

Modelling hydraulic fracturing with the J-integral

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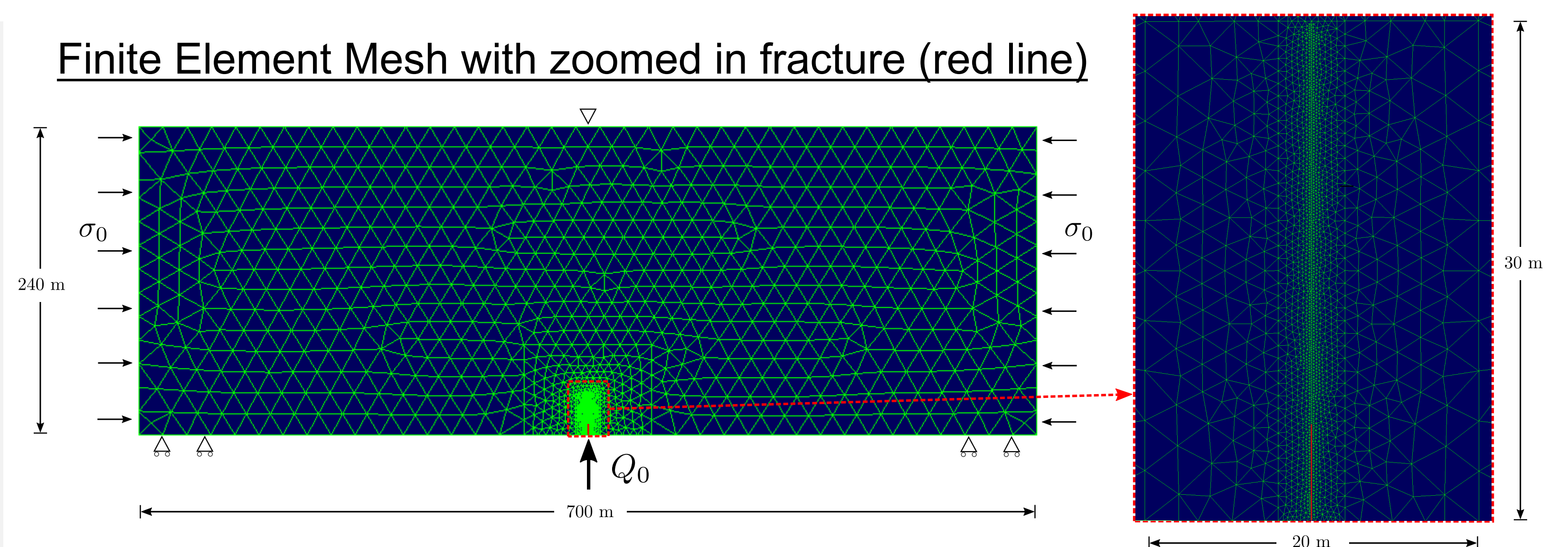
1 Introduction

The numerical simulation of hydraulic fracturing is an essential tool to optimize the stimulation of Enhanced Geothermal Systems (EGS). A hydraulic fracturing model must accurately and efficiently predict propagation in order to be applicable at reservoir scale. A particularly attractive option to simulate the propagation of “dry” fractures involves using the J-integral. The method is well-established to show excellent accuracy at coarser resolutions. However, the same success is not apparent when applying the J-integral to simulate hydraulic fracturing. This motivates the following questions:

- How does the J-integral perform in predicting the propagation of a hydraulic fracture?
- Can the J-integral be optimized to predict hydraulic fracturing?

2 Methodology

- Impermeable, linearly elastic solid
- Incompressible, Newtonian fluid
- Coupled solution process with the Finite Element Method
- Propagation simulated in both the toughness and viscosity-dominated regimes
- Zero-fluid lag assumed for deep geothermal reservoirs
- Fracture is propagated to a length of 15m



3 Assessment of the J-integral for Hydraulic Fracturing

- The J-integral can over-estimate the propagation criteria (K_I) by 200% in the viscosity-dominated regime of propagation
- The over-estimation can be almost entirely accounted for by the errors involved in the calculation of J_f within the J-integral

$$J = \underbrace{\int_{A^*} \left(\sigma_{ij} \frac{\partial u_j}{\partial x_1} - W \delta_{1i} \right) \frac{\partial q}{\partial x_i} dA}_{J_r} + \underbrace{\int_{\Gamma_+ + \Gamma_-} p \frac{\partial u_2}{\partial x_1} n_2 q d\Gamma}_{J_f},$$

Source of error!

