Fatigue Life Prediction of Complex 2D Components under Mixed-Mode Variable Loading

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Abstract

In defect-tolerant structures, accurate fatigue crack propagation and residual strength predictions under variable amplitude loading are essential to maximize the required time between inspections, minimizing costs. However, such task is not trivial for real structural components, which generally have complex geometries with cracks that may change direction due to mixed-mode loading. The use of global Finite Element (FE) software to predict both crack path and crack growth rate is not computationally efficient, because variable amplitude loading would require time-consuming remeshing at each propagation cycle. In this work, a two-phase methodology that is both precise and cost effective is presented, based on two pieces of software to numerically predict fatigue crack growth. First, the fatigue crack path and its stress intensity factor are calculated in a specialized (global) FE program, using fixed crack increments, resulting in only a few required remeshing steps. Numerical methods are used to calculate the crack propagation path, based on the computation of the crack incremental direction, and the stress-intensity factors $\mathbf{K_I}$, from the finite element response. Then, an analytical expression is fitted to the calculated $\mathbf{K_I(a)}$ values, where **a** is the length along the crack path. This $\mathbf{K_I(a)}$ expression is used as an input to a powerful general purpose fatigue design program based in the local approach. This (local) software has been developed to predict both initiation and propagation fatigue lives under variable loading, considering load interaction effects such as crack retardation or acceleration after overloads. This methodology is numerically and experimentally validated by benchmark tests of fatigue crack propagation in complex two-dimensional structural components. Cracks are fatigue propagated under variable amplitude loading in standard SEN and CTS specimens and on panels with oblique cracks, all with holes specially positioned to attract or to deflect the cracks. It is found that the combination of both global and local software is able to predict the (curved) crack path and remaining life in each case, even considering load interaction effects.

[1] Miranda, A. C. O., Meggiolaro, M. A., Castro, J. T. P., Martha, L. F. and Bittencourt, T. N., "Fatigue Crack Propagation under Complex Loading in Arbitrary 2D Geometries," Applications of Automation Technology in Fatigue and Fracture Testing and Analysis, *ASTM STP 1411*, A. A. Braun et al., Eds., ASTM, 2002.

