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Modeling of Complex Shaped Cracks

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The paper proposes modeling approaches of complex shape cracks. Structures may present many types of defects, of different irregular shapes and sizes, due to various reasons, and so it is very important for the model of the crack used to be accurate. There are three main categories for modeling of cracks; local stiffness reduction, discrete spring models, and complex models in two or three dimensions each proving to be reliable methods for generating finite element models.

Keywords: *modeling, crack, propagation, stiffness, branched crack.*

1. Introduction.

During operation, mechanical structures are subjected to the combined or separate effects of dynamic loads, temperature, corrosive environment, material fatigue and other facts which result in crack occurrence. In structural health monitoring, a successful detection of defects depends very much on the exact modeling of a crack. Most of the approaches for determining the presence, location, and severity rely on the modal data of a structure before damage occur. Defects affect the rigidity of structures by diminishing the natural frequencies and modify their modal shapes. These parameter changes depend on the type, size and position of the defect in the structure. Accurate modeling of these parameters is a very important factor in determining the dynamic characteristics of a damaged structure. To estimate the crack size and location, generally, a finite element model is used in correlation with experimental modal testing of the structure.

2. Types of cracks.

In structures, there may be many types of defects, of different irregular shapes and sizes. These occur due to material fatigue, delamination in the interface area of composites, defective materials due to inadequate production, superficial defects caused by impacts or corrosion.

The most common defect types found in structures are transversal, as shown in figure 1, or longitudinal, as shown in figure 2. In this figures, the main dimensions of the cracks are indicated.

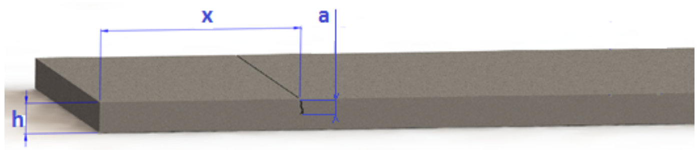

Figure 1. Transversal crack

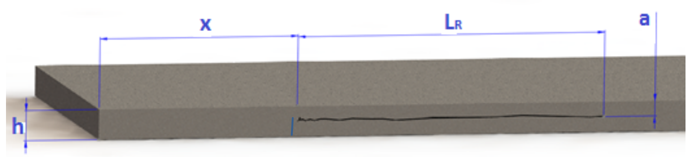

Figure 2. Longitudinal crack

During the functioning of a mechanical system or structure, defects can take a complex form by propagation. The phenomenon of bifurcation of cracks in fragile materials, that is, the division of one primary crack into two or more branches is well known: Schardin [1], Clark, Irwin [2], Kerkhof [3]. In the simplest case where a crack is divided into two secondary cracks, the angle (between symmetry line and branch) is approximately constant and measured up to about 15 °.

The advancement of a crack is also different in structures composed of different materials like composites, delamination being the most important failures of laminated composite materials. Authors [4] investigated the development of cracks in beams made of reinforced concrete using methods of correlating digital images presented in Figure 3. They observed that initially the crack is propagated as a single narrow, slightly curved band, but the presence of reinforcement prevents premature fracture and results in the development of crack branching.

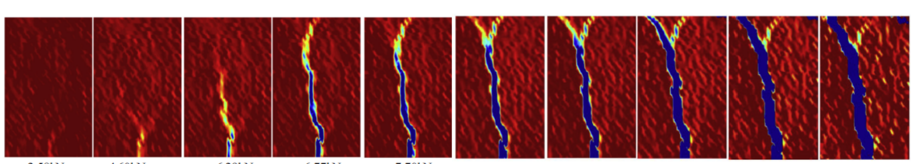

Figure 3. Crack propagation in reinforced concrete beams

3. Crack modeling approaches.

There are a number of approaches to the modeling of transverse cracks in beam structures reported in the literature, that fall into three main categories; local stiffness reduction, discrete spring models, and complex models in two or three dimensions [5]. Furthermore crack modeling can be divided into two broad categories, open cracks that are characterized by being open during vibration and alternating cracks that close and open during vibrations.

The local stiffness reduction is the simplest method for modeling a local crack. The model, shown in figure 4, consists in changing the local parameters of the structure to compensate the loss of stiffness for a defined crack type. This method is affected by mesh density and it has problems in matching damage severity to crack depth.

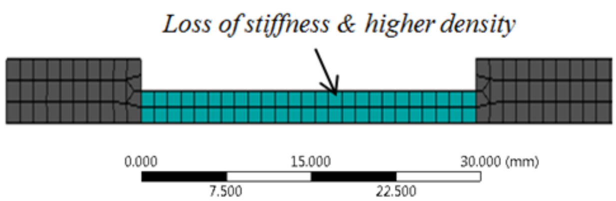

Figure 4. A zoom on the segment with a reduced thickness

A second method for modeling a crack is by inserting a rotational spring pinned at the crack location between two structural elements of a beam in order to model the increased flexibility due to the crack, presented in figure 5.