- The singular fluid pressures present in the viscosity-dominated regime are the cause for the difficulty in numerically evaluating J_f

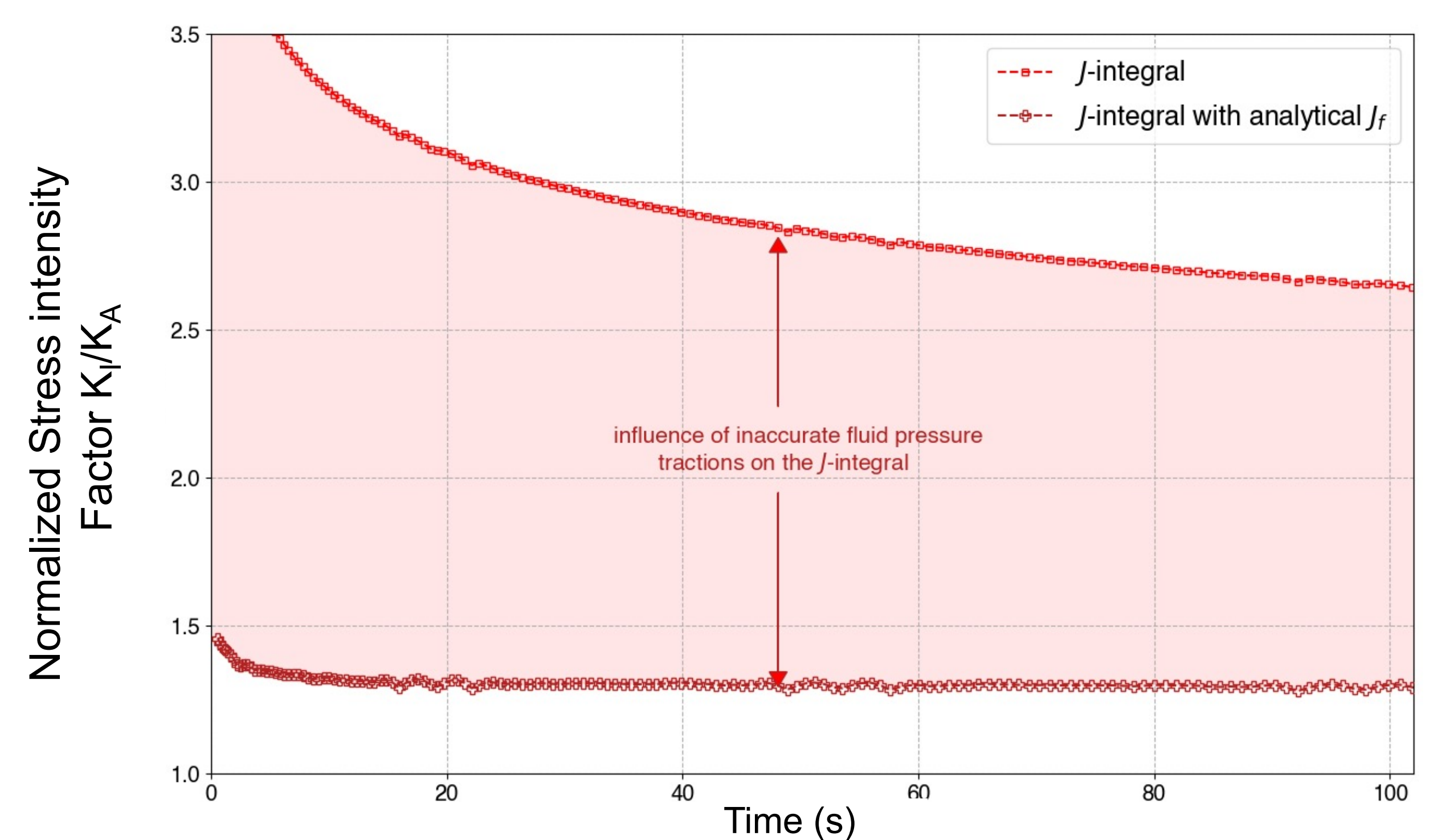


Fig 1: Prediction of the stress intensity factor by the J-integral in the viscosity-dominated propagation regime