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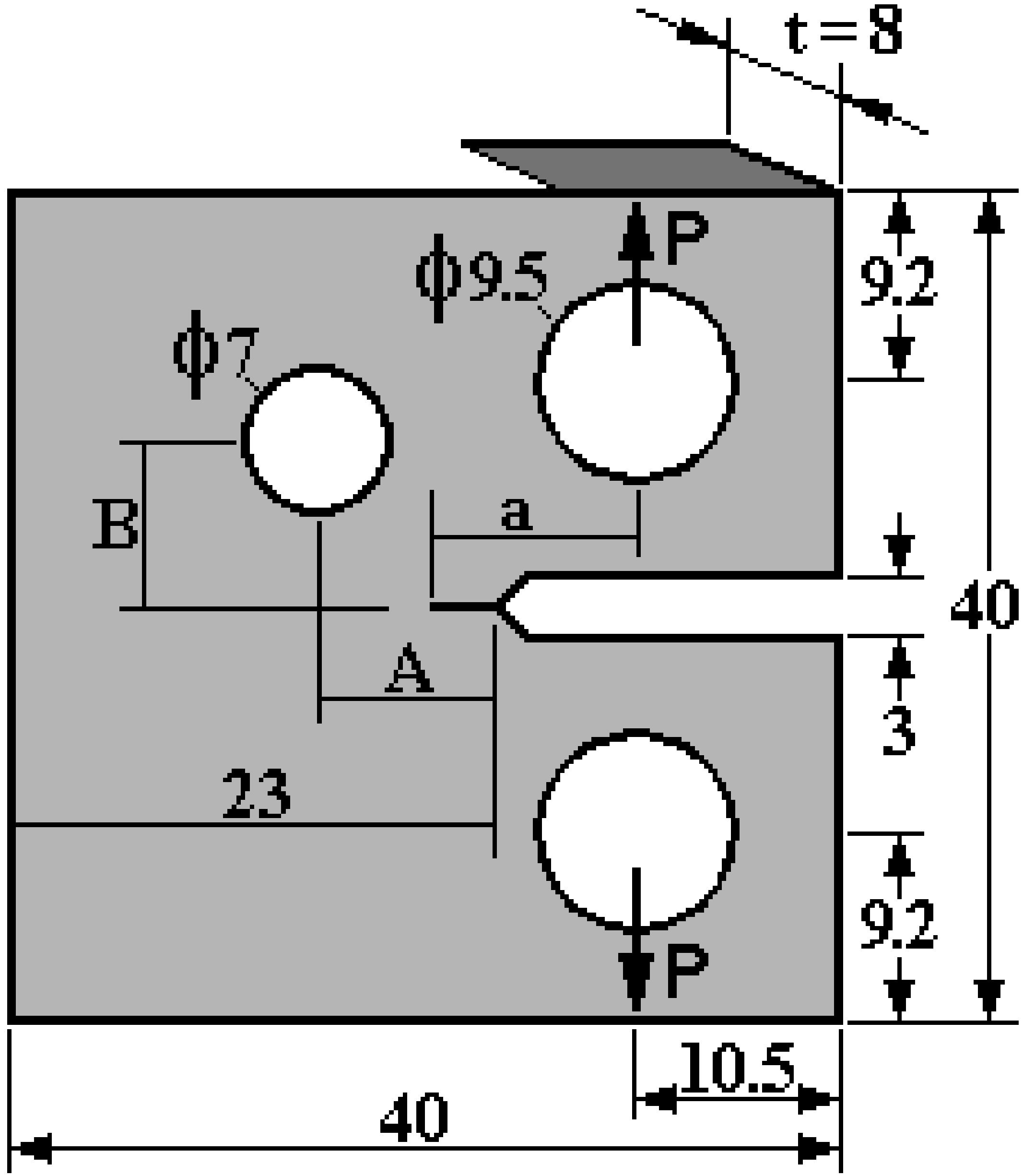
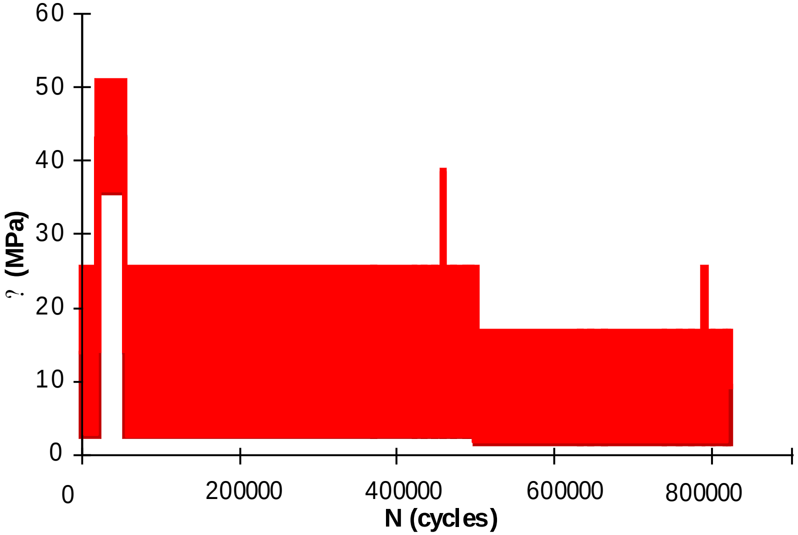
Software Development to Automate Fatigue Design

