I.O.S.U.D. Universitatea Politehnica Timişoara
Şcoala Doctorală de Studii Inginereşti

REZUMATUL *tezei de doctorat*

„ENGINEERING CRITICAL ASSESSMENT OF THE CYLINDRICAL SHELL STEEL STRUCTURES"

„EVALUAREA CRITICĂ A STRUCTURILOR METALICE CILINDRICE TIP CURBE SUBȚIRI (SHELL)"

În domeniul de studii universitare de doctorat: INGINERIE CIVILĂ
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Life safety of the structures, which includes several important aspects of vulnerabilities, represents great importance matter in a society.

In case of steel structures, existing of flaws in critical parts of structural elements may lead to failures of the elements and in case of lack of redundancy, even to collapse of the entire structure.

The thesis research is focused on fracture mechanics approach in assessing the existing flaws in steel shell structures and also presenting algorithms and procedures for designing structural elements taken into account future potential flaws affect.

Engineering critical assessment (ECA) is a fracture mechanic approach applied in expertise of the existing pipeline, pressure vessels and offshore type structures. A design and expertise ECA type is imposed also at common bridge or civil type structures. The Eurocode provisions and standards are presenting only a conservative approach with two implications: designing process with requirements in the calculation of the elements and or the joints (e.g. welded joints) and manufacturing and erection with requirements for the quality of the steel structure (which includes also the welding as a manufacturing process)

The thesis is presenting a detailed methodology for assessment and determination of the acceptability of flaws resulted from service life and detected in shell steel structures. Based on fracture mechanics approach, there are presented procedures and rules needed in maintenance, expertise and checking of these types of structures. This method of assessment of flaws/cracks represents the first step within a complex methodology based on fracture mechanics principle and followed by fatigue analysis of the assessed elements through which can be determined the remaining in service lifetime of the structure/elements of the structure.

The content of the thesis is described below:

Chapter 1

In Chapter 1 – Introduction is presented the importance of the topic. There are detailed several main flaws possible present in the steel shell type structures, factors for brittle fracture and different types of flaws causes.

Also is presented a study case – Aleksander Kielland drilling rig capsize, with direct cause – failure of a bracing due to fatigue. A fracture mechanics and fatigue approach is imposed for studying the fitness for service of the existing and designed structures.

Chapter 2

In Chapter 2 there is presented a synthesizing information regarding the fracture mechanics and application at steel shell structures. Linear elastic fracture mechanics to elastic plastic fracture mechanics and fatigue calculation are prerequisite for the subsequent chapters research. Standards methods for fracture parameters testing are presented.

Following fracture mechanics approach, based on damage cumulation principle, in service structure safety assessment can be made. A detailed procedure of this process is presented.

Chapter 3

The chapter is presenting the EN design approach for steel shell elements. The buckling strength is the most important parameter in the design of these types of structures. Generally buckling may be defined as the sudden failure, or instability, of a structural member subject to compression load. This instability occurs at a maximum point on the load-deflection curve at which point instability may fall into one of two categories: *Bifurcation of Equilibrium* or *Limit Load Buckling*. The important of imperfections of the shell elements is underlined and several design principles with direct application are revealed.

The thesis is presenting a study case – a steel shell structure billboard tower thirty meters high. There is presented EN load design procedure together with the load assumption process. In order to provide the needed input data for the Chapter 6 fatigue design, a detailed wind load calculation was done. Wind load evaluation is done for the given case – a detailed load evaluation is presented in Annex 1.

For determining the stresses in the shell elements, an in depth FEM type analysis was done in the area of a segment joint. Following the results, there were revealed stresses in the area of the welded joints.

Chapter 4

The Finite Element Method is applied for the shell structure billboard tower type. The tower presents a circular cross section with a diameter of 1680mm and is made of four segments - from the base to the top: Tube 1680 x 20 mm – 7 m, Tube 1680 x16 mm – 8 m, Tube 1680 x 12 – 7 m and Tube 1680 x 10 – 8 m. In a first step, the entire structure is considered and analyzed – linear structural analysis (LA), in order to determine the stresses in the critical sections. Following the results, the main internal forces on each section and the maximum Von Mises stress of the tower are presented.

After the linear analysis (LA), the buckling design forces are analytical calculated. Determining the critical stresses, the meridian and circumferential stress, is done using EN1991-1-6. The design of the stresses which appear in the walls of the tube pillar is done using shell theory - annex A2 of EN1991-1-6. A detailed design for the shell elements (each segment) is presented in Annex 2 of the thesis.

A second step of the design is using FEM to the segment joint design – the joint with the higher stress is taken into account. Different sections stress results were compared with the previous FEM analysis – the results were similar (with slight differences).

