellbore curvature, the influence of cross-sectional ovalization on the collapse strength of curved casing can not be neglected. The results show the importance to consider the cross-sectional ovalization arisen by the plastic deformation of casing as well as provide a reference for the choice of casing in production or other cases.
Fracture Control of the 2nd West East Gas Pipeline in China

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Keywords: Fracture; Reliability; Submerged arc welding; Pipelines.

ABSTRACT

The 2nd West East Gas Pipeline (2nd WEGP) is the first major pipeline project in China importing abroad natural gas resource and also the longest and largest quantities gas transmission line in the world with gas supply of middle Asian natural gas and adjusting gas supply of domestic gas from Tarim Basin and Ordos Basin. The primary target market is south china not covered by previous the 1st WEGP, and the market of North and East China is also taken into account through branch of the 2nd WEGP. It has one artery and 8 brancntches, starts at Khorgos of XinJiang Province, goes by way of provinces / districts / cities and finally reaches Hongkong. Its total length is 9 000 kilometers, in which the total length of artery from Khorgos to Guangzhou is 4 900 kilometers. Its design throughput is 30 billion cubic meters per year and its total investment is 142 billion RMB. The 2nd WEGP started at February 2008 and completed at December 2012.

Designed maximum operation pressure of the 2nd WEGP is 12 MPa, largest diameter of pipe is 1219mm and highest steel grade is X80. To ensure the long-term security and reliability in operation, fracture control program has been proposed through systematic research, including crack initiation control, brittle fracture control and ductile fracture control. The requirement of arrest toughness of the 2nd WEGP had been studied on the basis of pipe full-scale burst test data base in the world, Battelle two curve method (BTCM) and GASDECOM software. Full scale burst tests of X80 high-pressure gas pipeline had been successfully performed based on previous research results. The fracture control program of the 2nd WEGP was set up based on different fracture criteria and the principle of both security and economy. The arrestability of X80 spiral submerged arc welded (SSAW) pipe was firstly verified and a new correct factor of arrest toughness prediction was obtained. Results presented that the arrestability of SSAW pipe is better than longitudinal submerged arc welded pipe. It is also indicted that the absorbed energy of drop weight tear test (DWTT) can accurately reflect full-scale fracture behavior of pipe, an inverse relation between fracture separation and arrestability of pipe and an absorbed energy of DWTT required by fracture arrest is presented.
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The anthropogenic risks in industrial agglomerations of Siberia

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Keywords: anthropogenic risks, reliability and accidents risks, industrial agglomerations.

ABSTRACT

The non-zero risk conception of technical systems and objects of techno sphere accidents, the level of anthropogenic risk evaluation are the basis of nature- anthropogenic safety regulation of territorial formations and industrial agglomerations. The rate of anthropogenic dangers is constantly increasing nowadays.

There were more than 3000 emergencies in Siberian Federal District from 2007 – 2017. More than 80% from them were anthropogenic in origin.

During the analyses of Ministry of Emergency Situations (MES) reports the main types of anthropogenic emergencies in Siberia were found out and analyzed. The fires and explosions in objects of industrial and social value, accidents in heating system, power supply network, water supply and accidents on transport are the most wide-spread. The fires, explosions and accidents on transport (air, land) have the greatest rate by the number of dead. However, accidents in housing- and- municipal sphere bring the most material damage because of a large amount of injured people and economic consequences during accident elimination.

There are some examples of analyses of results technical diagnostic for techno sphere objects including fabricated constructions, mainland pipeline, etc and their using for estimating the reliability and accidents risks as well.

There are given quantitative measurements for various kinds of anthropogenic risks in some industrial agglomerations in Siberian Federal District (Krasnoyarsk territory, Kemerovo and Irkutsk regions).

The task is set to reduce the emergency risks which will lead to sustained development of the district and allow to minimize costs of accident elimination.
Creep Damage Analysis of Welded Mod. 9Cr-1Mo Steel Pipes Considering the Transition in Failure modes

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Keywords: Creep damage; Crack growth; Heat affected zone; Ductility exhaustion model.

ABSTRACT

The problem of premature failure of mod. 9Cr-1Mo steel (P91 steel) welded joints has received considerable attention in recent years. The transition of failure mode from ductile to brittle is believed to be the major reason for the reduction in creep strength of P91 steel welded joints for long-term service. However, the analysis technique for creep damage evolution is still not well established. This is partly because of the lack of detailed creep properties of heat affected zone (HAZ). In the paper, creep strain curves of HAZ were obtained by using simulated specimens kept under stresses from 50 to 120MPa at 650°C. Also, the change of the value of creep ductility of HAZ under different stress levels was also recorded. To gain a better understanding of the creep damage evolution in the welded joint, finite element analysis of the creep failure behavior of thick-wall welded pipes was carried out based on a ductility exhaustion model. It is shown that the predicted rupture times and failure locations match well with those observed in the creep rupture tests. On the other hand, the results suggest that the creep ductility of HAZ may play a significant role in the failure mode transition of P91 steel welded joints.
Effect of Strain Aging on Properties of X90 Line Pipe

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Keywords: X90; line pipe; strain aging; aging sensitive coefficient; microstructure.

ABSTRACT

Tensile and impact toughness test on X90 line pipe with different aging conditions were conducted to study the effect of aging conditions on properties of X90 pipeline steel. The result shows that yield strength and yield ratio of X90 line pipe would increase significantly with the introduction of strain aging, while the impact toughness and tensile strength have little change. The impact toughness of X90 line pipe would decrease with the introduction of 200°C, 5min aging. However, the impact toughness of X90 pipeline would increase with the increase of aging temperature and aging time (250°C, 1h). The tensile strength of X90 pipeline steel would decrease or increase slightly after the introduction of aging. While the yield strength and yield ratio would increase significantly after the introduction of aging, and the rising range of yield strength and yield ratio would decrease with the increase of aging temperature and aging time. Comprehensive analysis shows that the aging treatment have different effects on different X90 pipeline steel, mainly due to different microstructure and chemical composition of X90 pipeline between manufacturers during the trial production. The result of aging sensitive coefficient analysis shows that the effect of microstructure type is more significant than that of chemical composition, and X90 pipeline steel with dual-phase microstructure would has high aging sensitivity coefficient.
Simulation of Sealing Ability for Premium Connection
Based on ISO 13679 CAL IV Tests

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Keywords: Premium connection; Sealing ability; Contact pressure; ISO 13679; Finite element analysis.

ABSTRACT

To maintain the well integrity, the strength and sealing ability of premium connection should be in the safe scope. ISO 13697 Petroleum and natural gas industries – Procedures for testing casing and tubing connections is a general evaluation standard for casing and tubing connections and it can be taken as an important reference for the study of the performance of premium connections. Because of the disadvantages of experiment such as long period, high cost and high inquire on the facility, considering the economy and convenience of finite element method, three dimensional finite element model of a certain type premium connection is established, and the loads exerted on the premium connection is the loads in the tests of ISO 13679. The distributions of Von Mises stress and contact pressure in various cases are studied. The results show that the bending load has a great influence on the distribution of Von Mises stress and contact pressure for premium connection. The Von Mises stress and contact pressures on the sealing surface are smaller on the tension side and greater on the compression side. With increasing axial compression load, the contact pressures on the tension side are too small, which may arise sealing failure. After the thermal cycling tests, the contact pressure on the sealing surface slightly decreases, but the connection still maintain a good sealing performance through the whole tests. Finite element simulation can effectively simulate the ISO 13679 test procedure and obtain the stress and contact pressure distribution. It can be used as a reference for evaluating the performance of premium connections.
Fluid-solid Coupling Analysis of Jet Perforating Pressure Fluctuation Law based on AUTODYN

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Keywords: pressure fluctuation, fluid-solid coupling, jet perforating, law analysis, large deformation.

ABSTRACT

The great shock wave from detonation of jet perforation acts on the tubular column in the perforation section, which causes shock bending and shock failure accidents of tubular columns frequently. To interpret the pressure fluctuation law of jet perforation and provide references for dynamic response analysis of the tubular column in the perforation section, a finite element model of the combination of 7” ×12.65 mm P110 casing pipe and 2 7/8” ×7.82 mm P110 oil tubes was constructed by using the AUTODYN module. This model was used to simulate the fluid-solid coupling effect between perforating fluid and casing pipe and tubular column in the narrow long shaft under high-energy detonation. The peak energy after the first reflection of detonation wave was at the near end of packer, reaching 14528J/kg. It was 1.53 times of the initial impact wave energy (9471J/kg) at this point. The superposed energy was significantly higher than the initial impact wave energy. The perforating fluid density after the first reflection was increased by about 10% than the original density and by about 2% than the density when the detonation wave reached the point for the first time. The speed variation law of perforating fluid was related with its location. Due to the spaces generated by backfill detonation of perforating fluid, the back-flow velocity offset some impact speed. The speed of perforating fluid in the tubular column and annulus increased gradually as approaching to the packer, ranging between 110-148m/s. The perforating fluid speed in the annulus was significantly smaller than that in the tubular column. Due to the spaces generated by backfill detonation of perforating fluid, the back-flow velocity offset some impact pressure. Therefore, perforating fluid pressure in the tubular column and annulus increased gradually as approaching to the packer, ranging 216-406MPa. This verified the deduction of causes of shock bending and shock failure of perforating tubular column close to the pack.
Gradient and non-gradient-based first order reliability method for robust and accurate structural reliability analysis

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Keywords: Structural reliability analysis; First order reliability method (FORM); particle swarm optimization (PSO); harmony search optimization (HS); directional stability transformation method (DSTM).

ABSTRACT

The first order reliability method (FORM) may provide unstable and inaccurate results for gray/highly nonlinear performance functions. In this study, FORM approaches based on gradient and non-gradient methods are compared for both accuracy and robustness of results in nonlinear/complex reliability problems. Two gradient based sensitivity vectors using steepest descent search direction as (HL-RF) and directional stability transformation method (DSTM) are compared to two non-gradient approaches of harmony search optimization (HS) and particle swarm optimization (PSO). A refined probabilistic model using FORM is used for non-gradient optimization methods. The accuracy and robustness of FORM-based gradient formulations and refined FORM-based non-gradient approaches are compared on nonlinear/complex performance functions. The comparative results demonstrate that the PSO-based refined FORM provides accurate and robust results compared to FORM using HL-RF and DSTM. In addition to that, PSO shows superior performances compared to HS and gradient-FORM in complex engineering structures applications.
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Numerical and Experimental Dynamic Analysis of a Snow Shelter on a High-Speed Railway Bridge

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Keywords: steel snow shelter; railway bridge; aerodynamic pressure; resonance; snow cover.

ABSTRACT

Steel snow shelters are constructed to prevent snow cover on bridges that lie between high-speed railway tunnels. However, the dynamic behaviour of these structures as trains pass over the bridge remains an open problem because of its complexity [1]. To clarify the dynamics of steel snow shelters and verify their safety under a range of situations, we performed field measurements and numerical simulations of a steel snow shelter installed over a bridge.

Figure 1 shows the numerical models constructed in this study, which consider the aerodynamic loads around the moving train, the mass of snow on the roof, and the interactions between vehicle, the bridge, and the steel snow shelter [2]. Numerical model parameters of the Young’s modulus of the concrete and the peak aerodynamic values were chosen to match the results of field measurements. Simulations were run in DIASTARS III software developed for use in Japan’s Railway Technical Research Institute [3].

Figure 2 shows the validation of the simulation model against the experimental results. The strain responses at the bottom of the H-steel columns of the steel snow shelter as calculated by the simulations agree well with the measured values.

![Image](image1.png)

**Fig. 1.** (a) Numerical model for bridge and steel snow shelter; (b) numerical model for aerodynamic load around train.

Figure 2 shows the validation of the simulation model against the experimental results. The strain responses at the bottom of the H-steel columns of the steel snow shelter as calculated by the simulations agree well with the measured values.

![Image](image2.png)

**Fig. 2.** Experimental validation of numerical simulated stress at the bottom of H steel column.
Figure 3 (a) plots the maximum displacement of the bridge and steel snow shelter as a function of train speed. The horizontal displacement of the shelter corresponds to the magnitude of the aerodynamic loads around the train. However, in case of Ec=31 kN/m2, the maximum horizontal displacement increases rapidly around 260 km/h as the train resonates with the steel snow shelter. Figure 3 (b) illustrates how the bridge’s torsional response drives this resonance.

Figure 4 plots the effect of snow cover on the maximum stress generated in the inner flange at the bottom of the H-steel columns as a function of the train speed. The stress increases and the resonant train speed decreases as the amount of snow cover increases. Additionally, the strength limit of the flange at the bottom of the columns is about 150 N/mm2. The obtained results clarify that the maximum stress generated by a single train is far below the strength limit. However, assuming that the stress will be doubled if two trains pass over the bridge at once, the maximum stress of the H-steel with expected value of the maximum snow cover for 20 years may exceed the strength limit if the trains are travelling at 300 km/h. From Fig. 4, the maximum train speed would need to be under 260 km/h to ensure safety with expected value of the maximum snow cover for 20 years on the steel snow shelter.

Fig. 3. (a) Maximum displacement of bridge and steel snow shelter as the function of train speed; (b) traveling train induced shelter resonance via bridge response.

Fig. 4. Snow cover effect on the maximum stress of the inner flange at the bottom of H steel columns as the function of the train speed.

REFERENCES
Head injury of standing subway passengers and the optimization design of subway interior during a collision

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Keywords: Subway standing passengers; Secondary collision; Brain injuries; Numerical simulation; Optimization.

ABSTRACT

The subway passenger passive safety has recently become a widespread concern. The standing passenger in the subway may suffer severe brain injuries from the secondary contact with the ground. In this paper, three different standing passenger scenarios models are set up using MADYMO multi-body dynamics software. On this basis, head–ground impact processes are reconstructed using validated FE head models, and important biomechanical indices (e.g., coup pressures, contrecoup pressures, von Mises stress and shear stress) are extracted and analysed brain injury. Finally the subway interior parameters influence is studied and optimized, including handrail height (mm), friction coefficient and floor stiffness (MPa), using the response surface method (RSM) and the Adaptive Simulated Annealing (ASA). The results show that: (1) in the subway collision accident, the brain of the standing subway passengers is seriously injured, and the brain stem is the main part of brain damage (2) The change of the subway interior parameters has a great influence on the standing subway passenger brain injury. The degree of brain injury can be reduced by optimizing the subway interior parameters. This study could reveal the mechanism of brain injury and provide guidance for the subway safety design.
Fig. 2. Flow process diagram about the brain injury assessment.

| Table 1. | Brain injury biomechanical indexes of SSPs in three different postures. |
|------------------|------------------|------------------|------------------|------------------|
|                  | Intracranial pressure (kPa) | Von Mises stresses (kPa) | Shear stresses (kPa) |
|                  | coup pressure | contrecoup pressure |                        |
| horizontal handrail | 228.68        | -76.52             | 0.76                  | 0.44             |
| ring handrail      | 231.64        | -75.91             | 0.80                  | 0.49             |
| vertical handrail  | 242.56        | -68.32             | 0.82                  | 0.51             |

| Table 2. | Definition of the design variables for the interior parameters optimization. |
|------------------|------------------|------------------|------------------|------------------|
| Design variable  | Value             | Rang             | Variable name    |
| horizontal handrail | L=1850.0          | 1830.0-1950.0    | handrail height(mm) |
| ring handrail     | E=70000           | 35000-105000    | friction coefficient |
| vertical handrail | f=0.490           | 0.300-1.000     | floor stiffness(MPa) |

| Table 3. | Optimization results of minimum CP. |
|------------------|------------------|------------------|
| Optimal design parameters | Min. CP(kPa) |
| horizontal handrail | L=1950.0 mm, f=0.300, E=45319 MPa | 157.78 |
| ring handrail      | L=1950.0 mm, f=0.420, E=41975 MPa | 123.17 |
| vertical handrail  | L=1400.0 mm, f=0.760, E=35000 MPa | 137.95 |

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Ensuring Safety of Rail Transport under the Terms of the
Contact Interaction of the Wheel with the Rail

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Keywords: Contact interaction, Railway wheel, Traffic safety, Fatigue damage.

ABSTRACT

The railway wheel is a crucial element of the rolling stock. Traffic safety depends on the quality of its functioning. This paper reflects an attempt to theoretically predict the service life of the wheel with accounting for the conditions of its contact interaction with the rail.

The purpose of the work is to determine of the mileage of the wheel up to the moment of the occurrence of a defect in its rim.

According to the results of computer simulation of the processes of accumulation of contact fatigue damages in the wheel rim, quantitative estimates of their changes along the metal depth were determined. The results indicate the presence of two extremes in the distribution of the wheel service life over the rim depth - on the surface and at a depth of 4 ... 5 mm. This is consistent with observations: surface defects can be healed by wear; defects at depth can develop in the form of chisiterns, chipping, splitting of metal that can be eliminated during turning.
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Study of the influence of wind in weigh in motion of railway vehicles

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Keywords: Weigh-in-motion (WIM); Lateral Winds.

ABSTRACT

In the present paper, a study of the influence of the wind in the estimation of the axle loads of a railway vehicle was carried out. The study lies within the scope of the weigh in motion system developed in the PEDDIR project, in which the axle loads are indirectly determined through measurements obtained in strain gauges installed in the railway tracks, [1].

The objective of this study is to quantify the influence of the wind in the weigh in motion system’s accuracy and to determine above which velocity of this action the load measure is invalid. As a result, a relation between the wind and train speeds and the error obtained in the axle load measurements has been achieved. Above a certain wind intensity, the results must be carefully evaluated, since their error exceeds the limits defined by the EN 15654-1 [2]. This European Standard states two limits for this study depending on the train velocity, from 30 to 80 km/h it is defined a maximum permissible error of ±5,0 % and for 80 to 160 km/h of ±10,0 %.

The wind actions applied to the Alfa Pendular vehicle model were calculated considering only the static behavior despising any turbulence phenomenon. Both components of this action were applied, vertical and horizontal direction, as well as the moment generated by the discrepancy between the geometric center of the carbody surface and its gravity center. According to EN14067-6 [3], these actions are defined as the result of the wind pressure multiplied by the exposed area, mitigated by a vehicle aerodynamic coefficient, for each direction. These coefficients were obtained using the correlations from Baker et al. [4].

Several wind and train speeds have been considered in order to analyze their influence in the weighing error of the system. In this study, it was considered a simplified model of the ballast rail track. The algorithm used to solve the interaction problem, as well as the methodology applied to identify the operation loads revealed high levels of accuracy. The wheels’ numbers and the lateral wind’s direction of application are illustrated in the Fig. 1.

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Fig. 1 – Illustration of the lateral wind direction and the enumeration of the train wheels
RESULTS

In a first approach, the influence of the wind action was quite notorious even for a low train velocity, i.e. for 20 km/h and a wind action above 15 m/s the error exceed 5%. For higher train velocities, the weighing of the trains starts to deviate for lower wind velocities. Fig. 2 presents the error in the weighing for each wheel of the vehicle, and it is possible to verify the wheels from the back bogie are the ones that suffers the most deviation with the wind action.

Fig. 2 - Error in the weighing for each wheel of train’s right side

As shown in Fig. 3, the errors on both sides of the train are not equal, concluding that the discharge from the right side and the charge on the left side are not equivalent. Furthermore, the right side (the windward side) is the one that suffers the most discrepancies in the weighing.

Fig. 3 – Percentage of error for all the wind velocities in the first wheel of each bogie for each direction

REFERENCES

An improved backward statistical inference to fatigue assessment of high-speed railway structures

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Keywords: Probability percentiles; Small sample; High cycle fatigue; Railway vehicle; Welded structures.

ABSTRACT

Based on original backward statistical inference method, this work proposed an improved statistical inference approach (termed as ISIA) to fit the fatigue probabilistic S-N (P-S-N) curve with very finite life data or small sample problem. The novel scheme captures the optimal parameters that can efficiently express the relationship between life distribution and stress levels in terms of the search path. Meanwhile, the life standard deviation (SD) under different stress levels is obtained through the conversion of fatigue life. To formulate the more realistic P-S-N curve of full-size structures, the life distribution effect of small-size specimens is considered when fitting curves. Results show that the slope and intercept of newly-proposed fatigue P-S-N curve for (X-x-x-x) type life data exhibit a relative error less than 3%, and the predicted fatigue life is approximately 5% of the group method (TGM). Furthermore, the predicted life is only 0.1% of (x-x-x-x) type life data by the classical method (TCM). For the welded joints widely used into high-speed railway vehicles, the present ISIA can achieve more conservative and reliable life predictions. It is thus concluded that the newly-proposed ISIA can not only ensure the accuracy of life distribution particularly during high cycle fatigue regime but also acquire more conservative P-S-N curve as opposed to standard methods such as TGM and TCM.

Acknowledgements

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**Prediction of Contact Fatigue Damage to Rails by Computational-Experimental Methods**

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**Keywords:** Fatigue, Service life, Degradation process, Computational-experimental methods, Rails.

**ABSTRACT**

The assessment of the operational data related to the failure of rails showed that these failures are often caused by defects of contact-fatigue nature. The purpose of the work is to calculate the service life of the rails before the formation of contact fatigue cracks. The calculation was carried out using modern software systems such as MSC.MARC. Advanced modeling features of these programs have contributed to improvement of the quality of forecasting, and, consequently, to securing safety of railroad transport. As a result of this work, computer models have been developed that allow one to carry out more complete service life assessments, taking into account factors that previously were not taken into account.

This work was focused on the assessment of the reduction of service life of rails due to the increase of axial load; factors that have a dominant positive and negative influence on the degradation process are listed.
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Fatigue failure analysis of express freight full sliding side covered wagon based on rigid-flexibility model

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\textbf{Keywords:} Fatigue failure; Rigid-flexibility model; Full sliding side covered wagon; Experimental result; BS7608 standard.

\section*{ABSTRACT}

Express freight full sliding side covered wagon has become one development directions of the fast freight railway transportation. The full sliding side covered wagon not only has the advantage of hi-cube capacity but also has the characteristics of easy loading and uploading. The car-body stiffness is decreased for the full sliding side cannot support the main structure, so the resonance vibration of flexible car-body greatly affects the dynamics performances. The dynamic loads can lead to the initiation of fatigue cracks then eventually cause failure of the car-body. Vehicle system dynamics tests is combined with related experiment to study the fatigue failure of rigid-flexibility model of express freight full sliding side covered wagon which is excited with the track irregularity. In this paper, the confidence values of the rigid-flexibility model are improved by the consistency analysis with the experimental and numerical model of mode, acceleration and dynamic stress of sample car-body experiment. The fatigue parameters of BS7608 standard is employed to evaluate the fatigue life of key welding structure with a dynamic stress response of the flexibility carbody. The analysis has shown that it is possible to use the method at an appropriate stage on the anti-fatigue design of express freight full sliding side covered wagon.

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The influence of foreign object damage (FOD) on the fatigue strength of surface induction hardened axle steel

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Keywords: Foreign object damage; Induction hardened S38C axle steel; Fatigue strength; Morphology.

ABSTRACT

Foreign object damage (FOD) is one kind of factors leading to premature failure of railway axle. The effects of FOD on fatigue strength of high-speed railway axles is rarely found. In this work, the morphology of various damages on CRH2 axles was then investigated statistically. FOD was simulated by firing cubical projectiles to the specimen surface prepared from induction hardened S38C axle by a laboratory gas gun. Bearing steel and tungsten steel were selected for projectiles and impact velocity can change by adjusting the gas pressure. Geometrical parameters of FOD were quantitatively measured by 3-D microscope. The specimens were then subjected to fatigue testing until final fracture. Scanning electron microscopy (SEM) was used to characterize fracture features. It is found that FODs on the CRH2 axle surfaces can be divided into two sorts: scratches and notches. The depth of notches is larger than that of scratches and local deformation and material loss were found in the notches. Simulated experiment shows the majority of FODs by gearing steel are scratches and the effects on fatigue strength can be neglected. Tungsten steel cube vertex pierced into the surface and extruded local material out of target surface, left with tetrahedral notch. Fatigue strength of specimens impacted by tungsten steel projectiles at 100m/s declines by 40%, with little disparity compared with that of specimen damaged by higher speed. Stress concentration, micro-crack and adiabatic shear band responsible for the reduction of fatigue strength.

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Updated parallel computing strategies for nondeterministic dynamic analysis of railway bridges

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Keywords: dynamics; railway bridges; nondeterministic analysis; parallel computing; GPU.

ABSTRACT

Nondeterministic dynamic analysis of railway bridges is a field under continuous evolution due to the simultaneity of a number of current problems and capacities. In this regard, the main difficulty faced by bridge engineers is the uncertain nature of some key parameters that govern the dynamic behaviour of the bridge. Such dynamic behaviour has received increased attention since the appearance of high-speed railways, particularly due to possible resonance effects under train passages at speed greater than 200 km/h.

The prediction of the dynamic response has relied largely on a deterministic basis, with a considerable number of papers already published in renowned journals. But also some researchers have explored the possibilities of nondeterministic analysis, where parameters such as damping, cross-section inertia, area of the ballast layer, modulus of elasticity and stiffness of the bearings have been already identified as the ones with a largest influence on the dynamic response [1]. Also, in reference [2] the train running safety on short span bridges was analysed from a probabilistic point of view. Coincidently, both references [1] and [2] exploited the well-known Monte Carlo and Latin Hypercube techniques.

Environmental factors may as well influence the dynamic behaviour of a bridge in a way that it is difficult to quantify from a deterministic point of view. For example, in reference [3] the effects of seasonal temperature variations are analysed with a view to carrying out a reliability assessment. In a way similar to references [1-2], the methodology employed relies also on Monte Carlo and Latin Hypercube simulations.

As pointed out significantly during the public defence of [1], the time involved in the calculations required for nondeterministic analyses is a big issue that forces the researchers to keep the numerical models as simple as possible, in order to reduce the computer time required for each individual simulation.

Each individual simulation can be regarded as the passage of a given train, at a given speed, over the bridge with given properties of their mechanical/geometrical properties. If the train is simulated with a complete interaction model and the bridge is a multi-span viaduct, the total computer time may render the nondeterministic analysis unfeasible: an example where 15 different trains had to be simulated, at 15 different speeds, over 1000 random variations for a Monte Carlo analysis, would amount to a total of 225000 simulations. If each simulation took one minute to complete, one would need 156 days to complete the simulation. If fewer simulations were carried out for each bridge, say 500, each of them requiring 0.5 minutes, still one would need 39 days. And even if each simulation took only 6 seconds, one would need almost 8 days.

These figures are far too high to be acceptable in an engineering office nowadays. How long would be a “reasonable duration” for a busy engineer forced to wait for its nondeterministic analysis to end? This question is difficult to answer in an absolute sense. In order to grasp an order of magnitude consider the following situation: an engineer sends out an analysis on his computer at 18:00 hours and the analysis is
completed right at 8:00 when he is back in the office, so that he can exploit the results obtained by the computer during the night hours. Would that 14 hours computational cost be acceptable nowadays, or would that be considered a too slow analysis? Certainly it would be acceptable for a high responsibility calculation, but not for preliminary analyses where trial and error are essential in defining an initial solution.

