GeomInt2: CAU (June 2021)

Mechanical Model:

The benchmark solution of a Double Cantilever Beam (DCB) is adopted to verify the implemented hybrid Finite/Discrete Element method (FDEM). The DCB problem is consisted of two beams being pulled apart, bonded by the aid of an adhesive material at the specimen mid-plane (Fig.1). As a well-accepted method, the test is usually used for determination of Mode-I fracture toughness. The numerical results of FDEM simulation(Fig.2) is in good agreement with the exact analytical solution provided by Anderson (1995) [1].

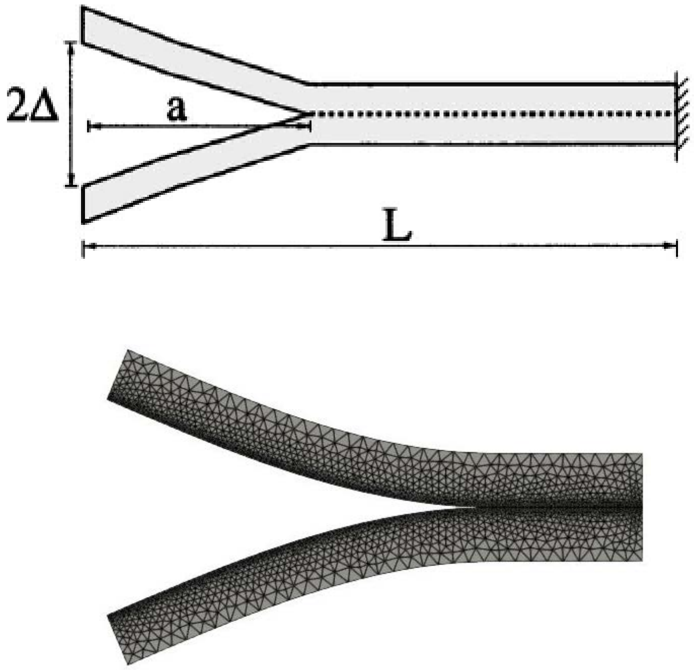


Fig. 1. a) Schematic representation of DCB b) Mesh details and Result of FDEM simulation

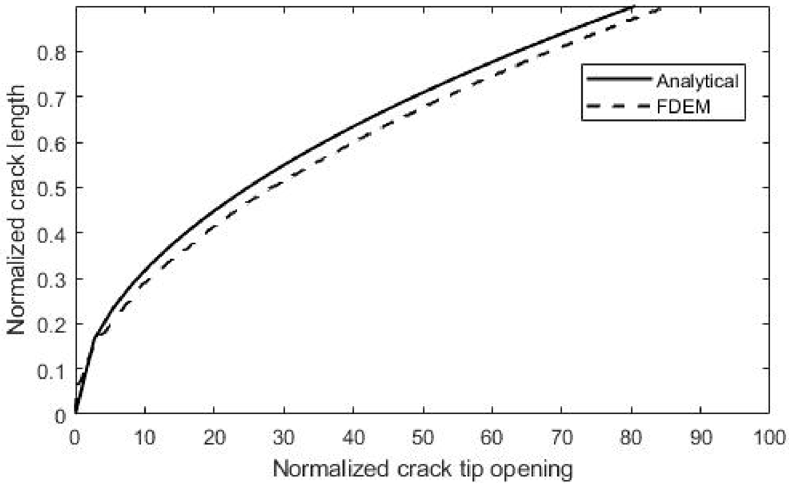


Fig.2. Normalized crack length (a/L) against Normalized crack tip opening (Δ/δ_c) of DCB for analytical and FDEM solution