4 The Novel J_V -integral for Hydraulic Fracturing

- A J_V -integral (see below) has been constructed which overcomes the limitations of the classical J-integral in the viscosity-dominated regime

$$J_V = \int_{A^*} \left(\sigma_{ij} \frac{\partial u_j}{\partial x_1} - W \delta_{1i} \right) \frac{\partial q}{\partial x_i} dA + \underbrace{\langle w p_f \rangle_{\hat{x}_q}^{\hat{x}_0}}_{\text{Optimal asymptotic reformulation}} - \alpha \frac{(\mu' V)^{2/3} (E' \hat{x}_0)^{1/3}}{\beta},$$

- Using asymptotic solutions to evaluate J_f analytically underlies the excellent performance of the J_V -integral in predicting the fracture length
- A mesh refinement study shows great accuracy up to coarse levels of refinement of the fracture (2m), with both linear and quadratic elements
- The J_V -integral can be formulated to predict propagation across the entire toughness-viscous regime, and extract the propagation velocity

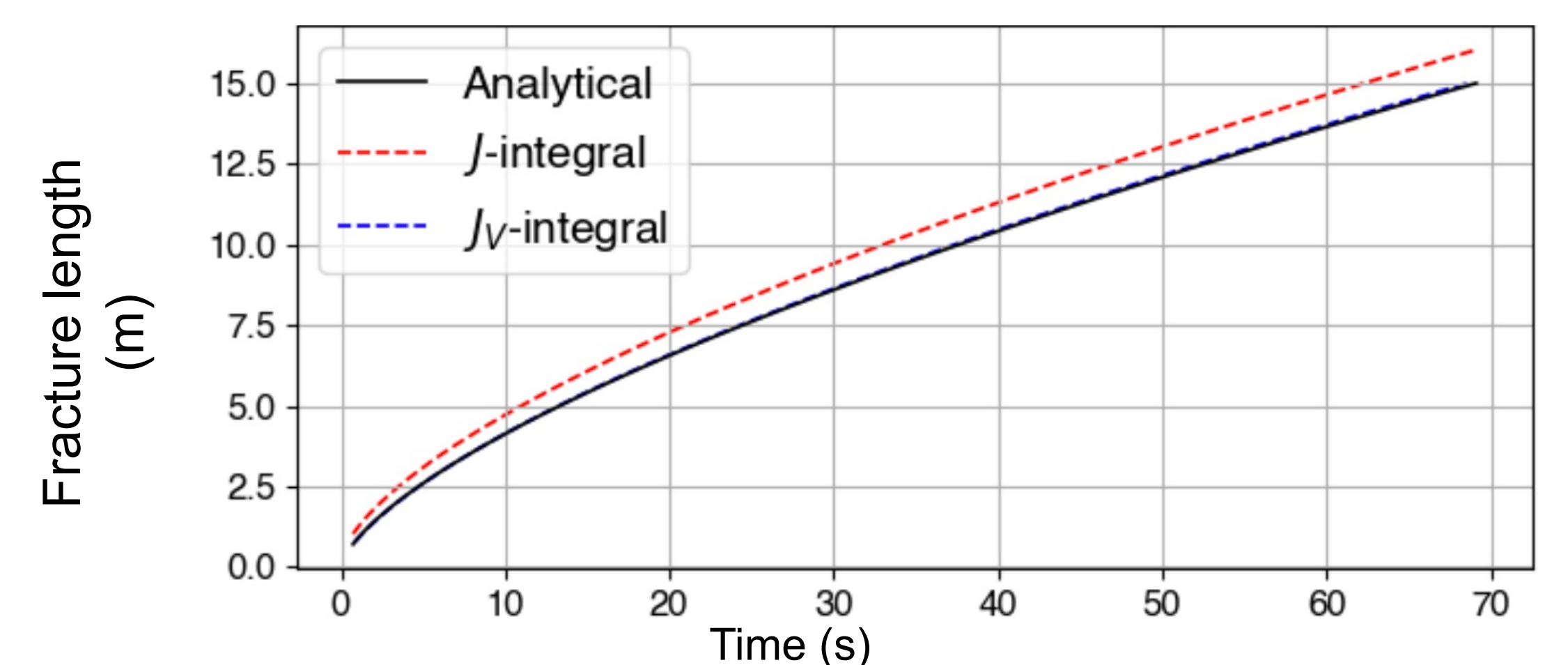


Fig 2: Predictions for the evolution of the fracture length in time for the viscosity-dominated propagation regime