But the preceding rough figures can be somewhat refined to give a more detailed view. During the design stage, a future bridge is analysed under multiple trains. Probably one will find 2-3 critical trains at certain critical speeds. For a good resolution in a nondeterministic analysis, where the properties of the bridge will vary in a random manner, one cannot choose only one “resonance” speed, but one needs at least a number of speeds around the expected peak. Therefore, considering 10-15 different values of speed is not unreasonable. So, the lowest prediction of the total computer time would be, for 500 simulations: (500 bridge samples) \times (3 trains) \times (10 speeds) \times (6 seconds) = 1.04 days, which is not bad but still very slow if a flexible workflow (trial and error) is required. Let aside if each simulation takes more than 6 seconds, or if one needs more that 500 bridge samples.

In general, it can be concluded that reducing the computational cost of nondeterministic analyses is essential for enabling the widespread use of these powerful techniques in engineering offices. That is precisely the main reason for this ongoing research. At the Universitat Politècnica de València, in cooperation with the Universitat Jaume I of Castellón, we have organized a multidisciplinary team of structural engineers, computer engineers and physicists with the aim of optimizing the computational procedures for developing nondeterministic dynamic analysis of railway bridges.

In a first effort, a train-bridge interaction code has been adapted to GPU resources. The main application, written in Fortran, has been refactored in order to capture all matrix multiplication operations within the application. A new C function has been compiled and linked with the Fortran code; the C function is called whenever a matrix multiplication is required. This function performs basic memory pointer conversions and then uses either the OpenCL or CUDA library function calls to perform the operation on the local GPU. Both OpenCL and CUDA libraries are supported in order to maximize portability to non-NVIDIA GPUs or to maximize performance by using the more advanced CUDA technology. More specifically, we have used optimized libraries for linear algebra operations such as cuBLAS and clBLAS.

In a second effort, the code has been adapted to a distributed system to be able to run on a cluster with varying number/types of GPUs. Basically, MPI programming model is used to launch server processes and kernel processes. A server process is in charge of receiving matrix multiplication requests and performing such operations on a local GPU. On the other hand, a kernel process is in charge of running the application for a set of input parameters and to trigger matrix multiplications to the server processes. To do this, the C function coded previously has been extended to support MPI communication with the server (servers) and to send matrix multiplication operations through the network. As future work we plan to optimize and balance matrix multiplication operations between all cluster resources, including GPUs and CPUs.

This work has allowed us to determine optimal matrix sizes in order to derive it to GPU, and compare total computer times in Monte Carlo simulations. For the sake of keeping the computational cost within reasonable limits that allow the development of the investigation, we have used a 2D train-bridge interaction model. The next steps of the work will make use of 3D interaction models where the capabilities of these new parallel strategies will be fully exploited.

REFERENCES

Experimental validations on the failure of bogie welded frame into metro railway vehicle

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Keywords: fatigue crack; welded frame; wheel polygon; rail corrugation; metro transportation.

ABSTRACT

With the increased attentions on energy consumption and manufacturing cost, high-speed railway has been a huge potential transportation. For high-speed railway, the bogie primarily consisting of welded frame and hollow axles is the most important load-bearing component in metro vehicles, which undergoes a variety of continuous and irregular load that changes randomly during operation. Under the continuous action of dynamic load, the bogie load-bearing components will produce cumulative fatigue damage that can potentially affect the operational safety of the metro [1-3]. By the end of 2017, the total operating mileage of urban rail transit in China was about 5539 km and is expected to exceed 9000 km by 2020. However, various problems have been observed during operation, such as the cracks occurred around the motor suspension seat, on the ATC suspension beam and positioning block. The positioning block was welded on the spring sleeve, the cracks initiated from the weld toe of the positioning block and propagated to the spring sleeve about 110mm, shown in Figs. 1.

Fig. 1. The picture of crack position of the spring sleeve

In order to find out the ultimate cause of the crack failure of metro bogie frames, failure analysis and track tests were carried out in the present study. Fracture morphology analysis and metallographic analysis were conducted to determine failure modes, and On-track test employed various strain gauges and acceleration sensors mounted on the bogie frame and axle boxes to obtain the acceleration and stress response information of the bogie. The fracture morphology of crack source is represented by the scanning electron microscopy shown in Fig. 2, where the parallel fatigue striations were observed at the fatigue crack source, which is the most conspicuous feature of fatigue failure.

Fig. 2. Micro-fracture morphology of the well-weld section
An intact section of the weld was prepared as a metallographic specimen. IMC digital dynamic signal acquisition system was employed in present study, the device has high precision and fast response, which can collect data continuously throughout the whole process, as shown in Fig. 3. The speed-time-frequency of point D02 is shown in Fig. 4. Fig. 5 gives the amplitude spectrum of the dynamic stress.

**Fig. 3.** Strain gauge points around the positioning block

**Fig. 4.** The speed-time-frequency diagram at point D02

**Fig. 5.** The amplitude spectrum of the dynamic stress

Systematic studies of fracture and metallographic analysis was employed to obtain failure modes and fracture characteristics of the weld toe of spring sleeve. On-track test was carried out to obtain acceleration and stress response information of the weld toe of spring sleeve. After that, the test data analysis in time domain and frequency domain was conducted. (1) The fracture properties of the weld toe of spring sleeve are representative of fatigue failure, micro-defects were observed in the failure region; (2) The dynamic stress response in frequency domain has obvious main frequencies and consistent with the speed, and dynamic stress on the spring sleeve of the side beam is highly coherent with the vibration acceleration of the axle box and frame in the time domain and frequency domain; (3) The vibration frequency generated by the wheel polygon and the rail corrugation phenomenon is highly coherent with the dominant frequency of dynamic stress at the cracked area, indicating that the wheel polygon and the rail corrugation phenomenon have a significant effect on the dynamic stress amplitude at the cracked area.

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An innovative approach for an inverse dynamic model of a freight wagon

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Keywords: freight train; on-board monitoring system; wheel/rail contact forces; inverse dynamic model;

ABSTRACT

Ensure a safety environment and a continuous sustainable operation system are key aspects for rail administrations and rolling stock companies. Unfortunately, Infrastructure managers are currently depending on inspection cars to assess the track geometry quality, leading to unnecessary constrains for the operation service administrators. Alternatively, these undesired restraints can be mitigated with the implementation of an on-board monitoring system in in-service vehicles. It is a reliable and non-invasive system capable of identifying both track and train operation conditions.

The purpose of this paper is to describe a first approach to the development of an inverse dynamic model of a freight wagon. Therefore, an experimental campaign was performed on a *Laagress* model that operates along all the *Beira Alta* line, as shown in Figure 1, providing more than 200km of raw data.

The on-board system consists of a set of eight accelerometers attached to the rear wheelset and the carbody and a group of five *LVDTs* used for measuring the relative displacements between them. Thus, the accelerometers were fixed on the left and right axleboxes and on the both sides of the carbody, according to the lateral and vertical direction as sketched in Figure 2. The *LVDTs* were divided in two groups, one per side, in Figure 2 is presented the right one. The raw signals were sampled at a 2 KHz rate and stored to be processed off-board in agreement with *EN14363* [1].

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*Fig. 1. a) wagon route; b) carbody with container*

*Fig. 2. a) Scheme of the monitoring sensors; b) LVDTs configuration*
In the meantime, a 3D numerical model of the freight train was developed considering an almost multibody formulation, as it is represented in Figure 3. Its geometric properties were obtained from the engineering drawings, whereas the mechanical ones were taken from the literature. Therefore, this model lacks calibration with uncertainties mainly related to the lateral dynamic behaviour.

![Fig. 3. Numerical vehicle model: a) 3D view; b) front view](image)

Even so, a numerical simulation was carried out considering the real irregularities profiles and some of the results are presented in Figure 4. Despite missing calibration, the numerical results revealed to be remarkably accurate when compared to the experimental ones.

![Fig. 4. Numerical vs Experimental results](image)

Finally, an inverse dynamic model based on the inertial responses was applied to the numerical results in order to determine the wheel/rail contact forces. The estimated forces were compared with the ones acquired from the numerical simulation, revealing a high level of accuracy. These results are exposed in Figure 5.

![Fig. 5. Numerical vs Inverse model results](image)

REFERENCES

Research on multidisciplinary fatigue optimization design method in structural design of high speed train

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Keywords: Multidisciplinary optimization; Multi-body dynamics; Finite element method; Multi-objective optimization; high-speed train.

ABSTRACT

Aiming at the shortcomings of single-discipline fatigue design and life prediction optimization design method for high-speed trains, considering the characteristics of structural design integrity, a durability analysis method for key structural components based on multidisciplinary fatigue optimization design is proposed. According to the characteristics of vibration fatigue and structural failure of key structural components of high-speed trains, the multi-disciplinary fatigue design of vehicle body components is carried out from the perspectives of materials, loads and structural design. In the research process, qualitative and quantitative analysis and comparison of multi-objective optimization analysis (MOO) and multi-disciplinary optimization (MDO) processes were carried out. At the same time, considering the actual example, considering the vibration characteristics of the vehicle structure, the typical load spectrum and the complex material characteristics, the failure characteristics of the structural components are analyzed in detail. The research results are shown that there are certain limitations in single-disciplinary fatigue design and analysis. In order to effectively solve the complex engineering structure failure problem, it is necessary to fully consider the vibration characteristics of the entire vehicle structure. Through the multi-disciplinary fatigue design and optimization method of high-speed train structural components, the safety and structural integrity of key structural components of rail transit can be better guaranteed.

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Influence of pit on the fatigue strength of surface induction hardened S38C axle steel

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Keywords: Surface induction hardening; Pit; Electron discharging corrosion; Four point bending fatigue; Axle steel.

ABSTRACT

To study the influence of pit on the fatigue strength of surface induction hardened S38C axle steel, the fatigue limit of specimens with variously depth electrical discharge corrosion and tungsten steel sphere indentation was tested respectively. The fractography was carried out by scanning electron microscope (SEM). The results show that the fatigue limit of specimens with electrical discharge corrosion was decreasing with depth of the pit and cracks initiate on the pit surface which is rough and brittle. The fatigue limit declined by 35% when the electrical discharge pit depth is 160μm, while tungsten steel ball indentation with the same depth has no effect on the fatigue limit. The finite element method (FEM) simulation result shows that the fatigue crack was avoided around the indentation with working harden and residual compressive stress distribution.

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The influence of laminar plasma surface strengthening on microstructure and rolling contact fatigue of high-speed wheel/rail steel

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Keywords: Rolling contact fatigue; Surface strengthening; Laminar Plasma; Wheel/Rail steel.

ABSTRACT

The plastic deformation and local microstructure changing are important reasons for rolling contact fatigue (RCF) damage of the high-speed railway wheel. The effect of surface strengthening on RCF behaviour of high-speed railway wheel steel is not clear. In this work, the surfaces of CRH3 wheel steel (ER8) and rail steel (U71MnG) were treated by Laminar Plasma Technology through Orthogonal Experiment Method. Moreover, the wheel/rail RCF behaviour was investigated with appropriate plasma process parameters. XRD and SEM were used to characterize the heat affected zone (HAZ) microstructure. Wheel/rail RCF behaviour was studied by 3-D microscope, SEM and TEM. Results show that the cross section of HAZ is crescent-shaped, the microstructure consists of martensite, retained austenite and undissolved ferrite, and the microhardness is significantly increased. Therefore, rail steel is easier to hardening than wheel steel. The plastic deformation and flow of wheel steel can be significantly suppressed during the rolling contact fatigue test, and the fatigue life is also extended. Due to local strain vary at interface, it is easy to initiate fatigue crack on the subsurface, then the crack gradually propagate to cause delamination of the hardened layer.

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Keywords: High-speed trains; Wheels; Interior noise; regression analysis.

ABSTRACT

The out-of-roundness is a periodic irregularity around the wheel circumstance. It frequently appears in the operating high-speed trains. Since it can cause severe accidents such as derailment, it has received great concerns from practitioners and researchers. Due to the fact that limited number of vibration censors are currently installed to capture the signals of out-of-roundness, measuring the interior noise of the train has become one alternative used by many maintenance works in China. However, there is still no scientific study to investigate the effectiveness of using interior noise to estimate the degree of out-of-roundness. In this preliminary study, we have investigated the relation between the power spectrum density of the main frequency of the interior noise and the high-order degree of out-of-roundness via regression analysis. With the data we obtained, we have discovered that the relation can be expressed as a logarithmic function.
Numerical simulation and test verification of new method for evaluating fatigue life of train coupler

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Keywords: Heavy truck; Coupler; Extended main S-N curve; Fatigue assessment.

ABSTRACT

New computational analysis method is proposed for the evaluation of the fatigue life for the heavy forklift truck coupler. The numerical simulation and experimental process of estimating the fatigue life of the coupler is introduced by using the extended main S-N curve method of casting structure. Consider the effect of plate thickness $t$, instead of $a_c$, and R ratio effect, the formula for correcting equivalence structural stresses of the truck couple is:

$$\Delta S_{mn} = \frac{\Delta \sigma_t}{a_c I(r)\sqrt{1-R}}$$  \hspace{1cm} (1)

Under the displacement control condition, $I(r)$ equation can be fitted into equation (2) and (3).

$$I(r) = \frac{1.23-0.364r-0.17r^2}{1.007-0.306r-0.178r^2}$$  \hspace{1cm} (2)

$$I(r) = 2.1549 \cdot r^6 - 5.0422 \cdot r^5 + 4.8002 \cdot r^4 - 2.0694 \cdot r^3 + 0.561 \cdot r^2 + 0.0097 \cdot r + 1.5426$$  \hspace{1cm} (3)

The formula for calculating fatigue life is:

$$N = \frac{C}{(\Delta S_{mn})^m}$$  \hspace{1cm} (4)

Above equation, $N$ is the fatigue life of hook structure, $\Delta S_{mn}$ is the combination of the range of membrane stress variation range and bending stress variation range, $C$ and $m$ are the parameter of material property.

The numerical simulation results and experimental process is shown in the following figures.

Figure 1. Finite model of coupler-to-pull ligands

Figure 2. The stress distribution of hook head
The extended main S-N curve fatigue method for the heavy loading truck hook can be obtained from the above works and the fatigue life predict S-N curve shown at figure 5.

\[ Y = 17811X^{-0.24} \]

The combination of the calculated finite element simulation results data and the experimental data results in a relatively accurate prediction of the fatigue life of the heavy truck S-N curve. The curve can be used to analyze and calculate the fatigue life of couplers (especially hook head) of different structures under the same material and process under different stress conditions.

REFERENCES


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On the residual life assessment of surface hardened S38C axles of high-speed railway vehicle

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Keywords: Damage tolerance design; Non-destructive inspection interval; Compressive residual stress; High-speed railway axles.

ABSTRACT

Basic mechanical properties, radial residual stress field and fatigue crack growth (FCG) data of the induction hardened S38C axle are acquired experimentally. The residual compressive stress is firstly rebuilt into the real axle model by the surface unit pressure method and iterative method. Based on measured FCG model and load spectrum, the residual life of S38C axle with assumed defects is thus evaluated in the framework of fracture mechanics. Results show that the negative residual stress has a considerable hindering effect on the crack growth before the crack fully penetrates the hardened layer. The crack located at the middle shaft is subjected to the compressive state that keeps the crack closed as long as the initial crack depth is smaller than 4 mm. By contrast, the crack would propagate rapidly once the depth is larger than 9 mm, and the lifetime of each stage will be less than 60,000 km. The remaining life predicted by standard Paris law and advanced NASGRO equation are about 285,000 km and 893,000 km, respectively. The calculated mileage can provide an important support to determining the non-destructive inspection intervals for the running safety of S38C axles.

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Safety assessment of a train running over the Volga River high speed railway bridge subjected to crosswinds

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Keywords: train running safety; crosswinds; stochastic wind model; train-bridge interaction; railways.

ABSTRACT

1. Introduction

With the continuous development of new high-speed railway (HSR) lines around the globe, the evaluation of the train running safety has become increasingly important in the engineering point of view. Strong crosswinds may further worsen the train running safety and, in a limit situation, cause the derailment of the vehicle. In the present paper, the train running safety against crosswinds on the new Volga River Bridge belonging to the future Russian HSR line between Moscow and Kazan is accessed.

2. Vehicle-structure interaction model

The train-structure dynamic interaction problem is solved using the direct method developed by [1]. In this method, the governing equilibrium equations of the vehicle and structure are complemented with additional constraint equations that relate the displacements of the contact nodes of the vehicle with the corresponding nodal displacements of the structure. Montenegro et al. [2] extended the formulation to take into account the geometry of the wheel and rail and the behavior of the contact interface.

3. Stochastic wind model

The Kaimal spectrum [3] has been considered in the present work to define the lateral component of the fluctuating wind. This spectrum density function $S_u$ is defined as

$$f S_u(z,f)$$

$$u_z^2 = \frac{200 x}{(1 + 50 x)^{5/3}}$$

$$x(z,f) = \frac{zf}{U_z}$$

where $f$ is the frequency, $u_z$ is the shear velocity of the flow, $z$ is the height relative to the ground and $U_z$ is the mean wind velocity at height $z$. In order to take into consideration the interdependence between the generated wind time-histories in the several points of the bridge deck, the coherence function proposed by Davenport [4] is adopted. The wind time-history $u(t)$ in each generation point is given by

$$u(t) = \sqrt{2} \sum_{i=1}^{N} \sqrt{S_u(f_i)} \Delta f \cos(2\pi f_i t + \theta_i)$$

where $\Delta f$ is frequency increment and $\theta_i$ is a random phase angle generated from an uniform distribution in the interval $[0,2\pi]$.

Figure 1 shows the wind forces applied to the bridge and train, respectively, as well as the wind speed vector acting on both sub-structures.
4. **Volga River Bridge and Results**

The Volga River Bridge consists of a prestressed concrete bridge formed by 4 continuous spans of $98 + 2 \times 190 + 98$ m. The deck consists of a cast-in-place box girder with 6200 mm width and height ranging from 5000 mm at the middle of each span to 12500 mm over the piers, as shown in Figure 2.

The crosswind stability of trains can be evaluated by analysing the critical wind speeds that the train can withstand before exceeding the unloading criteria (ratio between dynamic and static force of two wheel from one side of the bogie, as defined in [5]). When these critical wind speeds are plotted for different train speeds, the resulting graphic is denominated running safety chart. Figure 3 presents this chart relative to the Volga Bridge for train speeds ranging from 140 km/h to 420 km/h. By observing these charts, it is possible to conclude that the train safety is significantly dependent on both the train and wind speeds, since for the lower train speed the unloading criterion is exceed only for a mean wind speed of 26 m/s, while for the maximum speed, the train can safely withstand only with winds with mean speed up to 18 m/s.

**REFERENCES**


DOUBLE COMPOSITE ACTION SOLUTION APPLIED ON A BRIDGE SUBJECTED TO HIGH-SPEED TRAIN TRAFFIC

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Keywords: High-speed railways; Double composite action; Bridge dynamics; Railway bridges.

ABSTRACT

This study addresses the static and dynamic behavior of La Scarpe bridge inserted in the French high-speed line TGV Nord. The original structure, composed of a steel-concrete deck with structural typology of a continuous beam, was modified by addition of a concrete lower slab in the region of negative bending moment, transforming it into a structure known as double composite action. Such modification allows an economy mainly due to the increase in flexural and twist stiffness with lower steel expenditure. The concrete in the compressed region is introduced along the cross-section submitted to negative moment, while the section submitted to positive moment, may present reduction compared to the original structure, due to reduced efforts.

In high-speed railways systems, the double composite action structure stands out due to its efficiency, being currently applied in numerous bridges throughout Europe. In the literature, there are several studies seeking to evaluate the improvements presented by such structures [1], while others seek to study the design and construction method of the double composite action [2]. However, there are no studies in the literature showing the influence of this type of solution in the implicit running safety criteria proposed by European standards [3, 4], namely the bridge deformation and bridge vibration control criteria defined in EN1990 Annex A2 [3]. Therefore, the evaluation of the behavior of the double composite action solution in the dynamic and static characteristics of the viaduct, in particular in the indicators that implicitly analyze the running safety, and its comparison with more conventional solutions are an important outcome to the scientific community.

A methodology was first developed for static and dynamic evaluation of the original bridge’s deck considering the cracked and uncracked conditions of the deck. The proposed model was validated by comparing the results with the numerical and experimental data provided by Figueiredo [5]. In general, the numerical models developed for the cracked and uncracked decks showed good correlation with the numerical and experimental data provided by Figueiredo [5], indicating torsion modes similar to the experimental ones. Modeling was conducted through programming in the parametric design language (APDL) of the ANSYS® [6]. The model was developed with a three-dimensional mesh of finite elements in which the various structural elements of the deck are modeled using beam (BEAM188) and shell (SHELL181) elements assuming a linear elastic behavior of materials. The concrete slab is modeled using thin shell elements, which enables better evaluation of deformation effects due to shear stress in the slab plane, without definition of effective widths.

Subsequently, the methodology developed was applied to the deck with double composite action and the results were compared with those obtained in the conventional deck. The results of static and dynamic analyses showed that the structure with double composite action is more efficient than the conventional
composite deck, presenting a reduction of the vertical displacements and accelerations of the deck as show in Fig. 01.

![Graph showing maximum vertical accelerations](https://via.placeholder.com/150)

**Fig. 1.** Maximum Vertical acceleration in the deck: (a) existing solution and (b) double composite action solution.

Even adopting similar inertias for both models, the distribution of the bending moments proved to be more favorable in the alternative solution. In addition, improvement in the deck flexural stiffness and substantial increases in its torsional behavior were observed, especially when it comes to the asymmetrical loading (situation in which only one track is loaded by the train). Such improvement is due to the presence of the lower slab that closes the shear stress flow, thus making the section more similar to a box girder.

In terms of traffic stability criteria, the vertical acceleration of the double composite action deck presented better results than the existing, showing that, for this case, it could be a competitive solution. As expected, when verifying deck twist, the torsional stiffness proved to be higher in the double composite action deck, reducing the displacements up to 33.9% when comparing to the existing solution. The verification of the maximum vertical deformation of the deck, showed that for the symmetrical loading (two loaded tracks), the advantage of the double composite action deck is not so notorious (maximum deflections differences below 9%). However, when only one track is loaded, the differences between the maximum displacements obtained in the loaded beam are very significant, with a decrease in the double composite action deck higher than 20%. Lastly, although the passenger comfort is considered very good in all the spans of both solutions, the double composite action deck presents a better performance for this criterion. This occurs because the displacement that is used to indirectly assess the passenger comfort derives from an asymmetric loading, which is better supported by the alternative solution analyzed in the present work. Although a rigorous design calculation is necessary, the pre-dimensioning presented in this article showed a reduction of 12% in steel weight and a general improvement in the indicators used for safety evaluation. Thus, the double composite action solution may offer a competitive alternative to be considered when designing high-speed railway bridges.

**REFERENCES**

Stress state grade evaluation method for welded frame of railway rolling stock

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Keywords: Railway rolling stock; Welding joint; Anti-fatigue design; Stress state grade; Evaluation method.

ABSTRACT

Fatigue failure of welded joints is the main form of structural failure of railway rolling stock in service. BS EN15085-3, the main guiding standard for welding design, emphasizes that the stress state grade must be evaluated in the first design link in order to carry out the follow-up production and inspection work. But this standard does not give any specific methods for evaluating the stress state grade. Based on the theories of ASME-BPVC-VIII-2:2015, DVS 1612-2014, IIW-2008, this paper carries out the research on the evaluation method of stress state grade of welded joints for complex welded structures, and puts forward the evaluation method of stress state grade of welded joints based on different standard systems. In order to evaluate efficiently, C language and APDL language are used to program the stress state grade assessment method, and the stress state grade evaluation method of welded joints is verified in the design of welded frame of railway wagon.

As a typical complex welded structure, the frame welded joints has potential safety hazards of fatigue failure. So the feasibility of the evaluation method is verified by the frame. The structure and load-bearing characteristics of H-type welded frame of wagon are analyzed. A finite element model of hexahedron element of frame with welds is established. The supporting conditions and loads are consistent with the test outline. The load is carried out according to the fatigue test requirements of EN13749:2011. The fatigue analysis of the welded joints of the frame was carried out by combining the visual and fast screening function of Hyper-View module. By using the developed procedure for evaluating the stress state of welded joints, the stress state evaluation of welded joints of railway wagon welded frame is completed.

Based on ASME-BPVC-VIII-2:2015, DVS1612-2014, IIW-2008 standards, the stress grade of welded joints was evaluated. The rigor and applicability of stress state assessment of welded joints under different standards are compared. According to the stress state level, the location of welded joints with potential safety hazards can be optimized, which ensures the reliability of welded joints in the design stage. In this study, a multi-standard method for evaluating the stress state of welded joints with complex structures is proposed. In the process of anti-fatigue design of welded structures of rolling stock and other complex products, it has important engineering popularization value.
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Fatigue reliability analysis of motor hanger for high speed train based on Bayesian updating and subset simulation

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Keywords: Motor hanger; D-optimal experiment; Bayesian updating; Subset simulation; Fatigue strength; Fatigue reliability.

ABSTRACT

In order to improve the analysis accuracy of fatigue strength and reliability of motor hanger for high-speed train, Bayesian statistical method is introduced to propose a fatigue reliability analysis method for motor hanger based on Bayesian updating and subset simulation. Firstly, considering the influence of various uncertain parameters on the fatigue strength of motor hanger, the APDL language is used to establish the parametric model of the motor hanger. The D-optimal experiment design is carried out to calculate the fatigue strength of the motor hanger. Secondly, the least square method is used to fit experimental data to establish a polynomial response surface function which characterizes the fatigue strength of the motor hanger. Based on the MATLAB platform, Bayesian iteration is used to updating the fatigue strength deviation in the next stage, and the prediction accuracy is continuously corrected and improved. Finally, the subset simulation method is used to analyze the fatigue reliability. The research results show that the prediction accuracy is improved significantly after the fatigue of the motor hanger is corrected based on Bayesian updating. At the same time, the use of subset simulation improves the accuracy of reliability analysis. This method provides a new solution for fatigue reliability analysis of rail vehicles and their ancillary equipment.

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The influence of wheel polygonal wear on the fatigue life of railway wheelset axle shaft

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Keywords: wheel polygonal wear, coupled vehicle/track dynamic model, residual life of axle shaft, NASGRO.

ABSTRACT

Wheel polygonal wear, regarded as wheel radial irregularities along the wheel circumference, can lead to high frequency and high magnitude impact loads at the wheel/rail interface, especially under the high-speed operation. Such impact loads could excite some vibration modes of the wheelset axle shaft, and further contribute considerably to the dynamic stress in the wheelset axle shaft thereby low the fatigue life. In this study, a comprehensive coupled vehicle/track dynamic model consisting of a typical high-speed rail vehicle model and a slab track model is developed to study the influences of wheel polygonal wear on the dynamic stress developed in the wheelset axle shaft and its residual life time in the presence of initial crack. In the model, the wheelset and the slab track are modelled as flexible components through the modal approach, while the bogie frame and car body are treated as the rigid component. The validity of the proposed model is demonstrated through comparing the axle box acceleration with those obtained via a field test.