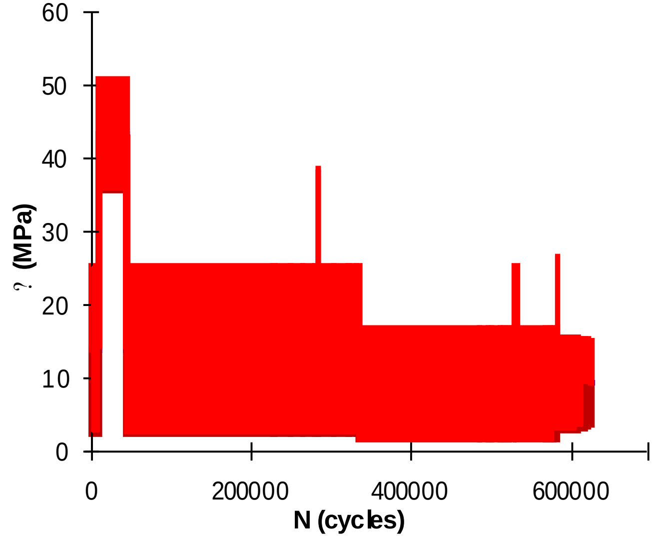
- a software named **V i D a** was developed to automate fatigue design by all ***local*** methods, including ***load interaction effects***
- a **FE** companion software called **Quebra2D** predicts the ***curved crack path*** in ***arbitrary* 2D *geometries***, calculating its associated $\mathbf{K_I(a)}$
- this approach is experimentally validated by ***fatigue crack propagation*** tests under ***variable amplitude loading*** in standard CT specimens with ***holes*** specially positioned to attract or to deflect the cracks

