NARRATIVE PROGRESS REPORT

PRF# 56743-DNI9
PROJECT TITLE: ANALYTICAL MODELLING AND NUMERICAL SIMULATIONS FOR HYDRAULIC FRACTURING INITIATION IN POROUS ROCK FORMATIONS
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a) Activities undertaken during the reporting period (*from September 1, 2017 to August 31, 2018*)

1. Upon the development of the rigorous analytical solutions for the borehole hydraulic fracturing initiation in both isotropic and transversely isotropic rocks, the numerical simulations were further conducted by using the commercial software ABAQUS. The complicated boundary conditions involving the coupling between the total radial stress and injection-induced pore pressure over the sectioned borehole interval have to be applied through the development and incorporation of the user subroutines. Two user subroutines, i.e., URDFIL and DLOAD, were successfully programmed in FORTRAN for this purpose (*Task 2 in the project schedule pertaining to the ABAQUS subroutines development has been completed*).

2. An ABAQUS model was established to rigorously simulate the coupled responses of the borehole as well as the surrounding rock formations due to the drilling process. On leverage of the above two well-designed and verified user subroutines, the hydraulic fracturing operations, i.e., fluid discharge loading over a segment of the borehole surface, has also been properly simulated. The numerical results were compared with the already developed analytical solutions and an excellent agreement has been observed, see Fig. 1. Cross checking and validation between the analytical and finite element numerical results for the transversely isotropic case have also been conducted (*Task 2 in the project schedule pertaining to the implementation of subroutines into ABAQUS and verification with theoretical models has been completed*).

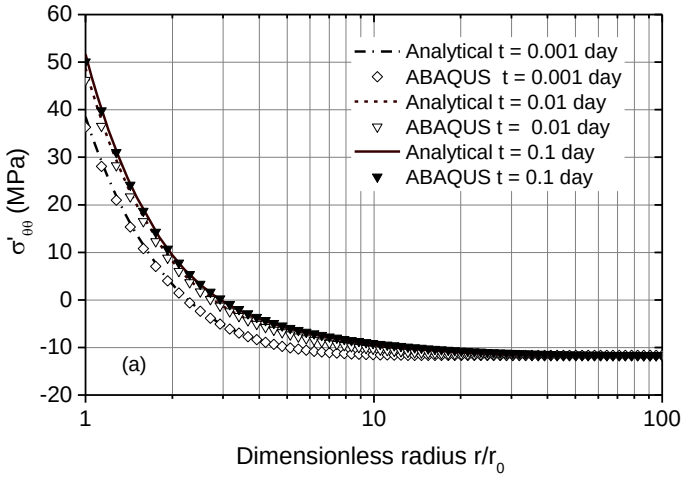

Fig. 1. Comparison between the ABAQUS simulation results and the analytical solutions

3. A conceptual framework has been established in regards to the hydraulic fracturing initiation simulator development based on MATLAB platform and the analytical solutions previously developed. Some progress has been made on the preliminary GUI development for the numerical simulator, as shown in Fig. 2, and currently the research team is striving to add more available features from MATLAB so as to make the developed interface as functionable and simple as possible for the end users to interact with (*Task 3 in the project schedule, part of which has been completed*).

b) Impact of the research

1. The research is expected to advance our understanding on the initiation mechanism of wellbore hydraulic fracturing through analytical method and related computational modelling. The rigorous analytical solutions already developed, for both isotropic and transversely isotropic rock formations, are the first comprehensive, definite ones of their kind. The ABAQUS numerical modelling, on the other hand, not only justifies the validity and accuracy of the proposed analytical approach, but also verifies the reliability of the user subroutines written for the purpose of correctly