Through the proposed numerical model the effects of wheel polygonal wear on the stress state of wheelset axle shaft is investigated considering different vehicle speeds, wear amplitudes and harmonic orders so as to characterize stress cycles arising from the wheel polygonalization-induced impact loads. The results suggest that the high-order wheel polygonal wear can yield high magnitude wheel/rail contact force at the wheel/rail interface at a speed of 300 km/h, and further excite the secondary bending vibration modes of wheelset axle shaft, thereby contribute considerably to the dynamic stress developed in the wheelset axle shaft, as shown in Figure 1. The dynamic stress of wheelset axle shaft at a given point exhibits the combination of a low- and high-frequency dynamic stress. It is believed that the low frequency component is related to the bending stress caused by the wheel rotation, while the high frequency component is mainly due to the impact load cased by the high order wheel polygonal wear. It is thus expected the high order wheel polygonal wear can pose more significant influence on the bending stress of wheelset axle shaft when some bending vibration modes are excited. The EN standards (EN 13103/13104) in absent of considering wheel polygonal wear-induced loads could overestimate the fatigue lifetime of a wheelset axle shaft in the presence of wheel polygonalization, especially under high speed operating condition.

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Figure 1. Typical dynamic stress in the axle shaft due to the wheel polygonal wear.

Moreover, the NASGRO equation is further employed to evaluate the residual life time of axle shaft in the presence of pre-existing crack considering a typical load spectrum arising from track irregularities and wheel polygonal wear. It is expected that the obtained result can facilitate the development of maintenance interval in the presence of wheel polygonal wear.

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Failure mechanism and life assessment under defects
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Experimental study on low cycle fatigue life of hard alpha inclusion Ti-6Al-4V with different nitrogen content

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Keywords: titanium alloy, hard alpha inclusion, low cycle fatigue, nitrogen content.

ABSTRACT

The hard alpha inclusion in titanium alloy forming during the melting process is one of the main factors affecting its low cycle fatigue resistance. The hard alpha inclusion is composed of a compound of N, O and Ti, of which the microstructure appears to be similar with the alpha phase structure. The difference in the amount of nitrogen contained in the inclusions makes the hardness and elastic modulus different from the matrix. This results in a divergence of the stress field around the hard alpha inclusions with different nitrogen contents, which in turn affects the life of the crack initiation. Therefore, it is important to study the failure modes of hard alpha inclusion with different nitrogen content, aiming at the guidance for accurate fatigue life prediction.

In this paper, several hard alpha particles with different nitrogen content are artificially placed between two Ti-6Al-4V disks, which are then bonded together welding and hot isostatic pressing (HIP). During the HIP process, material at the interface melts and blends with the inclusions, resulting in a good representative of that in regular material fabrication. Samples were taken from the disk where inclusions exist, assisted by the nondestructive examination. In order to avoid the influence of the surface roughness on the test results, the surface of the test piece was uniformly polished.

Fractographic observations are conducted on the fracture surface after the low cycle fatigue test. It was found that cracks in some specimens originate from inclusions, while cracks in the others initiate from the surface of the specimens. After involving the distance between defects to specimen surface, it turns out that cracks tend to initiate from the inclusions as they locate close to the surface. When the inclusions are buried deep inside the specimens, the specimens with low-nitrogen-content inclusion tend to crack from the surface; while those with high-nitrogen-content tend to crack from the inclusions. This indicates that a competitive mechanism exists between the distance to surface and the nitrogen content of the inclusions in terms of crack initiation.
Analysis of toe-base fatigue in stud shear connectors:
the hot spot stress approach

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Keywords: Stud shear connector; Toe-base crack; Fatigue strength; Hot spot stress; FEA

ABSTRACT

The stud shear connector is one of the most widely used shear connectors owing to its higher capacity, obvious ductility and orientation-independent in plane shear property\textsuperscript{[1]}. The studs are usually connected with steel beam by welding. The geometric discontinuity and the notch effect of the welding zone make the stress concentration effect of the toe-base remarkable. In addition, the heat affect zone (HAZ) during welding process produces residual tensile stress which is not conducive to fatigue of the toe-base\textsuperscript{[2-4]}. Therefore, these factors make the welding zone become the key part of the anti-fatigue design of studs.

The hot spot stress method and the sub-model technology were used to predict the fatigue strength of the toe-base fatigue for studs\textsuperscript{[5-7]}. The factors affecting the hot spot stress amplitude of the base plate toe, such as element size, toe type, toe chamfer radius and Poisson’s ratio, are considered. The results show that the hot spot stress obtained by three-point quadratic extrapolation is about 12% larger than that by two-point linear extrapolation, as shown in Fig.1. When the chamfering radius is 2 mm, the hot spot stress amplitude of the welded toe decreases by about 35% compared with that without chamfering, as shown in Fig.2. The chamfering setting can improve the fatigue performance of the welded toe. The hot spot stress amplitude calculated by the biaxial strain considering Poisson effect is about 10% higher than that calculated by the uniaxial strain, as shown in Fig.3. The fatigue strength of weld toe of the base plate with the hot spot stress amplitude is FAT107, as shown in Fig.4. The hot spot stress amplitude method can be used to evaluate the fatigue strength of the stud weld toe on the base plate.
The three-point extrapolation hot spot stress method is written as Eq. (1):

$$\sigma_{hst} = 2.52\sigma_{0.4t} - 2.24\sigma_{0.9t} + 0.72\sigma_{1.4t}$$  \hspace{1cm} (1)

Two-point extrapolation hot spot stress method is written as Eq. (2):

$$\sigma_{hsl} = 1.67\sigma_{0.4t} - 0.67\sigma_{1.0t}$$  \hspace{1cm} (2)

The standard fatigue life curve is shown as Eq. (3):

$$\log \Delta \sigma_{ht}^* = 3.38 - 0.2144\log N$$  \hspace{1cm} (3)

**REFERENCES**


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Failure analysis and service life prediction of 80SH casing steel under thermal cycle service environment

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Keywords: Failure analysis; Life prediction; Thermal cycle; Low-cycle fatigue.

ABSTRACT

The main exploitation process of heavy oil is cyclic steam huff and puff. Cyclic operation causes cumulative damage to thermal recovery casing and causes a large number of failures. Failure analysis shows that the main failure factor of thermal recovery casing is the low cycle fatigue process caused by thermal cycle, which results in the decrease of strength of casing material, thus causing casing fracture and failure. Based on the failure analysis results, the low cycle fatigue tests of 80SH thermal recovery casing steel under different temperature, strain, pre-strain and other conditions were carried out. The influencing factors, life prediction model and criterion of service safety of casing materials under thermal recovery service conditions were first proposed, which provides a strong theoretical basis for the service safety design theory of thermal recovery casing materials. The research shows that the strain limit and low cycle fatigue life are the two core issues of service life. Life predictions need to satisfy two criteria. The first is the strain criterion. The strain limit should be lower than the total strain during the long service life. And the second is the low cycle fatigue criterion, which satisfies the expectation of low cycle fatigue life under the three conditions of strain, mean strain and temperature.
Fatigue lifetime prediction of cracked components using FM-TOOL/FM-PIPE software

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Keywords: fatigue; structural components; FEM; fatigue crack growth.

ABSTRACT

In the paper, the results of the experimental research of metallic components subjected to cyclic loading are presented. Based on the fatigue test results, the kinetic fatigue fracture diagrams (KFFDs) were determined and the fatigue lifetime of selected structural elements with defects was simulated in the numerical environment. Calculations were carried out using FEM (Finite Element Method) and the newly developed FMTOOL/FMPIPE tool - calculator (Fig. 1). The paper describes also the obtained differences and the application of various analytical models as well as the strategies of the precritical fatigue crack growth modelling.

Fig. 1. GUI of the fracture mechanics calculator developed by Nobo Solutions S.A.
Kinematic Accuracy Reliability Analysis for Aircraft Cabin Lock Considering Manufacturing Tolerances and Wear

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Keywords: kinematic accuracy reliability, aircraft cabin lock, manufacturing tolerance, wear.

ABSTRACT

Kinematic accuracy reliability is an important performance characteristic to evaluate the quality of motion mechanisms. For an aircraft cabin lock as the research object, the degradation of kinematic accuracy is a common failure mode of the aircraft cabin lock and it may cause that the lock hook can hardly hook the lock ring, which can lead to serious accidents. Therefore, this paper develops the kinematic accuracy reliability analysis for the aircraft cabin lock considering manufacturing tolerances and wear. Firstly, the kinematic accuracy function is derived through the analysis of functional principles of the aircraft cabin lock. Then, the manufacturing tolerances including the dimension tolerances and hinge clearances and accumulated wear damage in kinematic pairs are synthesized and introduced into the kinematic accuracy function. Finally, the reliability model is presented based on the limit state function. A practical application of an aircraft cabin lock is provided to illustrate the proposed method for reliability evaluation.
Low cycle fatigue life assessment of Ti-6Al-4V containing hard α gradient inclusions

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Keywords: titanium alloy, hard alpha inclusion, low cycle fatigue, Eshelby method.

ABSTRACT

Hard alpha inclusion is one of the typical defects in Ti-6Al-4V alloy, of which the shape, position and hardness are prominently different from the matrix, and have a great influence on the local stress field. In assessing the life of components containing inclusions, conventional methods generally ignore the effect of inclusion properties on crack initiation life and treat inclusions as cracks. Due to the singularity of crack tip stress filed, the equivalent crack method might contribute to an overestimated stress level around the inclusions, contributing to an underestimated fatigue life. Therefore, reasonable quantification of the inclusion properties and the local stress field is the key to accurately assess resistance to fatigue loadings.

In this paper, a low cycle fatigue test of Ti-6Al-4V alloy with hard alpha inclusions is carried out, which is then compared with the fatigue life prediction on equivalent cracks. The results show that equivalent crack method agrees well with the fatigue test for inclusions located near the specimen surface, and turns out to be smaller for inclusions inside the specimen. Moreover, the elastic modulus of different parts of the matrix and inclusions are measured by nano-indenter to identify the gradient properties of hard alpha inclusions. Above observations mean that the crack initiation process of the specimens with inclusions near the surface is relatively short; while the specimens with inclusions on the interior have a longer crack initiation process, and the crack initiation life of hard alpha inclusions cannot be neglected.

To further illustrate the influence from distance to surface and elastic modulus gradient, the Eshelby method is then employed to describe the local stress field around inclusions, which is therefore modified by the introduction of distance to surface and variant elastic modulus.
Modeling fatigue crack propagation based on uncertainty theory

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Keywords: fatigue; uncertainty; small samples; uncertainty theory; belief reliability

ABSTRACT

Fatigue is one of the most common failure mechanisms of mechanical systems, which has been widely noted and studied. The fatigue crack propagation law can be derived by carrying out fatigue crack propagation experiments (FCPE). But there exist uncertainties in FCPE, which will affect the cognition of fatigue crack propagation law. Meanwhile, when the number of experiment samples is small, it may lead to the lack of knowledge about population. Generally, imprecise probability methods are presented to quantify the uncertainty in the case of small samples, including Bayesian method, interval probability method, and fuzzy probability method. These imprecise probability methods assign the value space to the model parameters for describing the uncertainty. But the expression of the value space in most studies is greatly influenced by subjective information. There are interval expansion problems in the calculation process with these methods. Therefore, the problem how to quantify the uncertainties in FCPE with small samples has not been well solved. Uncertainty theory which is proposed by Prof. Liu can be used to quantify uncertainty in the case of small samples or even no samples [1]. In the framework of uncertainty theory, Kang et al. established the belief reliability theory [2]. Thus, in this paper, the uncertainty theory is utilized to quantify the uncertainties in FCPE with small samples, and an uncertain fatigue crack propagation model is proposed. The main research results of this paper are presented as follows.

The modelling foundation of this paper is the determinate fatigue crack propagation models (1)(2) considering crack closure and the retardation effect caused by overloads [3][4].

\[ \frac{da}{dN} = C \left( \Delta K_{\text{eff}} \right)^m, \Delta K_{\text{eff}} = K_{\max} - K_{\text{op}} \]  

where \( K \) is the stress intensity factor, \( \Delta K_{\text{eff}} \) is the effective stress intensity factor range, \( K_{\text{op}} \) is the stress intensity factor at the crack closure. \( da/dN \) is the crack propagation rate, \( C \) and \( m \) is the material parameters.

\[ \frac{\pi}{8} \left( \frac{K_{\text{op}} - K_{\min}}{\sigma_y} \right)^2 = \frac{\pi}{8} \left( \frac{K_{\max} - K_{\min}}{2\sigma_y} \right)^2 - \frac{\pi}{8} \left( \frac{K_{\max} - K_{\text{op}}}{2\sigma_y} \right)^2 \]  

where \( \sigma_y \) is the yield stress. When considering the retardation effect of overloads on the fatigue crack propagation, \( K_{\max} \) is expressed as the following formula.

\[ K_{\max} = Y \sigma_{\max} \sqrt{\pi a}, \quad \sigma_{\max} = \begin{cases} \sigma_{\text{ol}}, & \text{applying overloads} \\ \sigma_{\text{max}}, & \text{others} \end{cases} \]  

where \( \sigma_{\text{ol}} \) is the stress level of overload.

Based on the above models, the uncertainties in FCPE are considered. In terms of internal factors, there are individual differences in the material parameters of the samples with the same material. In addition, for external factors, there is uncertainty from overloads \( \sigma_{\text{ol}} \) in the load spectrum. This paper assumes that the material parameter \( C \) and the size of overloads \( \sigma_{\text{ol}} \) are uncertain variables. In the framework of the uncertainty theory, the normal uncertain distribution is used to describe them as equation (4). Combining the determinate fatigue crack propagation models with the quantification results of the uncertainties in FCPE with small samples, an uncertain fatigue crack propagation model is conducted. Based on the belief reliability theory, the uncertain fatigue crack propagation model is consist
of three equations, including degradation equation (5), margin equation (6) and metric equation (7). The degradation equation describes the mechanism of fatigue crack propagation. The margin equation is defined as the distance between the current crack length and the critical crack length. The metric equation is the quantification of the uncertainties in the degenerate equation and the margin equation, which measures the reliability.

\[
\Phi_e(c) = \left(1 + \exp\left(\frac{\pi (e_i - c)}{\sqrt{3} g_i}\right)\right)^{-1}, \quad \Phi_m(\sigma_a) = \left(1 + \exp\left(\frac{\pi (e_j - \sigma_a)}{\sqrt{3} g_j}\right)\right)^{-1}
\]

(4)

where \(\Phi\) is the uncertainty distribution, \(e_k, g_k\) \((k=1, 2)\) are the mean and standard deviation respectively.

\[
a_i = a_0 + \sum_{j=1}^{i} \Delta a_j = a_0 + \sum_{j=1}^{i} C (\Delta K_{eff,j})^n
\]

(5)

where \(a_0\) is the initial crack length, \(\Delta a\) is the crack propagation increment, \(i\) and \(j\) are the number of load cycles.

\[
M = a_i - a_c = a_0 - \sum_{j=1}^{i} C (\Delta K_{eff,j})^n
\]

(6)

where \(a_c\) is the critical crack length.

\[
R_b(N_f) = 1 - \Psi(N_f, e_1, g_1, e_2, g_2, m)
\]

(7)

where \(\Psi\) is the uncertain distribution of fatigue life, \(N_f\) is the number of load cycles.

To estimate the unknown parameter \(\Theta=(e_1, g_1, e_2, g_2, m)\), the uncertain statistics analysis is presented correspondingly. Then a simulation case is used to illustrate how to use the proposed model. Meanwhile, from discussions about the sensitivity of the proposed methodology to the sample sizes in Fig.1, it’s found that more samples will significantly contribute to more stable belief reliability evaluation.

![Fig. 1. The sensitivity of the proposed methodology to the sample sizes](image)

In this paper, the application of uncertainty theory to modelling the uncertainties in FCPE with small samples is a meaningful attempt, and has reference significance.

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The effect of crack-tip constraint in structural integrity assessment

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Keywords: Structural integrity, Fracture criterion, Crack growth, Mixed-mode loading, Non-singular T-stress components.

ABSTRACT

The effect of the crack-tip constraint parameters, namely, the non-singular T-stress components, in some problems of structural integrity assessment is discussed by means of two-parameter fracture mechanics concept.

The three-dimensional crack tip stresses including and stresses are incorporated into the von Mises yield criterion to describe the crack tip plastic zone. It is shown that there is strong effect of out-of-plane constraint (specimen thickness) on crack tip plastic zones.

The methodology of the criterion of average stress in the fracture process zone ahead of the notch tip is employed to develop failure assessment diagrams and the constraint-dependent fracture toughness for a solid with a finite notch/crack under mode I loading taking into account crack-tip constraint in terms of the non-singular T-stress. A validation study is made from results on through-thickness center-cracked plates made of different materials and tested in tension at various temperatures. The safety factor against fracture for a notch-like defect is introduced in basic equations of structural integrity as a function of the T-stress as well as the yield stress, the elastic stress concentration factor and the safety factor against plastic collapse.

The fatigue crack propagation law is written in the modified form taking into account the non-singular T-stress by means of the correction function. In this case, the T-stress reflects the crack-tip constraint. To describe the mutual effect of the externally applied stress and residual stresses on the crack-tip stress field, the well-known superposition method of the principle of linear elastic fracture mechanics is used. The effect of welding residual stresses on fatigue propagation of the internal surface semicircular crack is analyzed in the case of welded joint of the pipeline.

The local fracture criterion of the maximum average tangential stress in the vicinity of fracture process zone including two terms of the William’s series solution for the mixed mode I/II loading has been used for predicting the angle of surface crack growth under conditions of rolling-sliding.
**Study on welded joints stress state grade of aluminum alloy EMU body**

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**Keywords:** Aluminum alloy car body; Welding joint; DVS1608; IIW-2008; The stress level.

**ABSTRACT**

Using DVS1608-2011 and IIW-2008 and BS EN15085-3 standards, the stress state grade of welded joint of Aluminum Alloy EMU body of was studied. Firstly, the calculation methods of the stress state grade of aluminum alloy welded joints analyzed by DVS1608-2011 and IIW-2008 standards were studied, and the two methods were programmed by the APDL language of ANSYS. Then, the finite element model of Aluminum Alloy EMU body is established, and the static strength calculation result of the body is compared with the test result, and the error is basically within 10%. Finally, under the acceleration fatigue load provided by BS EN12663 standard, the fatigue analysis was carried out on the welded joint of the vehicle body, and the stress state of the welded joint of the vehicle body was studied according to IIW-2008 and DVS1608 standards respectively. The results show that the assessment method based on IIW-2008 standard is more rigorous, and the maximum stress factor of the longitudinal weld between the side beam and the side wall is 0.811, the position occurs in the area where the longitudinal weld of the side beam and the side wall is close to the lower door Angle. The stress state is medium, and the rest of the weld stress states are low.

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Notched fatigue evaluation of components under size effect

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Keywords: notch effect, size effect, relative stress gradient, fatigue, life prediction

ABSTRACT

Subjected to cyclic load conditions, engineering components generally fail at low stress levels owing to irreversible microplastic deformation followed by crack propagation and final fracture failure of the whole component. Crack normally initiates at regions with geometric discontinuities, which named as notches, often in the form of grooves, holes, keyways and fillets. Notches exert important influence on the fatigue life of cyclically loaded parts for their stress raising effects, which brings enormous challenges to mechanical integrity and service reliability assessment; but unfortunately, according to the functional demands for connection, transmission, assembly etc., macroscopic notches are virtually inevitable in real-life applications [1]. Another important influencing factor which always appear in pairs with notches is size effect. On the one hand, because of time and cost considerations as well as restrictions on test equipments, fatigue strength assessment of large-scale structures and components is usually performed based on experimental data derived from small-scale specimens, thus a proper transfer from small specimens to large-scale structures requires the consideration of size and stress-gradient induced micro notch effect [2], [3]. On the other hand, in engineering design, similar structures widely exist, taking the case of aeroengine, there are compressor and gas turbine blade-disc attachments of different scales, a model combing notch as well as size effect will make the analogy analysis possible, thus avoid repetitive work and shortening analysis time.

Geometry caused stress concentration contributes to inhomogeneous stress distribution. Whereas domains near the surface quickly reach yield strength and are therefore plastically strained, neighbouring material that is less stressed will support the highly stressed area thus shielding it [4]; therefore, traditional methods which only considers critical points no longer serve notch effect. To provide a better description, series of models have been developed, which can be summarized as: highly stressed volume-based approaches, stress gradient-based approaches, critical distance-based methods and average weighted stress methods [5]. Among them, average weighted stress methods, including stress field intensity approaches [6] and effective stress method [7], seems to provide reasonable description of contributions from the elements inside the effective volume to the fatigue process. However, methods considering the joint action of notch and size effect are still lacking. Recently, referring to effective stress method, Wang et al. [8] developed a stress gradient modified critical distance method, which seems to be a promising approach to account for combined notch and size effect of any geometry features. Specially, they noticed that the relative stress gradient presents a major influence on the average spacing of fatigue striations, which affirms its important role in both notch and size effect evaluation. However, it only
considers the average weighted stress on a single line, lacking of a comprehensive description of fatigue
damage in the whole fracture process volume; moreover, the extension still remains to be verified by a
wide range of notch geometries before its practical application, thus more thorough investigation are still
merited to push the work on this field forward.

In this work, by adopting the elasto-plasticity FE analysis, fatigue evaluation of metallic materials
considering the combination of notch and size effect are investigated. Inspired by the effective stress
method, this work attempts to evaluate the fatigue state with by weighting damage parameters of elements
inside the fracture process volume; coupling with a weight function related to relative stress gradient, a
weighted damage can be obtained which intends to characterize notch and size effect while maintaining
advantages of damage parameters in fatigue damage quantification. Specially, damage parameters of
several commonly used models, including SWT [9] criterion, Walker [10] criterion, etc., which consider
mean stress correction is employed. A comparison of the predicted results with experimental data of
TA19 alloy, 45# and Q235 steels specimens of different scales indicates a sound conformity and validates
the applicability of the method based on weighted damage parameter.

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Effect of Mn content on cyclic plastic behaviour of low-carbon bainitic steels

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Keywords: Fatigue, Low-cycle regime, Bainitic steel, SEM, TEM.

ABSTRACT

Bainitic steels are outstanding materials to meet the current demands of automotive and railway industries. Although the high added-value products of such industries are usually designed in a such a way that materials only deform in an elastic manner, local plastic deformation can occur at the geometric discontinuities. Especially in the case of critical geometric discontinuities, accurate structural integrity assessments require a deep knowledge of the cyclic plastic behaviour. Recent studies have demonstrated that the addition of Mn, in such alloys, prolongs the bainite transformation, particularly the incubation period, which changes the final microstructure and, therefore, the fatigue properties. In this ambit, a study relating the fatigue behaviour with the Mn content is of great interest. This paper aims to study the low-cycle fatigue behaviour of bainitic steels with various Mn contents, namely 0%, 2.3%, and 3.2%. Fully-reversed strain-controlled tests, at room temperature, are performed at strain amplitudes ranging from 0.6% to 1.0%. Before tests, microstructure is observed by SEM and TEM. The fatigue damage mechanisms associated with the different Mn contents are examined by SEM.
Environmental effect on structural integrity
H-IRAS2019-EESI

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Assessment of Local Stresses and Strains in Notched Components Subjected to Extreme Loading

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Keywords: notch, local stress; local strain; stress concentration factor; strain concentration factor.

ABSTRACT

As the processes of fracture of technical system’s components are usually initiated in stress concentration zones (such as fillets, holes, welds, grooves and keyholes that are commonly referred to as notches) a problem of assessment of stresses and strains in these zones becomes critical for securing structural integrity and safety of technical systems. Assessment of the material response to various loading scenarios in these zones is thus one of the key problems in ensuring structural integrity and safety. Such assessment should be carried out not only for the cases of normal loading regimes that cause elastic ($\epsilon<\epsilon_Y$) and limited elasto-plastic ($\epsilon<\epsilon_{lp} \sim 5\epsilon_Y$) response of the material in the notch zone, but also for the cases of extreme loading that causes extensive plastic strains and general yielding of the cross section when maximum local strains tend to fracture values that can reach up to $\epsilon_f \sim 50$–70\% or $20\epsilon_Y$. This will allow one to estimate residual strength and remaining lifetime of highly damaged structures [1, 2].

The accumulation of strain in post-yielding situation is a complicated task. Closed form solutions are only available for a relatively small number of specific cases. Three types of approaches are used in notch

![Stress strain conversion rules for different strain ranges](image)

1 – Stress-strain curve, 2 – Pseudoelastic states; 3 – Pseudoplastic states;

$\Phi_L$ is a linear SSCR, $\Phi_{M-G}$ is Molski and Glinka SSCR, $\Phi_{N}$ is a Neuber’s SSCR according to equation (1), $\Phi_M$ is a Makhutov’s SSCR according to equation (2); $\epsilon_{max}$ is maxim local strain at the notch root, $\sigma_{ef}$ and $\epsilon_{ef}$ are pseudoelastic stresses and strains at the notch root, $\sigma_{pf}$ and $\epsilon_{pf}$ are pseudoplastic stresses and strains at the notch root; I – range of elastic strains; II – range of limited plastic strains; III – range of extensive plastic strains

The accumulation of strain in post-yielding situation is a complicated task. Closed form solutions are only available for a relatively small number of specific cases. Three types of approaches are used in notch
mechanics: experimental strain measurements, numerical simulations, and approximate analytical methods also known as stress-strain conversion rules (SSCR) [3-6]. These SSCR include: the so cold linear rule that is based on the assumption that strain concentration factor is equal to theoretical stress concentration factor $K_{\varepsilon} = K_t$; Molski and Glinka (or Equivalent Strain Energy Density) method which assumes that the strain energy density in the notch root $W_\varepsilon$ is related to the energy density due to nominal stress and strain $W_n$ by a factor of $K_t^2$: $W_\varepsilon = K_t^2 W_n$, and Neuber rule which is the approximate analytical method that is the most widely used for estimation of the stress-strain behaviour of notched components upon local yielding occurs.

$$K_\sigma K_\varepsilon / K_t^2 = 1$$  

where $K_\sigma$ and $K_\varepsilon$ are stress and strain concentration factors in elasto-plastic region, $K_t$ – theoretical (elastic) stress concentration factor.

This method tends to overestimate local strains, but proved to be useful in predicting maximum local strains and stresses in case of limited plasticity when the extent of the plastic zone around the notch tip is small in comparison with the elastic area surrounding the plastic zone. However, the accuracy of the method drops considerably when extensive plastic strains develop.

The paper describes a modification of the Neuber rule that allows one to assess elasto-plastic material response at the notch root to extreme loading when maximum notch strains are close to fracture strain values and general yielding over the entire cross section occurs.

$$K_\sigma K_\varepsilon / K_t^2 = F(K_t, \sigma_n, m)$$

where $\sigma_n$ is nominal stress, $m$ is strain hardening exponent, $F(K_t, \sigma_n, m) = \left( \sigma_n / K_t \sigma_n \right)^{0.5(1-m)[1-(\sigma_n/\sigma_n - 1/K_t)]}$ is a correction function that was introduced into Neuber equation (1) on the basis of generalization of available numerical and analytical solutions as well as the estimation of a huge volume of experimental data [1, 2].

The proposed phenomenological model fits well to available experiment data on stress-strain response of material at the notch root in wide ranges of plastic strains. It allows describing the performance of the notched component not only under normal loading regimes but also to predict component behaviour when it is subjected to abnormal loads. The presented approach provides the opportunity to assess residual strength and remaining lifetime of highly damaged structures.

