

Analysis of damaging process and crack propagation

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Abstract. Supervising and health monitoring of structures can assess the actual state of existing structures after initial loading or in the state of operation. Structural life management requires the integration of design and analysis, materials behavior and structural testing, as given for several examples. Procedure of survey of structural elements and criteria for their selection must be strongly defined as it is for the offshore gas platforms. Numerical analysis of dynamic loading is shown for the Aeolian vibrations of overhead transmission line conductors. Since the damper's efficiency strongly depends on its position, the procedure of determining the optimum position of the damper is described. The optical method of caustics is established in isotropic materials for determination of the stress intensity factors (SIFs) of the cracks in deformed structures and is advantageously improved for the application to fiber-reinforced composites. A procedure for simulation of crack propagation for multiple cracks was introduced and SIFs have been calculated by using finite element method. Crack growth of a single crack or a periodical array of cracks initiated at the stiffeners in a stiffened panel has been investigated.

1 Introduction

The accumulation of fatigue damage over time is a principal degradation mechanism, which usually leads to crack initiation in critical structural components. In extreme situations, the growth of these cracks can lead to the collapse of structure. Damaging process analysis is significant for determination of reliability of mechanical components while the numerical simulations of crack appearances and growing will process phenomena of structural damages.

2 Survey and health monitoring of structural elements

Control of structural elements must be done periodically by the survey rules defined for specific structure [1]. Categories for both life safety and consequence of failure considerations must be taken into account. Inspection strategy is regulated on risk assessment and evaluation of structural elements integrity and is based on likelihood of particular component failure. The criteria are based on loading intensity, stresses, stress concentration of elements and joints and other influences to the assessment of structure fatigue life [2].

There is an increasing importance of supervising and health monitoring of structures with regard to control durability, stability and safety as well as to estimate the life span of the structure.

Structural life management requires the integration of design and analysis, materials behavior and structural testing. As important for this study is the description of the survey of different parts of structures; we use as an example of the offshore platforms, where is a request for the survey rules defined to ensure the control of selected structural elements.

Assessment of service life should be given due to accumulated fatigue degradation effects. Preselecting of areas to be surveyed should be based on an engineering evaluation of areas particularly susceptible to structural damage (Figure 1), or to areas where repeated inspections are desirable in order to monitor their integrity over time [3].

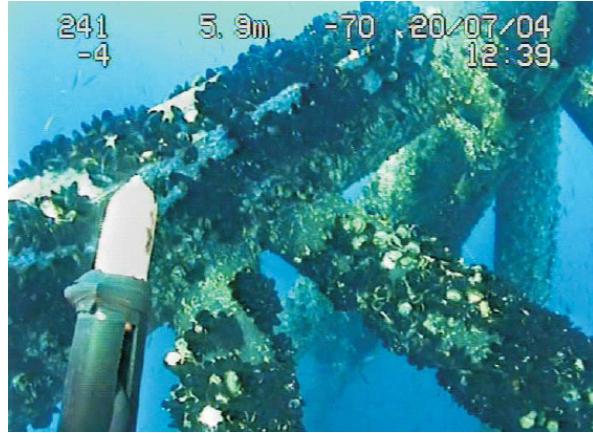


Fig. 1. Underwater inspection of structural elements [4].

3 Analysis of dynamic loading

Sometimes numerical analysis of dynamic loading and its optimization is important even in the designing of the structure to reduce possible damages. Usually should be combined by the experimental verification. Significant example is given here for the Aeolian vibrations in electrical transmission line (Figure 2), where severe damage or even breakdown of the conductor can occur due to material fatigue [5].

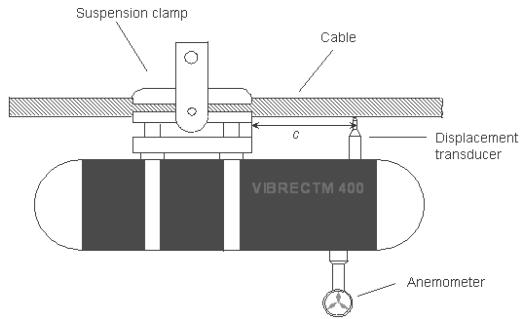


Fig. 2. Measuring of Aeolian vibrations of transmission line by VIBRECTM 400.

