On the supershear transition in heterogeneous media

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Introduction

During an earthquake, frictional rupture fronts mainly propagate at sub-Rayleigh speed along tectonic faults. However, evidence of supershear propagation have been reported in several occasions. Contrarily to sub-Rayleigh, supershear rupture results in high stresses and particles velocities far away from the interface. The transition between these regimes occurs via the Burridge-Andrews [1-2] mechanism which is well defined for homogeneous case. However, realistic interfaces such as geological faults involve heterogeneities, which alter this mechanism via the emission and reflection of elastic waves. Evidence of facilitated supershear transition due to both in-plane and out-of plane heterogeneities have been observed numerically [3-5]. In this study, we focus on the importance of the spatial distribution of in-plane heterogeneities, for organized and randomized heterogeneous pattern.

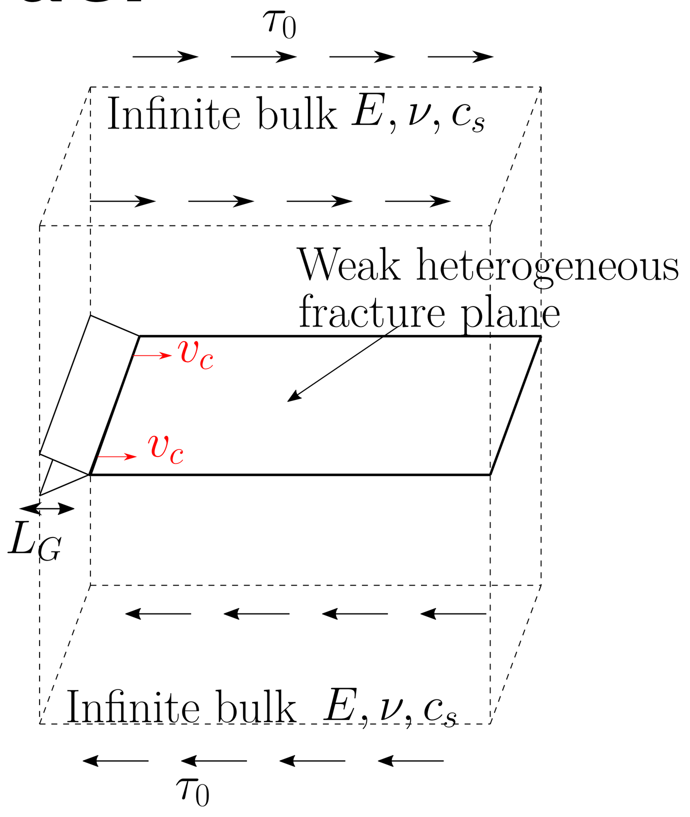
Method

We use a boundary integral formulation [6] to solve the tractions and displacements at the interface between two semi-infinite solids. The general 3D elastodynamics is written as:

