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THE STUDY OF THE CRACK APPARITION AND PROPAGATION ON A 60 CUBIC METERS STEEL TANK

Matei-Cosmin Baciu
"Dunarea de Jos" University of Galati,
Faculty of Naval Architecture, Galati, Domneasca Street, No. 47, 800008, Romania,
E-mail: baciumateicosmin@yahoo.ro

Bogdan-Ioan Bahrim
"Dunarea de Jos" University of Galati,
Faculty of Naval Architecture, Galati, Domneasca Street, No. 47, 800008, Romania,
E-mail: bogdanbahrim@yahoo.com

Cristina Bîrlădeanu
"Dunarea de Jos" University of Galati,
Faculty of Naval Architecture, Galati, Domneasca Street, No. 47, 800008, Romania,
E-mail: cristina.biraldeanu1@yahoo.com

Cristina Serea
"Dunarea de Jos" University of Galati,
Faculty of Naval Architecture, Galati, Domneasca Street, No. 47, 800008, Romania,
E-mail: serea.cristina04@yahoo.com

Costel Iulian Mocanu
"Dunarea de Jos" University of Galati,
Faculty of Naval Architecture, Galati, Domneasca Street, No. 47, 800008, Romania,
E-mail: costel.mocanu@ugal.ro

ABSTRACT

International Association Of Classification societies inspect every year all safety systems from the LNG/LPG ships, regarding the storage tanks. The cargo in the tanks of gas carrier is partially liquid and partially vapour in normal condition. However, when the tank structure collapses, the vapour tries to escape or leak through the opening, resulting in decreasing the pressure inside the tank. These drastic lowering of pressure inside the cargo tank results in rapid boiling of liquid and increase in vapour formation. The pressure of the escaping vapour becomes very high and leads to a shock wave or explosion in presence of a fire source, completely destroying the tanks structure and surrounding areas. This matter determined the beginning of the study about the cracks that appear on a tank that is 10 meters long, has 3 meters in diameter and is made of steel plates with a 45 millimetres thickness.

Keywords: tank, crack, air pressure, FEM analysis, Cosmos, Femap

1. INTRODUCTION

In exploitation, because of the loads, the structural elements can be destroyed, mainly because of the apparition and propagation of cracks. The cracks appear in the areas where the stress concentrators reach values higher than the break limit. Once the crack appears, it propagates in the direction in which the material resistance is low. Analytically, the crack apparition and propagation is hard to analyse. Numerical mathematics offers multiple solution for this problem, which caused many disasters.

Engineering analysis of mechanical systems have been addressed by deriving differential equations relating the variables of physical principles. Although, once formulated, the mathematical models are often impossible to resolve, especially when the resulting models are nonlinear partial differential equations.

The finite element method is the main meshing technique used in structural mechanics. The basic concept of the finite element method is the subdivision of the mathematical model into non-overlapping elements of simple geometry named finite elements. The response of each element is expressed in terms of a finite number of degrees of freedom (DOF) characterized as the value of an unknown function, or functions, at a set of nodal points.

Objectives of FEM in this Course

- Understand the fundamental ideas of the FEM
- Know the behaviour and usage of each type of elements covered in this course
- Be able to prepare a suitable FE model for structural mechanical analysis problems
- Can interpret and evaluate the quality of the results (know the physics of the problems)
- Be aware of the limitations of the FEM (don't misuse the FEM - a numerical tool).

A crack is a line on the surface of something along which it has split without breaking apart.

The main reason for failure of Tank Structure:

- Improper maintenance of tanks;
- Corrosion of the tank structure;
- Relief valve of the tank is malfunction or stuck;
- Mechanical damage to the tank;
- Material failure;
- Tank structure severely exposed to flame or fire.

2. THEORETICAL BACKGROUND

Irwin extended Griffith’s theory in elastic-plastic materials domain and he determinate three solicitation modes. In general, we consider three basic modes for crack growth, although mixed-mode growth is also possible. Mode I is the opening or tensile mode where the crack faces separate symmetrically with respect to the x1-x2 and x1-x3 planes. In Mode II, the sliding or in plane shearing mode, the crack faces slide relative to each other symmetrically about the x1-x2 plane but anti-symmetrically with respect to the x1-x3 plane. In the tearing or anti-plane mode, Mode III, the crack faces also slide relative to each other but anti-symmetrically with respect to the x1-x2 and x1-x3 planes.