Maximum stresses in the conductor at the suspension clamp and at the damper clamp can be significantly reduced. Since the optimal damper position, among other parameters, depends on the span length also, the best results can be achieved by determining the damper position for each span inside the line section [6]. In order to examine accuracy of the developed computational program, as well as correctness of the estimation of the data used (wind power, data on the damper's mechanical

impedance, and mechanical characteristics of the conductor), results generated using the developed computer program and data from field measurements are compared. A very high correlation between these data has been observed (Figure 3).

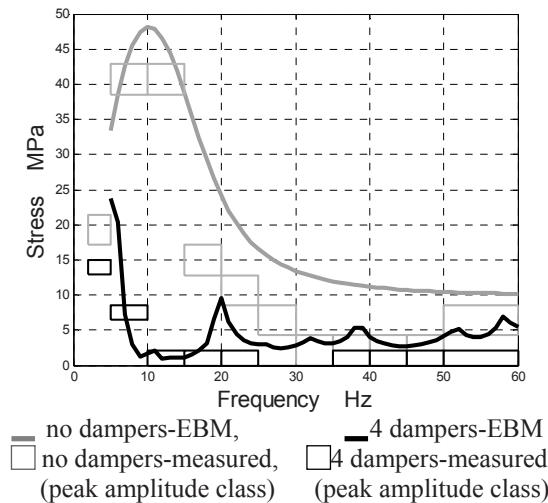


Fig. 3. Comparison of numerical results (EBM) and data from field measurements.

4 Experimental determination of stress intensity factor

There are several experimental techniques in fracture mechanics that are employed for determining the stress intensity factors (SIFs) of the cracks in deformed structures. They are used to record the actual situation in order to get reliable information about the on-site structure and structural elements. The optical method of caustics is established for the application to mechanically isotropic materials [7] through the process of SIF's evaluation and is advantageously improved for the application to fiber-reinforced composites [8].

The elastic constants in composites for the usual orthotropic mechanical structure have significant mismatch in the directions of the principal axes of orthotropy. The stress-intensity factors are determined for the series of material specimens in laboratory conditions. The results are shown here (Figure 4) for only one type of material in which the mechanical properties are extremely different along the two principal axes (longitudinal L and transversal T) and representative for orthotropic case: $E_L = 186$ GPa, $E_T = 28$ GPa, $G_{LT} = 8$ GPa, $\nu_{LT} = 0.188$. The thickness of this particular material plate CFRP 186 was 2.45mm, made of carbon-fiber reinforced plastics. Three different orientations of the crack ($0^\circ, 45^\circ, 90^\circ$) to the axis L were examined.

The analysis of the shape and size of experimental caustics (Figure 5) will provide an experimental value of measured SIF. The procedure of SIFs determination could be realized under the real loading/exploitation conditions at the observed structural part containing crack(s). The above method can estimate the risk of crack propagation by comparing the measured value of SIF to the critical value of SIF as the material property.