5 Conclusion

- The J-integral is inadequate at predicting the propagation of hydraulic fractures in the viscous regime
- A generalization of the J-integral to simulate hydraulic fracturing across the entire toughness-viscous regime is possible with the J_V -integral
- The J_V -integral is demonstrated to be highly accurate, with great potential for simulations at the reservoir scale

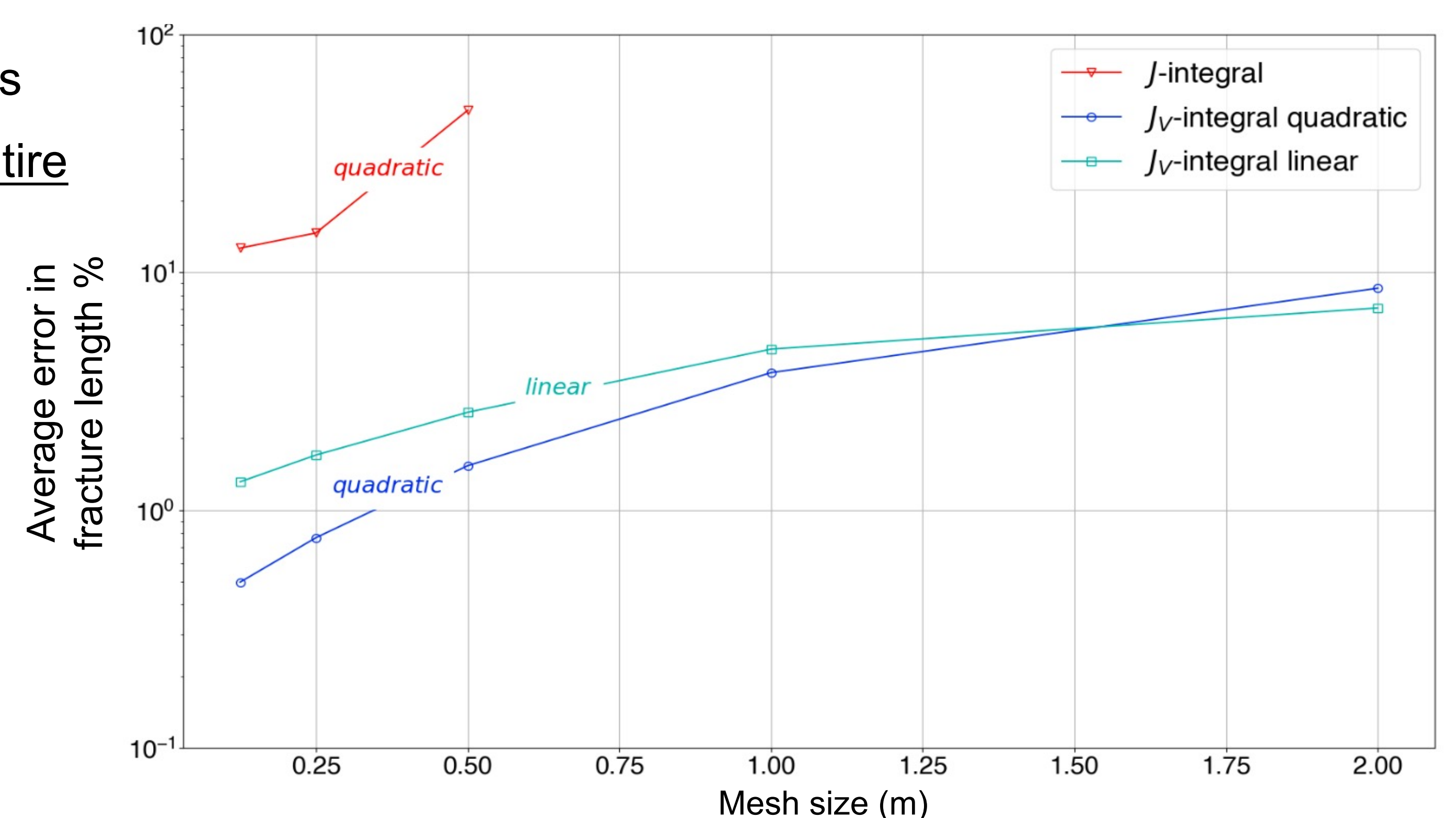


Fig 3: Average percent error in fracture length at various refinements along the fracture in viscosity-dominated regime