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Modeling of interface failure in a thermal barrier coating system on Ni-based superalloys

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Keywords: Ni-based superalloy; TBC system; interface; FEM; delamination mechanisms

ABSTRACT

Thermal barrier coatings (TBC) systems are widely used to protect turbine blades and other components of gas turbine engines from direct exposure to severe thermal loading. To reliably predict performance and service life of these systems, the better understanding of the TBC failure phenomena is required. The residual stresses developed during thermal cycling are of primary importance, as their magnitude and distribution govern the durability of TBC systems. The mechanisms controlling the durability and the damage evolution in TBC has been described \cite{1-2}, it has been shown that the residual stress analysis based on the real interface morphology provides more accurate results than those obtained with simplified structure models \cite{3}.

In the present work, finite element modeling is employed to study interface delamination mechanisms in TBC on a single-crystal Ni-based superalloy. The considered TBC system consists of four layers: the 2 mm thick substrate (ZhS 32), the 30 μm thick NiCoCrAlY-bond coat (BC), the 60 μm thick EB-PVD partially stabilized zirconia (ZrO\textsubscript{2}-7wt%Y\textsubscript{2}O\textsubscript{3}) top coat (TC), and α-Al\textsubscript{2}O\textsubscript{3} thermally grown oxide (TGO) of an average 7 μm thickness. A three-stage thermal cycle (heating at the rate of 0.5 °C/h, dwelling at 1100 °C for 22 h and cooling down to room temperature within 0.5 h) corresponding to the operating conditions of gas turbine blades is considered. No temperature gradient within the TBC system is implied.

Simulations are performed with geometry parameters corresponding to those obtained with microstructure analysis on TBC cross-sections of turbine blade samples after the high temperature cyclic oxidation (Fig. 1a). To evaluate the effect of the interface geometry on the residual stress state and interface delamination two cases of the TGO profile are analysed: regular sinusoidal undulation with constant thickness and abnormal (irregular) shape of TGO with symmetrical penetration into TC and BC layers. It is assumed that materials of all layers are homogeneous and isotropic. Substrate, TC and TGO are treated as viscous-elastic materials while BC exhibits an elastic and viscous-plastic behavior. The Norton power-law is employed to compute the creep rate. The temperature-dependent properties of the TBC components are taken from the literature sources \cite{4-6}.

The finite element model includes about 25000 eight-node generalized plane strain elements with the mesh refinement near the interfaces (Fig. 1b). Symmetry and periodicity boundary conditions are imposed on opposite lateral edges while the nodes at bottom are fixed along the y-direction. Cohesive zone elements are used to reproduce the crack initiation and propagation along the TGO/BC and TC/TGO interfaces. A mixed-mode cohesive law involving both normal and tangential surface separation is adopted in the model. For comparative purposes, the calculations without accounting the interface delamination are also carried out.
It has been found that the morphology of the TGO layer significantly influences not only the magnitude and distribution of thermal residual stress, as it was shown in our previous study [7], but also governs the mechanism of interface failure. For the regular TGO shape the debonding cracks occurring on cooling form at the peak of TGO/BC interface and at the valley of TC/TGO interface (Fig. 1c). Whereas only the TC/TGO interface delamination is observed in case of the irregular TGO profile which is consistent with the experimental findings. The extent of delamination is determined by the location of compressive stress normal to the interface. Possible scenarios of further crack propagation are discussed.

Interface delamination results in the stress distribution different from that for the TBC system with intact interfaces as there is less interaction between the layers with different thermomechanical properties. In general, the increase of compressive stress in TGO and decrease of tensile stress in the BC and TC layers are observed.

A parametrical study has been performed to assess the relative significance of different simulation parameters (bond coat plasticity, cooling rate, creep and interface strength characteristics) on the residual stress level, initiation and evolution of interface failure. The results of numerical calculations allow identifying possible mechanisms and regions of the TBC system failure.

**REFERENCES**


Displacement evaluation system based on video imaging and unmanned aerial vehicles

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Keywords: unmanned aerial vehicle (UAV); video camera; displacements; image processing; laboratory and field tests.

ABSTRACT

Structural integrity evaluation is regularly based on permanent or temporary monitoring systems, generating amounts of data that, after processing, enable the identification of structural performance indicators. These indicators will help facility managers on the adoption of the best strategies and practices in maintenance and rehabilitation of the structures under their responsibility.

In the particular case of high-rise structures, such as telecommunications towers, physical conditions exist that hinder or render completely impossible the measurement of displacements using contact systems, typically based on LVDT type transducers. In such cases non-contact systems are normally preferred, namely those based on video or laser technologies, mounted on unmanned aerial vehicles (UAV’s) \[1\].

On this research a contactless displacement measurement system is presented, based on video technology mounted on board of an UAV.

The setting of the measurement system presented includes a DJI Matrice 600 Pro UAV, a DJI Zenmuse X5 high-resolution video camera and a precision target for increased accuracy.

The UAV georeferencing is performed by means of a Real-Time Kinematic (RTK) precision geolocation system, with a base-station. Dynamic displacements corrections are estimated by means of a double integration of the measurements returned by the internal accelerometers installed on the UAV chassis.

An estimation of the target displacements is obtained using advanced image processing techniques based on Matlab\textsuperscript{®} Image Processing Toolbox\textsuperscript{®} (Fig. 1a).

Validation of the video acquisition and measurement system and the image processing technique was performed using both laboratory and field tests.

The laboratorial test involved the measurement of the displacements of the precision target mounted on a small-scale shake table with controlled sinusoidal movements. Displacements measurements were conducted using the test video system and a LVDT transducer. Results have shown a very good correspondence between the records obtained by both techniques, including the situation where the video system was mounted on the UAV \[2\].

The field test was conducted on the Monte da Virgem telecommunications tower (VN Gaia., Portugal). This tower has a 126 meters high bottom shaft made from reinforced concrete, on top of which
lies a 51 meters high steel pole, amounting to a total height of 177 meters. The test itself consisted on the evaluation of the horizontal displacements of the tower at an elevation of 104.4 meters under specific wind conditions inducing a significant amplification of the structural dynamic response [3]. Results have shown the efficiency and robustness of the video measurement system on exterior locations allowing the estimation of the tower maximum displacements under particularly challenging wind conditions (Fig. 1b). The video system displacement records have shown a very good correlation with the records obtained from the double integration of the accelerations recorded by an accelerometer installed on the tower. The installed accelerometer is a PCB, model 3713F112G capable of evaluating near 0 Hz (DC) frequencies, enabling the identification and recording of displacements for quasi-static movements effects.

![Fig. 1](image)  
**Fig. 1.** Video measurement system: a) precision target tracking; b) field test on the Monte da Virgem telecommunications tower.

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**ACKNOWLEDGMENTS**

The authors would like to express their deepest recognition to Altice and in particular to Eng. Jorge Garcia, for their support on the experimental campaigns conducted on the Monte da Virgem telecommunications tower.
Aerodynamic and Structural analysis on HAWT Blade using FSI method for low wind conditions

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Keywords: Renewable energy, Wind turbines, Aerodynamic analysis, Structural analysis, HAWT blade.

ABSTRACT

Wind turbines are the greatest invention in the field of renewable energy. Important parameter which improves the performance of wind turbine are its aerodynamic and structural stability, so to analyse these parameters under low wind condition must be simulated through Computational fluid dynamics (CFD) software where the blade analysis will be done and problem will be identified. In this paper wind turbine GE 1.5 XLE turbine which consist a hybrid blade which is made of S818 S825 and S826 at root mid and tip respectively is used to simulate in low wind speed environment. For this FSI (Fluid Solid Interaction) method can be used which works on governing equations of continuity and Navier-Stoke’s equation. In this work the CFD simulation as well as FEA simulation will be carried out one after another which gives us the fundamental results related wind turbine operation in desired environmental condition. CFD model is simulated using ANSYS-FLUENT module. As wind condition favours low wind speed regime in our study hence we can perform initial analytical study by using Blade Element Moment theory (BEM). The numerical solution will be carried out by simultaneously solving the three-dimensional continuity, momentum and the Navier-Stoke’s equations in a rotating reference frame using a standard non-linear k-ω SST solver, which shows the rotational. These three-dimensional models are used for predicting the performance of a horizontal axis wind turbine. FEA model is simulated using ANSYS- MECHANICAL module. In this structural analysis on wind turbine blade is performed for the wind load condition obtained from the CFD analysis. This gives result regarding total deformation, equivalent stress, force reaction and moment reaction being generated on the blade because of wind loading at low speed conditions, which results the performance of wind turbine at low wind conditions.
**Effect of cracks on dynamic parameters and lifetime of hydraulic units**

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**Keywords:** crack; hydraulic turbine; lifetime; runner; vibration state.

**ABSTRACT**

Traditionally, an indicator of the reliability and quality of the hydraulic unit operation is the vibration state. The vibration state monitoring of the hydraulic unit can be carried out periodically using a portable system, or on-line mode. Modern diagnostic or monitoring systems combine up to 200 sensors that record the state of the unit main parameters and the vibration at different points.

As practice shows, even the most advanced diagnostic systems of hydraulic units cannot identify cracks not only in the early stage but also having a long size. Fig. 1 shows examples of sufficiently long cracks in the blades of Francis hydraulic turbines, which were not detected by the diagnostic system, and were found only under the unit inspection during repair.

![a) Source [1] b) Source [2]](image_url)

**Fig. 1.** Examples of fatigue cracks in Francis turbine runner.

Presented on Fig. 1 cracks are typical examples of fatigue damage for the Francis turbine runner after long operation. They appear in the welding zone of blades to the hub or rim and, obviously, limit the hydraulic turbine lifetime [3]. The growth of cracks occurs as a result of the impact of variable hydrodynamic loads, so just the distribution of dynamic stresses in runner predominantly determine the hydraulic unit lifetime. However, determining the real dynamic stresses under the actual operating conditions of the hydraulic unit is a very difficult task even now.

A large number of experiments show that there is often no correlation between the parameters measured during vibration tests and the level of dynamic stresses in its main elements (see Fig. 2).
To research the effect of cracks on the hydraulic unit lifetime the dynamic system "runner – shaft – support bearings" of the vertical Francis hydraulic unit was studied. The following dynamic parameters characterizing the dynamic system response have been defined: the eigenvalues and corresponding mode shapes, participation factors, effective masses for each direction of excitation for each eigenvalue. Some results presented in Table 1.

Table 1. Dynamic parameters.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Eigenvalues, Hz</th>
<th>Participation factors</th>
<th>Effective masses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>Y</td>
<td>Z</td>
</tr>
<tr>
<td>1</td>
<td>16.74</td>
<td>149</td>
<td>80.7</td>
</tr>
<tr>
<td>2</td>
<td>16.74</td>
<td>-80.7</td>
<td>149</td>
</tr>
<tr>
<td>3</td>
<td>22.29</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>28.89</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Notice: X, Y, Z, Rx, Ry, Rz – the direction of movement and rotation relative to the coordinate axes

The calculations have shown that due to the high rigidity of the structure, the appearance of cracks very little effect on changes in the frequency spectrum or vibration amplitude. It was also found the presence of eigenvalues the excitation of which is not accompanied by a vibration response on the support bearings. For example, participation factors and effective masses at mode 4 in all directions (see Table 1) are equal to zero. At the same time, dynamic stresses in the runner blades act and they cause cracking in the zone of joint of the blades with the hub or rim.

This means that the existing diagnostic and monitoring systems do not allow identifying cracks and, accordingly, not allow to correctly assessing the lifetime of the hydraulic unit or the time of safe operation up to needed repair.

The conducted studies show the shortcomings of the existing diagnostic and monitoring systems of hydraulic units from the standpoint of lifetime assessment and make it possible to determine the priority directions of their development for the near future.

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Fatigue of Steel and Composite Structures
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Fatigue behaviour of notched carbon/epoxy laminates immersed in sea water

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Keywords: fatigue, Miner’s law, Fracture surfaces, Variable-amplitude tests, Sea water, notched carbon/epoxy laminates.

ABSTRACT

This paper aims at studying the fatigue response of notched carbon/epoxy laminates immersed in sea water subjected to cyclic loading. The specimens, whose geometry consisted of a rectangular bar with a central hole, were immersed in natural sea water for 35 and 60 days. Fatigue tests were conducted under pulsating constant-amplitude loading using sinusoidal waves and a frequency of 10 Hz. Fatigue tests for control samples, i.e. not immersed in sea water, were also performed. Digital image correlation techniques were used to evaluate the strain fields in the vicinity of the notch. After the tests, fracture surfaces were observed by Optical Microscopy to identify the main fatigue damage micro-mechanisms. Although the mass variations, relatively to the control samples, caused by water absorption were lower than 1%, significant losses in the fatigue endurance were found, more specifically 5% and 11% for the series of 35 and 60 days of immersion, respectively. Finally, variable-amplitude tests for different stress ratios and immersion exposure times were performed. Prediction based on the Miner’s law are in good agreement with the experimental observations.
Fatigue Properties of Advanced High Strength Steel Plate Welded by Hybrid Plasma Arc Welding

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Keywords: High Strength Steel, Hybrid Plasma Arc Welding, Gas Metal Arc Welding, Fatigue, Residual Stresses.

ABSTRACT

In this paper, an application of HPAW (hybrid plasma arc welding) in welding of AHSS (advanced high strength steel) Q500D in manufacturing industry is reported. The fatigue life of welding joints with HPAW and GMAW (gas metal arc welding) is investigated. To find out the difference of fatigue life, both optical microscope and electron microscope analysis are carried out.

Advanced high strength steel plate Q500D of 12mm thickness is obtained and sectioned to dimension of 800mm×150mm. Plates were joined by HPAW and GMAW, techniques at the flat position (1G / PA).

Table 1. The experimental results of fatigue life tests (Stress ratio R=0.1, test stress= 340MPa)

<table>
<thead>
<tr>
<th>Welding method</th>
<th>Sample number</th>
<th>Fatigue life (N/kC)</th>
<th>Test time/min</th>
<th>LgN</th>
<th>Average fatigue life/kC</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMAW</td>
<td>G-1</td>
<td>158.9</td>
<td>28</td>
<td>5.2011</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G-2</td>
<td>173.2</td>
<td>31</td>
<td>5.2385</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G-3</td>
<td>210.5</td>
<td>39</td>
<td>5.3233</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G-4</td>
<td>145.8</td>
<td>25</td>
<td>5.1638</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G-5</td>
<td>136.9</td>
<td>22</td>
<td>5.1364</td>
<td></td>
</tr>
<tr>
<td>HPAW</td>
<td>H-1</td>
<td>253.9</td>
<td>45</td>
<td>5.4047</td>
<td>165.06</td>
</tr>
<tr>
<td></td>
<td>H-2</td>
<td>272.8</td>
<td>54</td>
<td>5.4358</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H-3</td>
<td>223.2</td>
<td>42</td>
<td>5.3487</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H-4</td>
<td>286.2</td>
<td>58</td>
<td>5.4567</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H-5</td>
<td>264.7</td>
<td>51</td>
<td>5.4228</td>
<td>260.16</td>
</tr>
</tbody>
</table>

To get the fatigue life of welding joints, the plates were cut into standard test pieces according to GB/T 13816-1992. The fatigue life of welding joints is measured by QBG-400 high-frequency fatigue testing machine with the static loading of -400~+400kN, dynamic loading of 0~200kN and test frequency of 60~300Hz. The sample is clamped along with the axial direction, and stress of 340MPa in this paper is applied. When the crack is occurred, the fatigue life test is finished. However, to find out the reason, the sample with a fatigue crack is clamped with stress of 170MPa until the sample breaking apart. The values of fatigue life are shown in Table 1. The sample with the fracture surface is cut with the dimension of 60mm × 40mm × 12mm, and the fracture surface is observed with optical microscope and electron microscope in order to get fracture mechanism, which is shown in Figure 1.

As shown in Table 1, the fatigue life of welding joints with HPAW and GMAW are measured. It can be seen from Table 1 that with the same geometric dimensioning and the same stress of 340MPa, the average fatigue life of HPAW welding joint with 260.16 thousand is 57.62% longer than those of GMAW with 165.06 thousand. Furthermore, the maximum fatigue life of sample G-3 with GMAW is 210.5 thousand, which is shorter than the minimum fatigue life of sample H-3, which is 223.2 thousand. That is to say, all of the fatigue life values with HPAW are longer than those of GMAW. Furthermore, according to the reference [1], it can be obtained that in the 95% confidence interval, the fatigue life of welding joints with HPAW increased from 30.28% to 93.78% than those of GMAW.
As shown in Figure 1, Figure 1 (a1) and (b1) is fatigue fracture surface of welding joints of GMAW and HPAW, and the Figure 1 (a2) and (b2) is the partial enlarged view of (a1) and (b1). The reasons of the fatigue life of welding joints with HPAW being longer than those of GMAW can be concluded as follows. First and foremost, the proportion of crack origin (shown with red dashed line), crack extension area (shown with yellow dashed line) and interruption area (the other parts) is different with different welding method. And the proportion of interruption area with GMAW is larger than those of HPAW, which cause the crack propagation rate of welding joints with GMAW is larger than those of HPAW. Therefore, the sample of welding joint with GMAW is prone to fracture. Secondly, the crack origin of welding joint with GMAW is nearly welding seam, but those of HPAW is nearly base metal. That is to say, at the same stress of 340MPa, the welding joint of GMAW because of greater stress concentration in the welding toe is easier to fracture in comparison with those of HPAW. Last but not least, as shown in Figure 1 (a1), the sample of GMAW fractures from three crack origin, but the sample shown in Figure 1(b1) of HPAW fractures only one crack origin.

REFERENCES

Multiaxial fatigue life evaluation in notched components via a rapid elastic-plastic TSED approach

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Keywords: multiaxial fatigue; fatigue notch effect; total strain energy density.

ABSTRACT

Modern automotive industry, driven by recent environmental policies, faces an urgent need for the production of lighter vehicles with reduced fuel consumption and lower pollutant emissions [1]. In this challenging scenario, mainly due to their balanced features in terms of cost, strength-to-weight ratio, and corrosion resistance, high-strength steels remain key materials. Nevertheless, the complex design of most critical components in conjunction with adverse loading scenarios make such components very prone to fatigue failure [2,3]. Therefore, the development of new effective engineering approaches able to predict the fatigue lifetime quickly and at minimum cost can be an attractive solution to address the current challenges of industry. This paper proposes a rapid methodology to predict the fatigue life in notched components subjected to multiaxial loading histories on the basis of an effective value of the total strain energy density ($\Delta W_T$) evaluated at the notch region. The modus operandi (see Figure 1) consists of: (i) calculating the $\Delta W_T$ value at the notch region; (i) definition of an effective value through the Line Method of the Theory of Critical Distances [3]; and (iii) prediction of fatigue lifetime via a fatigue master curve relating the ($\Delta W_T$) with the number of cycles to failure [4].

In order to assess the accuracy of the proposed approach, a series of in-phase combined bending-torsion tests under pulsating loading conditions ($R=0$) were performed in cylindrical specimens with lateral U-shaped notches made of DIN 34CrNiMo6 high-strength steel. Multiaxial loading scenarios comprised bending moment to torsion moment ratios ($B/T$) equal to $B/T=2$, $B/T=1$, and $B/T=2/3$, and three orientations of the bending moment with respect to notch root ($\theta=0^\circ$, $\theta=45^\circ$, $\theta=90^\circ$). For each loading case, three stress levels were tested. The notch surface was monitored in situ to correlate the crack length with the number of cycles and, to define, in a subsequent stage, the number of cycles to crack initiation. Crack initiation length was defined via the El-Haddad [5] parameter ($a_0$) given by the following equation:

$$a_0 = \frac{1}{\pi} \left( \frac{\Delta K_{th}}{\Delta \sigma_0} \right)^2 \Longleftrightarrow a_0 = \frac{1}{\pi} \left( \frac{7.12}{353} \right)^2 \Longleftrightarrow a_0 = 129 \times 10^{-6} \text{ m} \Longleftrightarrow a_0 = 129 \mu\text{m}$$

(5.25)

where $\Delta K_{th}$ is the range of the threshold value of the stress intensity factor and $\Delta \sigma_0$ is the fatigue limit stress.

Fig. 1. Multiaxial fatigue life prediction model proposed in the current study.
range of the unnotched specimen. Complementary, an elastic-plastic finite-element model representative of the notched geometry used in the bending-torsion tests was developed. The cyclic response of the material was described via a purely kinematic elastic-plastic hardening model assuming two main premises: (i) the isotropic elastic behaviour is modelled by the generalised Hooke’s law; and (ii) the plastic behaviour is modelled by the von Mises yield criterion, coupled with an Armstrong-Frederick non-linear kinematic hardening law under an associated flow rule. The fatigue master curve was defined through a mixed-numerical approach from smooth samples, tested under uniaxial fully-reversed strain-controlled conditions with strain amplitudes in the range 0.5-2.0% [6].

Figure 2 plots the predicted fatigue lives against the experimental values for the different series of tests. For the sake of clarity, two scatter bands with factors of two were drawn, i.e. $N_p=2N_i$ and $N_i=2N_p$. As can be seen in the figure, both the experimental results and the numerical predictions are very well correlated; only a single case of the B=2T (0°) series is outside the delimited region. In addition, numerical lifetimes tend to be conservative which is interesting from a practical point of view. Furthermore, the proposed methodology leads to good predictions, either for both higher and lower lives, which is another positive aspect. In conclusion, the proposed approach that considers an effective value of the total strain energy density nearby the crack initiation site from elastic-plastic numerical models defined on the basis of the Line Method of the Theory of Critical Distances is adequate to correlate the fatigue lifetime with the number of cycles for lateral U-shaped notches undergoing in-phase combined bending-torsion loading.

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Local strain and intrinsic dissipation in HCF for stainless steel with welded joint

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Keywords: Welded joint; High cycle fatigue; Intrinsic dissipation; Fracture characteristics.

ABSTRACT

Welded structure is widely used in aerospace and transportation fields; however, the fatigue failure of welded joints restricts the safety application in engineering. The fatigue damage analysis from the energy point of view has a theoretical significance and practical application value for further understanding the fatigue failure mechanism of welded joints. In this paper, digital image correlation (DIC) and infrared thermography (IRT), were used to measure the deformation and surface temperature fields during high cycle fatigue of 310S stainless steel with welded joints. The DIC is used to observe the inhomogeneity of local deformation in the base material area and the welding area. The IRT provides the temperature augmentation distribution in the surface of the specimen and the intrinsic dissipation is calculated by solving the local heat diffusion equation. The test results showed that in the high stress area, the fatigue failure occurred mostly in the welded joint. On the contrary, in the low stress area, the fatigue failure occurred mostly in the heat affected zones (HAZ). The intrinsic dissipation and storage energy fields are given out to estimate the fatigue damage and to localize the crack initiation site.
NOVEL PRE-STRESSED HYBRID PRECAST FRAME (PHPF) WITH PLATE JOINTS

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Keywords: pre-stressed frames, precast structure, hybrid frames, extended end plates, column splicing.

ABSTRACT

The traditional PC (Precast Concrete) approach has the drawback of being difficult for connections. Steel frame construction offers the advantage of rapid construction, but suffers from high cost and lower fire resistance. The pre-stresses hybrid precast frame (PHPF) with joints implemented in steel frames is an innovative structural system which has been developed to overcome the shortcomings of traditional construction precast methods, offering the economic benefits of concrete and the constructability of structural steels. The PHPF is itself a pre-stressed hybrid composite structural system that maintains the advantages of both pre-stressed precast concrete structures and steel frames, improving productivity and quality of precast frames similar to those of steel frames.

The novel PHPF consists of pre-stressed precast concrete frames connected with metal plates at the end of precast members. The new technology combines steel and concrete with a structural solution for the economy of concrete construction with the speed of steel construction, offering advantages not only in structural stability, but also in constructability, cost-effectiveness, and environmental friendliness. The new construction method has proven to reduce cost by shortening the construction period, construction resources, and construction wastes. The reduced CO2 emissions relative to traditional structural systems were observed as well.

The PHPF method has also been shown to reduce the construction period by up to 30% (enabling construction of each floor in 3 - 4 days) compared with convention concrete construction while achieving cost savings of 2 - 10% and reducing construction waste with offering many other benefits. The bearing-wall system in new high-rise apartment construction can be replaced by the PHPF to reduce construction material quantity, eventually to increase productivity and cost savings by shortening the construction period. PHPF is based on Smart Green engineering and management technology which is an innovative approach developed for the increased constructability, productivity and economic feasibility. The engineering and management innovation embodied in the PHPF method can be verified by multiple patents in Korea.

The PHPF-related technologies developed to date represent considerable progress towards a novel building structural system and construction technology. Efforts with considerable success, however, are being made to further enhance the PHPF technology. The innovative PHPF technology is expected to make a significant contribution to the advancement of the construction industry as well as to environmental resource conservation.
Acknowledgements

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The Weibull and the Stüssi methods to model the Wöhler curves. Application on German antique bridges

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Keywords: Fatigue, Lifetime, Estimation, Weibull, Stüssi.

ABSTRACT

Preserving the structural integrity of historical bridges made of wrought iron is a mandatory technical requirement in several countries in Europe. A reliable fatigue lifetime estimation of these bridges allows to propose adequate maintenance policies to keep these historical structures as part of the patrimonial legacy for the next generations. In this paper, two models to depict the Wöhler curves are considered and their results are compared with those from the linear model of Basquin used in the international standards.

The estimation of the fatigue lifetime of antique steel bridges has been studied by several researchers [1], [2], [3], [4]. One alternative for predicting the fatigue life of steel structures is based on the Wöhler curves which are obtained from experimental fatigue data. Considering the stress based approach, several models have been proposed to represent the Wöhler curves. In this paper, two probabilistic models based on a Weibull distribution are considered.

The model proposed by Castillo et al. given by

\begin{equation}
F\left(\log N;\log \Delta \sigma\right) = p = 1 - \exp\left(-\left[\frac{\log (N - B)\left(\log \Delta \sigma - C\right)}{\delta}\right]^\beta\right)
\end{equation}

and the model proposed by Toasa and Ummenhofer which is based on the Stüssi equation given by

\begin{equation}
P = 1 - \exp\left(-\left[\frac{\Delta \sigma - R_n + aN^b\Delta \sigma}{1 + aN^b} - \alpha\right]^\beta\right)
\end{equation}

On the one hand, the model given by Eq. (1) describes properly the asymptotic behaviour of the fatigue life in VHCF. However in LCF the model cannot be applied. On the other hand, the model given by Eq. (2) describes properly the fatigue life in LCF but in VHCF it is much more conservative than the model of Castillo.

These models are applied on the experimental data obtained from seven German antique bridges. These bridges were made of wrought iron and built between 1850 and 1900. The obtained results are compared with the fatigue strength curve of Eurocode 3 (m = 3), the curve propose by Greiner and Taras (m = 5) and the model of Basquin applied in ISO 12107 and ASTM E739-10.
Based on the experimental results and on the comparisons mentioned above, it can be concluded that a suitable estimation of the fatigue life can be made by combining the Weibull model in VHCF and the Stüssi model in LCF.

Fig. 1. Wöhler curves for a failure probability of 5%, 50% and 95%.

REFERENCES


**Fatigue Behavior of Shear Connections with Preloaded Injection Bolts in a Bridge Strengthening Scenario**

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**Keywords:** Fatigue, Preloaded injection bolts, Strengthening, Puddle iron

**ABSTRACT**

Maintenance and safety assurance of old riveted bridges deserve special attention. These structures are prone to present high levels of structural degradation due to their long service life. Repairing and strengthening operations of old riveted steel bridges may use alternative fastening techniques, such as rivets, welding, high strength friction grip bolts, fitted bolts and injection bolts – see Figure 1. The mechanical performance of injection bolts has been demonstrated essentially based on quasi-static or creep tests, which strengthen the importance to assess its fatigue strength [1]. Injection bolts can be produced from standard bolts adapting them for the resin injection process [2].