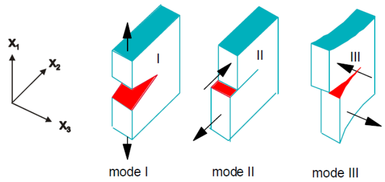

Fig.1 Three basic loading modes for a cracked body: (a) Mode I, opening mode; (b) Mode II, sliding mode; (c) Mode III, tearing mode

Considering the position of the flaw, the geometric shape of the tank, mechanical and chemical properties of the material, the work temperature, etc., we use a series the following parameters:

- J-integral;
- Expansion Force of the crack;
- Crack Tip Opening Displacement;
- The intensity of the stress factor, K;
- Breaking resistance;

The J contour integral is extensively used in fracture mechanics as an energy-based criterion for determining the onset of crack growth. For most practical problems there is no analytical solution for the J-integral. The numerical determination of the J-Integral using the finite element method is relatively straightforward. [3]

We may write the J-Integral as:

$$J = \int_{\Gamma} W dz - \int_{\Gamma} \frac{\partial U_i}{\partial x} ds$$

or alternatively as:

$$J = \int_{\Gamma} w d\eta - \int_{\Gamma} (\sigma_n - \tau_n) \begin{bmatrix} \dfrac{\partial u_n}{\partial \xi} \\ \dfrac{\partial v_n}{\partial \xi} \end{bmatrix} ds$$

where we have:

$$w = \frac{1}{2E}\left(\sigma_{xx} + \sigma_{yy} + \sigma_{zz}\right)^2 +$$
$$+ \frac{1+2\nu}{E}\left(\tau_{xy}^2 - \sigma_{xx}\sigma_{yy} - \sigma_{yy}\sigma_{zz} - \sigma_{xx}\sigma_{zz}\right)$$

$\sigma_n = \sigma_{xx}\cos^2\alpha + \sigma_{yy}\sin^2\alpha + \tau_{xy}\sin\alpha\cos\alpha$

$\tau_n = (\sigma_{yy} - \sigma_{xx})\sin\alpha\cos\alpha + \tau_{xy}(\cos^2\alpha - \sin^2\alpha)$

$u_n = u\cos\alpha + v\sin\alpha$; $v_n = -u\sin\alpha + v\cos\alpha$

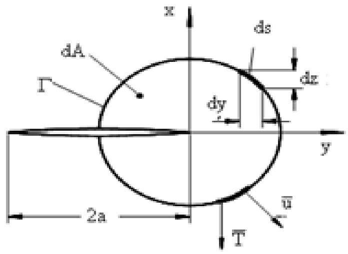

Fig. 2. The definition of the J-integral

3. STRUCTURAL ANALYSIS

3.1 Structure meshing

Firstly, the geometry of the tank was designed, with the principal dimensions of 10 meters long and 3 meters in diameter, with plates having a thickness of 45 millimetres, using the finite element modelling software Femap. In this phase, the plates were also attributed the type and properties of the material used, which in this case is steel. Following the mesh applied on the structure, rectangular plate type elements were used, QUAD, resulting in 13164 elements and 15358 nodes.

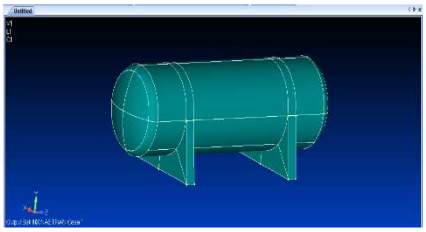

Fig.3 The geometry of the tank

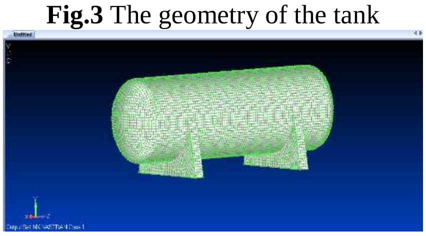

Fig.4 The geometry with mesh in Femap

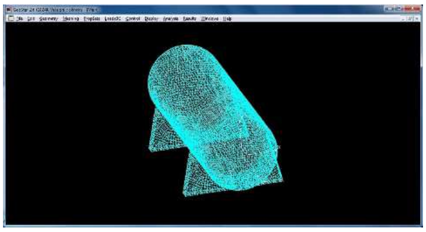

Fig.5 The structure imported in Cosmos

3.2 Loads

The load used on the structure consisted in constant pressure applied on elements, having an initial value of 6 bars, increasing gradually to 43,5 bars.