For the segment joint model is done also an advanced analysis - linear buckling analysis (LBA). The elastic critical buckling resistance ratio is determined from the eigenvalue analysis (LBA) applied to the linear elastic calculated stress state in the geometrically perfect shell (LA) under the design values of the load combination. The first ten buckling eigenvalues were calculated, thus resulting the critical buckling resistance value used as a multiplication factor for the elastic loads.

All buckling eigenmodes present deformed shapes (buckling) at the lower part of the 16 mm thickness segment – nearby the joint area (immediately to the joint stiffeners).

Chapter 4 presents also the application of FEM in analysis of behavior of steel elements and welded joints with cracks as a prerequisite for chapter 6.

Chapter 5

At chapter 5 is presented a detailed experimental part for material and fracture mechanic testing which include the chemical analysis of the steel composition, traction tests, Charpy V-notch test, in order to determine the amount of energy absorbed by a material during fracture, the *J* integral curve, the fatigue crack growth.

The laboratory testing and measurements were done at Faculty of Mechanical Engineering – University of Belgrade and also at the Politehnica University of Timişoara.

Following the test results complex fracture and fatigue calculations were done in chapter 6.

Chapter 6

The structural integrity and life assessment can be considered as a mandatory request in the designing and manufacturing process.

Chapter 6 is presenting the procedure for determination of crack acceptability based on fracture toughness with Failure Assessment methods (FAD-1 and FAD-2) which can be applied to any type of steel shell structure with welded joints. Different types of locations were taken into account – from in the plate flaw (e.g. flange plate joint near the welded joint), to the curved shell circumferential flaw (e.g. in the shell element).

The assessment is using BS7910 /2013. Thus were assessed common ten types of flaws met at steel shell cylindrical structure elements using failure assessment diagrams – level 1 – FAD -1. The results are presented the acceptability level for each type of flaw with comparative graphs, determining also the critical dimension of the flaw.

The level 2 assessment approach (FAD-2) is done for 43 types of steel shell elements flaws.

For each flaw was calculated the failure assessment diagram (FAD-2) (presented in Annex 3). Different comparisons between group of flaws were done, revealing the critical crack like flaw. Also the critical value of flaw dimensions were calculated for each flaw type.

A major contribution is done in Chapter 6, presenting the procedure for determining the safety in service of the shell steel structures using engineering critical assessment approach.

The methodology establishes clear rules for assessment of structural elements with cracks, determining the initial flaws, assessed flaws and critical values of the cracks. A detailed fatigue design and assessment procedures are presented.

Using CrackWise software, there was applied fatigue based engineering critical assessment on a real case – the billboard tower like steel shell cylindrical structure. For the fatigue evaluation, a detailed wind load calculation was done taken into account the cycles given for a wind recording (data supplied by the Romanian INMH institute). Following the structural analysis of the five load cases, was assessed the stress in the structure segment joint. Using Rainflow algorithm, the results were processed and was determined the block of stresses with stress ranges and the appearance frequency of them.

For all 43 flaw type cases the fatigue ECA approach was applied, revealing the number of cycles – number of blocks (years) until failure. For the flat plate type flaws (FP type), several assessments were done – the B dimension (indicated the length of the stress affected area), was taken as 200mm, 500mm and 1000mm, thus underlining the stress redistribution in the shell element.

For each type of flaw the ECA was applied and resulted a plotted graph indicating the number of years until failure and the critical flaw dimension (results presented in Annex 4). All the results were compared and were revealed the most critical flaws – with the lower number of years until failure.

Based on the detailed procedures described in Chapter 6, on conclusions to the assessment done on each type of flaw, the assessment methods can be applied very easy in current design practice with different material characteristics.

The presented study is based on experimental results done at Faculty of Mechanical Engineering University of Belgrade and also at the Politehnica University Timişoara, and revealed the needed parameters (K, J, δ) on which are based the fracture mechanics principles.

The main personal contributions, through the research, are the followings:

- Fracture mechanic approach for steel shell structures
- Shell type structures FEM design for a given case
- Experimental research for determining the fracture mechanics parameters
- Engineering critical assessment, a prerequisite in design and expertise of steel shell structures

The main features of ECA approach in this thesis are:

- Better safety of the shell structures
- Defining the service inspections intervals
- Risk under control
- In service lifetime assessment

ECA is an engineering design approach trend that will continue to evolve from the structural design from to the manufacturing process.

Dissemination of research results was done by a number of two papers published in ISI Web of Science WoS indexed journals, one paper published in a scientific conference volume indexed ISI and a number of ten papers published in BDI indexed journals and volumes of scientific conferences.

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