![Injection bolt](image)

**Fig. 1.** Injection bolt.

Experimental fatigue tests were performed to assess the fatigue strength of bolted connections with preloaded injection bolts in comparison to bolted connections with preloaded high strength bolts in the context of a structural rehabilitation of an old metallic bridge. As is presented in Figure 2, specimens are composed of steel plates manufactured with new steel S355 and plates composed of puddled iron extracted from a centenary Portuguese bridge. A total of 45 specimens were tested varying the type of connections (single and double shear), type of bolt (injected and non-injected) and stress range (high, medium and low). Two M24 bolts of high strength class 10.9 were used and the bolt preload was determined as 70% of its ultimate tensile strength. The adhesive used for injection bolts was the epoxy based resin Sikadur®-52. Specimens were tested on a WALTERBAI Universal Testing Machine rated to 600 kN. All fatigue tests were carried out under load control with a stress R-ratio equal to 0.1. The test frequency was set to 5 Hz for all tests except for one high-cycle fatigue tests where test frequency was defined as 10 Hz.
For single shear specimens, fatigue failure was obtained in the puddle iron plate. The comparison between
the fatigue experimental data with the S-N curve proposed in EC3-1-9 [3] showed that this standard does
not represent a safe design criterion when the fatigue behavior is conditioned by old metallic materials. In
this case, there was no beneficial effect for injection bolts. For double shear specimens, fatigue failure
was obtained mainly in the S355 plate and, consequently, fatigue strength results are in accordance with
the design curve proposed in EC3-1-9 [3]. In this sense, a S-N curve was fitted to the obtained data with a
slope of $m = 5$. This proposal led to fatigue design curve for preloaded high strength bolts with a detail
category of $\Delta\sigma_C = 135$ MPa and a fatigue design curve for preloaded injection bolts with a detail category
of $\Delta\sigma_C = 170$ MPa, as shown in Table 1, which means an increase of 26\% when injection bolts are used.

![Fig. 2. Tested bolted connections: a) Single shear; b) Double shear.](image)

**Table 1.** Summary of proposed S-N curves and comparison with EC3-1-9.

<table>
<thead>
<tr>
<th>Single shear preloaded bolted connections</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of bolt</strong></td>
<td><strong>Conditioned by old metallic material</strong></td>
</tr>
<tr>
<td></td>
<td></td>
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<tr>
<td>Non-injected bolts</td>
<td>$m = 5$</td>
</tr>
<tr>
<td>Injection bolts</td>
<td>$m = 5$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Double shear preloaded bolted connections</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of bolt</strong></td>
<td><strong>Composed (but not conditioned by...) of old metallic material</strong></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-injected bolts</td>
<td>$m = 5$</td>
</tr>
<tr>
<td>Injection bolts</td>
<td>$m = 5$</td>
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</table>

**REFERENCES**


**ACKNOWLEDGMENTS**

The authors acknowledge the Portuguese Science Foundation (FCT) for the financial support through the post-doctoral grant SFRH/BPD/107825/2015. The authors gratefully acknowledge the funding of PROLIFE - Prolonging Life Time of Old Steel and Steel-Concrete Bridges (RFSR-CT-2015-00025) by Research Fund for Coal and Steel (RFCS).
Evolution of the design of iron and steel railway bridges in France at the end of the 19th century

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Keywords: fatigue; railway bridge; regulations; iron; steel

ABSTRACT

During the second half of the 19th century, advances in metallurgy and strength of materials led to changes in the regulations for the construction of metal bridges. Steel has competed with wrought iron and new experimental observations of metal characterization under cyclic loading have introduced the consideration of metal fatigue in the calculation of bridges. Indeed, it was after disasters like the collapse of the Tay Bridge in Scotland that the need to take into account variable loads (wind loads) was mentioned in the design of the bridges, and in particular for large spans bridges.

Based on Wöhler’s experiments (1860-1870), many simple calculation formulas have been proposed to take into account (working) stress variations in iron and steel elements of railway bridges. The 1891 French regulation introduced for the first time resistance criteria for wrought iron and steel parts that took cyclic loads into account [1].

With this regulation, the Ministère des Travaux Publics in France indicates, for instance, that for steel bridges the working stress limits (in kg/mm\(^2\)), in case of variable loadings are described in Eq. (1) for compression or tension loadings and in Eq. (2) for alternative tension and compression loadings.

\[ \sigma_{\text{lim}} = 8 + 4 \frac{A}{B} \] \hspace{1cm} (1)

\[ \sigma_{\text{lim}} = 8 - 4 \frac{C}{B} \] \hspace{1cm} (2)

A and B are respectively the minimum and the maximum loads to which the studied part is subjected.

B and C are respectively the maximum load (absolute value) supported by the studied part, and the maximum load in the opposite direction.

In addition, the 1891 regulation specifies for the first time the dimensioning of railway bridges from a type train. New type trains will be proposed in the next regulations, in 1915 and 1927.

The French railway network includes over 30 000 km of railway tracks and more than 5000 metallic bridges [2]. Since some of these bridges were built during the second half of the nineteenth century, they have been in service for over a century and they need adapted measures for their maintenance. Due to the increase of rolling speed and axle load, fatigue is one of the main phenomena to take into account in order to extend the safe service life of metallic bridges. In order to better understand how old bridges behave, SCNF Réseau has defined a specific Fatigue Agressivness Index which enables to compare the effect of different rolling stocks [3]. This index was tested for the abovementioned historical type trains (1891, 1915 and 1927) in comparison with type train that can be found in European norm EN 1991-2 and other modern trains.

For these calculations, a set of different real stringers was considered, including different periods of construction, different spans and inertias. The fatigue curve described by Taras and Greiner was also considered [4].
It appears that knowing the design rules of old metallic bridges and their evolution over time (including loads and material characteristics), allows to better understand the behaviour of structures that have more than 120 years of exploitation and that undergo periods of maintenance, restoration or even reinforcement.

REFERENCES


Case Study: Structural Safety and Stability of the Bridge on the Paraopeba River in Moeda – MG

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Keywords: Steel Bridges; Structural Safety; Numerical Analysis.

ABSTRACT

A railway bridge over Paraopeba river was built in Moeda – MG, however, the railway line to which it was destined to was deactivated and, in order to reuse it as a road bridge, a concrete deck was installed on it. Upon closer inspection, anomalies were revealed and its cause was found to be the installation of the new deck.

According to Jacinto et al. (2011) \cite{1}, the attention about existing bridges' safety has increased in the world technical and scientific community, partly because of the occurrence of major accidents involving these structures.

This work intends to contribute to the structural evaluation of steel bridges through numerical analysis. For this purpose, it was created a three-dimensional numerical finite element model of the structure using the SAP2000\textsuperscript{®} software, in which the acting loads were applied in accordance with the standards ABNT NBR 8800 \cite{2}, ABNT NBR 6123 \cite{3} and ABNT NBR 7188 \cite{4}.

![Bridge's Side View](image1)

**Fig. 1.** (a) bridge's side view; (b) bridge's three-dimensional numerical model.

Composed by ASTM A36 structural steel riveted profiles, the bridge is 57.0 meters main span length, 5.0 meters height, approximately 8.6 meters total height in relation to the level of the river, 5.9 meters width, and 4.5 meters distance between pillars.

Acting loads were applied on the structure according to \cite{2}, respecting the combinations and the necessary increase and reduction coefficients. Wind loads were calculated according to \cite{3}, for the basic speed of 32 m/s. The variable weight overload of the train-type was applied on the concrete deck in the four bridge's central spans, where, according to the load lines evaluated, they presented the worst loading hypotheses, which was expected because the bridge is simply supported. Table 1 presents the description of linearly applied loads and their respective values.
Table 1. Acting loads applied to the structure of the bridge.

<table>
<thead>
<tr>
<th>Acting load</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind to leeward (height of 8.0 m)</td>
<td>2,024 N/m</td>
</tr>
<tr>
<td>Wind to leeward (height of 13.6 m)</td>
<td>3,971 N/m</td>
</tr>
<tr>
<td>Wind to windward (height of 8.0 m)</td>
<td>1,446 N/m</td>
</tr>
<tr>
<td>Wind to windward (height of 13.6 m)</td>
<td>2,836 N/m</td>
</tr>
<tr>
<td>Train-type overload</td>
<td>600,000 N</td>
</tr>
</tbody>
</table>

The outcomes obtained by the model nonlinear analysis indicate the occurrence of buckling due to the axial compression load in some structural elements, a phenomenon also observed during the bridge first inspection, as explained in Fig. 2.

Fig. 2. (a) structural elements that reached the first failure mode; (b) bending of the pillars’ angle brackets; (c) bending of the truss diagonals.

Thus, in order to ensure that the bridge is safely reused, it is proposed as a structural reinforcement the locking of the truss diagonals and the pillars’ lateral locking of the three end spans, as shown in Fig. 3. In order to ensure a good working state, it is also suggested to place a warning sight on the bridge informing the maximum weight capacity.

Fig. 3. Structural reinforcement: (a) horizontal locking of the truss diagonals; (b) horizontal locking of the pillars.

REFERENCES

Fatigue crack propagation simulation of orthotropic bridge deck based on extended finite element method

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Keywords: Fatigue; XFEM; Crack propagation; Compact-Tension specimen; Orthotropic bridge deck.

ABSTRACT

Orthotropic Steel Decks (OSDs) are widely used in various types of steel bridges due to its benefits of light weight, high load bearing capacity and speedy construction. However, fatigue remains as the predominant problem for OSDs. Many researchers have investigated fatigue issues of welded joints through experiments but is not a cost-effective solution. Therefore, it is necessary to combine experimental data with numerical approaches. Fracture mechanics approach has already shown its reliability and can be used to model and analyze fatigue crack propagation. In this paper, two numerical simulations are performed to predict the fatigue crack propagation using extended finite element method (XFEM).

The first part deals with the fatigue crack propagation of a two-dimensional Compact-Tension (CT) specimen. Virtual Crack Closure Technique (VCCT) was used in the XFEM-based linear elastic fracture mechanics for crack propagation analysis by the direct cyclic approach and selecting Power Law mix-mode model to compute the equivalent fracture energy release rate. The crack propagation appears when the energy available for the crack is high enough to overcome the fracture resistance of the material. To evaluate the efficiency of the assumed material parameters, the numerical results of different stress ratios were compared with the results of the fatigue coupon tests [1] (see Figure 1). The numerical results provided a good agreement with a maximum difference of 0.03% in the slope (m) and 1.48% in the intercept (C) of the power law equation. It is noted that the material parameters and stress intensity factor distribution along the crack front need to be further investigated based on three-dimensional model.

Figure 1 Fatigue crack propagation rates obtained from the numerical simulation compared with the test results
In the second part, an automated simulation on fracture crack propagation of three-dimensional OSD structure is performed to predict the fatigue crack growth originating from the weld toe and propagating to the top of the deck plate. The simulated results of the crack propagation were calculated until half of the deck plate thickness assuming it to be the point of final failure [2] and validated against the beach marks measurement from the fatigue test [3] (see Figure 2). Paris constant C was predicted to be 55% lower than the IIW recommended value [4], when the numerical results are correlated with the beach marks measurement. In this study, a constant material property is assumed for a preliminary investigation and is applied using VCCT to the XFEM-model for the analysis. However, it is noted that the fatigue crack propagation rate is different for the base material, welds and HAZ zones and the Paris constants can differ at such location. Furthermore, the effect of residual stresses and micro-structure change will be further investigated in the future.

![Fatigue Crack Growth Obtained from XFEM Simulation](image)

**Figure 2** Fatigue crack growth obtained from XFEM simulation is fitted with test results in two sequences.

The Paris law implementation in ABAQUS® for material constant $C_3$ and $C_4$ were computed corresponding to the material constant $C$ and $m$ from the following relationship between strain energy release rate and stress intensity factor: $C_4=m/2$ and $C_3=C.E^*C_4$ where $E^*=E$ for plane stress condition and $E^*=E/(1-\nu^2)$ for plane strain condition.

**REFERENCES**


Fatigue crack growth in long term operated bridge metallic materials and strengthening solutions

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Keywords: Fatigue crack growth rate; Puddle iron; Strengthening; CFRP.

ABSTRACT

Structural integrity studies of old metallic bridges are essential to contribute for the state of knowledge related to their material mechanical properties and structural performance. One key aspect related to structural integrity of bridges is the fatigue behavior of its materials and structural components. Scientific investigations have been performed to characterize the fatigue crack growth behaviour of old steel extracted from civil engineering structures \cite{1,2,3}. Different methodologies can be implemented to extend the fatigue life of a structure. Implementing externally-bonded fibre reinforced polymer (FRP) plates has been studied as a methodology for repairing and strengthening steel structures with fatigue damages \cite{4}. The most relevant advantages of FRP materials to increase the fatigue strength of steel components are their very high strength-to-weight ratio and their excellent resistance to corrosion. A comparative study between standard fatigue strengthening techniques (such as stop hole, welding and bolting) and implementing FRP materials was performed by Jiao et al \cite{5}. They concluded that the fatigue life was significantly longer when FRP materials were used.

The implementation of fracture mechanics approach to assess the fatigue life of a structural element requires the evaluation of the stress intensity factor in order to compute the relevant fatigue crack growth rate. Generally, the stress intensity factor of steel plates reinforced with CFRP has been evaluated with FE method \cite{6}. According to Karbhari \cite{7}, the effectiveness of the reinforcement is higher for long cracks compared to short cracks, since the reduction of the stress intensity factor is not significant for short cracks. Wu et al. \cite{8} focused on developing formulas to compute the stress intensity factor (SIF) for centre-cracked tensile (CCT) specimen strengthened with CFRP strips. They developed and experimental validated correction factors in order to have into account the beneficial effects of CFRP bond width.

Scientific investigation on the fatigue crack growth behaviour of old metallic materials strengthened with FRP plates are still low. Lesiuk et al. \cite{9} conducted an experimental investigation using CT specimens. They were extracted from a centenary railway metallic bridge located in Kluczbork, Poland. Specimens were strengthened with CFRP patches bonded to the specimen with a two-component epoxy-based adhesive, named Sikadur®-31. The edge of CFRP patches were coincident with the crack tip and with its fibres oriented perpendicularly to the expected crack propagation path. This CFRP patches are commercially known as Sika®CarboDur®S1014/180. Two types of strengthening were studied as is presented in Figure 1: full-face patches and two 12 mm wide patches. Results showed that this solution can extend the fatigue life of metallic components. Full face reinforcement achieved longer fatigue life.
Numerical investigations were performed in order to determine SIF for strengthened and non-strengthened CT specimens. Finite element analyses were performed with 3D models using ABAQUS® software. SIF were computed for different values of crack length: 19 mm, 24 mm, 29 mm and 34 mm. It was observed, that both strengthening methodologies using CFRP patches contribute to reduce significantly the value of SIF, namely for longer crack lengths. When the crack is not in the zone covered by CFRP patches (a = 19 mm), the SIF reduction is low – which is clear from the physical point of view, but it increases significantly when the crack is longer. The difference between full face strengthening and two patches strengthening is not high. This study shows that using CFRP patches to improve the fatigue strength of materials can be a very good solution, however further investigation is needed especially concerning the interface properties between CFRP patches and old material component.

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Evaluation of biaxial (axial+torsional) high-cycle fatigue behaviour of S355 structural steel


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Keywords: Multiaxial fatigue; High-cycle fatigue, S355; structural steel

ABSTRACT

There are countless structural engineering applications where a multiaxial fatigue state can be identified. As it is well known, a multiaxial stress state is more critical and undesirable for any kind of structural element than a uniaxial stress state and, as such, it requires a special attention and evaluation of material behaviour.

In order to fulfil this idea, an experimental campaign was elaborated with the aim to test and evaluate biaxial high-cycle fatigue behaviour of S355 steel. This steel is mostly used in structural applications, such as wind turbine towers and bridges [1][2]. The most relevant mechanic properties of this steel can be found in Table 1, which is based on [3], and where $E$ is young modulus, $f_y$ is yield strength and $f_u$ is tensile strength.

<table>
<thead>
<tr>
<th>Table 1. S355 steel properties[3]</th>
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</thead>
<tbody>
<tr>
<td>$E$ (GPa)</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>211.60</td>
</tr>
</tbody>
</table>

This work aims to obtain experimental fatigue curves for different stress ratios ($R$), as well as, calculate a multiaxial fatigue damage parameter for a high cycle fatigue domain. The influence of a biaxial state and different kinds of loads (axial and torsional) in fatigue life will also be evaluated. Besides, experimental tests are carried out for various stress ratios to demonstrate and analyse how this parameter affects fatigue life. The impact of shear stress on fatigue behaviour of S355 steel is a relevant topic and it will also be a matter of study.

There were conducted two different tests: axial and biaxial (axial and torsional loads). An hourglass shape specimen with a minimum section area of 44.18 mm$^2$ was chosen for both axial and biaxial tests (Fig. 1). Experimental tests were carried out in force control, since it is desired to assess high-cycle fatigue domain. Besides, sinusoidal loads were applied with a frequency of 10Hz. For biaxial tests it is important to highlight that shear stress and normal stress signals are in phase, which, in other words, means that loading is proportional. Moreover, until now, shear stress value has been defined as half of normal stress value. The axial and biaxial tests were performed by MTS 810 testing system, which is characterized by a maximum capacity of 100 kN, and MTS 809 Axial/torsional test system with an axial maximum capacity of 50kN and torsional maximum capacity of 0.5 kN.m, respectively.
Experimental tests are still ongoing, and results obtained until now can be found in Table 2, where $\sigma_a$ is normal stress amplitude and $\tau_a$ is shear stress amplitude. In this way, it is expected to perform these experiments for other stress ratios as well as to change reason between shear stress and normal stress in order to assess impact of these parameters on fatigue behaviour of S355 steel. After that, a multiaxial fatigue damage parameter will be calculated based on a suitable high cycle fatigue criterion [4]. A deterministic curve and experimental results will be presented, and a finite element model will be developed with the aim of determine the maximum local stress state.

Table 2 Results obtained until now from biaxial (torsional+axial) and uniaxial (axial) tests

<table>
<thead>
<tr>
<th>Loading</th>
<th>Ratio</th>
<th>$\sigma_a$ [MPa]</th>
<th>$\tau_a$ [MPa]</th>
<th>Number of Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial+Torsional</td>
<td>0.01</td>
<td>174</td>
<td>87</td>
<td>313815</td>
</tr>
<tr>
<td>Axial+Torsional</td>
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Methodology for the Structural Integrity Assessment of the “Constitución de 1812” Bridge, over the Bay of Cádiz (Cádiz, Spain)

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Keywords: In-service inspection; Fissure; Inspection threshold size; BS7910; Structural redundancy.

ABSTRACT

According to the requirements of the latest standards for calculating structures and bridges in Spain, EHE-08 [1] and EAE-11 [2], the inspection and maintenance plan written up for the “Constitución de 1812” bridge, over the Cádiz bay [3], includes a section dedicated to the inspection of defects or cracks that can appear in the steel deck. The estimation of critical sizes for these defects has been made by performing a structural integrity assessment of the deck, based on the BS7910 [4] standard, obtaining critical crack sizes in the order of 6 mm [5]. In practice, these crack sizes cannot be detected by visual inspection, so a new methodology for the structural integrity assessment in bridges is proposed. This methodology consists, on the one hand, of using the highest possible analysis level of BS7910 [4] and, on the other hand, of using structural redundancy criteria to justify that the structure is in safe conditions even in the presence of visible cracks. The objective of the methodology is to provide a reasoned justification of the safety of the structure in the presence of defects or cracks that can be detected during a visual inspection.

This document defines the bases of the proposed methodology and establishes the criteria considered for the refined calculation with BS7910 [4] and for the structural redundancy. The methodology described below is defined with more detail in a flowchart. In each step of the flowchart, an increasingly refined calculation is carried out to justify a crack size exceeding the established inspection threshold or, failing that, to establish a lower inspection threshold.

REFINED CALCULATION WITH BS7910

BS7910 [4] has three levels of crack analysis, depending on the application and availability of material data. Option 1 is a conservative procedure, relatively simple to use and does not require detailed stress-strain data for the materials being analysed. Option 2 is based on the use of the stress-strain curve of the tensile test of the specific material, giving less conservative results. Option 3 uses numerical analysis to generate the material failure assessment diagram (FAD). The proposed methodology first considers the FAD defined in option 1 and, for successive iterations, uses the FAD options 2 and 3. Options 2 and 3 are more expensive to implement than Option 1 as they require specific laboratory testing and/or special simulation and material modelling calculations. The modified structural integrity assessment technique proposed here is based on the specifications of BS7910 with the following design and testing criteria:

- Refined FADs: Options 1 to 3 of BS7910 [4]
- Real material properties: yield stress and ultimate tensile stress obtained from the materials used on site. These values are slightly higher than those indicated in the standards, which means a slight increase in the load-bearing capacity of the structure. On the other hand, since these are actual data, they would not
be affected by the coefficient of reduction of the mechanical properties of the material required by the limit state calculation method.

- Real fracture toughness of the material: in a conventional calculation in bridge engineering, conservative estimations of toughness obtained from Charpy results are generally used. Instead of that, the proposed methodology proposes to consider the real value of the fracture toughness of the material of the specific structural element.
- Consideration of temperature: it is proposed to perform the fracture toughness tests of the material considering the historical temperature records in the area of the structure.
- Detailed calculation of residual stresses: the proposed methodology proposes to perform detailed analyses to accurately determine the residual stresses in the concrete joint.

**REDUNDANCY CRITERIA**

Redundancy in structures and bridges can be defined as the ability of a structural system to support loads after damage or failure of one or more of its members [6]. This capacity is conditioned by the ability of the structure to redistribute the loads from the damaged area, either in the transverse or longitudinal direction of the bridge.

Current regulations consider redundancy based on resistance modifying factors or load modifying factors. These factors are defined on the basis of a subjective assessment of the operational importance of the structure and of safety criteria.

The redundancy is based on the following design criteria:

- **Actions considered:** following the structural redundancy criteria of the NCHRP 406 report [7], it will be verified that the bridge has sufficient capacity to withstand the design stresses (dead loads + two H20 trucks + a distributed service load), values that are not factored.
- **Limit deformations:** the bridge design standards does not refer to the deformations to be considered when evaluating a damaged bridge. The NCHRP 406 [7] report proposes that in service, with an unfactored load, the maximum limit deflection should be $L/100$, as exceeding this value would make the bridge unsuitable for traffic. The value of $L/100$ can also be considered as a limit in the case of a damaged bridge.
- **Calculation models:** the analysis of the structural redundancy of a bridge requires the use of a structural model and a finite element package that considers the elastic and inelastic behaviour of the materials, as well as the possibility of a second geometric order analysis. The non-linear model can be used both for the analysis of an intact structure and for the study of different damage scenarios.

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Fatigue reliability evaluation of orthotropic steel bridge decks based on site-specific weigh-in-motion measurements

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Keywords: fatigue reliability; orthotropic bridge deck; weigh-in-motion.

ABSTRACT

The fast-growing traffic volumes and loads will become a safety hazard for existing bridges especially in developing countries. One of the problems induced by heavy traffic loads is the fatigue damage accumulation in the welded joints of steel bridges [1]. This study aims to develop a computational framework for fatigue reliability evaluation of orthotropic steel bridge decks using site-specific traffic data. Long-term monitored traffic data of a highway was utilized to simulate stochastic traffic load model, and the traffic growth ratio was also included to consider the future traffic. In order to solve the time-consuming problem in the bridge finite-element analysis using the traditional stress-spectrum simulation approach, a novel and efficient computational framework was presented based on neural networks. The proposed computational framework was subsequently utilized to evaluate fatigue reliability of the welded joints in a steel bridge deck. Numerical results show the efficiency and accuracy of the framework, where approximately 180 training samples is essential for training the 6-types of vehicle meta-models. When the annual growth rate of the traffic volume and the GVWs are both 0.5%, the fatigue reliability index of the bridge in the 100th year decrease from 5.94 to 2.87 and 0.92, respectively.

Reference

A perspective on the generalization of the Stüssi full-range fatigue model for various damage parameters

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Keywords: Fatigue, Wöhler Curve, Stüssi model, High-cycle fatigue, Low-cycle fatigue, damage parameters, metallic materials, structural details.

ABSTRACT

A new perspective on the generalization of the Stüssi full-range fatigue model [1] for various damage parameters is proposed. The Stüssi full-range fatigue model [1], for all fatigue regimes from very-low-cycle fatigue (VLCF) to very-high-cycle fatigue (VHCF), is based on stress damage criterion. Recently, Karunananda [2] proposed the generalization of the Kohout-Věchet (KV) fatigue model for strain fatigue damage parameter. Correia [3] has recently proposed the generalization of the Kohout-Věchet (KV) fatigue model for other fatigue damage parameters, such as, Smith-Watson-Topper (SWT) parameter, Walker-like strain parameter, energy-based parameter in uniaxial loading conditions, among others. As is well known, engineering structures are subject to different loading conditions, from quasi-static monotonic loading to long term dynamic/cyclic loading. As a rule, mechanical engineering structures are designed for high- (HCF) and low-cycle fatigue (LCF) regimes whereas civil engineering structures (e.g. railway and road steel bridges, offshore and onshore structures, logistics structures, etc.) are designed for high-cycle fatigue (HCF) regime. Recent studies have suggested the use of approaches based on stress and strain damage parameters to take into account low-cycle fatigue regimes [4].

In this way, a perspective on the generalization of the Stüssi full-range fatigue model for several fatigue damage parameters, to be used in fatigue life prediction of materials and structural details, is presented.

In the design codes [5], the fatigue Wohler’s or S-N curves are used to describe the fatigue behaviour of metallic structural details. The traditional S-N curve proposed by Basquin [6], covering medium- and high-cycle fatigue regimes, is given by

\[ \sigma = aN^b \]

where \( a \) and \( b \) are the fatigue strength coefficient and exponent, respectively. In the design codes [5], this law can be presented in the following form:

\[ \Delta \sigma \cdot N^m = C \]

where \( C \) and \( m \) are material constants.

The Kohout-Věchet (KV) fatigue model covers all fatigue regimes, low- (LCF) and high-cycle fatigue (HCF) regimes [7] and is given by the following relation:

\[ \sigma(N) = a \left( \frac{(N + B)C}{N + C} \right)^b \equiv \sigma_m \left( \frac{N + B}{N + C} \right)^b \equiv \sigma_1 \left( \frac{1 + N/B}{1 + N/C} \right)^b \]

(3)
where, where $a$ and $b$ are the Basquin parameters, $\sigma_{\infty}$ is the fatigue limit, $\sigma_1$ is the ultimate tensile strength, $B$ is the number of cycles corresponding to the intersection of the tangent line of the finite life region and the horizontal asymptote of the ultimate tensile strength, and $C$ is the number of cycles corresponding to the intersection of the tangent line of the finite life region and the horizontal asymptote of the fatigue limit. Thus, Correia-Kohout-Věchet (CKV) fatigue model [3] for several fatigue damage parameters based on stress, strain and energy is given by

$$
\psi(N) = \psi_e \left( \frac{N + N_u}{N + N_e} \right)^b \equiv \psi^{ULCF} \left( \frac{(N + N_u)N_e}{N + N_e} \right)^b \equiv \psi^{UHCF} \left( \frac{1 + N/N_u}{1 + N/N_e} \right)^b
$$

(4)

where $\psi_e$ is the limit fatigue damage parameter, $\psi^{ULCF}$ is the ultimate fatigue damage parameter for the low-cycle fatigue regime, and $\psi^{UHCF}$ is the ultimate fatigue damage parameter for the high-cycle fatigue regime.