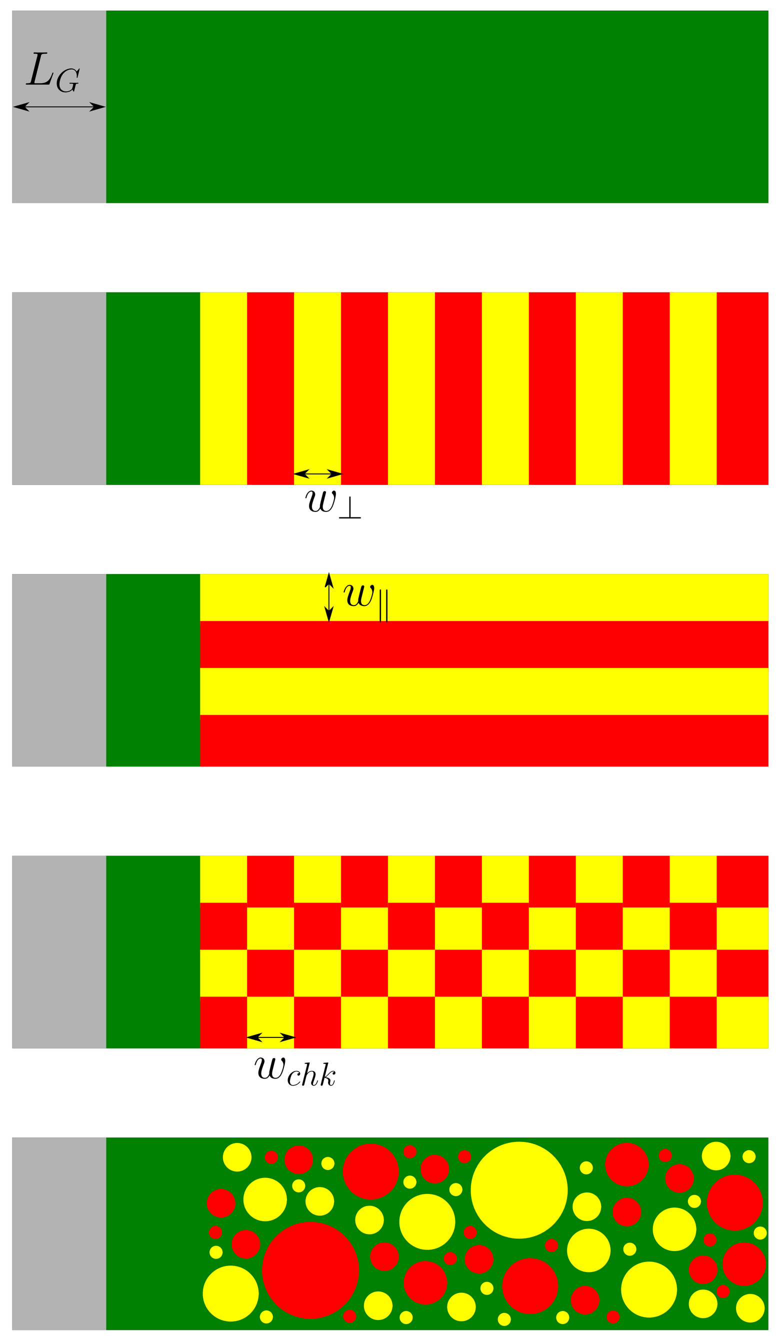
$$\boldsymbol{\tau}^{\pm}(x,z,t) = \boldsymbol{\tau}^{0\pm} - \boldsymbol{V}^{\pm}\frac{\partial \boldsymbol{u}^{\pm}}{\partial t}(x,z,t) + \boldsymbol{f}^{\pm}(x,z,t)$$

- $\boldsymbol{\tau}^{0\pm}$: Far field loading
- $\boldsymbol{V}^{\pm}\frac{\partial \boldsymbol{u}^{\pm}}{\partial t}$: Radiation damping
- $\boldsymbol{f}^{\pm}$: Accounts for the history of displacements

