An inverse analysis method for applications to borehole drilling in hydrocarbon industry and to diagnostic monitoring of dams.

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Present challenges in engineering mechanics turn out to include reliable assessments of stress states and material properties in depth. Such assessments are required by safety in offshore and onshore borehole drilling for hydrocarbon extraction (namely provisions to avoid events like the Gulf of Mexico disaster, 2010) and are necessary for design of provisions to be taken in possibly deteriorated aging dams (e.g. concrete dams affected by alcali-silica reaction).

A novel method of inverse analysis investigated at present by our team for materials and stress state characterization in depth is preliminarily presented here as a contribution to the session in honor of Tomasz Hueckel. The proposed procedure can be outlined as follows, with reference to applications in the hydrocarbon industrial context and with limitations to the sequence of operative stages (experimental and computational details, still subject of current research, will appear in journal papers).

The drilling device ("driller") is stopped at a site of interest during perforation. A novel tele-controlled device called herein "dilatometer" is sent along the borehole to reach the "driller". It contains eight radial gauges, at 45° angular distance from each other, apt to measure (and to telecommunicate on surface) radial displacements of the hole surface. The drilling device moves ahead extending the hole (say along a length of a dozen of times its diameter). The forces on the new surface generated by this advancement are obviously known (being equal to zero or to pressure due to possible presence of mud in the hole). Such change of stress state gives rise to radial displacements which are measured by the above gauges and recorded by a computer. A second novel tele-controlled equipment, called here "radial indentation system", is sent down close to the dilatometer. Four indenters (90° one from the other) with suitable tip geometry are pushed radially against the whole surface by jacks. Digitalized "indentation curves" (namely plots of force versus puncher displacement) are generated, and "logged", namely tele-transmitted at surface as signals and stored in the computer.

Both operations (driller advancement and wall indentation) are modelled by suitable finite element computer codes. Simulations of such tests ("direct analyses") can be performed when values of the sought parameters are assumed, as preparatory conjectured quantities or as values of the unknowns within an iterative (step-wise) algorithm for "inverse analysis".

Two inverse analyses are necessary to the present purposes: (a) on the basis of experimental data from the indentation stage, the identification of the surrounding material properties is performed; (b) on the basis of the radial displacements induced by the driller advancement, the stress state before such advancement is estimated making use of the linear elasticity moduli provided by back-analysis (a).

The main features of both back-analyses can be briefly outlined as follows. The approach is deterministic, centered on the minimization, with respect to the sought parameters as unknowns, of the "discrepancy function" which quantifies the discrepancy between experimental data and their counterparts as functions, through the test simulation models, of the unknown parameters. If available, the covariance matrix can be exploited in the formulation of the discrepancy function to minimize.

The above minimization problem is solved by a "trust region" algorithm of mathematical programming, made computationally fast by "radial basis functions" interpolations (instead of test simulations by finite element direct analyses) after “model reduction” by “proper orthogonal decomposition”. Such reduction is time-consuming but is carried out “a priori”, once-for-all, for each category of inverse analysis applications, thus becoming very fast and economical.

So far merely computational exercises (including “sensitivity analyses”) have been performed with encouraging results. Extensions of the above parameter identification method to quasi-brittle fracture and hydraulic fracture in geo-materials and concrete, might be successful and practically advantageous with respect to the present engineering practice and standards, both in dam engineering and in hydrocarbon industry. Further current developments concern the mathematical and computational procedure, namely comparisons among diverse algorithms (genetic algorithms, artificial neural networks) and diverse approaches (stochastic Kalman filters instead of deterministic discrepancy minimization).

Other challenging developments (but methodologically rather obvious) might concern applications to tunneling and to superficial geological formations (like Toc Mountain, the collapse of which caused the Vajont disaster, 1963), instead of present techniques like “coring” and “over-coring”. However the novel experimental equipments, here merely envisaged, require detailed design by experts and resources for realizations and testing, requirements to be satisfied only by collaborations among teams with various specific backgrounds.