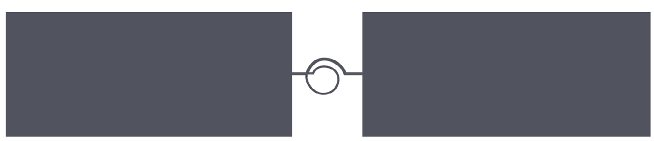

Figure 5. Rotational spring model

The equivalent rigidity of the spring is computed relative to the crack depth using fracture mechanism methods. The major difficulties of this method are the fact that it can be relevant only for beam like structures and the relationship between the spring thickness and crack depth needs to be derived.

The last method produces more accurate models and presents more complex procedures to define a crack. The difficulty in applying this method is the need to revise the mesh as the crack position changes.

The first procedure is by removing elements relative to the size and location of the defect. Figure 6 shows this in the case of plate elements and shows the side view of the mesh used.

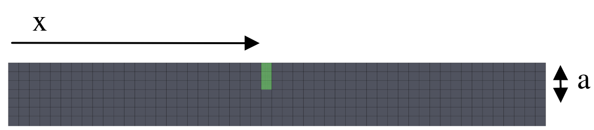

Figure 6. Complex models in two or three dimensions.

Clearly, more complex methods may be used, such as adding adequate boundary conditions between elements, separating the crack with lines or faces.

4. Proposed crack model

Based on the models presented in the literature, we propose a more complex general model of type "Y"- shaped defect, with different angles of penetration of the crack branching into the material with the main dimensions shown in Figure 7. Based on the fact that any damage has its own signature, it is possible to define a database that can be used as a reference base in defect detection methods.

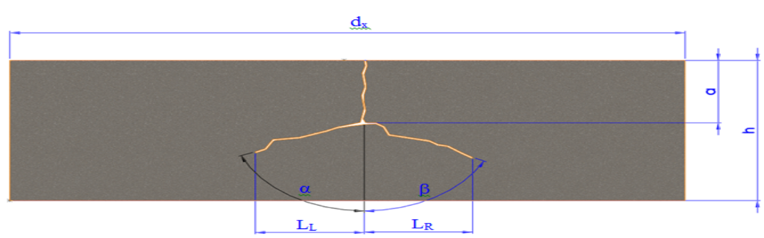

Figure 7. General dimensions of a maximum two branched crack.

Some particular cases of the Y-shaped crack are presented in the following. For example in the case of a cantilever beam having a T-shaped crack with its main dimensions presented in figure 8, the beam was meshed by using hexahedral elements of maximum 2 mm size, resulting in a model containing 39501 elements and 197961 nodes.

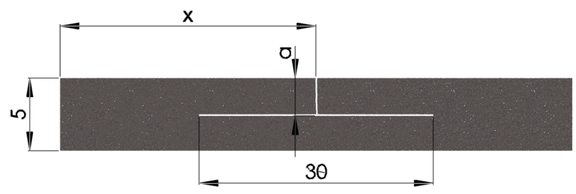

Figure 8. T-shaped crack.

The crack was modeled by inserting boundary conditions in the interface between 3 separate elements presented in figure 9.

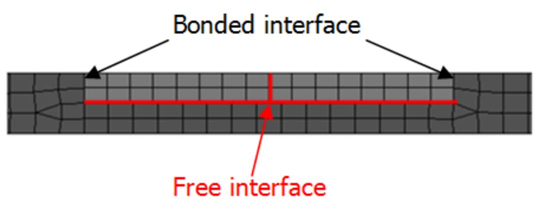

Figure 9. Defined boundary conditions.

Furthermore, we extended the study in paper [11] for a prismatic steel bar with L - shaped defects of different types taken one by one using the FEM simulation results according to the location of the cracks, with dimensions presented in figures 10 and 11.

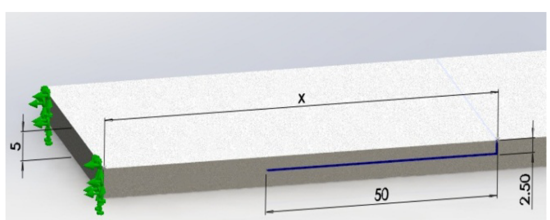

Figure 10. L-shaped crack - delamination oriented to the left

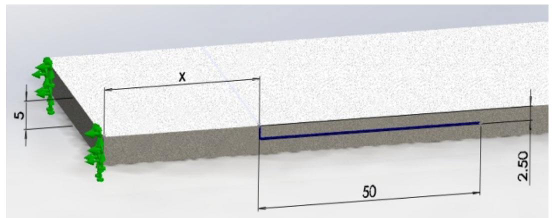

Figure 11. L-shaped crack - delamination oriented to the left right

5. Conclusion.

This paper presents methods for modeling complex shaped cracks in structures by involving several procedures, each having its own advantages as well as disadvantages.

The local stiffness reduction method is the simplest to model damage but suffers from problems in matching crack depth to damage severity and its affected by the mesh quality.

The rotational spring procedure evolved from fracture mechanism methods is useful only for beam-like structures.

Complex models in two or three dimensions produce more detailed and accurate models then the methods previously discussed. However, the difficulties in applying these methods in structural damage assessment is that they require a large number of degrees of freedom and the mesh needs to be revised every time the location of the defect changes.

The complex shape model of Y- shape comprehends most of the defect types that can be present in structures, so it is easier to create a database for using in structural health monitoring techniques.

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