The nonlinear equation of the S-N curve for metallic materials proposed by Stüssi [1] is given by:

$$
\Delta \sigma = R_m + aN^b \Delta \sigma_{\infty} \frac{1}{1 + aN^b}
$$

(5)

where $\Delta \sigma$ is the stress range during the fatigue test, $N$ the number of cycles to failure, $R_m$ ultimate tensile strength, $\Delta \sigma_{\infty}$ the fatigue threshold, and $a$ and $b$ the geometric parameters of the material. In this sense, using the assumptions of CKV fatigue model, a perspective on the generalization of the Stüssi full-range fatigue model can be made and expressed by

$$
\psi(N) = \psi_m + aN^b \psi_{\infty} \frac{1}{1 + aN^b}
$$

(6)

where, $\psi$ is the fatigue damage parameter that can be based on stress, strain and energy, $\psi_m$ is the ultimate fatigue damage parameter for the low-cycle fatigue regime and $\psi_{\infty}$ is the ultimate fatigue damage parameter for the high-cycle fatigue regime. The parameters $\psi_m$ and $\psi_{\infty}$ can take the form proposed by Correia [3] depending on the damage parameter under consideration (stress, strain, energy, etc.).

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Application of carbon fiber-reinforced polymers for fatigue strengthening of an existing railway metallic bridge

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Keywords: Fatigue; Wöhler Curve; Railway steel bridges; FRP plates; Reinforced critical structural details.

ABSTRACT

The main concern in old railway riveted metallic bridges, from the 19\textsuperscript{th} and 20\textsuperscript{th} centuries, that are still operating, is the fatigue damage due to the long operational period they have been subjected (often for economic reasons), along with the increase of traffic intensity, which can reduce substantially the strength of these structures. Many old railway riveted steel bridges are considered historical structures in which structural modifications affecting the original structure need to be avoided. Traditional reinforcement methods are based on the application of steel plates that are bolted or welded to the original structural members. Problems associated with the use of these techniques have led to the increasing use of fiber-reinforced polymer (FRP) plates. The composite construction system was developed in the 1980s with the use of FRP plates in structural members that can be assembled into a wide range of high performance structures. The fatigue strengthening and assessment of railway metallic bridges using fiber-reinforced polymers has not yet been studied \cite{1}.

In this paper, fatigue analysis of a critical detail reinforced by carbon fiber-reinforced polymers (CFRP) plates of the Bristol Bridge is presented. This critical detail with some cracks were identified by British Rail Network. The fatigue analysis is based on design rules proposed by EN1993-1-9 standard \cite{2} where the fatigue damage evaluation is obtained using the Palmgren-Miner rule and the design S-N curve ($\Delta\sigma_c=112\text{MPa}$, $m_1=3$ and $m_2=5$) for a typical connection reinforced with CFRP plates proposed by Hu-Feng-Zhao \cite{3}. A static analysis, using different types of fatigue trains present in EN1991-2 \cite{4}, with aim to obtain stress-time history in the critical structural detail were carried out. The stress values were multiplied by dynamic amplification coefficient in order to take into account the dynamic characteristics of the loading as proposed by EN1991-2 standard (Annex D) \cite{4}. The count of cycles from stress-time history was made based on the rainflow counting algorithm using FDT (fatigue damage tool) software as well as fatigue damage accumulation evaluation. Finally, a comparison of the fatigue damage accumulation results obtained for the critical details non-reinforced and reinforced with CFRP plates is made.

Bristol Bridge is located in the Stonehouse region of Gloucestershire, which connects the cities of Bristol and Gloucester under the A419 road between the cities of Newton and Stonehouse (see Figure 1). There is no record date for the original construction of the bridge, although it was completely rebuilt in 1973. This 25-meter-length bridge has an effective span equal to 22 meters, positioned at a height of 5.31 meters and a slope of 14.5\textdegree. There are walkways with steel plate decks cantilevered off both sides of the deck. The box girders are supported on steel block bearing plinths on concrete bearing shelves. The abutments and wingwalls are made of reinforced concrete with masonry facings. The parapets comprise steel post and rails at the edges of the cantilever walkways.
The last inspections of the bridge were carried out in 2017 and 2018 by the responsible entity, British Rail Network. From the document drawn up based on one of the inspections to the bridge it was possible to identify the geometries for the cross-sections. This railway bridge was built with S265 steel ($E=270 \text{GPa}$) and has 6 different cross-sections for the box girder. The crossbeams are in I cross-section and the connection between cross girder and stringer is made using an inverted T cross-section (see Figure 2c).

Structural modelling of the Bristol bridge deck was performed in Robot® software (version 2019) using 3D beam elements. Figures 2a) and 2b) shows the global structural model with the identification of the structural details under consideration, respectively. In Figures 2c) and 2d), the cross-section of the critical detail without and with CFRP plates (at mid span), respectively, can be shown. In this analysis, the train types used are based on the EN 1991-2 Annex D, since there are no records available on the types of train that have been passed over the bridge. The CFRP plates used to reinforce critical steel structural details on both sides of the cross section are produced by Sika® and are called CarboDur® ($E=270 \text{GPa}$ and $t=1.2 \text{mm}$).

In Table 1 are presented the values of fatigue damage accumulation evaluation for different rail traffic scenarios and considering the critical steel structural detail (at mid span) non-reinforced and reinforced with CFRP plates. The increase of fatigue life can be verified in the order of 40% to 50% depending on the loading scenarios, light and heavy, respectively.

In Figures 3 and 4, the influences of the speed of movement of the trains as well as increase of the thickness of CFRP plates in the fatigue damage accumulation assessment, respectively, are presented (critical detail at mid span). The results show that the speed of movement of the trains is very important in the evaluation of fatigue damage accumulation on the other hand, increasing the thickness of the CFRP plates was found to have little effect.
Table 1. Damage evaluation for different rail traffic scenarios.

<table>
<thead>
<tr>
<th>Damage evaluation</th>
<th>Light</th>
<th>Rail traffic Standard</th>
<th>Heavy</th>
</tr>
</thead>
<tbody>
<tr>
<td>per day without CFRP plates</td>
<td>2.581E-04</td>
<td>1.010E-03</td>
<td>1.202E-03</td>
</tr>
<tr>
<td>per year without CFRP plates</td>
<td>9.421E-02</td>
<td>3.685E-01</td>
<td>4.387E-01</td>
</tr>
<tr>
<td>years without CFRP plates</td>
<td>10.6</td>
<td>2.7</td>
<td>2.3</td>
</tr>
<tr>
<td>per day with CFRP plates</td>
<td>1.205E-04</td>
<td>5.770E-04</td>
<td>7.164E-04</td>
</tr>
<tr>
<td>per year with CFRP plates</td>
<td>4.398E-02</td>
<td>2.106E-01</td>
<td>2.615E-01</td>
</tr>
<tr>
<td>years with CFRP plates</td>
<td>22.7</td>
<td>4.7</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Fig. 3. Influence of the speed of movement of the trains in the fatigue damage accumulation assessment.

Fig. 4. Influence of the increase of the thickness of CFRP plates in the fatigue damage accumulation assessment.

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Dynamic analysis and fatigue assessment of an existing railway steel bridge in Portugal

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Keywords: Dynamic Analysis; Fatigue; S-N Curves; Modal Superposition Method; Railways.

ABSTRACT

In this work, a dynamic analysis of the Várzeas railway bridge model is carried out and a fatigue analysis of a critical detail is performed. A series of dynamic analyses were performed in order to analyse its dynamic behaviour due to the passage of the Alfa Pendular train, using an algorithm based on moving loads and the modal superposition method [1]. The Várzeas railway bridge, represented in Fig.1, is steel bridge situated in the Beira Alta railway line, across the Várzeas river, near the town of Luso in Portugal. The bridge model has been developed in ANSYS [2] and is presented in Fig. 2.

The moving loads model is characterized by a set of constant loads corresponding to the static loads of the train axles. Obviously, this set of loads has to be separated from each other, according to the train geometry. The dynamic response of a structural system with N degrees of freedom, at a certain time-instant, may be evaluated considering the system of Eq. (1):

\[ M \ddot{u}(t) + C \dot{u}(t) + K u(t) = F(t) \] (1)

where \( M, C \) and \( K \) are, respectively, the matrices of mass, damping and stiffness and \( F(t) \) represents the nodal forces vector. The modal superposition principles may be used to efficiently compute any type of quantity \( \psi \), such as displacements, velocities, accelerations and stresses through the following equation [1]

\[ \psi(t) = \sum_j \left( \psi_j \cdot Y_j \right) \] (2)

where \( \psi_j \) is the respective modal quantity taking into account the modal shape of the \( j \)th vibration mode.

The dynamic analysis of the bridge was performed considering a traffic composed by the Alfa Pendular train with a 5-140 km/h speed range. The damping coefficient used was \( \zeta=0.5\% \), according to EN1991-2 [3], and the time step was 2 ms. The responses in terms of displacements and accelerations for a node situated in the midspan of span 3 of the Varzeas bridge are plotted in Figs. 3 and 4, respectively. In terms of displacements, it can be concluded that considering the contribution of vibration modes with frequencies...
up to 100 Hz is sufficient for obtaining reasonable results. However, for the accelerations, there are still some differences when considering the contribution of modes up to 100 Hz and 200 Hz. This is because the studied bridge is a steel bridge that is characterized by a large amount of local modes that significantly influence the acceleration fields.

The fatigue analysis was performed for a critical detail corresponding to the connection between the upper crossbeam and the upper chord of the vertical trusses at the midspan of span 3. The stresses in this connection were evaluated for different train speed and are presented in Fig. 5. The time step and damping coefficient were the same to the ones used in the dynamic analysis, and the traffic picked for this analysis was composed by the Locomotive-hauled freight train (fatigue train type 5, according to EN1993-1-9 [4]). Fig. 6 presents the fatigue damage for 1 year, considering the S-N curve 71 and assuming a traffic of 32 fatigue trains type 5, which is equivalent in tons to the heavy-traffic mix recommended in [4]. From this figure, it is possible to conclude that, when considering the contribution of modes with frequencies up to 30 Hz, the damage is null and, consequently, the bridge has an infinite life span in terms of fatigue. However, when considering a higher number of modes, the damage is no longer null, proving the importance of evaluating the number of modes that should be considered in the dynamic analysis.

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Multiaxial fatigue life evaluation using strain energy-based critical plane approach

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Keywords: Critical plane, multiaxial fatigue, equivalent strain energy, life prediction, non-proportional hardening

ABSTRACT

With the development of aircraft engines, hot section components are often subjected to complex multiaxial loadings, which often result into fatigue failure [1-2]. In general, the multiaxial fatigue life can be predicted by von Mises equivalent strain or stress criterion [3]. However, under out-of-phase or non-proportional loading conditions, the principal axes of stress and strain rotate during cyclic loadings, causing additional cyclic hardening of the material, which results into more fatigue damage [4-5]. Until now, various multiaxial fatigue models have been developed for multiaxial fatigue life prediction, among them, the Fatemi-Socie criterion has been commonly used in practice [3]. Since the fatigue damage of the material is caused by the critical value of shear stress along the slip direction on the slip plane, and then the accumulation of local slip belt, the critical plane is generally located in the maximum shear stress (strain) range plane traditionally. However, the normal stress on the critical plane usually accelerate the crack growth process [4-5], thus it is of great significance to locate the critical plane for fatigue life prediction of real components. In particular, various multiaxial fatigue models have been put forward by combining the critical plane-based method with stress/strain-based parameters [6] as well as strain energy-based damage parameters, which combine the effects of loading histories and both states of stress and strain.

In the current work, a critical plane-strain energy model is proposed for fatigue life prediction of metals subjected to both in-phase and out-of-phase loadings. Specifically, it combines the shear and normal strain ranges on the plane of maximum shear strain range by the von Mises criterion, and introduces a weight factor to correct the von Mises equivalent stress. Then combining the equivalent strain and corrected stress yields an equivalent energy damage parameter. According to the proposed damage parameter, the multiaxial fatigue life prediction model was derived together with the Coffin-Manson equation. Experimental data of GH4169, TC4 and Al7050-T7451 alloys are used for model validation. Results show that the proposed damage parameter gives more accurate predictions than others under either multiaxial proportional or non-proportional loadings.

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Low-cycle fatigue behaviour of H13 steel produced by selective laser melting

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Keywords: AISI H13 steel, low-cycle fatigue, cyclic deformation behaviour, laser sintering metals, functional materials.

ABSTRACT

Additive manufacturing is a common term used to describe a group of advanced manufacturing technologies that create objects, in an incremental form, by adding material in a layer-by-layer fashion. Driven by a significant number of technical and business benefits, and also due to its inherent flexibility, in particular the greater freedom design compared to the conventional subtractive approaches, AM is being considered for a growing variety of application domains, such as fabrication of components, local repair or partial rebuild, and, last but not least, redesign of parts for alternative usage.

Although these new technologies have brought new perspectives for fabrication, either in terms of shape solutions or in terms of assembly possibilities, additive manufacturing processes are unequivocally complex and, currently, systematic knowledge on the mechanical behaviour of final products is far from optimal. The aim of this paper is, therefore, to study, in a systematic manner, the cyclic plastic behaviour of AISI H13 steel manufactured by selective laser melting. For this purpose, low-cycle fatigue tests of standard cylindrical specimens, under fully-reversed strain-controlled conditions, with strain amplitudes ranging from 0.3\% to 1.0\%, are performed. Before testing, microstructural features are investigated by optical microscopy and the size and density of anomalies (i.e. porosities, lack of fusion, inclusions, micro-cracking, among others) are quantified via CT-scan. After testing, fracture surfaces are examined by scanning electron microscopy to identify the main fracture damage micro-mechanisms.
Fatigue damage analysis and performance upgrade of cable-supported steel bridges in China

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Keywords: Fatigue; Cable-supported steel bridge; Damage mechanism; Performance upgrade; probabilistic finite element analysis.

ABSTRACT

Cable-supported steel bridges have been widely used due to their strong spanning capacity and aesthetic shape. Subjected to the large number of repetitive vehicle and wind loads, the bridge may experience fatigue problems that result in troublesome repair activities and traffic interrupt, and the fatigue problems could become more severe as the bridge becomes longer and more flexible. This paper presents a review on the fatigue damage observed on several super long-span bridges in China, including the Runyang bridge, the Sutong bridge and the Jiangyin bridge with the main spans of 1490m, 1088m and 1385m, respectively. Cracking in longitudinal diaphragm, hanger-to-girder connections and short suspenders, etc., are reported, and a probabilistic finite element analysis procedure is proposed, where the coupled influence of multiple uncertain factors and loads is taken into account. Based on the proposed analysis procedure, fatigue damage mechanism is discussed, and maintenance measures and design optimization are suggested, so as to upgrade the fatigue performance of cable-supported steel bridges.
Experimental investigation of fretting fatigue behavior of steel wires

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Keywords: Fretting-fatigue; wire cable; wear; fracture, morphology.

ABSTRACT

Steel wire cables that consist of parallel wires or helical wires have been utilized as cable-supported structures, hoisting devices and cableway systems in the infrastructure, coalmine and industry for its high intensity and low bending stiffness [1]. However, premature failure is usually observed in civil engineering cables under long-term repetitive loads [2]. The wire in the cable is subjected to cyclic stress induced by fluctuating external loads, accompanied by fretting wear resulting from inter-wire relative sliding and high contact stress. Due to the interaction of cyclic stress and fretting wear, the wire suffers from fretting-fatigue, accelerating the crack initiation, propagation and final fracture, even the failure of wire cables [3].

To investigate the fretting fatigue behaviour of steel wires, several fretting fatigue tests have been conducted based on a proposed test equipment. The influence of stress amplitude and normal force on fretting fatigue behaviour of steel wires was investigated. After fretting fatigue tests, the morphologies of fretting scars and fractures of the steel wires were observed to examine the failure mechanisms. Besides, the fretting fatigue lives of these steel wires due to different displacement ranges and normal forces were analysed to identify the characteristic of fretting damage quantitatively.

Fig. 1(a) shows a schematic of the developed test equipment, which can conduct fretting fatigue testing under constant normal force. The fretting fatigue test equipment consists of a fatigue testing machine and a wear assembly. The upper gripping head of the fatigue testing machine drags the wire specimen back and forth to produce cyclic stress and relative displacement. The wear assembly provides external fretting wear under the action of normal force loading device. Strain gauges were applied to obtain the strain variations of the tested wires, which can be used to evaluate the tangential force. Fig. 1(b) shows the picture of the fretting fatigue testing, where high strength low alloy wires with a diameter of 5mm that are usually used in civil engineering cables were tested.

![Schematic of test equipment and picture of fretting fatigue testing](image-url)
A sinusoidal loading mode was applied to provide fatigue stress, whose mean stress and stress range are shown in Eq. (1).

\[
\sigma_m = 0.45 \sigma_u - \sigma_a, \quad \sigma_a = 180 \text{MPa}
\]

where \( \sigma_m \) is mean stress; \( \sigma_u \) is ultimate stress, which is 1835 MPa according to material tests; and \( \sigma_a \) is stress range.

Fig. 2 presents the typical fretting scar and fracture surface of the tested wire, where the fretting scar is similar to ellipse with the long axis along the sliding direction. According to the morphologies of the fretting scar shown in Fig. 2(a), detached particles and furrows were observed in the surface of the fretting scar along the sliding direction, revealing the existence of adhesive wear and abrasive wear. The reason for the polishing is that the wear fragments were initially generated in the adhesive wear and then acted as the third body in the abrasive wear. The crack occurred at an edge of the scar in long axis direction, i.e. at boundary between the slip and stick zone, perpendicular to the sliding direction. Fig. 2(b) presents typical fracture surfaces of the tested wire due to fretting fatigue damage, which reveals that the fracture initiated from the fretting scar.

Table 1 gives the fretting fatigue lives of tested wires as the stress range increased from 180 MPa to 540 MPa with the normal force equal to 120 N. It is observed that an increase of the stress range results in the accelerated crack nucleation and propagation and thereby the decreased life. The increase of stress range makes the partial slip significant, resulting in the increase of slip zone and fretting damage.

<table>
<thead>
<tr>
<th>Stress range</th>
<th>Fretting fatigue life</th>
</tr>
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<tbody>
<tr>
<td>180 MPa</td>
<td>Within 3.6x10^5 and 4.2x10^5</td>
</tr>
<tr>
<td>360 MPa</td>
<td>Within 6.8x10^5 and 8.2x10^5</td>
</tr>
<tr>
<td>540 MPa</td>
<td>Within 1.5x10^6 and 1.87x10^6</td>
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ACKNOWLEDGMENTS

Support from the Natural Science Foundation of Jiangsu under Grant No. BK20130023, the Education Department of Jiangsu under Grant No. JHB2012-1 and the Graduate Research Innovation Project of Jiangsu Province under Grant No. KYLX15-0087 is gratefully acknowledged.
Degradation and Conservation of Ancient (Historical) Materials and Structures
J-IRAS2019-ISCD

Organized by:

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The remains of the old steel industry in Africa: the need to safeguard the last well-preserved furnaces of iron metallurgy

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Keywords: Africa; furnaces; metallurgy; preservation; heritage.

ABSTRACT

My proposal deals with the issue of the preservation and safeguarding of the furnaces used for iron production in Africa according to the direct process. Until its occupation by the European Powers at the end of the 19th century, the African continent was the area of significant iron production which can be described as industrial. Archaeological and ethno-archaeological research undertaken on this subject from the beginning of the 20th century until today attest that the landscapes of the continent contain countless remains of this metallurgical activity. The earliest periods of ancient iron metallurgy in Africa began with the second millennium BC, at least, in Tenere area (Niger), while the most recent periods end in the first half of the 20th century AD. The iron production furnaces studied by archaeologists and anthropologists across the continent are of very varied dimensions and shapes. In some areas, such as Guinea Conakry, Mali or Burkina Faso, we can still find furnaces in a fairly good state of conservation. Because these clay-built furnaces are not only exposed to climatic bad weather, but also to human activities, they are thus threatened with destruction. So it is therefore urgent to consider actions for their preservation as heritage artifacts. Over the last few decades, UNESCO has set up a new program to classify some major iron production workshops in order to promote their preservation as part of the world’s heritage of humanity, Thus encouraging States to put in place provisions for the enhancement of these sites of ancient iron metallurgy in Africa. Hence the interest of the proposed subject.

Within the framework of this conference, first, I will show the morphological and functional complexity of the furnaces that still exist by region, based on my own field investigations, but also those of other researchers, and secondly, I will propose new ways for the preservation of these furnaces for future generations.
REFERENCES


ACKNOWLEDGMENTS

I would like to thank the Director of the Prehistoric Ethnology Team, Mr Pierre Bodu, and the Director of the “Africa Theme” laboratory, Mr Manuel Gutierrez, of UMR 7041, ArScan, Université Paris 1 Panthéon-Sorbonne - CNRS, for their support.
Monitoring the potential effect of particulate matter on cultural heritage. Contribution of an environmental monitoring system

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Keywords: Air pollution monitoring system; urban heritage preservation; PM10; PM2.5; mobile environmental monitoring station

ABSTRACT

The air pollution has a contribution to the degradation of surfaces of historical buildings and monuments [1]. The impact of pollutants emitted into the atmosphere on materials is enormous and often irreversible. Corrosion caused by chemicals and soiling caused by particles can lead to economic losses but, more importantly, to the destruction of our cultural heritage, degradation of the public spaces, infrastructures and facilities [2]. Moreover, the effects of the air pollution in façades and on the structural systems lead to unexpected costs for the buildings maintenance. So, these effects must be monitored and assessed for making possible to act in time for minimizing or eliminating the adverse effects and the unexpected costs over the cultural heritage to preserve the identity and memorial value.

Domestic and industrial sources but mainly road traffic sources are the principal sources of emissions of air pollution in cities, which affect directly the quality of life, infrastructures and spaces in urban areas. Several studies of materials have indicated that atmospheric corrosion influenced by acidifying pollutants is costly. Extensive damage has also been observed on historical and cultural structures and monuments calcareous stones, medieval glass and metals. Therefore, evaluating and monitoring the urban environment quality inside the urban areas becomes very important to the urban heritage conservation through the creation of the new environmental policies to minimize and control the air pollution consequences over the urban spaces [1,2,3].

This work presents a methodology to evaluate, on a regular basis, the potential impact of atmospheric pollution on monuments. It uses a monitoring system to collect samples of particulate matter and then analyzes its composition and assesses the degree of risk of degradation. This study is being applied in the Portuguese midsized city of Vila Real where the urban pollution assessment and their effects in urban infrastructures was considered the main goal.

For the development of the project, two systems have been created: A website for the acquisition and the storing of the data; and a technological solution for the data acquisition constituted by one mobile unit of measurement. The mobile unit of measurement is equipped with an air particulate matter monitor/collector (PM10 and PM2.5), a meteorological station, and communication and positioning devices. The devices are connected with the router installed inside the mobile unit that is connected with a database.
This mobile environmental monitoring station carries out measurements in different points of the city that are part of the urban monitoring network. In the urban monitoring network, a set of data is collected and transmitted to the analysis center (air pollutants concentrations and meteorological data). The particulate matter samples are also collected for posterior physical and chemical analysis in laboratory, for identifying the potential corrosion effect influenced by acidifying pollutants substances that constitute the particulate matter. The website to data acquisition is illustrated in Figure 1.

The data collected include: Time - date and hour of the measurements; particulate matter concentration; particulate matter collection on polytetrafluoroethylene (PTFE) membrane filters with polymethylpentene support ring (2 μm porosity, Ø47 mm), meteorological data (relative humidity, air temperature and wind speed and predominant wind direction).

The samples were evaluated in order to determine the type, chemical composition, morphology and size of the collected particles. In order to obtain chemical and morphological characterization, the following techniques were used: Scanning Electron Microscopy (SEM), Energy Dispersive Spectroscopy X-rays (EDS), X-Ray Diffraction (XRD).

Historical monuments in urban areas act as passive repositories for air pollutants present in the surrounding atmosphere [5], and the analytical results could confirm that.

In conclusion, this system can provide a large database and important information to use in the decision-making process of urban planners. With this type of data, it is possible to act in time with the goal to protect the urban spaces and avoid the degradation or the irreversible damages in the urban heritage.

REFERENCES
**Monitoring and Control of Schedule and Cost Performance in Facade Conservation**

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**Keywords**: Conservation Works, Schedule and Cost Performance, Earned Value Management

**ABSTRACT**

Feedback is crucial to the success of any project. The performance information and project progress, just in time and addressed to the manager, allows to identify and anticipate problems, and consequently make adjustments to keep it within the limits of time and cost. Earned Value Management (EVM) is a technique used to measure the progress of a project. EVM provides information that enables integrated schedule and cost monitoring by providing performance indicators on the status of the project and estimates for completion.

The article describes the application of the EVM technique to a contract for the rehabilitation and conservation of facades of a building. We conclude that this model presents satisfactory results and its implementation demonstrated easily and effectively in control of rehabilitation and conservation of facades. The application of EVM has shown that it is possible to evaluate the performance of works of short schedule and with low complexity of tasks, since control parameters are calculated to quantify deviations of time and cost and to make relevant decisions about the strategy to work.

However, the EVM should be used to make an overall analysis of the work performance, and in the monitoring of schedule and costs is necessary to identify the tasks that contribute most to the deviations and then make the control of their resources in order to adopt appropriate corrective measures.
Radon Risk Analysis in a Set of Public Buildings in Minho Region, Portugal: From Short-Term Monitoring to Radon Risk Assessment

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Keywords: Radon risk assessment, radon remediation, radon risk mitigation, short-term monitoring.

EXTENDED ABSTRACT

Radon gas is considered by the World Health Organization (WHO) as one of the most important agents responsible for lung cancer [1][2]. Hence, radon people exposure in badly ventilated and extensively occupied rooms increases drastically the risk of health problems. Since new legislation is already in force in Portugal to combat radon risk problems [3], the discussion of a mitigation strategy to reduce occupants’ radon risk exposure is an issue of great actuality, of greater urgency and of extreme necessity.

An administrative building made with granite stonework and founded over granite rocks, located in an inner city of Minho region, North of Portugal, was extensively assessed to characterize indoor radon concentration, air temperature and relative humidity in a set of strategically selected office rooms. The monitored rooms were chosen due to their high occupancy levels over long periods of time. A ground floor office room extensively occupied was taken for radon risk analysis showing hazard concerning occupants’ radon gas exposure.

The experimental assessment was based upon short-term measurements of one complete week over both seasons — winter and summer — to test the effect of outdoor climate on indoor radon concentration, air temperature, and relative humidity.

Graphs in Figure 1 show the variation over one week of the instrumented parameters for a ground-floor office with ten occupants working seven hours a day, during a normal working week. The time periods for human occupancy undertaken by the users are directly identified in the plots.

Fig. 1. Indoor radon, air temperature and relative humidity variation over one week – winter and summer analysis
Behavior of Precast Concrete Columns with Unusual Cross-Section


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Keywords: Precast concrete column; numerical modelling of concrete; combined compression and bending; unusual cross-section.