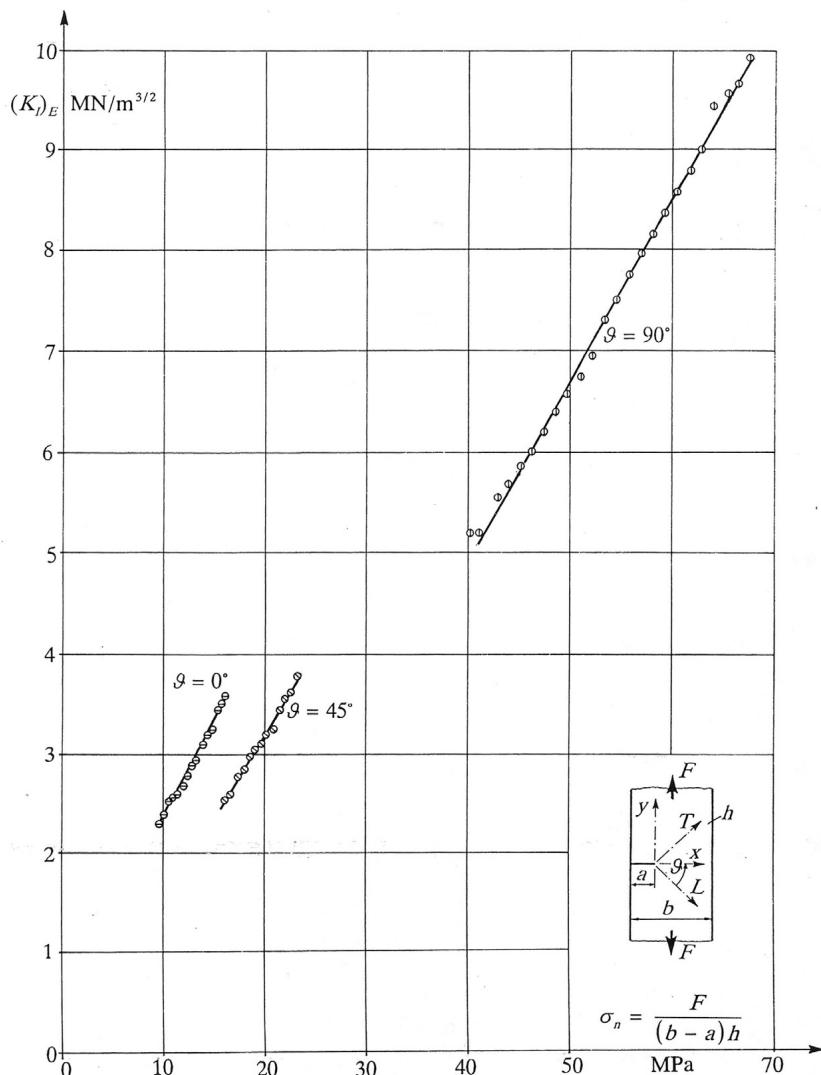


Fig. 4. Stress-intensity factors vs. nominal stress for CFRP 186.

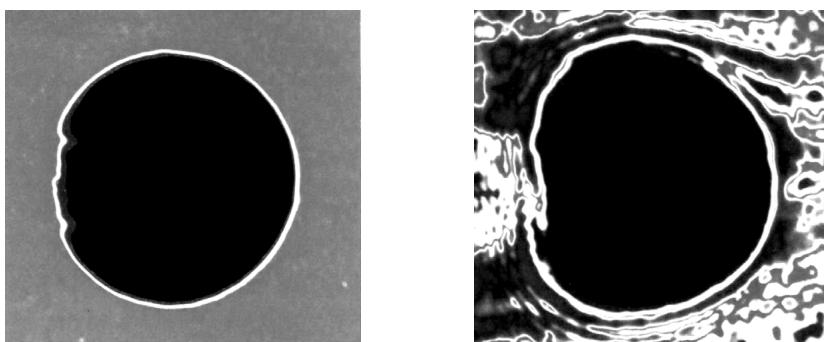


Fig. 5. Mode I caustics around the crack tip for the isotropic and orthotropic material.

The unified structural/mechanical material characterization will also enable the material modeling during the process of construction design, e.g. for the fiber reinforced composites, the adaptation of the material to the shape of the designed structural part. Research is nowadays extended to the application of the method of caustics in body contact (bearings, meshed gears), both in static and dynamic loading conditions.

5 Crack growth analyses

Crack growth is interesting to be studied for the proper evaluation of the reliability of structural parts. Fatigue cracking of stiffened panels is an important issue for aged aircraft and ship structures. Under a variety of loading and environmental conditions fatigue cracks may initiate at sites of stress concentration due to geometrical discontinuities.

Fatigue crack propagation tests with cyclic stress of constant amplitude and frequency were carried out on stiffened panel specimens damaged with a single crack or an array of collinear cracks, until fracture occurred (Figure 6). A numerical simulation procedure for multiple propagating cracks which takes account of crack interaction was introduced [9]. The Mode I stress intensity factors, K_I , were calculated from finite element nodal displacements results. A bending effect due to the cut stiffeners has been taken into account in the stress intensity factor calculation. The experiment and numerical simulation showed a higher crack growth rate in the case of the stiffened panel with three cracks, which is due to cut cross sectional area and crack interaction. The experiment and numerical simulation (Figure 7) showed a higher crack growth rate in the case of the stiffened panel with three cracks, which is due to cut cross sectional area and crack interaction [10].