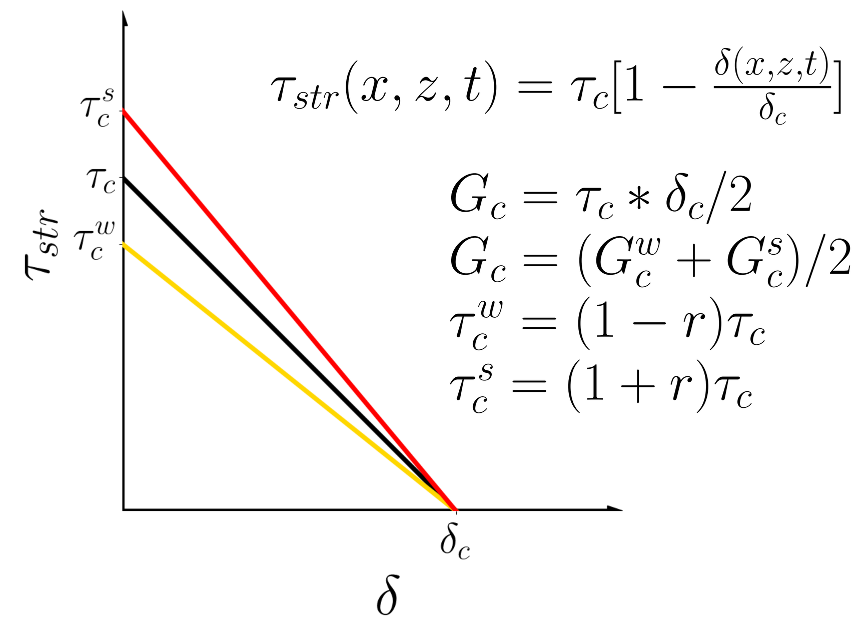
Model



- Two semi-infinite solids
- Linear elastic bulk
- Remote mode II loading τ_0
- Weak heterogeneous interface