ABSTRACT

Verification of precast concrete elements, both in ultimate limit state and in service can be performed according to prescriptions of several standards which also allow an assessment with tests on physical models or with an appropriate physically nonlinear analysis. The present paper presents an evaluation of precast concrete columns with an unusual cross-section, designed to be used in a system with precast concrete columns, beams, slabs and panels. The column’s cross-section presents recessions and protrusions which are used to produce connections with the panels that seal the building. In order to assess the behavior of this column in service and in ultimate limit state, tests were performed. Four real-size columns were tested under combined bending and compression with different eccentricities for loading until failure. Afterwards, a numerical model was developed in the finite element code ANSYS Mechanical APDL v. 18.2 [1], considering physical and geometric nonlinearities. An analytical model presented by Pereira et al. (2013) [2] was adapted for the analysis of the columns and their behavior in service was estimated. Finally, the columns strength were calculated according to the procedures from EN 1992-1-1:2004 [3]. Results obtained with the four different methods were compared and evaluated.

Four columns with the geometry presented in Fig. 1 and total length of 3400 mm were tested under combined compression and bending. For the reinforcement, four 12.5 mm bars were used in the longitudinal direction and 5 mm stirrups were regularly placed every 150 mm. Two columns were tested with eccentric compression in the x axis and two others had an eccentricity in the x’ axis (rotated 45° in relation to x). The eccentricities in the x axis were 82 and 310 mm respectively (tests E1 and E2) and about the x’ axis, of 72 and 264 mm (tests E3 and E4 respectively). A displacement gauge was installed in the middle of the column to measure its transverse displacement and a console was casted with the column to allow the eccentric loading. Tests were conducted horizontally after 28 days of curing of the concrete, which presented average compressive strength equal to 33.5 MPa.

Fig. 1. Column dimensions in millimetres.
Numerical models were developed in the finite element commercial software ANSYS Mechanical APDL v. 18.2 [1] to simulate the column’s behavior. For modeling of concrete, the SOLID165 element was used. For the reinforcement, LINK180 elements were adopted. MPC184 elements were used in order to apply the eccentric loading, instead of modeling the consoles in Fig. 1. A 20 mm mesh was adopted. The materials models was adopted according to the prescriptions of EN 1992-1-1:2004 [3].

Figure 2 shows the force vs. displacement curves for all four columns, obtained with the three different methodologies. A dashed red line represents the strength calculated using the procedures from EN 1992-1-1:2004 [3].

From the results it was possible to conclude that the behavior of precast concrete columns with unusual cross-section were well determined for the different methodologies evaluated. It was noted that, in general, the formulations from EN 1992-1-1:2004 [3] predicted, within an adequate margin of error the strength of the column. Numerical modelling was able to assess the behavior of the concrete appropriately, except for the test E3.

![Diagram of force vs. displacement curves for columns E1, E2, E3 and E4.](image)

**Figure 2** - Force vs. displacement curves for columns E1, E2, E3 and E4.

**REFERENCES**

ANALYSIS OF MORTARS USED IN THE REHABILITATION OF WALL COATING

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Keywords: Mortars; Coatings rehabilitation; mechanical strength.

ABSTRACT

Two types of lime-based mortars were used in the rehabilitation of wall coverings, and the need to study their mechanical behaviour and durability arose.

About the mechanical behaviour were analysed flexural strength, compressive strength and the peeling stress at the "pull-off" test.

As to durability, particularly in view of the rising damp and infiltration, this study was performed by capillary water absorption test and immersion due to water absorption at 48 (atmospheric pressure) for the determination of water content, focusing on its state of degradation, in order to mitigate the risks of choice.

In this study, the results obtained in the tests of a traditional lime mortar with a 1:3 volume trace with the samples of a prefabricated mortar of hydrated lime were compared, and in both mortars obtained values close to those recommended.

However, the traditional hydraulic lime mortar has a peel force resistance well above the prefabricated mortar, and the recommended amount in domestic articles.
Assessment of Footpaths Design on Renovation of City Centres

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Keywords: soft modes; footpaths; city centres; urban environment.

ABSTRACT

Planning and developing the renovation and revitalization of historical city centres is a complex task, which demands integration across various fields of design and knowledge. A key concern in the renovation of city centres is the sustainability of the design solutions, and a central issue in this case regards the minimization of road traffic in these core areas. In this context, the option for soft mobility modes, such walking or cycling, is almost imperative nowadays. Thus, a walkable city centre significantly improves sustainable mobility, contributing for the reductions in air and noise pollution and greenhouse gas emissions, and also increasing the attraction as commercial, cultural and leisure destination. To achieve this purpose, the permeability of the city centre should be worked, allowing the pedestrians to move easily around the historical centre.

Promote a walkable city centre depends on how well the footpaths connections work and coexist with the other soft mobility modes and public transport, giving pedestrians the better choice in how to make their journeys. The geometrical design of the footpaths should also not be neglected, although in a historical city centre such characteristics are strongly conditioned by the existing urban morphology. For this reason, the assessment of those issues in a design phase is quite relevant for the perception of the overall quality of the proposed solution for the footpaths and the pedestrian streets [1] [2].

The main goal of this work is to present a set of indicators which can assess the footpaths design in the context of renovation of historical city centres. Four indicators were developed in order to evaluate the geometrical design and the ease of use of the footpaths, and the connection with public transport. These indicators were quantified and combined according to a combination procedure, resulting in a synthetic score for the Assessment of Footpaths Design on Renovation of City Centres (AFD), which reflects the quality of the proposed design solution.

The Width indicator and the Slope indicator evaluate the width and the slope of the footpaths, in order to ensure pedestrian to move easily around the city centre. This evaluation is carried out by using two transformation functions which gives, respectively, the indicators scores $S_{wd}$ and $S_{sl}$, with a value ranging on a scale of 0 to 2 and of 0 to 1, respectively, as follows [2] [3] [4] [5]:

\begin{align*}
S_{wd} &= 0 & \text{if } W \leq 1.5 \\
S_{wd} &= 0.4W - 0.6 & \text{if } 1.5 < W < 4.0 \\
S_{wd} &= 1 & \text{if } W \geq 4.0 
\end{align*}

(1)
In case of pedestrian streets/car-free zones, it should be added 1 to the Swd value calculated above.

where $W$ is the width of the footpath (m).

$$S_{sl} = \begin{cases} 1 & \text{if } S \leq 2.0 \\ -0.125S + 1.25 & \text{if } 2.0 < S < 10.0 \\ 0 & \text{if } S \geq 10 \end{cases}$$

where $S$ is the longitudinal slope of the footpath (%).

The Footpaths Length Gauged by the Number of Intersections indicator measures the frequency of occurrence of traffic roads intersections for the total length of the footpaths. This evaluation is carried out by using a transformation function which gives the indicator score $S_{gi}$, with a value ranging on a scale of 0 to 1, as follows [6]:

$$S_{gi} = \begin{cases} 0 & \text{if } W \leq 1.5 \\ (1/300) LI - 1/3 & \text{if } 1.5 < W < 2.0 \\ 1 & \text{if } W \geq 2.0 \end{cases}$$

where:
- $LI = LF/(NI+1)$ is the footpaths length gauged by the number of intersections; $LF$ is the total length of the footpaths; $NI$ is the total number of intersections with traffic roads.

The Connection With Public Transport indicator measures the ease of access to public transport in the city centre in terms of distance. This evaluation is also carried out by using a transformation function which gives the indicator score $S_{pt}$, with a value ranging on a scale of 0 to 1, as follows [7]:

$$S_{pt} = \begin{cases} 1 & \text{if } D \leq 150 \\ -(1/600)D + 1.25 & \text{if } 150 < D < 750 \\ 0 & \text{if } D \geq 750 \end{cases}$$

where $D$ is the maximum distance to the nearest public transport stop, measured in the less favorable point of the footpaths network (m).

Finally, the final score to the Assessment of Footpaths Design on Renovation of City Centres, $S_{AFD}$, with a value ranging on a scale of 0 to 1, is set according to the equation bellow:

$$S_{AFD} = \frac{S_{wd} + S_{sl} + S_{gi} + S_{pt}}{5}$$

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“Branco Micaela” granite: buildings and superficial finishes

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Keywords: Branco Micaela, Surface Finishing, Construction, Ornamental stone, Transgranitos.

ABSTRACT

Natural ornamental rocks have been used since ancient times in construction. In recent years, the use of rocks, such as granite, to produce tile, facades or roads has had a great expansion either, in residential buildings, or in great architectural works, [1](Vásquez, 2010). In many areas of Portugal, granite is found and, in addition, its extraction and processing employs a significant amount of labour (much of which is qualified). The rock is exported to several markets, thus contributing to currency entrance. [2] (Gonçalves, 2010).

For the commercialization of ornamental stones it is necessary to determine the physical and mechanical properties for use in the aforesaid applications, as well as, to estimate the durability of the surface finishes [3,4] (Shehata et al., 1990; Sousa et al., 2012). Portugal is a country with a long tradition in the extraction and transformation of rocks occupying the tenth world position, a decent position given its size (Sousa L., 2012).

The granite samples used in this work were collected at the Transgranitos quarry, located in Aguiar da Beira, north of Portugal. “Branco Micaela” granite samples were collected, and subjected to different finishes: polished, honed, sawed, flamed and shot blasted. After the respective finishing process, samples were tested in order to quantify their colour and brightness, and it was verified how these factors vary with the finishes processes, in dry and wet conditions.

This work allowed to verify the existence of colour and brightness variations cause by the surface finishing processes and to verify the effect of water in these parameters allowing new commercial approaches for the "Branco Micaela".

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Study on historical value mortars

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Keywords: Mortars, SEM characterization, history, Conimbriga

ABSTRACT

The rehabilitation of buildings or historic landmarks has gained in importance over the years. It is increasingly important to safeguard the cultural identity and history of a country. In this research the mortars of the Roman city of Conimbriga were studied, being one of the oldest archaeological cities in Portugal.

Conímbriga has its origin in a Celtic Castro of the tribe of the Conii, at the end of the Iron Age. It was occupied by the Romans from 139 BC. It was under the Emperor Augustus Empire, in the second century AD, that the city achieved its splendor, having then been built public baths and a Forum. With the decline of the Empire in the late fourth century, a monumental defensive wall was erected, which did not prevent the assault of the city by the Suevi, in 468, and the consequent decline of the city. Large excavations carried out throughout the 20th century revealed a valuable and complex set of buildings, including thermal baths, an aqueduct that runs more than 3,400 meters from the source, and remains of a Christian basilica, probably from the 6th century.

In this type of rehabilitation works the use of mortars was predominant, hence the importance of their study to know how they behave. In order for a rehabilitation intervention to be successful it is necessary to know the existing support in place to guarantee the compatibility of the materials.

It was necessary to go “in situ” to collect the samples with the proper authorization of the Museum of Conimbriga. These mortar samples were analyzed and characterized by scanning electron microscopy (SEM) for further analysis. The composition of the samples will allow to adjust dosages and to choose a restoration mortar, as close as possible, to the one that was collected in order to preserve the maximum historical identity of the place.

REFERENCES

ANALYSIS OF THE FC 250 CAST IRON MICROSTRUCTURE, UNDER THE EFFECT OF A PHOSPHORIC ACID SOLUTION

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Keywords: Corrosion; Phosphoric acid; Cast Iron; Immersion; SEM.

Abstract

The study of the prevention against corrosion of metals by phosphoric acid has been increasing due to its great use in industrial processes such as the production of fertilizers and food products. About 5% of the profits of industrialized nations are spent in the fight against corrosion. Several studies have been carried out to determine the corrosive behavior of cast iron in acidic and basic media, but the resistance to corrosion in phosphoric acid has not yet been studied. The present work analyses the effects of phosphoric acid (H3PO4) on the corrosion of FC 250 cast iron, in its structure and properties, using mass loss analysis and scanning electron microscopy (SEM). The studies were performed after samples immersion in acid solutions with concentrations of 1, 2 and 3% of content for 86,400 and 424,800 s at room temperature and in a solution of 3% by 323,15 K and 373,15 K, for 21,600 and 43,200 s. The highest losses were found in the percentage of 3%, at higher temperatures and lower immersion time. H3PO4 characterizes the oxidation state in gray cast iron, which can compromise its structure and properties. The higher percentage of the acid causes greater mass losses, the temperature reacts in an analogous way and in longer times the loss is sustained.

REFERENCES


Study of the dust produced in rehabilitation works

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Keywords: Dust, SEM characterization, Rehabilitation works, Safety

ABSTRACT

Urban rehabilitation is becoming more frequent nowadays. With cities full of falling buildings and no space to build new ones, the only solution is to rehabilitate the existing heritage in order to give new life to the vacant buildings and repopulate the cities. In this type of works more dust is produced than in a new work. In addition, the origin and composition of existing materials is often unknown and can therefore pose many risks to the health of workers. Meaning, dust is breathable and can remain in the air for a long period of time, being invisible to the naked eye and very light.

When a building is being demolishing, the production of dust increases significantly. Depending on the type of materials to demolish, the risk of occupational diseases, or risks, to the health of workers may be great. To avoid such risks, preventive measures must be taken in the execution of the tasks.

In this study, the dust of two rehabilitation works in the district of Viana do Castelo was studied through experimental tests in order to verify the composition of the demolished materials. Particles characterization was done, using scanning electron microscopy (SEM). Then, with the tests results, the chemical composition of the existing materials was analyzed in detail. After that, the chemical components of demolished materials were carefully studied to identify which of these particles could represent a risk to the workers’ health.

As a conclusion the preventive measures that workers must take when performing rehabilitation works are presented, depending on what type of materials they are potentially exposed.

REFERENCES
Nonlinear Dynamic Analysis of Overhead Transmission Lines

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Keywords: Overhead transmission lines, Wind forces in cables, Aerodynamic damping, Non-deterministic dynamic wind action, Nonlinear dynamic analysis.

ABSTRACT

Transmission line structures are important components of the urban infrastructure system. These structures are composed basically of cables (conductors and ground wires), towers and insulators. Several researchers point out that the occurrence of accidents in transmission lines can raise serious problems in certain society sectors, mainly due to the sudden electrical equipment disconnection.

Considering that most accidents involving overhead transmission lines have occurred at wind velocities lower than the maximum recommended in the design standards and, most of the times, without rupture of conductors cables, it is believed that this problem may be associated with the effects of geometric nonlinearity and/or dynamic effects of atmospheric turbulence \cite{1}.

This work presents an evaluation of the structural behavior of transmission lines (TL’s) subjected to non-deterministic dynamic wind loading on the cables, considering geometric nonlinearity and aerodynamic damping. The aerodynamic damping was determined according to the formulations proposed by Davenport \cite{2} and Stengel \cite{3}. The numerical methodology was developed using the ANSYS\textsuperscript{®} finite element analysis software. The maximum responses obtained in the dynamic analyses (complete model) were compared with the results from equivalent static analyses according to IEC 60826:2017 \cite{4} (isolated tower model).

The models were elaborated according to a real transmission line segment located in Rio Acima, state of Minas Gerais, Brazil. The tower under study belongs to a power transmission system of 138kV of Companhia Energética de Minas Gerais, denominated Tower 50. Fig. 1a shows the layout with its main dimensions (in meters), cable spans and adjacent towers, and Fig. 2b shows the numerical model of the structure.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{Fig. 1. (a) layout of the transmission line segment (without scale); (b) complete numerical model.}
\end{figure}
Table 1 shows the maximum forces (tension and compression) on the tower elements, obtained through the linear equivalent static analysis of the isolated tower model and the nonlinear dynamic analysis of the complete model. Fig. 2 presents the percentage differences between the compression forces in legs for the methodologies evaluated considering different wind speed values.

**Table 1.** Maximum forces for wind velocity equal to 30 m/s (kN).

<table>
<thead>
<tr>
<th>V₀ [m/s]</th>
<th>Methodology</th>
<th>Bracing Tension</th>
<th>Bracing Compression</th>
<th>Leg Tension</th>
<th>Leg Compression</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>IEC 60826:2017 [4]</td>
<td>7.02</td>
<td>7.63</td>
<td>55.29</td>
<td>70.91</td>
</tr>
<tr>
<td></td>
<td>Stengel et al. (2017) [3]</td>
<td>15.02</td>
<td>17.33</td>
<td>178.44</td>
<td>192.66</td>
</tr>
<tr>
<td></td>
<td>Davenport (1988) [2]</td>
<td>17.74</td>
<td>18.94</td>
<td>196.70</td>
<td>208.73</td>
</tr>
<tr>
<td></td>
<td>Stengel et al. (2017) [3]</td>
<td>30.26</td>
<td>33.88</td>
<td>274.96</td>
<td>274.74</td>
</tr>
</tbody>
</table>

The dynamic analyses performed considering the aerodynamic damping proposed by Stengel [3] presented higher results than those obtained considering aerodynamic damping proposed by Davenport [2], due to the lower values of aerodynamic damping. The differences between the outcomes obtained from the dynamic analysis (complete model) and from the equivalent static analysis (isolated tower) were significant, which demonstrate the importance of performing a nonlinear dynamic analysis with the complete structural system and suggest the review of the standards for overhead transmission lines design.

**REFERENCES**


Safety and risk assessment in engineering
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Vector model of the engineering infrastructure risk

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Keywords: usefulness, potential, risk, hazards, safeguards.

ABSTRACT

The subject of the article is the concept of a vector risk model and its application in the process of risk estimation and evaluation in relation to the basic features of the utility of engineering infrastructure. This model, with the help of dimensions such as e.g.: functionality (F), reliability (N), safety (B), continuity of operation (C), etc. as well as parameters concerning conditions and operating environment (E) takes into account the set of potential hazards to engineering infrastructure and a set of risk factors resulting both from the structure of the engineering infrastructure itself and its environment. This model allows for easy selection or development of the method of risk estimation and management, which in turn may be the basis for determining the current level of the usefulness of engineering infrastructure and the risk of its loss. The value of IT risk is determined using synthetic indicators expressed in the form of conventional potentials calculated on the basis of parameters and indices of basic engineering infrastructure elements. The model determined this way also allows, among others, for: continuous control of selected operational indicators of the basic elements of engineering infrastructure (for early detection of hazard, hazard and vulnerability analysis, risk assessment and evaluation related to individual features of engineering infrastructure), monitoring of infrastructure risk level and its changes to the music of introducing innovativeness and modern technological solutions to it, e.g. information technology solutions.
Application of risk-analysis methods in the maintenance of industrial equipment

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Keywords: risk, technical condition, blast furnace casing.

ABSTRACT

A Risk-analysis was developed for man-made hazard objects. But his approaches are effective in the maintenance of industrial equipment, where reliability methods are commonly used. For a long time, the safety of industrial equipment was ensured by supervising the rules of technical operation, occupational health and safety standards. However, a number of accidents at industrial facilities that occurred under design operating conditions, forced the experts to turn to the method of risk-analysis. The main disadvantage of the classical reliability approach is to take into account failures that have a different scale of consequences. A result of which the reliability function gets a “blurred” character. This leads to a reduction periods between inspections and overmaintenance effect.

Similar to the reliability methodology, there are two approaches to risk-analysis. In the combined approach (or classical) the properties of the system as a whole are considered. This includes, in particular, the method of F-N-curves (Farmer curves). Such models are invariant to the nature (physics) of the damaging process. In contrast, in the case of an individual (structural) approach, the risk model takes into account the failure physics [1]. This approach is promising for assessing the technical condition of industrial equipment.

The paper was aimed at the development and research of algorithms for assessing the technical condition of mechanical systems according to individual risk indicators of their elements. The task was to illustrate the application of algorithms on real equipment.

In risk-analysis, failures are "ranked" depending on the level of loss. Therefore, the predicted operating performance is more accurate. The concept of acceptable risk, on which the theory of industrial safety is based, provides for a staged reassignment of service lifetimes (updating). In case of multifocal damage of equipment, the obtained reliability or risk indices need anyway amalgamated. The amalgamation procedure is actual when using structural reliability methods. This may be in the action of a complex of damaging processes on the structural element, and in the action of a certain damaging process on the system of elements. The importance of amalgamating algorithms in maintenance is due to the fact that the planning of recovery operations takes place, at least, at the machine level. It is inappropriate to appoint inspections for only one element, since at that time the entire system will not be available. The amalgamation of indicators is carried out according to some rules, reviewing which, and developing new ones, is devoted to this report.

The structure of amalgamating formulas, which exclude excessive conservatism when calculating the reliability of the system, is found. New rules for amalgamating based on the risk indicator and on the basis of Lindley's distribution are obtained. It is recommended to use it for a large number of (more than 10) critical elements of the complex technical system and for multi-site damage. With less number of them, usually for simple technical systems (where the principle of the weak link is fair), it is suggested to
use a more usual form of the resource safety index [1]. It well meets the situation of several (4-7) degradation processes on the element of the technical system.

The application of risk analysis methods is demonstrated by the example of assessing the technical condition of the blast furnace casing. The wall (shell) of a blast furnace (BF) is a complex multilayer composition consisting of lining, coolers, compensating space (gap) and directly a steel casing. A downtimes blast furnace on the cause of shell failures is on average 20% and reaches more than 40% of all downtimes [2]. The most characteristic scenario of the failure of the BF shell is as follows: burnout (wear) lining → failure of the cooler → cracking (or bulging) of the casing area → break of the casing (depressurization of the furnace) [2]. The time of the each subsequent stage is shorter than of the previous one. New realities of the operation of the metallurgical complex in accordance with the standards of "Industry 4.0" require an increase in the BF campaign for more than 25 years with 95% available.

In view of this, the goal was to test the capabilities of the casing metal for such a long-term operation under real conditions. The objective is achieved by studying the degradation of the properties of the metal casing after the operational work and by determining the residual life of the casing.

REFERENCES

An improved Barycentric Lagrange double interpolation for solving Volterra integral equations of the second kind

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Keywords: Barycentric Lagrange interpolation, Volterra equation, Numerical examples.

ABSTRACT

An improved and sophisticated version of Barycentric Lagrange interpolation with uniformly spaced interpolation nodes is established and applied to solve Volterra integral equations of the second kind. The given improved version of Barycentric Lagrange polynomial is obtained by redefining it in a matrix form in such a manner that the round-off errors of the calculations are remarkably minimized. Achieving this advantage, the presented method consists of three steps; the first is based on the interpolation of the given data function and the unknown function by using the improved Barycentric Lagrange polynomials of the same degree. In the second step the kernel is interpolated twice with respect to both its variables by using the same interpolant polynomial of the same degree, so that it is transformed into a product of three matrices, where only one matrix is dependent on the given kernel. The importance of the third step may be summarized as follows: the interpolate unknown function is substituted twice into both sides of the considered integral equation. This enforcement provides the possibility to reduce the solution of Volterra equation into an equivalent algebraic linear system in matrix form without any need to apply collocation points. Moreover, seven illustrated numerical examples are solved. It turns out that, the obtained approximate solutions converge to the exact ones, which ensures the accuracy, efficiency, and authenticity of the presented method.
Numerical solution of a certain potential - type weakly singular Fredholm integral equation of the first kind using Newton interpolation

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Keywords: Fredholm integral equation, Newton interpolation, Taylor polynomial, Gauss–Legendre formula, Numerical solutions.

ABSTRACT

A computational technique is given for the numerical solution of Fredholm integral equation of the first kind with a singular unknown function and has a weakly singular logarithmic kernel. The presented technique based on Newton interpolation with an analytical treatment of the singularities. The singularity of the unknown is isolated by replacing it with a product of two functions; the first is badly behaved, while the second is regular. The singularity of the kernel is treated by parametrizing it and accordingly expanding its tow parametric functions into Taylor polynomial of the first degree about the singular parameter. The focal point of this paper can be summarized in the potentiality of transforming the improper integrals of the required numerical solutions into proper integrals. This achievement was an inevitable consequence due to the properties of Newton interpolant polynomial which was combined with the technique of isolating the singular part of the unknown function and with the technique of isolating the singularity of the kernel. Moreover, Gauss–Legendre formula is adapted and applied for evaluating the obtained proper integrals. Thus, by applying the collocation points method, the required solution is found to be equal to the solution of an algebraic linear system of equations. From the illustrated example it turns out that the obtained numerical solutions are convergent to the exact one.
Structural reliability analysis using Conjugate FORM-based Support Vector Regression

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Keywords: Support vector regression; conjugate first-order reliability method; structural reliability analysis, directional stability transformation method, finite step length.

ABSTRACT

Appropriate reliability methods for estimating the failure probability using most efficient and robust properties are important issues in structural reliability analyses. In this paper, an enhanced first-order reliability (FORM) using conjugate search direction was coupled with artificial intelligence technique called support vector regression (SVR) named as SVR-CFORM for structural reliability analyses. The conjugate FORM (CFORM) is formulated using adaptive formulas to search the most probable point to improve the robustness of iterative FORM formula, whereas the SVR is used to predict the performance functions to improve the efficiency of proposed reliability method. The performances for both efficiency and robustness of the proposed SVR-CFORM are compared by several FORM formulas as HL-RF, directional stability transformation method and finite step length using different numerical/structural reliability examples. Results indicate that the proposed SVR-CFORM method more efficiently improves the iterative FORM formulation with stable results compared to other studied FORM formulas.
Reliability analysis of slope stability considering the uncertainty in water table position

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Keywords: Slope stability; uncertainty modeling; Monte Carlo method; failure probability; groundwater table.

ABSTRACT

Slope stability is a major critical problem in civil engineering projects, which is encountered in many geotechnical structures including dams, embankments, and structures constructed along the slopes. The main objective of slope stability analysis is to find the most unstable slip surface that may cause failure in the slope. In conventional methods, instability potential is evaluated by calculating the factor of safety (FS), and the critical slip surface is the one with the lowest FS. However, due to the uncertainty involved in various input parameters, such as the geotechnical characteristics of soil, the deterministic approaches cannot necessarily find the most critical surface. Hence, a random walk method is utilized in this paper to demonstrate the possible slip surfaces. A schematic view of the slope studied in this paper (Lodalen slope [1]) and the random walk process to model an arbitrary slip surface are shown in Fig. 1a. An optimization algorithm known as simulated annealing is then applied to find the slip surface with the minimum FS [2]. The critical slip surface resulted from the optimization algorithm, as well as the results of the conventional circular method, are shown in Fig. 1b.

In continuation, defining the involved parameters as random variables, the problem is turned into a probabilistic model. The probability of failure corresponding to the most critical slip surface is then calculated using Monte Carlo sampling method [3]. Subsequently, proposing a simplified method, the groundwater position is defined as a random variable and is added to the previously established problem (Fig. 2a) [4]. The new critical slip surface and the corresponding failure probability are then calculated considering the groundwater table uncertainty. The results are shown in Fig. 2b. As seen, the average FS value is obtained equal to 1.049 which is rather smaller than the deterministic FS (i.e., FS=1.073). In this case, the failure probability is found equal to 26.06 percent, which is relatively high and indicates a high risk of failure.
The probability of failure corresponding to each arbitrary amount of FS is calculated, and the results are presented in the form of a cumulative probability curve in Fig. 3a. Furthermore, the scatter plot of FS corresponding to each water table position is presented in Fig. 3b with a curve fitted to data. This result is of practical significance since the water table location corresponding to the target probability level can be estimated and utilized in the subsequent analysis and design process.

