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Finite Element Well Integrity Analysis for Open-Hole and Standard Completion Systems in a Producing Reservoir

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The development plan of a hydrocarbon field includes the completion design of all the production/injection wells forecasted for the scenarios considered. The use of open-hole completions represents a particularly appealing choice for oil companies, given the economic advantage assured by this solution compared to conventional cased holes. However, to assess the feasibility of such a solution, the mechanical stability of the rock surrounding the borehole has to be verified not only in the drilling phase, but also over the stress regimes that the well will experience along its lifetime. Whenever the adoption of open-hole completions results in mechanical actions that may induce failure in the rock material, different completion systems have to be designed to assure wellbore stability, typically including a cemented steel casing. In this case as well, the rock compaction induced by the depletion in the near wellbore area may cause, in the completion structure, a stress regime that can possibly bring to the failure of the casing and/or the cement, eventually leading to the well shutdown and to significant economic loss ([1], [2]).
As already evidenced in past studies, ([3], [4]), finite element (FE) models are the most suitable tools to study and forecast the wellbore integrity during the well lifetime, by correctly describing the behaviour of the rock material, of the completion material and of the interfaces developing between them when subjected to the loads induced by the production.

By making reference to a case of industrial interest, the paper describes a methodology, based on numerical simulation with the FE method, to assess well integrity in the case of both open-hole and standard cased-hole completions.
The first phase of the study is focussed on the definition of the reservoir rock mechanical behaviour, in order to obtain the most proper constitutive law and relevant properties to describe the rock in the simulation models. In the case study presented, on the base of the results of laboratory tests, an elastic perfectly plastic constitutive law is used, with failure identified by the Hoek & Brown (HB) criterion, implemented in the FE codes using dedicated user subroutines; the properties are defined as a function of the void index *e*, thus introducing an ‘extended HB failure criterion’, specific for the materials of interest (Figure 1).
FE models at well scale have, then, been built accomplishing for a range of possible well trajectories and imposing pore pressures and pore pressure gradients in accordance with the forecasts provided by a numerical reservoir flow model.
The method allows, first, evaluating the stability lifetime of the analysed reference wells for the case of open-hole completions; results of the analysis evidenced the unfeasibility of such a solution; thus, further FE analyses were performed, this time including the casing and cement of a standard completion system.

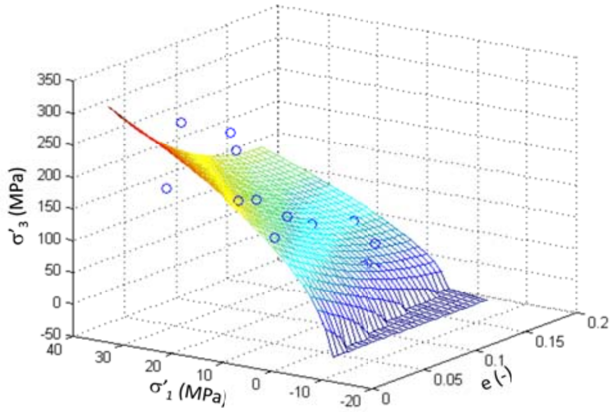

Figure 1 – 'Extended Hoek & Brown' failure criterion.

A staged approach has been considered by including in the simulations the different phases of the well life, from the drilling steps to the completion (Figure 2) and production phases; possible well damages developing in correspondence of particular stages of the exploitation could then be forecasted.

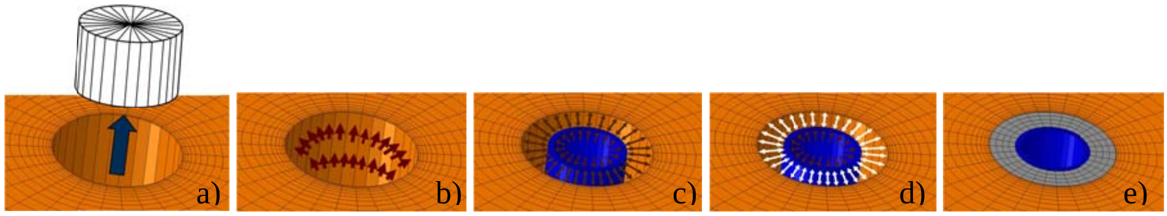

Figure 2 – a) Drilling phase (borehole elements removal; b) mud introduction; c) casing introduction; d) fluid cement introduction in the annulus; e) cement hardening (contact interfaces activation).

A key point of the simulations is the interaction behaviour at the contact interfaces between the rock formation, cemented annulus and casing steel; the parameters governing this behaviour are the most uncertain variables, thus sensitivity cases were run in order to evaluate the influence of the parameters defining the friction at the interfaces.

The FE simulations performed provide the evolution of stress and strain in the rock formation around the wellbore area as well as in the completions (if present); for open-hole completions, this allows assessing their feasibility as a function of the well trajectory; in the case of cased hole, the proper evaluation of stresses and strains in the completion material allows forecasting possible well damages that may develop in correspondence of particular stages of the exploitation, thus driving the design optimization in terms of well trajectory and completion material properties.

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