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Determining the crack acceptability in the welded joints of a wind loaded cylindrical steel shell structure

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ABSTRACT

Engineering critical assessment can be considered as a mandatory request in the civil engineering designing and manufacturing process.

The paper is presenting the procedure for determination of crack acceptability based on fracture toughness with failure assessment methods (FAD-1 and FAD-2) which is applied to a cylindrical steel shell structure with welded joints which is having the wind as the main load [7].

The stresses in the structure were determined based on a structural analysis. According to [3] an in depth finite element analysis was applied to the segment joint of the steel shell element (pillar), thus revealing the stresses in the joint (as well in the welded joints).

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

For each flaw was calculated the failure assessment diagram level 2 (FAD-2). Comparisons between groups of flaws were done, revealing the critical crack like flaw. Also the critical values of flaw dimensions were calculated for each flaw type [7]. The methodology establishes clear rules for assessment of structural elements with cracks, determining the initial flaws, assessed flaws and critical values of the cracks.

The conclusion of the research reveals the fracture resistance failure susceptibility of different parts of the segment joint given an existing discovered flaw. Based on the detailed procedures described in the paper, on conclusions to the assessment done on each type of flaw, the method can be applied from the design phase on these types of structure elements.

1. Introduction

Most welding fabrication codes specify maximum tolerable flaw sizes and minimum tolerable Charpy energy, based on good workmanship, i.e. what can reasonably be expected within normal working practices. These requirements tend to be somehow arbitrary, and failure to achieve them does not necessarily mean that the structure is at risk of collapse. An Engineering Critical Assessment (ECA) is an analysis, based on fracture mechanics principles, of whether or not a given flaw is safe from brittle fracture, fatigue, creep or plastic collapse under specified loading conditions. An ECA can therefore be used: *during design*, to assist in the choice of welding procedure and/or inspection techniques; *During fabrication*, to assess the significance of known defects which are

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Nomenclature

a	Half flaw length for through-thickness flaw, flaw height for surface flaw or half height for embedded flaw
B	Section thickness in plane of flaw
k_t	Stress concentration factor and
k_m	Stress magnification factor due to misalignment
K_I	The stress intensity factor (SIF)
K_r	Fracture ratio of applied elastic K value to K_{mat}
K_{mat}	The fracture toughness
M_m	Stress intensity magnification factor
$M_{t,Ed}$	Internal force - torsion moment design value
$M_{y,Ed}$	Internal force - Bending moment design value (y direction)
$M_{z,Ed}$	Internal force - Bending moment design value (z direction)
N_{Ed}	Internal force - Axial force design value
P_b	Primary bending stress
P_m	Primary membrane stress
Q	Secondary stress
Q_b	Residual bending stress
Q_{tb}	Thermal bending stress
Q_{tm}	Thermal membrane stress
Q_m	Residual membrane stress
S_{nom}	Nominal membrane stress for level 1 analysis
S_r	Ratio of applied load to flow strength load
$V_{y,Ed}$	Internal force - Share force design value (y direction)
$V_{z,Ed}$	Internal force - Share force design value (z direction)
σ_Y	The yielding resistance of the material
$\sigma_u \sigma_T$	The ultimate resistance of the material
σ_{max}	The maximum tensile stress
$\sigma_{x,Rd}$	Meridional design buckling stress [3]
$\sigma_{\theta,Rd}$	Circumferential design bucking stress [3]
$(Y \cdot \sigma)_P$	Contribution of the main stresses
$(Y \cdot \sigma)_S$	Contribution of the secondary stresses
W	Plate width in plane of flaw
Y	Correction factor
NDT	Non-destructive testing
FEA	Finite element analysis

unacceptable to a given code, e.g [1]., or a failure to meet the toughness requirements of a fabrication code; *During service*, to assess flaws found in service and to make decisions as to whether they can safely remain, or whether down-rating/repair are necessary [7]. The ECA concept (also named "*fitness-for-purpose analysis*") is widely accepted by a range of engineering industries.

For an analysis of a known flaw, the following information is needed: size, position and orientation of flaw; stresses acting on the region containing the flaw; toughness and tensile properties of the region containing the flaw.

The fact that knowledge of all these three aspects is necessary implies a multidisciplinary approach, involving.

stress analysis, NDT expertise and materials engineering.

The analysis is carried out in accordance with the British Standard procedure [2] (*"Guide to methods for assessing the acceptability of flaws in metallic structures"*). Although simplified analyses can be carried out based on code values of Charpy energy and maximum allowable stresses, it is usually necessary to carry out fracture-mechanics testing (critical *K, CTOD* or *J*) in order to obtain an accurate measurement of the material toughness. Additional stress analysis (e.g. by hand calculation or Finite Element Analysis) may also be required.

For design purposes, or for analysis of weldments which fail to meet a toughness requirement the ECA is based on a hypothetical "*reference flaw*" which is highly unlikely to be missed during inspection.

The case study of the paper presents the assessment on a steel shell element part of a billboard tower structure located in Romania – Brașov city. After erection in 2009, two inspections of the structure were performed by qualified personnel in order to assess the state of the structure. Following a visual investigation of the structural elements and the joints of the billboard tower, several cracks were discovered in the area of the segment joints of the tower [7].

The structure has two components: the column which is a 1680 mm diameter S355J2 steel quality tube and the head of the tower where the billboard is fixed. The head is made of a truss system in order to undertake the dead and wind loads and to transmit them directly to the pillar (Fig. 1).

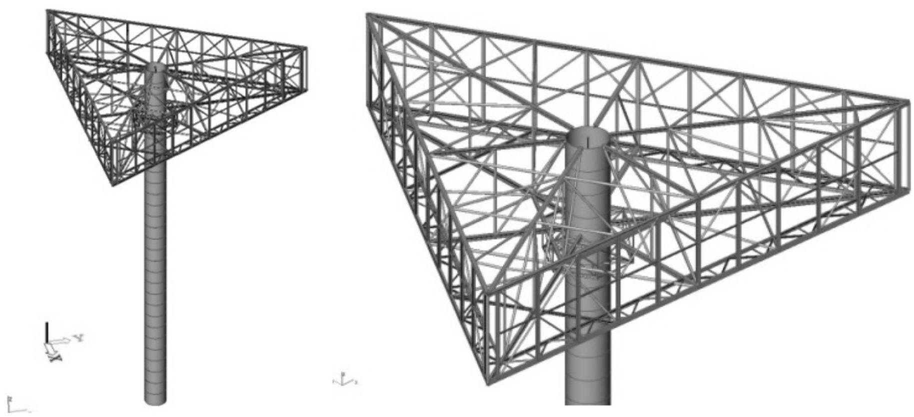

Fig. 1. Billboard tower geometry-general views.