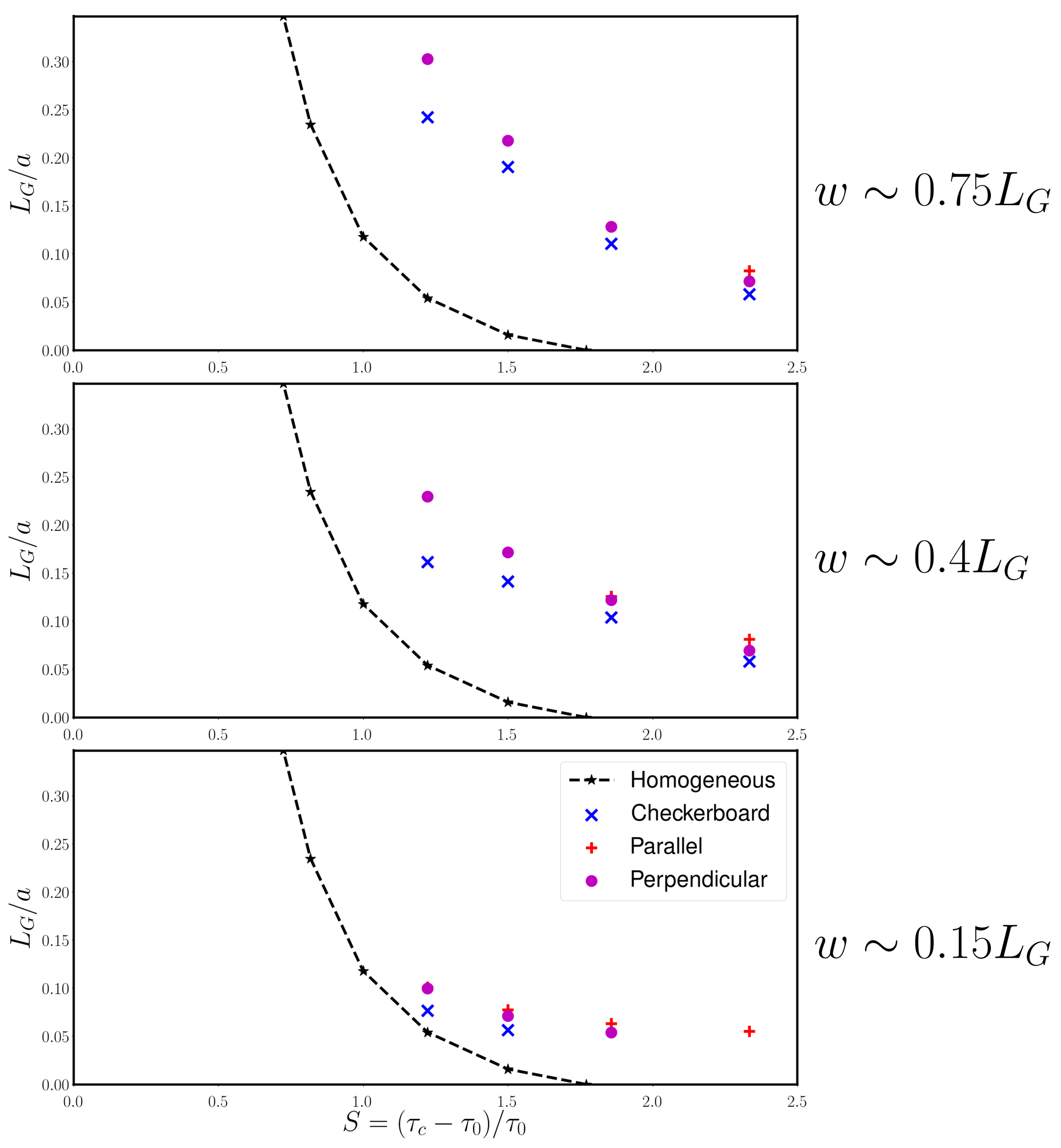


- Initial crack of length $L_G = \frac{2K_{II}^2}{\pi \tau_0}$
- Linear slip-weakening law
- Homogeneous toughness (green) G_c
- Weak and strong asperities