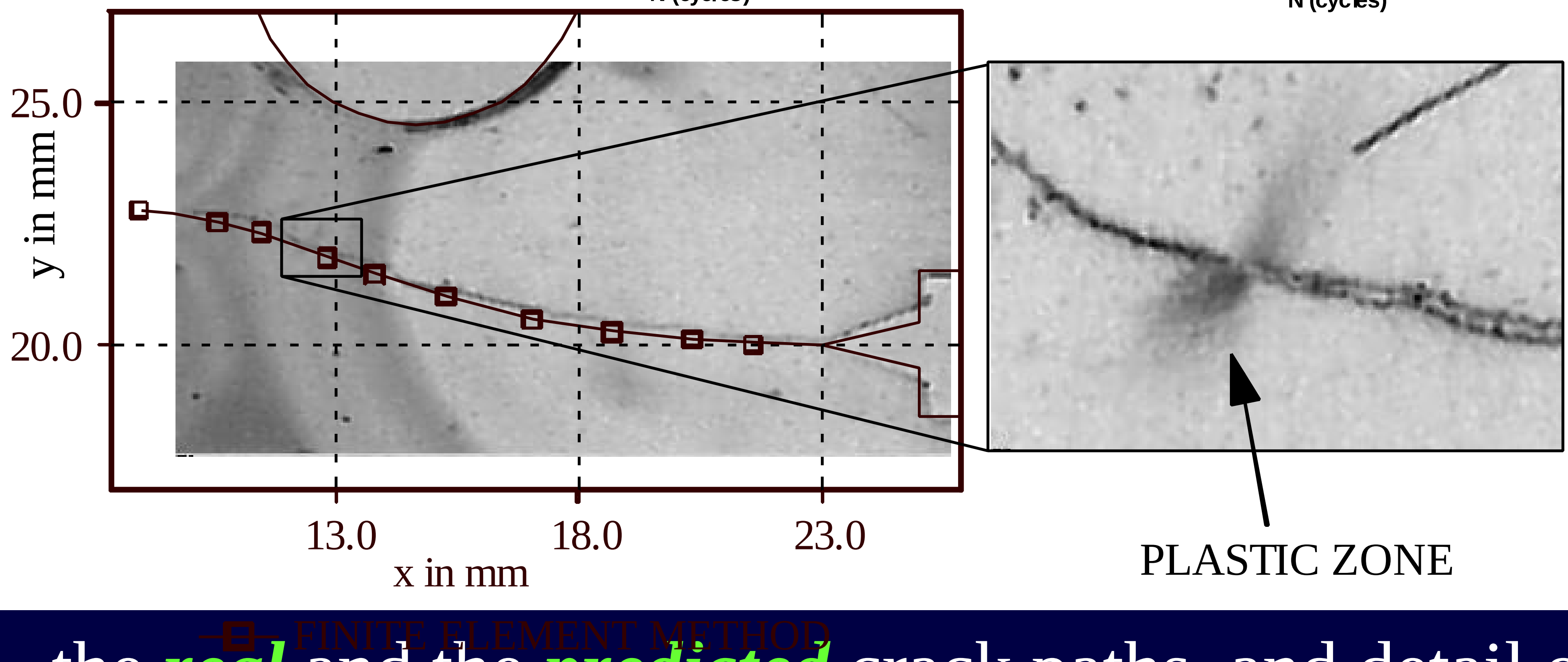


	A	B
CT1	8.3	8.1
CT2	8.4	6.9
CT3	8.1	8.1
CT4	7.7	6.7

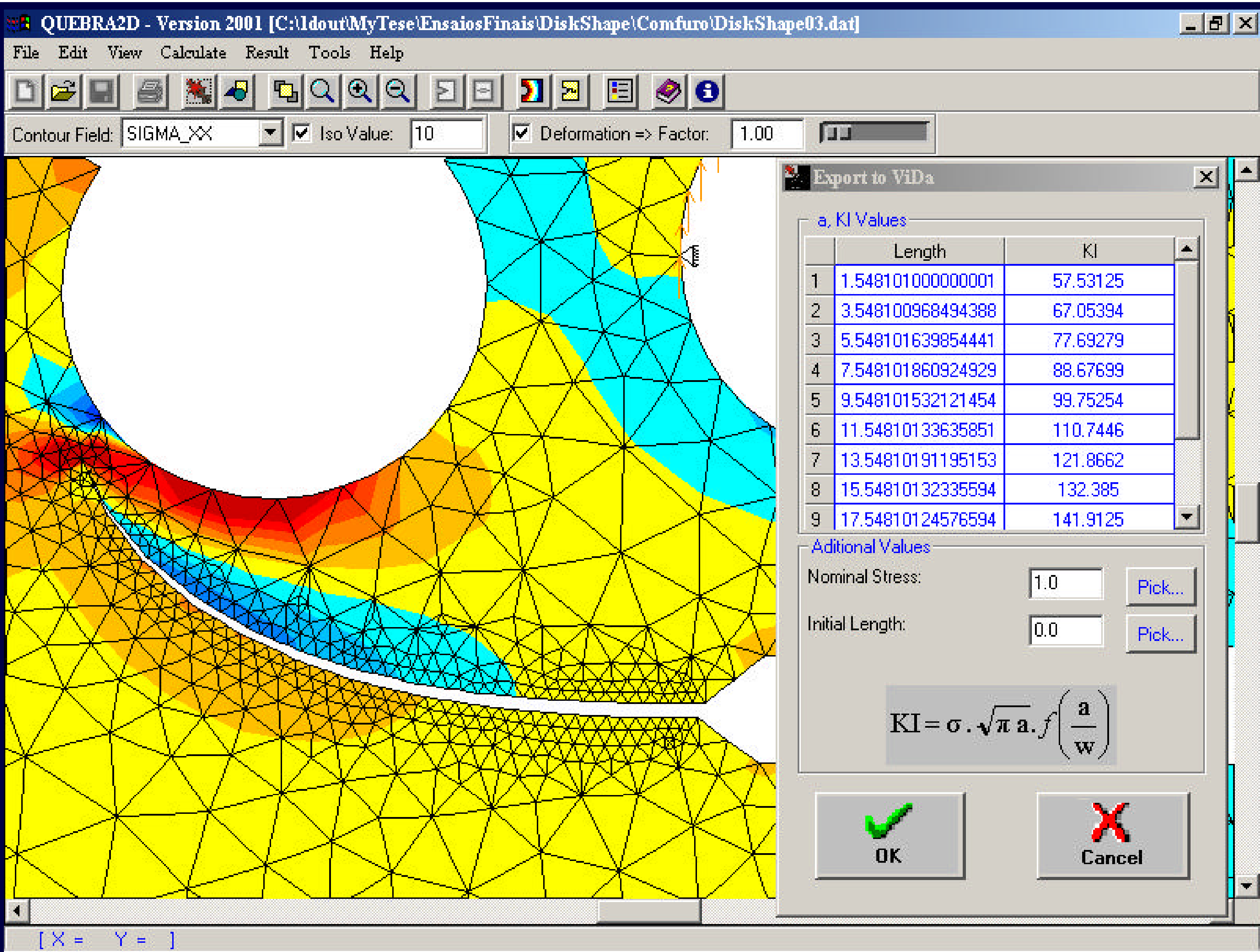
- holed CTS for the ***engineered*** experiments applied load histories:



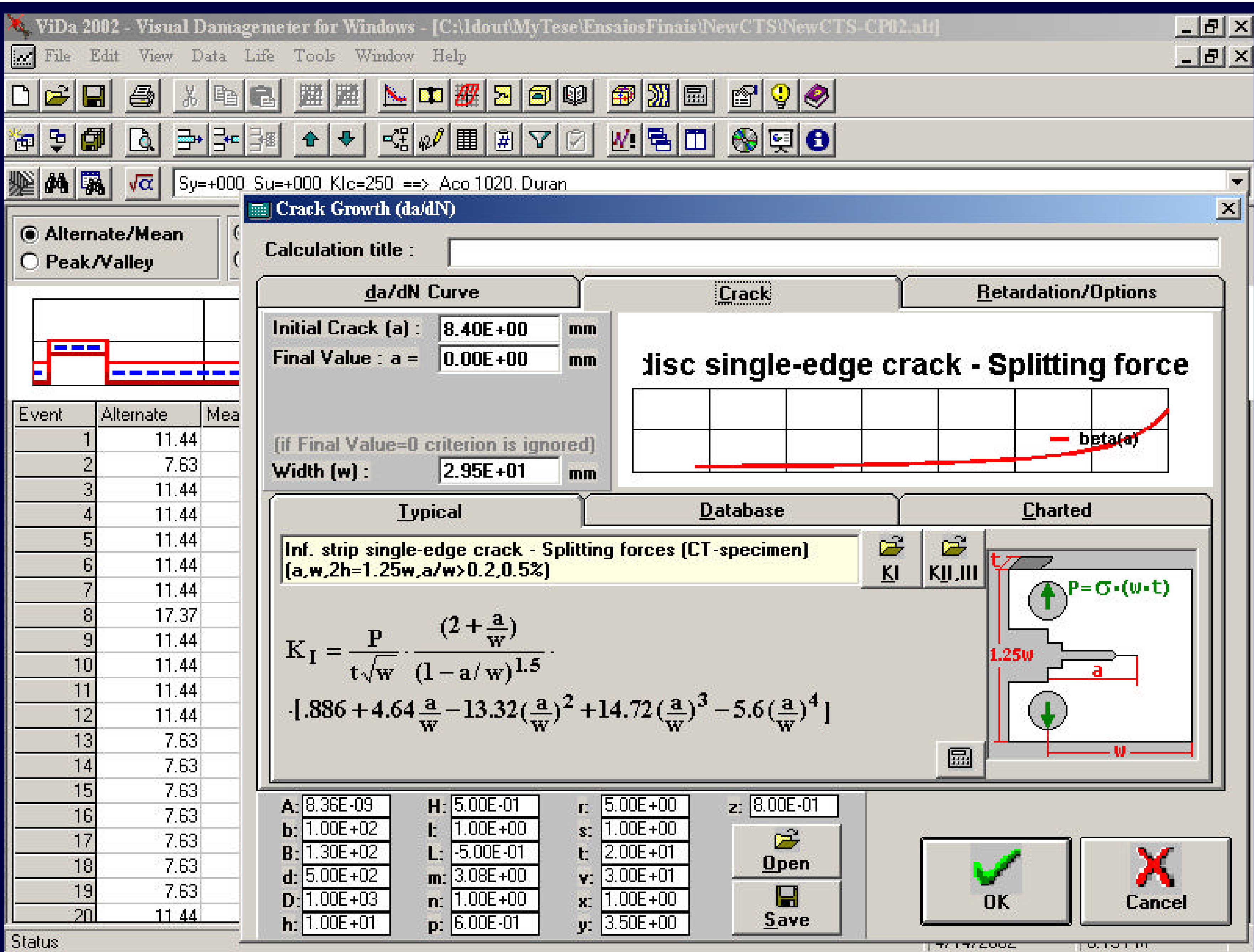




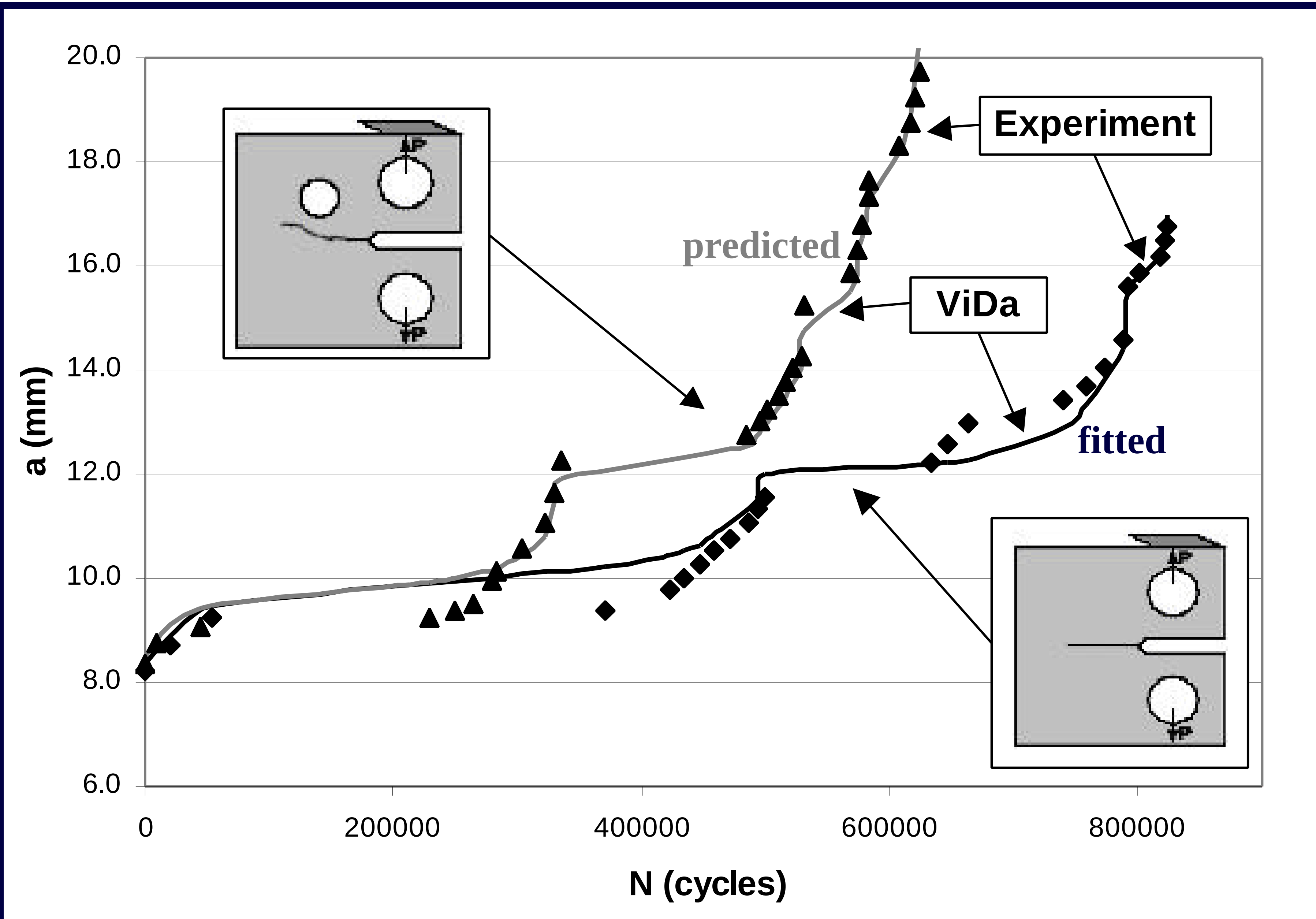
- the ***real*** and the ***predicted*** crack paths, and detail of an overload plastic zone