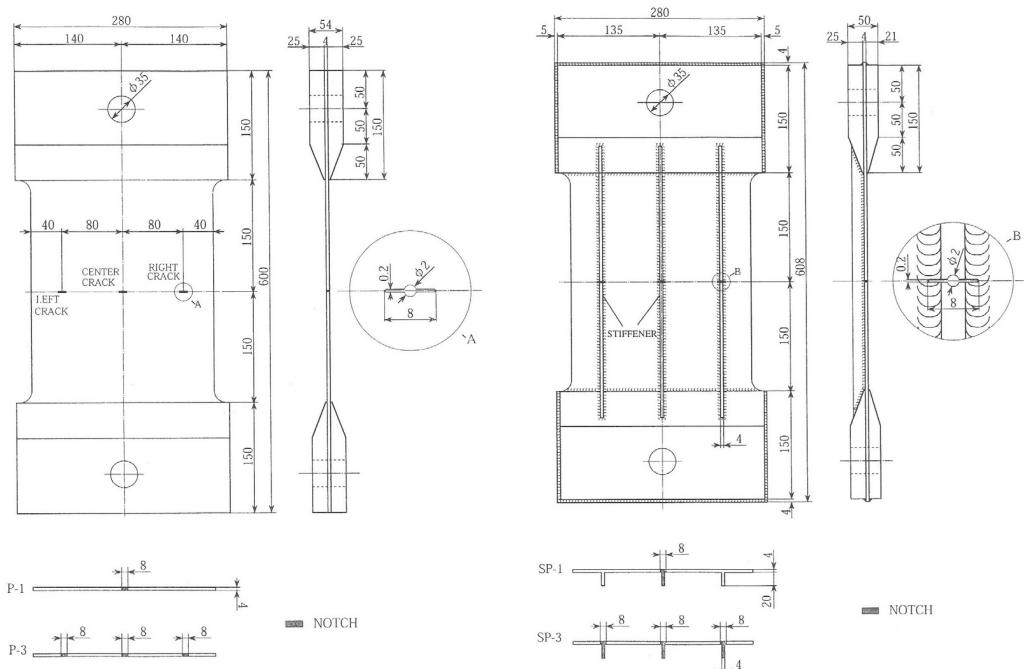


Fig. 6. Plate specimens P-1, P-3 and stiffened panel specimens SP-1 and SP-3.

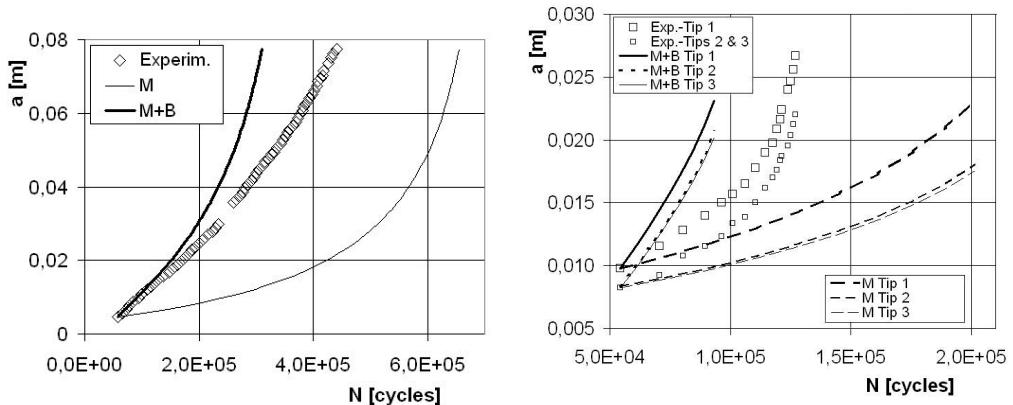


Fig. 7. Simulated and experimental a - N results for SP-1 and SP-3.

6 Conclusions

At the production stage it is necessary to provide the integrity of structure and during the operational phase to assure the fatigue life of the structure. Used properly, these procedures can prevent over-design and provide a balance between safety and costs to be achieved. An advanced experimental methods combined with the numerical simulations will provide the verification of behavior of element or making decision about the structural repairing or stopping the plant production.

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