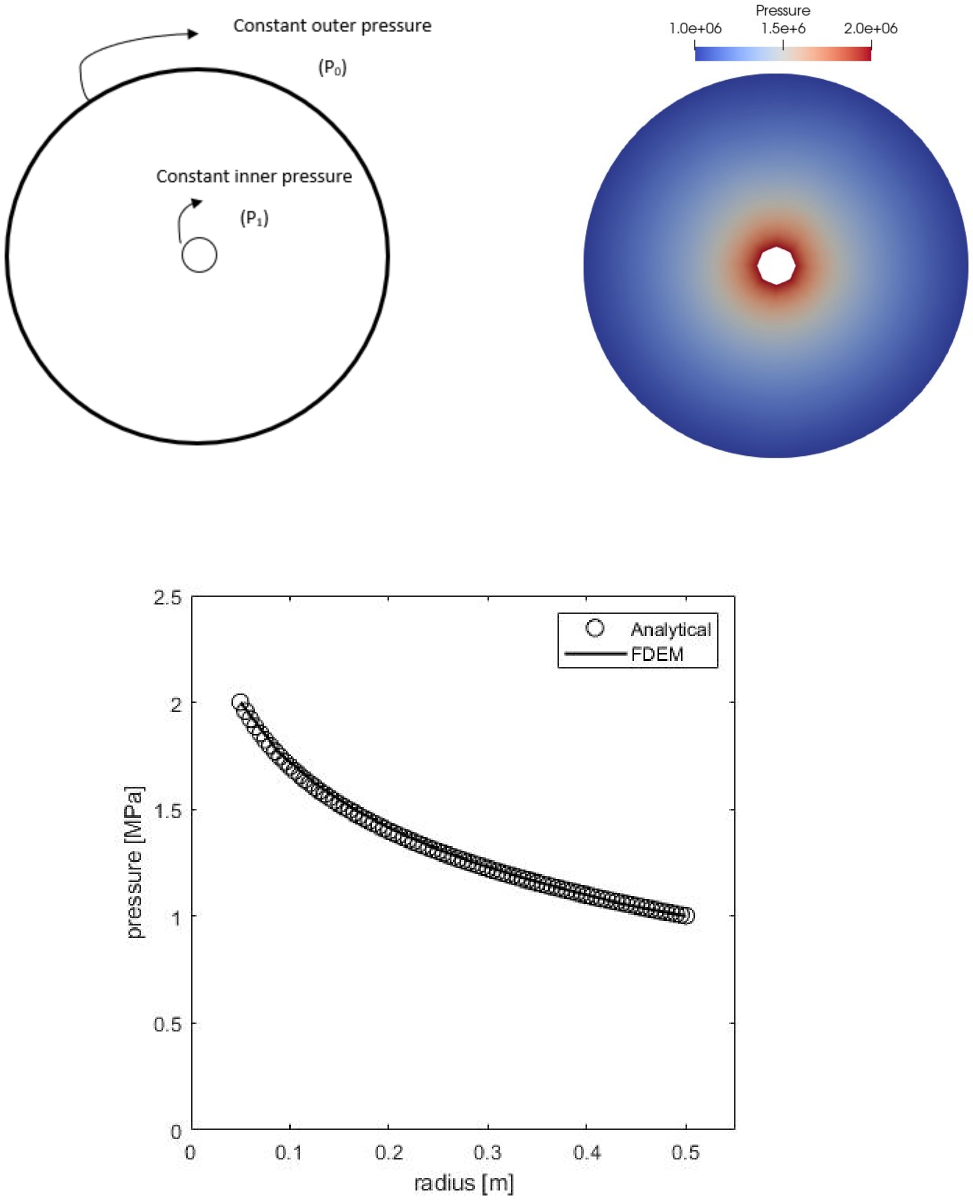
Hydro-Mechanical Model:

In order to capture the coupled hydro mechanical phenomena, a fully-coupled formulation is implemented within the framework of FDEM. In this model, fluid flow is only assumed to occur through the Flow Channels. The flow channels are created as an underlying network having the same characteristics of the main mesh topology. The adopted scheme from Lisjak et al. (2017) is fully coupled since the mechanical deformations are affected by the presence of an inter-element fluid pressure and the flow calculations are affected by the changes of mechanical aperture between finite elements as well [2]. The implementation is verified against analytical solutions for several benchmark flow problems. The benchmarks are as follows:

1) As shown in Fig. 3, the first example considers the radial flow from a pressurized hole in a permeable rock. We assumed $P_0 = 1MPa$ & $P_1 = 2MPa$ and $r_0 = 0.5m$ & $r_1 = 0.05m$. The solution satisfies the Laplace's equation:

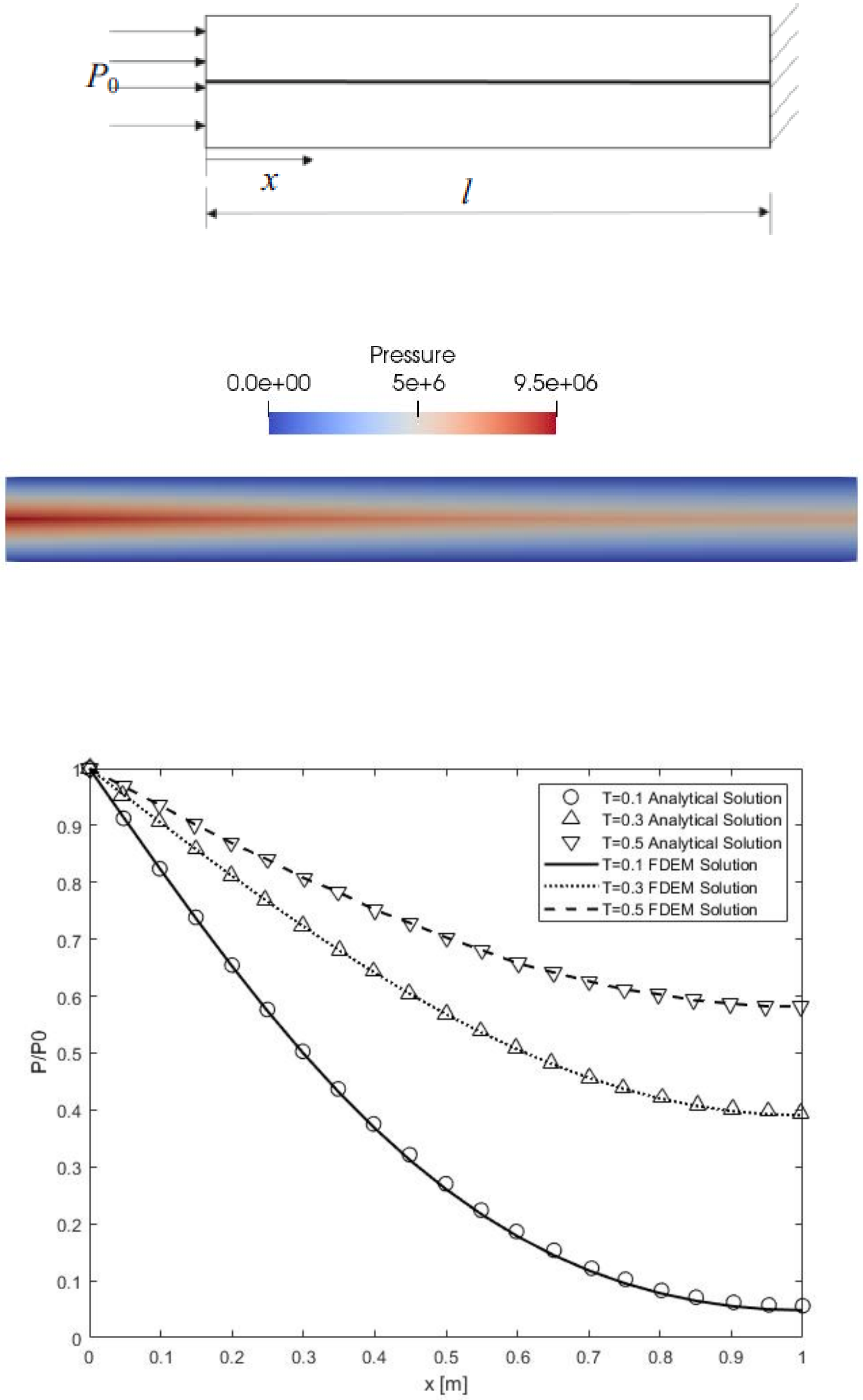
$$P(r) = P_1 + \frac{P_0 - P_1}{\ln\left(\frac{r_0}{r_1}\right)} \ln(r/r_1)$$

The results obtained from FDEM simulation is in complete agreement .with the analytical solution