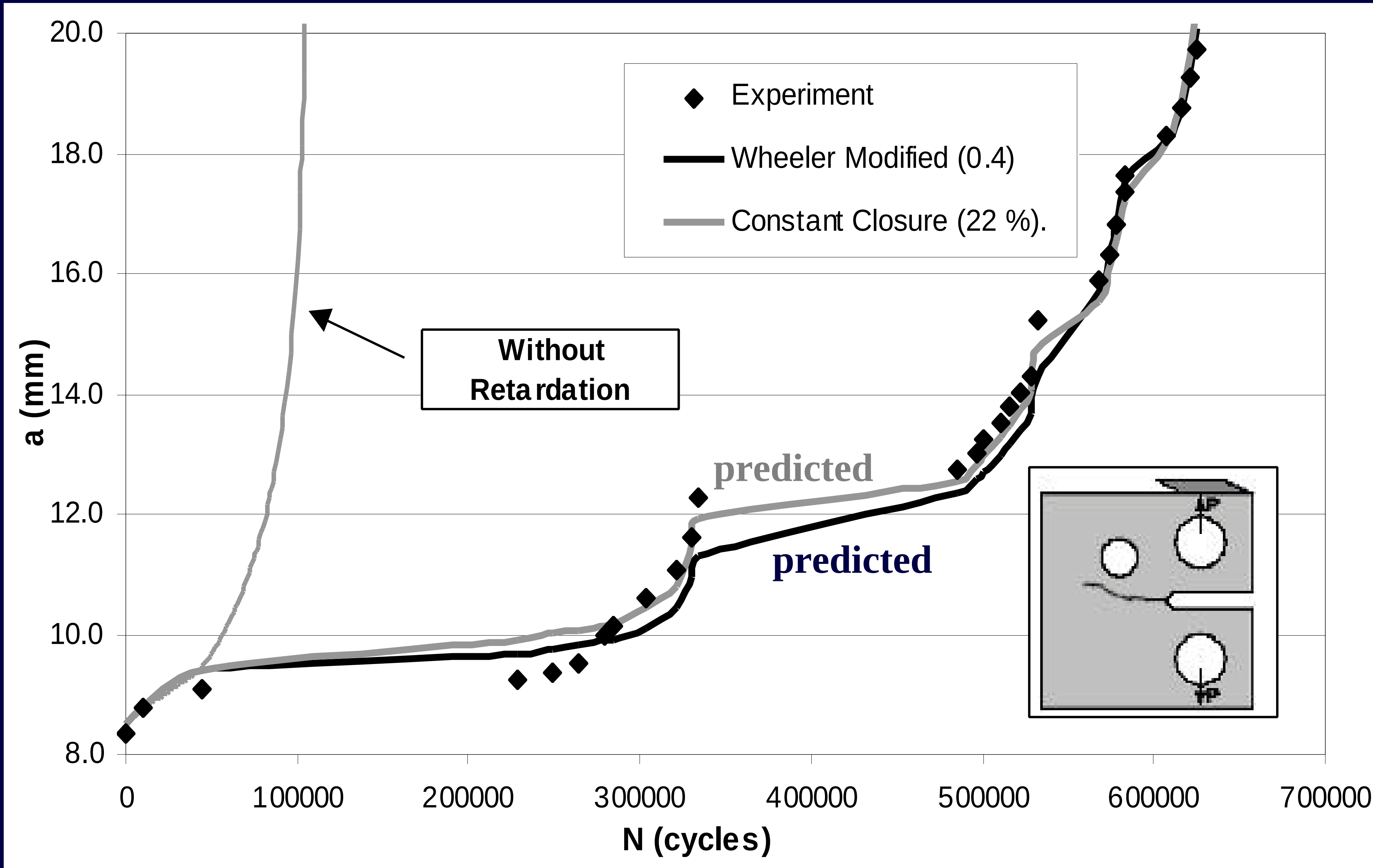
• screen output of the **Quebra2D** (*global*) software