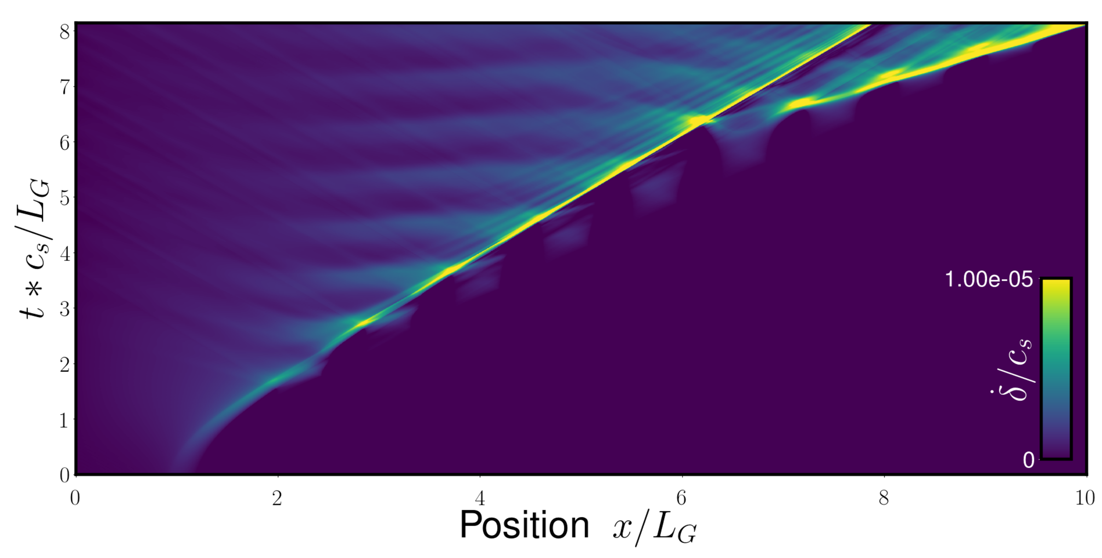
Results

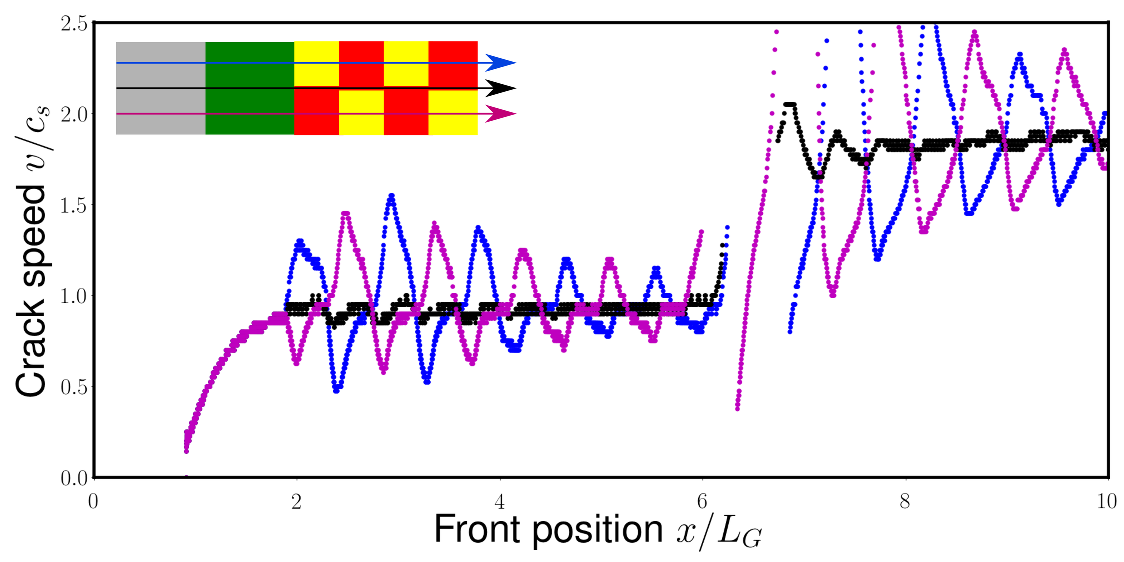
We perfom numerical simulations with various characteristic sizes of heterogeneities ranging from $0.15L_G$ to $0.75L_G$. We compare the crack lengths for which supershear velocity is recorded for given seismic ratios $S = \frac{\tau_c - \tau_0}{\tau_0}$.



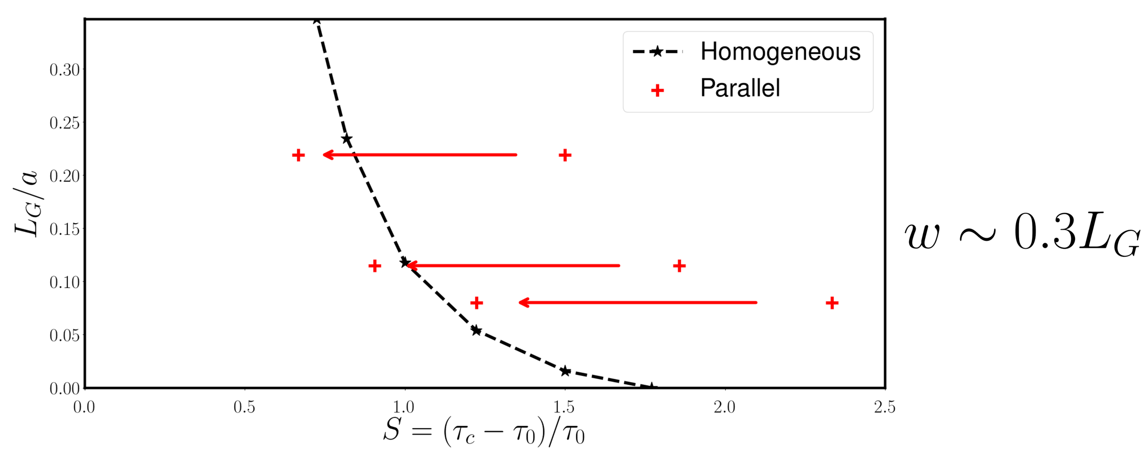
- Supershear transition occurs for shorter crack in heterogeneous interfaces.
- Supershear occurs in heterogeneous media for seismic ratio values that would never result in supershear for homogeneous cases.
- The stripes parallel to the crack propagation give the earliest transition.
- The transition length is inversely correlated with the heterogeneities size.

The transition is facilitated by the radiation of elastic waves when the crack interact with in-plane heterogeneities. These waves propagate faster than the crack and increase the intensity of the stress peak propagating ahead of it, leading to the nucleation of a daughter crack.