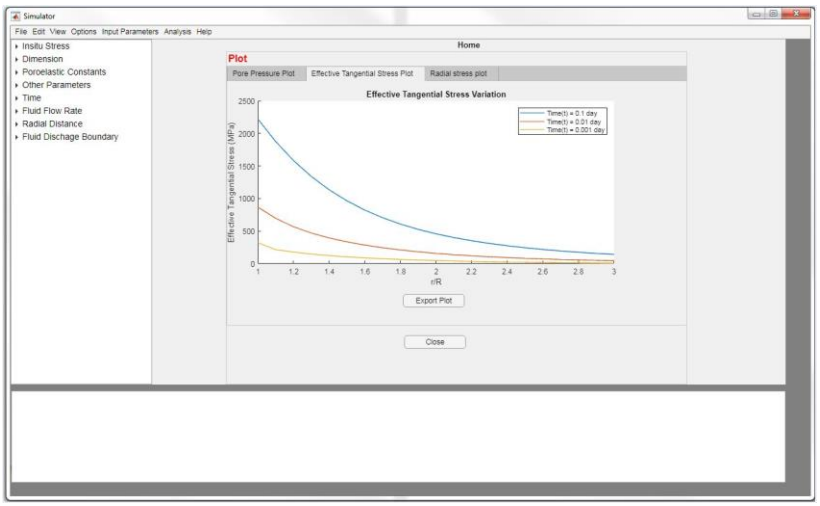

Fig. 2. Simulation tool development for the hydraulic fracturing initiation

describing the complicated coupled borehole injection boundary conditions. More importantly, the unique and powerful hydraulic fracture simulator being developed can be directly used for the unconventional reservoir exploration in the oil and gas industry.

2. All the above research objectives and outcomes align perfectly well with the PI's long-term career goal to "advance the understanding on the fundamentals of shale drilling and production geomechanics and establish himself as a leading contributor in the research field of petroleum geomechanics." The current research effort represents a significant first step towards building such a career in advanced/realistic, thorough, and systematical modelling of wellbore drilling and fracking problems, and in the concurrent development of a rigorous simulation model for evaluating and predicting the location and orientation of the hydraulic fracture initiation. The success of the present study will allow the PI to investigate further the hydraulic fracturing extension in the porous formations with the appropriate account of the rock toughness and its impact on the fracture propagation path, using either the commercial program ABAQUS and/or in-house developed finite element codes.

3. The output of the research includes the following two conference presentations at the EMI 2018 conference: *(a) Huang, C., and Chen, S. L. (2018). Poromechanics response of wellbore subject to hydraulic fracturing in transversely isotropic rocks. EMI 2018 Conference, MIT, Boston, USA, 29 May-1 June 2018; (b) Liu, K., and Chen, S. L. (2018). Theoretical analysis on undrained wellbore stability problem in anisotropic modified Cam Clay soil and its numerical verification. EMI 2018 Conference, MIT, Boston, USA, 29 May-1 June 2018*. Additionally, two manuscripts on the analytical derivation and numerical simulations have been submitted to journals and currently under review: *(a) Chen, S. L. (2018). Three-dimensional analytical poromechanical solutions for an arbitrarily inclined borehole subjected to fluid injection. Submitted to Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences; and (b) Huang, C., and Chen, S. L. (2018). Three-dimensional stress analysis of an inclined borehole subjected to fluid discharge in transversely isotropic saturated rock formations. Submitted to International Journal of Geomechanics, ASCE*. These research outcomes through publications in the high quality peer-reviewed journals will definitely be helpful for the PI to build a great reputation in his research area of petroleum geomechanics and become more nationally competitive, and to improve his opportunity for future federal funding.

4. The Ph.D. and M.S. students participating in this project have continued receiving a well-balanced training and research experience in the cross-disciplinary of geomechanics and petroleum engineering. During the reporting period, the two Ph.D. students Mrs. Kai Liu and Chang Huang, working together, have successfully completed the second research task related to the implementation of appropriate subroutines into ABAQUS models and verification with the previously developed analytical solutions. Each of them has published/submitted a number of papers based on their research progress on the analytical and numerical aspects of this project. The M.S. student, Mr. Krishna Adhikari, has also started working on this project while receiving training on mathematics related to the partial differential equations, principles on geomechanics and programming. He has made some progress on the preliminary GUI development for the numerical simulator based on the MATLAB platform.