

# ON INVERSE ANALYSES IN FRACTURE MECHANICS

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## ABSTRACT

As the material models become more realistic and complex, and the computational tools more powerful, the quantitative identification of constitutive parameters by inverse analysis acquires growing scientific interest and practical usefulness. Inverse analysis consists of two stages: (i) computer simulation of the experiments by employing the material model to calibrate; (ii) minimization, with respect to the sought parameters, of a suitable norm up to quantify the discrepancy between experimental data and the values provided by the simulation to the same measured quantities as functions of those parameters. The effects of measurement uncertainties (or experimental “noise”) and if possible of modeling errors on the final estimates have often to be investigated to assess the estimation reliability. A noteworthy by-product of the experimental test simulation are sensitivity analysis of measurable quantities with respect to the parameters to identify: in fact, sensitivity matrices may corroborate the identifiability of the sought parameters and orient the optimization of the experiment design.

In the above methodological context, with reference to fracture properties of quasi-brittle materials, this lecture is intended to provide a critical survey of the title subject through concise discussion of particular but representative practical problems in structural engineering and micro technologies recently tackled by the lecturer’s team.

(a) Traditional three-point-bending tests supplemented by electronic speckle pattern interferometry measurements on relative displacements have been performed on a quasi-brittle material (specifically, polymeric syntactic foam for a new kind of ships). A mode I cohesive crack model with a bilinear softening branch is adopted with four fracture parameters to identify. A novelty of this formulation is the analytical description of this model as a linear complementarity problem. In view of the dominant linear elastic background of the underlying modeling the simulation is based on a boundary element method specifically on the symmetric Galerkin one. The discrepancy minimization by a batch least-squares approach turns out to be nonsmooth and generally nonconvex and to exhibit the format of “mathematical programming under equilibrium constraints”, at present recurrent in econometry and management and numerically solvable by new “ad hoc” algorithms.

(b) The preceding cohesive crack model is considered for the fracture characterization of dam concrete by means of wedge-splitting tests. Extended Kalman-Bucy filter is studied here for a stochastic parameter identification leading to estimates and to a covariance matrix which quantifies the effects of the random uncertainties in the experimental data process. The peculiar LCP description mentioned in (a) is exploited to make cost-effective the repeated computations of sensitivity matrices required by the filtering process.

(c) Many existing dams built decades ago are deteriorated by physico-chemical aging processes (primarily by “alkali-silica reaction”). In order to

assess present mechanical properties crucial for the dam integrity assessment, the following in situ tests are proposed: two parallel holes are generated and pressurized so that fracture occurs between them, while diameter changes are measured by special dilatometric instruments. From these experimental data inverse analysis is employed to extract fracture parameters. The numerical study of this innovative methodology entails comparative assessment of gradient-based algorithms and artificial neural networks, with conclusions in favour of the latter from the engineering practice standpoint.

(d) Finally, with recourse to the above algorithms, indentation tests are investigated for the fracture characterization of ceramic materials at the micro scale. A pyramidal indenter is considered, so that development of cracks starting from the pyramid edges represents the dominant irreversible phenomenon during indentation. The novelty is represented by the subsequent mapping of the imprint (particularly of the residual cracks) and by the use of these deformation measures besides the traditional indentation curves for the discrepancy minimization. The inverse analysis technique in fracture mechanics via microindentation and imprint mapping combined is shown to provide mechanical characterization of anisotropic inelastic materials and thin film coatings.

The above case histories, outlined in this lecture, evidence that also in engineering applications of fracture mechanics, progress may be fostered by synergistic combinations of experiments, simulation and inverse analysis.