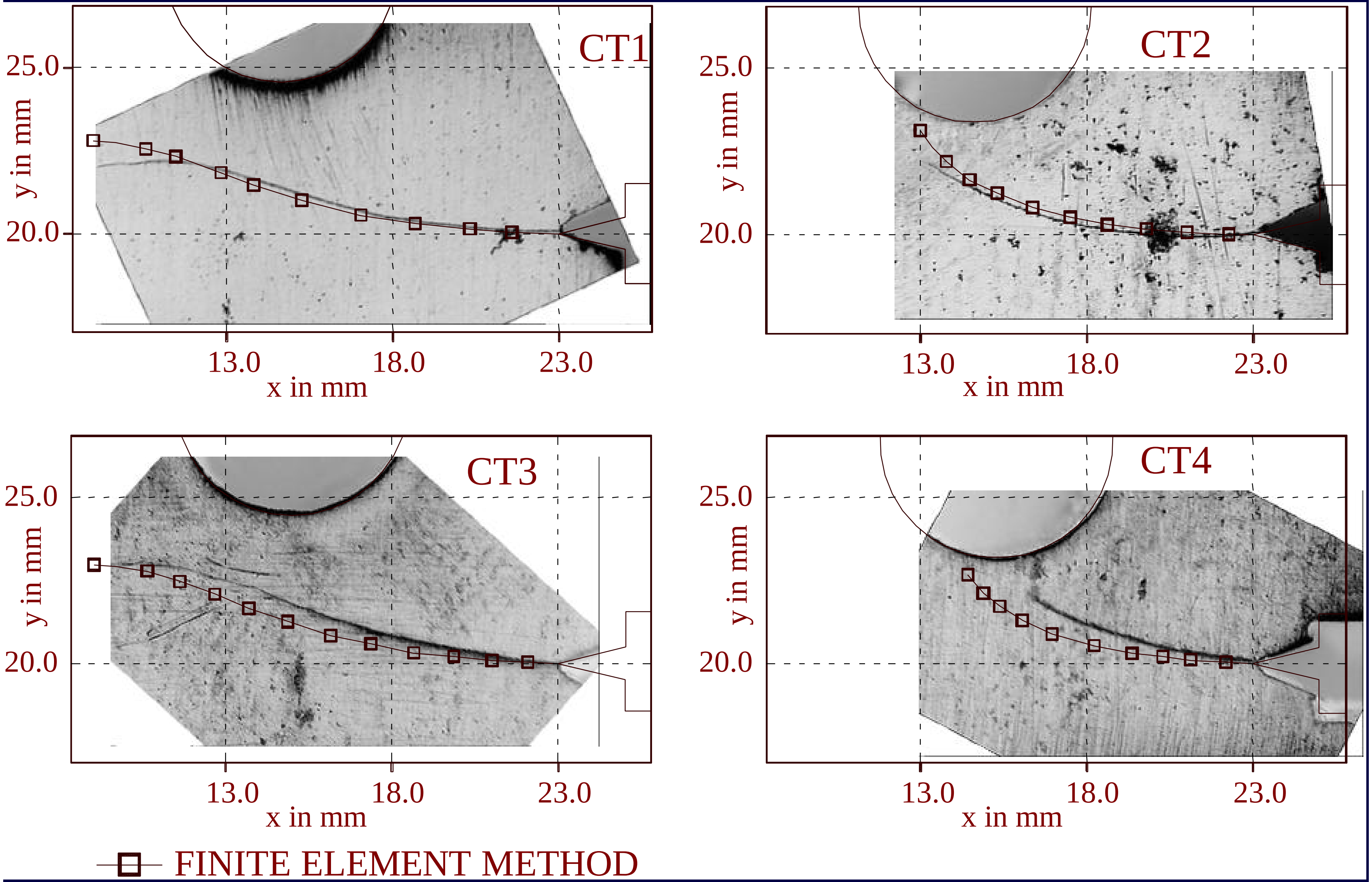
- screen output of the **V i D a** (*local*) software



• ***predicted*** and ***measured*** crack sizes on holed and standard CTs submitted to ***variable amplitude loads***



• ***measured*** crack sizes on holed CTs and ***Constant Closure*** and ***Modified Wheeler predictions***



• the ***experimental*** and the ***predicted*** crack paths

Conclusions

- the combination of both ***global*** (**Quebra2D**) and ***local*** (**V i D a**) software is able to predict the ***curved*** crack path and remaining life in ***complex structures***, even considering ***load interaction effects***
- **Reference:**

Miranda, ACO, Meggiolaro, MA, Castro, JTP, Martha, LF and Bittencourt, TN, “Fatigue Crack Propagation under Complex Loading in Arbitrary 2D Geometries,” Applications of Automation Technology in Fatigue and Fracture Testing and Analysis, *ASTM STP 1411*, A. A. Braun et al., Eds., ASTM, 2002

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Keywords: fatigue crack growth, finite elements, arbitrary geometry, variable loading.