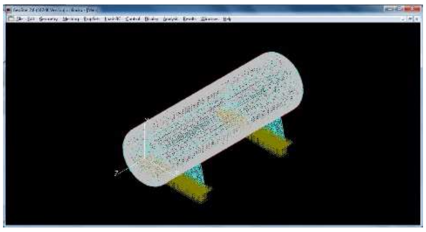

Fig.6 Load condition

3.3 Constraints

The tank structure is supported by 2 stands, which have been designed according to STAS rules, having a distance of 5 meters in between. The 2 stands have been constrained on all 6 DOF, on the inferior part.

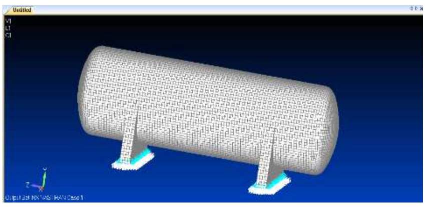

Fig.7 The constraints

3.4 Analysis

After running the static analysis, it resulted values of stress higher than the maximum resistance stress values of the steel. Secondly, the structure was imported from Femap to Cosmos, where the crack was initiated and the propagation on the connection area of the tank was observed, area in which the critical stress values appeared.

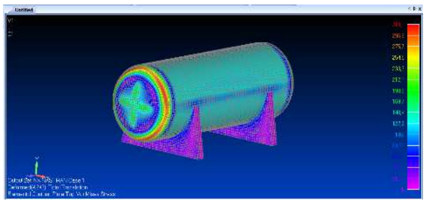

Fig.8 The result of the static analysis in Femap

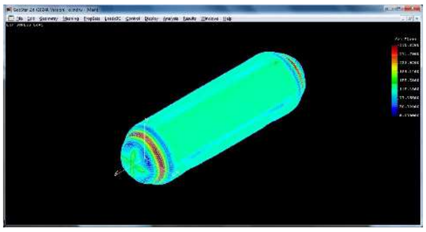

Fig.9 The result of the static analysis in Cosmos

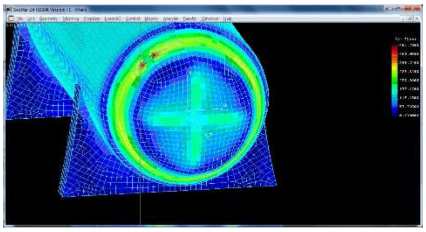

Fig.10 The crack

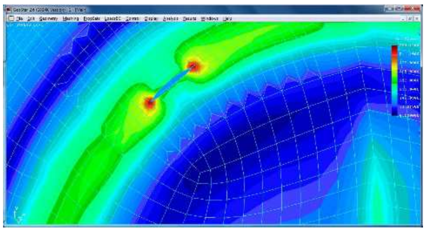

Fig.11 The crack analysis result on nodes

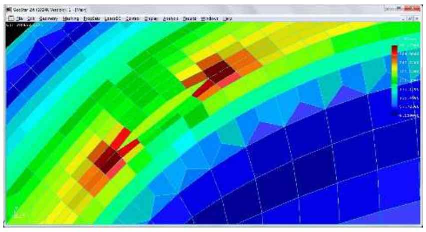

Fig.12 The crack analysis result on elements

4. CONCLUDING REMARKS

Following the study regarding the crack initialization and propagation on a tank made of steel plates having a thickness of 45 millimetres, loaded with air pressure having a value of 43,5 bars, the critical stress area was determined, where the crack occurs. A solution for this situation is strengthening this area using materials with higher stress strain values or by using stiffening rings.

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