lowF onfinedC state-Fig.3. Steady

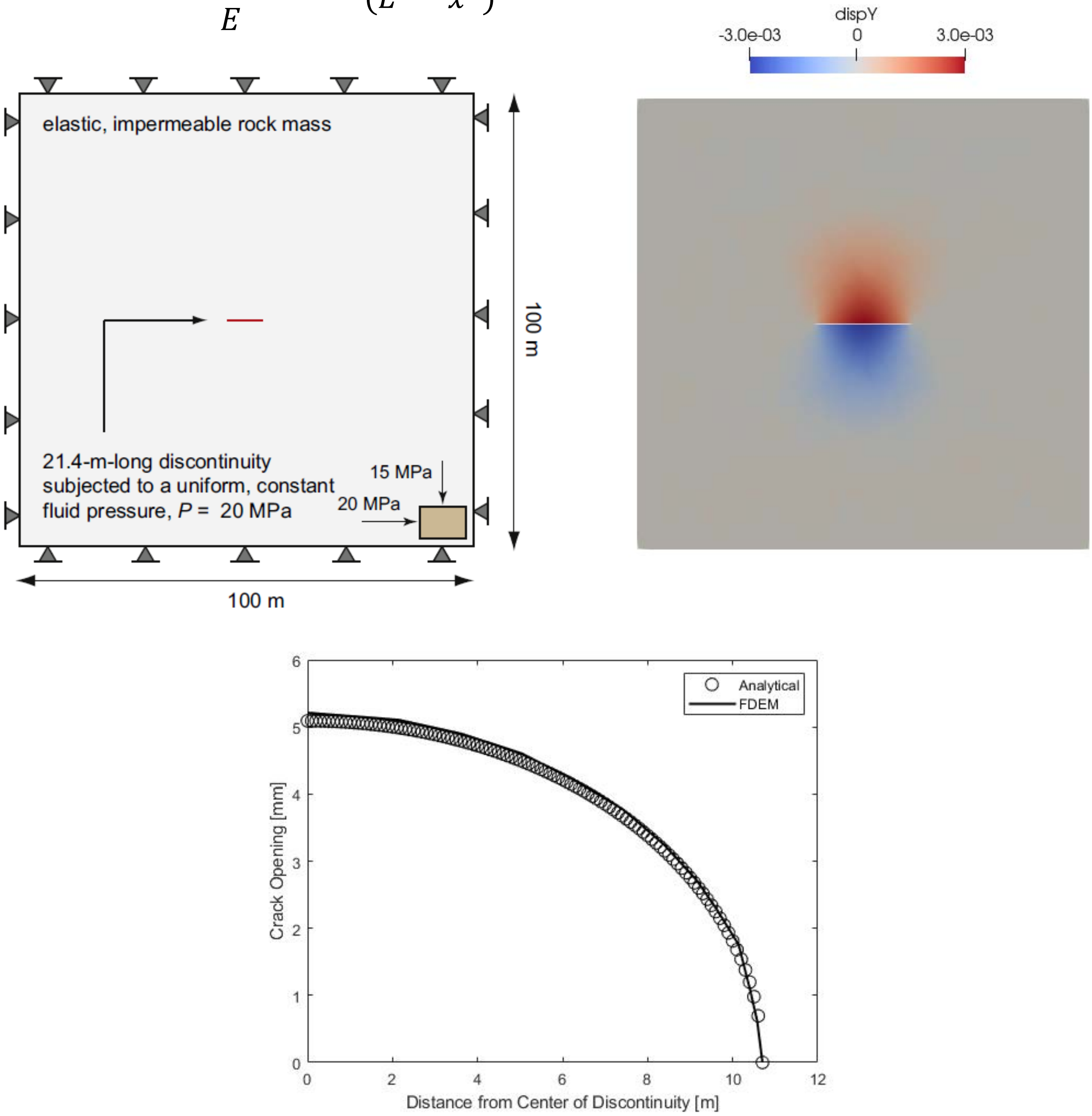
2) In order to assess the accuracy of the temporal discretization of hydro-mechanical formulation, the problem of the transient flow through a fracture with constant aperture is adopted. The fracture with a length of $l = 1m$ is initially dry and subjected to a constant pressure of $P_0 = 9.5\ MPa$ at the far-left end. The right end of fracture was assumed to be impermeable (Fig.4). The solution to this problem is equivalent to that of 1D heat conduction.



Transient Fluid Flow within Fracture Fig.4 (T: Dimensionless time parameter)

3) Finally, to illustrate the robustness of coupling function between mechanical and hydraulic solver, a numerical example including a $21.4\,m$ discontinuity within the elastic rock mass and subjected to uniform and constant pressure of $P = 20\ Mpa$ is considered. The elastic rock is under the effect of in-situ stress as depicted in Fig.5. The Young modulus and Poisson's ratio for the rock mass are $E = 40\ GPa$ & $\nu = 0.22$. According to [3], the opening displacement along the discontinuity can be computed as: (x is the distance from the center of discontinuity).

$$\frac{4(\sigma_v + p)(1 - \nu^2)}{E}(L^2 - x^2)$$



Pressurized Discontinuity in an Elasitc Rock Mass-Fig. 5. Fluid

References:

[1] T. L. Anderson, *Fracture mechanics: fundamentals and applications*. CRC press, 2017.

[2] A. Lisjak, P. Kaifosh, L. He, B. S. A. Tatone, O. K. Mahabadi, and G. Grasselli, “A 2D, fully-coupled, hydro-mechanical, FDEM formulation for modelling fracturing processes in discontinuous, porous rock masses,” *Comput. Geotech.*, vol. 81, pp. 1–18, 2017.

[3] A. P. Parker, “The mechanics of fracture and fatigue,” *An Introd.*, 1981.