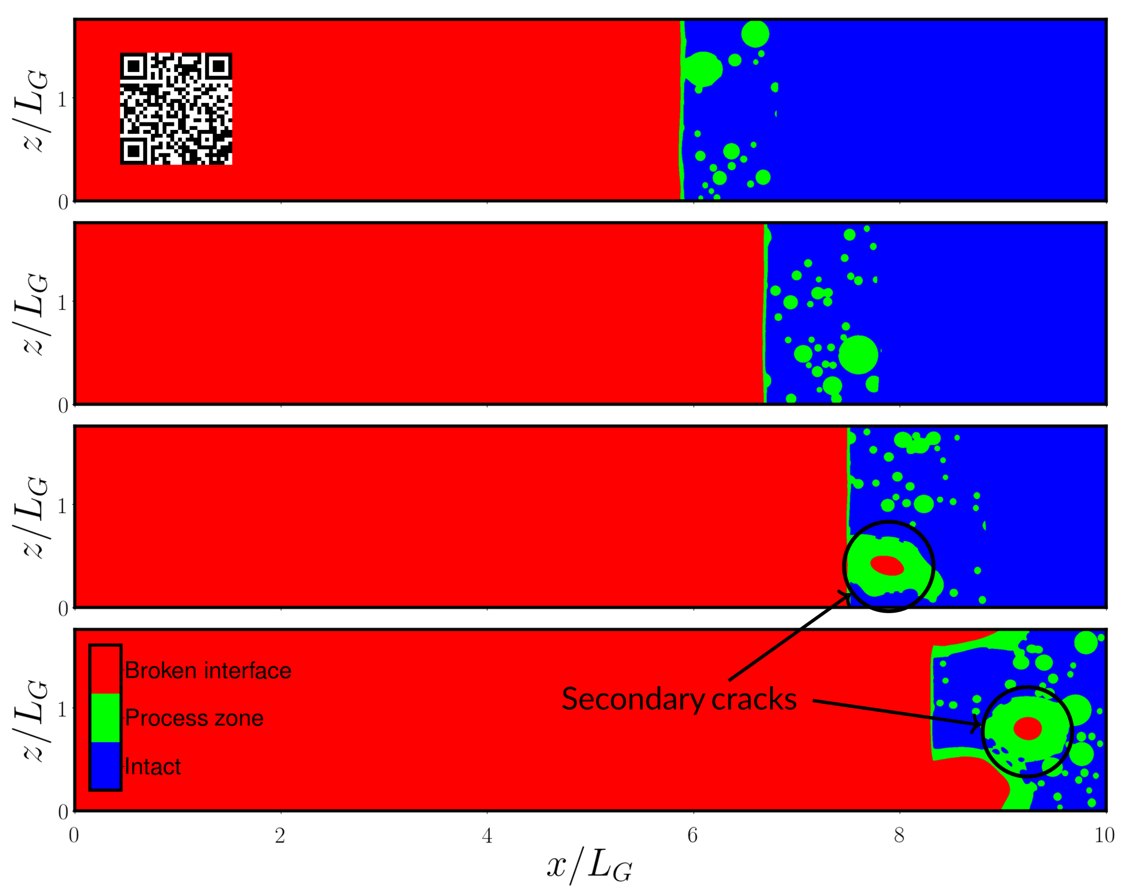


For the stripes parallel to the crack propagation direction, the transition occurs similarly as in an homogeneous interface with the seismic ratio of the weak stripes $S_w = \frac{\tau_c^w - \tau_0}{\tau_0}$.



Preliminary results - Random toughness

In interfaces with random distribution of toughness, multiple cracks are nucleated in front of the main one.



Conclusion

- The presence of small scale heterogeneities facilitate the supershear transition via the emission of elastic waves and the reduction of the effective seismic ratio.
- The heterogeneities size controls the transition.
- Due to the Lorentz contraction of the process zone, even very small heterogeneities seems to facilitate the supershear transition.

References

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