REFERENCES


ACKNOWLEDGMENTS

The authors would like to appreciate the facilities and support provided by Tongji University to conduct this research. Additionally, the comments and suggestions of Dr. Mingliang Zhou on the early version of this paper are highly appreciated.
STRUCTURAL RELIABILITY OF ELEVATED WATER RESERVOIRS UNDER WIND LOADING

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Keywords: Reliability, wind speed, hydraulic load, failure, concrete elevated tanks.

ABSTRACT

In the field of civil engineering, concrete water storage tanks are considered as hydraulic structures occupying a special place among other structures. The location of these tanks is based on hydraulic considerations related to the desired service pressure for subscribers whose solution is obtained by a compromise with the topographical constraints. In southern Algeria and the highlands; in order to ensure adequate pressure in the drinking water supply networks, the tanks are then elevated to high heights, which puts them under significant stress during windstorms and sandstorms conditions that are frequent in the South Algerian. As the severe weather conditions due to high winds are common, the elevated water storage tanks are designed to withstand to winds speeds included between 25 and 31 m/s according to the Algerian Wind Code. Until the 19th century, dimensioning codes of structures were based on empiricism and experience. The value of the admissible stress $\sigma_{adm}$ is determined by the ratio of the stress of ruin $\sigma_{rup}$ of the material on a safety factor noted “k” fixed in a conventional manner:

$$\sigma \leq \sigma_{adm} = \frac{\sigma_{rup}}{k}$$

This principle has the advantage of being easy to implement but it remains insufficient. Indeed, it does not allow taking into account the dispersion of each of the parameters involved in the calculation since the same coefficient is assigned to them, which can lead to over-dimensioning. On the other hand, constraint verification is not the only criterion involved in assessing the safety of a construction.

Since 1999, Algeria has adopted a wind and Snow code (RNV99), inspired by the Eurocode rules and the coherence with the verification methods to the limit states. The document is based on a probabilistic approach where the normal and extreme actions of the old rules are replaced by the unique concept of characteristic action defined by reference to a territorial zoning (snow, wind and sand) linked to local climatic specificities.

Given the uncertain and randomness of this phenomenon, the classical deterministic calculations of the engineer become limited since they do not integrate the notion of failure probability of the structure. In this study, a probabilistic approach based on Monte Carlo simulations is used to analyze the reliability of elevated water tanks submitted to hazard storm of wind loading. The limit state functions are related to the ultimate and serviceability limit states of the concrete elevated tank under wind analysis. This reliability approach, takes into account mainly two parameters which are the wind speed and the concrete compressive strength considered as random variable. Fragility curves depending on wind zones are obtained, where they demonstrate the dominant failure modes that can cause the structural failure.

As far as the support system of the tank is concerned, the failure mechanism to be investigated in this paper is the cracks formation in the concrete, by the compression constraints and tensile stress.
Taking into account the above, the first limit state function of compression can be formed as the difference between the maximum developed stress $\sigma_c$ and the admissible stress $\sigma_{c,\text{adm}}$. The second limit state function of traction can be formed as the difference between the maximum developed stress $\sigma_t$ and the admissible stress $\sigma_{t,\text{adm}}$. Figure 1 shows that the failure probability in the limit state of compression in the concrete of the most loaded columns, according to the different zones of the wind, is null. This proves that there is no risk of concrete failure by compression. The failure probability at the limit state of tensile stress as a function of the different wind zones is illustrated in Figure 2. The results show that the failure probability increase with the speed wind. For the wind zone I, this value is null, it is close to the limit value allowed for civil engineering structures ($10^{-8} < P_f < 10^{-3}$) in the wind zone II, and the structure is failing in the wind zone III.

**Fig. 1.** Failure probability of compressive strength as function of wind zone

**Fig. 2.** Failure probability of tensile stress as function of wind zone

**REFERENCES**

**Multi-objective optimization design of the rotor assembly using response surface methodology**

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**Keywords:** multi objective optimization; air compressor rotor; numerical simulation; surrogate model.

**ABSTRACT**

In fuel cell systems (FCS), air compressor which is a component of air supply subsystem plays a major role in the overall performance and cost [1]. In this study attention has being given to reduce the material usage of a particular component of a centrifugal type air compressor rotor assembly. The assembly consists of shaft, impeller, nut, sleeve and magnets (Fig. 1). In order to hold the magnets securely, sleeve is attached with interference fit. The assembly can run at the rotational speed of up to 125 krpm and at the temperature of 220 °C. Due to high forces induced on the sleeve, austenitic nickel-chromium based supper alloy Inconel 718 is used in order to improve its service life. Because Inconel 718 is very expensive, it is important to reduce the material usage of the sleeve while keeping the safety factors of magnet and sleeve satisfactory. The following design variables of the sleeve were selected for the multi objective optimization (MOO): sleeve thickness ($T$), sleeve length ($L$) and interference ($I$). Table 1 consists the design space of each design variable.

<table>
<thead>
<tr>
<th>Design variables</th>
<th>Initial design</th>
<th>Design Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T$ (mm)</td>
<td>1.65</td>
<td>Lower bounds</td>
</tr>
<tr>
<td></td>
<td>1.45</td>
<td>1.65</td>
</tr>
<tr>
<td>$L$ (mm)</td>
<td>100.1</td>
<td>92.1</td>
</tr>
<tr>
<td>$I$ (mm)</td>
<td>0.05</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Fig. 1. Schematic of the air compressor rotor assembly.

Numerical analysis was done using ANSYS mechanical and parameters correlation, response surface and multi objective optimization were done using ANSYS DesignXplorer. First using parameters correlation module, sensitivities of the three design variables were calculated. It was found that $L$ has little effect on the minimum safety factors of the two components. Due to this reason, sleeve length ($L$) was removed from the list of design variables in the optimization process. In order to reduce the material usage, sleeve length was fixed to be 4 mm, which is its lower bound value.
In order to cover most of the design space, a combination of design of experiments such as central composite design (CCD) (9 design points) and maximum entropy design (40 design points) was used. Total of 49 design points were used to obtain the surrogate model. CCD design points were used to properly capture the boundaries of the design space and maximum entropy design was used due to its high space filling capacity [2].

Surrogate model was obtained using non parametric regression from the available meta models based on the goodness of fit. Afterwards MOO was carried out using Multi-objective genetic algorithm (MOGA). The three objective functions used were minimum safety factor of sleeve and magnet and weight of the sleeve. Objective was to maximize the first two objective functions and to minimize the third objective function while having better or equal safety factor from the initial design. To obtain better or equal safety factor, constraints were used for the first two objective functions.

Candidate points obtained from the MOO was further validated using numerical simulation. From the validated candidates’ single candidate point is selected based on the weight saving. Compared to the original design up to 11.8% weight can be saved with little variation in the minimum safety factor of the magnet. Following Table 2. shows the results obtained from the MOO and percentage of weight saving achieved.

Table 2. Comparison between initial design and multi objective optimization results.

<table>
<thead>
<tr>
<th></th>
<th>Initial design</th>
<th>MOO results</th>
</tr>
</thead>
<tbody>
<tr>
<td>L (mm)</td>
<td>100.1</td>
<td>92.1</td>
</tr>
<tr>
<td>T (mm)</td>
<td>1.650</td>
<td>1.587</td>
</tr>
<tr>
<td>I (mm)</td>
<td>0.05000</td>
<td>0.04969</td>
</tr>
<tr>
<td>Min. safety factor of magnet</td>
<td>1.98</td>
<td>1.81</td>
</tr>
<tr>
<td>Min. safety factor of sleeve</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Percentage of weight saving (%)</td>
<td>-</td>
<td>11.8</td>
</tr>
</tbody>
</table>

In this study, numerical analysis as well as multi objective design optimization of air compressor rotor has been carried out. To find out which design variables should be used for the optimization, parameter correlation study has been conducted. It was found that sleeve length (L) has little effect on the minimum safety factor of the two components. Then response surface model is used to approximate the objective function with the rest of the two design variables. Multi objective optimization is done to find out the optimum design variables to maximize the minimum safety factor of the sleeve and magnet while minimizing the weight of the sleeve.

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ACKNOWLEDGMENTS
This research was financially supported by the Ministry of Trade, Industry, and Energy (MOTIE), Korea under the “Commercializing fuel cell electric vehicle component industry and R&D Support Program” (reference no. R0006468) supervised by the Korea Institute for Advancement of Technology (KIAT).
Ergonomic Reliability and safety Evaluation for the Control Interface Design Based on AHP-Fuzzy Improved by Delphi and Eye-Tracking Experiments

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Keywords: Ergonomic Reliability, AHP-Fuzzy, Delphi, Eye-Tracking Experiment.

ABSTRACT

In the process of machining, the operator's incorrect operation using the control human-computer interaction interface may lead to a disastrous effect on the whole production chain such as task failure, system failure and so on. The six types of using errors about human-computer interaction interface system (misperception, attention failure, perceptual confusion, fatigue operation, memory failure and slip) are proposed based on the cognition from users. According to the six types of using error, the ergonomic reliability and safety evaluation method is proposed under the different levels of fatigue. 3 different levels of fatigue are identified according to the blink number of operators’ eyes, hot points, the pupil changing detected by the eye-tracking instrument and subjective questionnaires. In the cases of different fatigue levels respectively, the number of using errors about the six types are recorded. Since the assessment figures are from the rational data collection and perceptual expert analysis, fuzzy analytic hierarchy process (AHP-Fuzzy) improved by Delphi is selected to make the ergonomic reliability and safety evaluation. During the data processing, the traditional AHP-Fuzzy cannot show the fuzziness of human judgments owing to the integer assignment comparing two pairs of evaluation indexes, the AHP-Fuzzy improved by Delphi can solve the problem. In addition, it can save the time of expert analysis and reduced a part of computation about the judgment matrix testing and adjusting for consistency. Taking the mechanical grinding equipment for example, the best human-computer interaction interface designs schemes is chosen according to the ergonomic reliability and safety evaluation method. Based on the practical operation and eye movement experiments, the using efficiency and accuracy of the human-computer interaction interface design schemes chosen by the evolution method is better than the original one to verify the evolution method validity.
PSO-BP Neural Network-based Strain Prediction of Wind Turbine Blades

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Keywords: Wind turbine blade, Full-scale static test, PSO-BP Neural Network, Strain prediction.

ABSTRACT

The full-scale static testing of the wind turbine blade is an effective means to verify the accuracy and rationality of the design of blade, and it is an indispensable part in the blade certification process. In the full-scale static testing, the strain of the wind turbine blade is related to the applied loads, loading positions, stiffness, deflection and other factors. At present, the current researches focus on the analysis of the blade failure causes, blade load-bearing capacity, the parameter measurement methods, and the correlation analysis between the strain and the applied loads, the loading positions and the blade displacements is rare. The correlation between the strain and the applied loads, loading positions, displacements, etc. is nonlinear, and the number of design variables is many, thus the calculation and prediction of the blade strain are very complex and difficult by traditional numerical methods. Moreover, in the full-scale static testing, the numbers of measuring points and strain gauges are limited, so the test data have insufficient significance to the calibration of the blade design. Thus, this paper makes a study on the new strain prediction method by introducing intelligent algorithms. Back propagation neural network (BPNN) improved by Particle Swarm Optimization (PSO) has significant advantages in dealing with non-linear fitting and multi-input parameters and the models constructed by BPNN improved by PSO (PSO-BPNN) have better robustness and accuracy. By taking the advantages of the neural network in dealing with complex problems, a strain-predictive PSO-BPNN model for full-scale static testing of a certain wind turbine blade was established, and the strain values of the unmeasured points were predicted. The accuracy of the PSO-BPNN prediction model was verified by the comparison with BPNN model and simulation test. The applicability and usability of strain-predictive neural network models were verified by comparing the prediction results with the simulation results. The comparison results show that PSO-BPNN can be used to predict the strain of unmeasured points of wind turbine blades during the static testing, and then provide more data for structural characteristic parameters calculation.
TEMPORAL ANALYSIS OF THE PERFORMANCE OF A RC STORAGE TANK CONSIDERING THE CORROSION

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Keywords: Concrete tank, westergaard method, performance, corrosion, concrete coating

ABSTRACT

The reinforced concrete (RC) water storage tanks are hydraulic structures that occupy a special place among civil engineering structures. Under the effect of hydrostatic and hydrodynamic loads, their walls undergo horizontal tensile stresses which are absorbed by horizontal reinforcements. Moreover, these structures are subjected to high aggressive atmospheric conditions that expose their walls to a risk of harmful corrosion. This dangerous phenomenon leads to the reduction of their reinforcement sections and consequently to the loss of their resistance and function.

In this paper, we propose a deterministic method for analysis of the tank wall performance, taking into account the corrosion phenomenon of tensile reinforcements under the effect of hydrostatic and hydrodynamic loads. To evaluate the hydrodynamic pressures, we use Westergaard method (1933) for an incompressible fluid and rigid structure. This method proposes a relationship that takes into account both the seismic acceleration and the water depth in the tank.

The reinforcement section in the wall is determined according to the concrete codes at limited states (BAEL91) and Fascicle 74. To introduce the effect of the reinforcement corrosion by pitting, we proceeded to the calculation of the residual section of the reinforcement as function of time (after corrosion), by using the relation of Duprat (2006). Moreover, to express the corrosion current, we adopted the model of Liu and Weyers (1998). This model takes into account several environmental parameters, such as the ambient temperature, the concentration of chlorides at the surface of reinforcement, which is determined according to the aggressiveness of the site of implantation of the structure, the environmental factor and the aging factor. To perform the deterministic analysis, we considered an environment of different aggressiveness with different concentrations of chloride at the surface of the reinforcements and for different coating.

The results obtained showed that pitting corrosion is affected by the environment aggressiveness. The initiation time of corrosion decreases considerably from a n environment of low aggressiveness (fig.1) to an environment of high aggressiveness (fig.2); which accelerates the propagation of this corrosion. This, of course affects the service life of the tank wall which is reduced by more than half by moving from a low aggressiveness environment to extreme aggressiveness environment; despite that the coating is important. For that, the consideration of the environmental criterion during the design of reinforced concrete tanks becomes necessary.

The analysis of the corrosion in function of the various parameters influencing the initiation time and the corrosion current (coating, critical concentration of chloride ions, resistivity of the coating concrete, diffusion coefficient) has shown that the service life of the tank can be lengthened by providing a large concrete-coating and decreasing the permeability of the concrete.
Fig. 1. Reinforcement section evolution as a function of time in low aggressiveness environment.

Fig. 1. Reinforcement section evolution as a function of time in high aggressiveness environment.

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Bayesian Linear Regression analysis of the effect of silica fume on concrete creep predictions and structures’ safety

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Keywords: Concrete creep; Eurocode 2; admixtures; silica fume; Bayesian methods.

ABSTRACT

An important evolution in the construction field is noticed nowadays. New high-rise buildings, bridges and dams are taking place all over the world where concrete has been used as a primary material. With the evolution in construction field, an improvement in the performance of concrete material became necessary [1]. This entails the incorporation of admixtures and additives to the mix composition which improve its properties and performance [2, 3]. Therefore, an accurate prediction of the behavior of these constructions is a must.

These additions affect also concrete deformations especially the creep, defined as the time-dependent deformations which reduce the volume of concrete with the impact of external load applied to the concrete element. Since creep deformations have an important impact on long-term integrity and stability of structures, an accurate prediction of these deformations is needed [4]. But design codes do not consider admixtures effects’ while predicting concrete creep, therefore, multiple studies were undertaken in this field. In their study, Choi et al. (2015) have proposed a model for the creep phenomenon of hardened cement mixed with expansive additives [5]. Also, Gong et al. (2016) have proposed, in their study, a creep model for a concrete member subjected to axial compression and suffering from sulfate attack [6]. In model B4, the effect of admixture type and percentage is taken into consideration by adding scaling factors to p2, p3, p4 and p5 parameters [7]. As for the Eurocode 2 (EC2) model, it does not consider the effect of admixtures on creep of concrete, therefore, this study aims at updating it by considering the admixtures’ effects, specifically, the silica fume (SF).

To study the impact of silica fume on creep predictions, a large experimental database coming from international laboratories and research centers is applied to evaluate the Eurocode 2 model by comparing the predicted creep compliance to the experimental measurements using CEB statistical methods [8]. An inaccurate estimation of the Eurocode 2 creep compliance for concrete with silica fume is noted. To overcome this difference, a calibration of the Eurocode 2 model is proposed by implementing correction coefficients that take the effect and percentage of silica fume into consideration.

These correction coefficients are implemented in the Eurocode 2 formula under two different approaches. As a first step, the correction coefficient is added to the Eurocode 2 formula without taking the percentage of silica fume into consideration, then the percentage of admixture is considered in the correction coefficient expression. To quantify these correction coefficients, a linearization of the creep model is performed, then a Bayesian analysis is applied. The Bayesian inference consists of multiplying
the expert knowledge already known and named as the prior distribution, by the likelihood function coming from the database. Therefore, a posterior distribution is defined which is an update of the knowledge already known using the latest database [9, 10]. More specifically the Bayesian Linear Regression method, which is an approach to linear regression in which the statistical analysis is undertaken within the context of Bayesian inference, is applied in this study to identify the correction coefficients.

After implementing the correction coefficients to the Eurocode 2 compliance formula, and to evaluate our updated Eurocode 2 creep model, the CEB statistical methods are applied. An improvement in the results is clearly shown. It can be noticed that the implementation of correction coefficients to the Eurocode 2 formula allows to predict accurately creep at the design stage and hence the long-term deflection. Therefore, the required measurements and precautions can be applied to avoid excessive deflections after construction. These predictions are more accurate by considering the percentage of silica fume into the correction coefficient expression.

This study shows that the Bayesian model assessment is an important procedure applied to update the Eurocode 2 creep model. The long-term serviceability of structures subject to creep is well improved by adopting such a design approach.

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The effect of molding compound on reliability of electronic components

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Keywords: Reliability; Mechanical properties, Numerical simulation, Electronic components.

ABSTRACT

Molding compound directly affects the quality and reliability of product during encapsulation process of electronic components. Microelectronic plastic encapsulated devices have gradually matured in packaging materials, chip passivation and production technology after years of development. However, there are still many hidden dangers in the reliability of plastic encapsulated devices, such as corrosion failure, popcorn failure, thermal shock failure caused by mismatch of coefficient of thermal expansion (CTE).

In this paper, the properties of five common epoxy molding compounds (EMCs), EK5600GHR, EK5600GH, EK5600H, GR700 and GR710, are tested, and their effects on the reliability of TO-252 devices are analyzed. Firstly, the heat resistance, glass transition temperature ($T_g$) and storage modulus of these EMCs are tested by Thermal Gravimetric Analyzer (TGA), Dynamic Thermomechanical Analyzer (DMA). The main parameters of EMCs are listed in Table 1. Then, construct the same geometric model as the actual size, as shown in Fig.1. Finally, the deformation and life of the device in high accelerated stress test (HAST) and high-low temperature cycle (T/C) test are analyzed by using the simulation tool ANSYS.

By analyzing the experimental results in Fig.2 and Fig.3, it is found that the storage modulus of the five molding materials drops rapidly near $T_g$ and the filler content of the same type of EMC is positively correlated with the storage modulus (200°C). HAST results of simulation show that the thermal deformation of the device mainly depends on the matching degree of coefficient of thermal expansion (CTE) between materials, and the hygroscopic deformation is closely related to the humidity of EMC, as shown in Fig.4 and Fig.5. T/C results of simulation show that the smaller the change of the storage modulus of the material, the longer the life of the device, as shown in Table 2 and Fig.6.

It is pointed out that the traditional experiment combined with simulation is an effective method to study the influence of molding compounds on device’s reliability. Since the properties of materials often restrict each other, the selection of molding compound should be based on the environment in which the plastic encapsulated device is placed.
Table 1. Main parameters of EMCs.

<table>
<thead>
<tr>
<th>Molding Compound</th>
<th>EK5600GHR</th>
<th>EK5600GH</th>
<th>EK5600H</th>
<th>GR700</th>
<th>GR710</th>
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<tr>
<td>Density ($kg/m^3$)</td>
<td>2.0</td>
<td>2.0</td>
<td>1.9</td>
<td>2.0</td>
<td>2.0</td>
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<tr>
<td>Specific heat ($J/kg\cdot°C$)</td>
<td>1533</td>
<td>1095</td>
<td>1180</td>
<td>625</td>
<td>709</td>
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<tr>
<td>CTE ($\alpha_1 \times 10^{-6}/°C$)</td>
<td>7</td>
<td>9</td>
<td>13</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>CTE ($\alpha_2 \times 10^{-6}/°C$)</td>
<td>37</td>
<td>33</td>
<td>59</td>
<td>31</td>
<td>30</td>
</tr>
<tr>
<td>Storage modulus ($130°C/MPa$)</td>
<td>7580</td>
<td>19622</td>
<td>17462</td>
<td>5404</td>
<td>2406</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
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<tr>
<td>Thermal conductivity ($W/m\cdot°C$)</td>
<td>1.1</td>
<td>1.05</td>
<td>0.9</td>
<td>0.93</td>
<td>1.0</td>
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<tr>
<td>$T_s$ ($°C$)</td>
<td>124</td>
<td>134</td>
<td>168</td>
<td>131</td>
<td>119</td>
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<tr>
<td>$C_{sat}$ ($130°C/10^{-6}g/mm^3$)</td>
<td>9.889</td>
<td>8.419</td>
<td>14.982</td>
<td>10.46</td>
<td>14.54</td>
</tr>
</tbody>
</table>

Fig 2. Storage modulus of EMC.

Fig 3. TG of EMC.
Fig 4. CTE and maximum thermal deformation.

Fig 5. Humidity and maximum hygroscopic deformation.

Table 2. Life.

<table>
<thead>
<tr>
<th>Molding compound</th>
<th>EK5600GHR</th>
<th>EK5600GH</th>
<th>EK5600H</th>
<th>GR700</th>
<th>GR710</th>
</tr>
</thead>
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<td>Amplitude of shear strain ($\Delta \gamma_p$)</td>
<td>0.022</td>
<td>0.018</td>
<td>0.019</td>
<td>0.024</td>
<td>0.025</td>
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<tr>
<td>Life (cycle)</td>
<td>2532</td>
<td>4558</td>
<td>4025</td>
<td>2024</td>
<td>1943</td>
</tr>
</tbody>
</table>
Fig 6. Relationship between life and variation ratio of storage.

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A dynamics analysis method for high speed railway bearing under uncertainty

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Keywords: dynamic characteristic, high speed railway bearing, uncertainty, ADAMS software, support vector machine.

ABSTRACT

The bearing system is wildly used in rolling machines. The dynamic characteristic of this system has been deeply studied. In this paper, the dynamics of high speed railway bearing is studied considering the randomness of loads. Firstly, the uncertainty loads acting on high speed railway bearing system is quantified. Secondly, the multi-body dynamics model is built using ADAMS software, and the bearing dynamics is analyzed under stochastic loads. Further, the interaction action between bearing elements is studied. Then, support vector machine method is employed to develop a mathematical model for multi-body dynamics of high speed railway bearing. Finally, the proposed method is validated using the experiment results.
Reliability and sensitivity assessment of aeroengine compressor blisk using improved weighted regression surrogate model method

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Keywords: dynamic reliability and sensitivity analyses; improved weighted regression surrogate model method; complex structure; fluid-structure interaction; compressor blisk.

ABSTRACT

To study the reliability and sensitivity assessment of aeroengine low-pressure compressor blisk stress with high-accuracy and high-effectiveness, by considering the effect of dynamic workloads, this paper develops improved weighted regression surrogate model method (IWRSM) based on extremum response surface surrogate model and improved weighted regression method. As for the proposed method, the extremum response surface surrogate model is utilized to process the dynamic reliability and sensitivity assessment to improve the computational efficiency, and the improved weighted regression method is used to find efficient samples with larger weights and smaller errors to enhance the calculative accuracy. The basic principle is firstly elaborated for the dynamic reliability and sensitivity assessment with the developed technique. And then the mathematical model of the IWRSM for compressor blisk stress is established, considering the effect of fluid-structure interaction and the random inputs (including inlet velocity, outlet pressure, angular speed and material density) within time domain [0, T]. Finally, the dynamic probabilistic analyses of compressor blisk stress is implemented via Monte-Carlo (MC) method. The direct simulation and extremum response surface method (ERSM) are employed to validate the effectiveness from the fitting accuracy and the simulation performance. Some conclusions are derived as below. The reliability probability and important degree of influential factors for compressor blisk stress are obtained using the IWRSM, and the analytical results can be used to guide optimization design. Besides, the developed IWRSM can improve the efficiency and precision of dynamic probabilistic analysis of compressor blisk. The dynamic reliability and sensitivity assessment with the IWRSM is effective and feasible for improve the designs of complex structure besides compressor blisk. Therefore, the efforts of this work provide a useful technique for the dynamic probabilistic analysis of complex structure with respect to working process.
Combined Experimental-Numerical Methodology to Evaluating the Fatigue Crack Growth Rates for the 1100 Aluminum

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Keywords: Fatigue; Crack Growth; Life Prediction; Constant Amplitude Loading; SIF; Aluminum.

ABSTRACT

Fatigue crack growth (FCG) is the main cause of failures and mechanical fracture in systems subjected to cyclic loading. Its evolution is related to material chemical and mechanical properties, surface and environmental characteristics, as well as loading types, amplitudes, frequencies and stress R-ratios [1-3]. This study aims to evaluate FCG rates by a combined experimental-numerical methodology for the 1100 aluminum specimens under consideration.

Aluminum is the second most used metal in the world, being only behind the steels. It is estimated that 8% of the Earth crust is composed of aluminum, being the most abundant structural metal. It is notable for its lightness, electrical conductivity, excellent corrosion resistance, high thermal conductivity, high mechanical strength when alloyed and good appearance [4-6]. Aluminum 1100, termed unalloyed and commercially pure with at least 99% purity, is highly resistant to chemical attack and weathering, and still has low cost, good weldability and good ductility for stamping [4,5]. It has been used in the aeronautical, automotive, chemical and packaging industries, as well as in general structures [7]. Additionally, it is sustainable, non-toxic and recyclable without losing its properties [5,6].

The proposed combined experimental-numerical methodology follows the workflow shown in Figure 1a. The experiments are being conducted in laboratory environment with temperature at 25°C. The single edge notched compact specimens (CT) of thickness equal to 0.3 mm were manufactured by electro erosion and is illustrated in Figure 1b. The sample is fixed on one side and the cyclic load is applied on the other, force between 10 and 40N with frequency 11Hz.

![Fig. 1. a) Combined Experimental-Numerical Methodology workflow; b) Specimens geometry.](image-url)
This experimental procedure consists in testing crack propagation (mode I) in the geometries previously related (Fig. 1b) using the proposed workbench. Initially, the samples are run until a pre-crack appears. After that, periodic images are collected at predetermined fixed intervals of 10 minutes (intervals considering preliminary tests), until the crack reaches a critical length (appearance of another exciting modes or high crack growth). The images are processed, and then, using Digital Image Correlation it is possible to identify the position of the crack tip and consequently calculate crack length for each test step.

As previous results, Fig. 2 shows the behavior of crack length by the number of cycles for some of the experimental tests already performed.

For the next steps, following the presented workflow, include the use of the Finite Element Method (FEM) to calculate the stress intensity factors for all experimental measurement steps [8]. The da/dN vs ∆K results [9] will be presented.

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