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Numerical Investigation of Microseismicity Using Bonded Particle Method

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Summary

In seismology, numerous small aftershocks can be triggered locally and at a considerable distance by a relatively large earthquake. This is true for microseismicity at the micro-scale too. Here we investigate the dynamic triggering of a microseismic event and its induced stress change to promote a more effective treatment method for production purposes, as well as suggest a mitigation method by advancing or delaying induced seismicity for safety purposes. The semi-analytical and numerical simulations of a microseismic source are presented, followed by a geomechanical modelling of compressive tests for investigating the dynamic and static triggering of microseismicity.

Workflow

Verification

In order to verify the validity and capability of the bonded particle method in computing stress changes by simulating microseismic displacement wave fields and stress fields under a monopole force, which acts as a microseismic source and points in the positive y-direction.

Semi-analytical solution

The relationship between displacement and strain obeys the geometric law and represents the geometric property (deformation), the relationship between strain and stress represents the material properties, including material strength and stiffness. The displacement field is constructed based on the ground displacement equation by Aki and Richards (2002). By applying the geometric law and constitutive law, the corresponding stress field can be computed. The relationship among displacement, strain and stress is summarized in Figure 1.

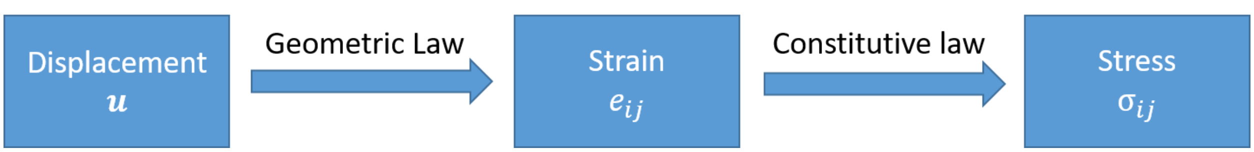

Figure 1 Relationship of displacement, strain and stress.

Numerical simulation

The numerical simulation part is presented by using a bonded-particle method, namely the Particle Flow Code, in 2D. Instead of having a continuous and isotropic medium, the assembly is constructed as a dense packing of varying-sized disk particles (Figure 2) that are bonded together by contacts. Each cycle of force-displacement calculation in PFC involves a series of the law of motion equation to solve for particle positions, which can then be applied again in the calculation cycle. The time step between each cycle is chosen to be very small so that no disturbance would propagate from any particle farther than its adjacent neighbour particles. The dimension and microproperties of the granite assembly are shown in Figure 2 and Table 1, respectively. The green outer region in Figure 2 is constructed to prevent the reflection of energy from the boundaries.

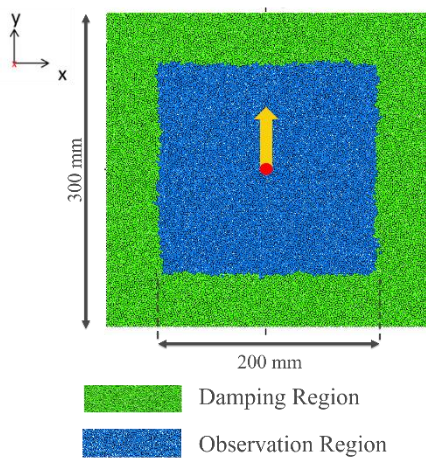

Figure 2 Model setup of assembly

Parameter	Value	Unit
Grain density	3169	kg/m^3
Grain Young's modulus	62	GPa
Stiffness ratio for grain	2.5	N/A
Friction coeffcient	0.5	N/A
Parallel bond Young's modulus	62	GPa
Stiffness ratio for parallel bond	2.5	N/A

Table 1 Microproperties of granite assembly

Compressive tests

After the verification of numerical simulation, the compressive tests are performed to investigate the static and deformation triggering effect of acoustic emissions as an analogy of microseismic events. The compressive test can be run dynamically by assigning a low level of damping parameter to simulate realistic attenuation in the rock (Hazzard et al., 2000). After each formation of a crack, it allows the stored strain energy to release in the form of a seismic wave, which potentially can trigger more acoustic emissions. The static run can be achieved by specifying a high damping parameter to facilitate the accumulation of strain energy and eliminate seismic wave propagation in the rock. For dynamic and static runs, they are also simulated under different confining pressure conditions.

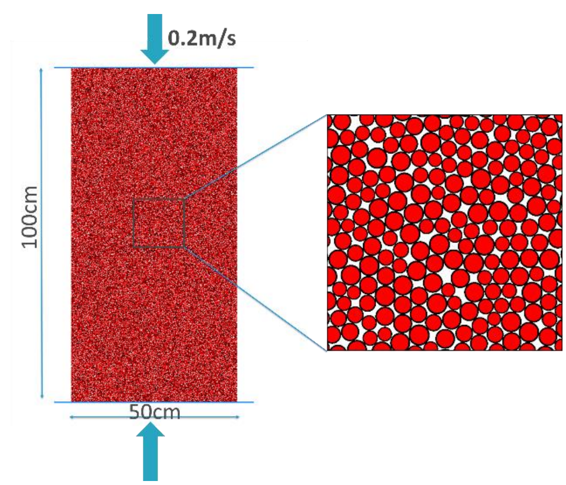

Figure 3 Model Setup of Compressive Tests

Except for the dimension, the properties of the granite assembly used in the compressive test is the same as the verification granite assembly (Figure 3). The granite is compressed under the velocity of 0.2m/s, with two confining pressure conditions: no confining pressure or 20KPa confining pressure.

Results, Observations, Conclusions

Verification

We compare these analytical displacement fields with the numerical results from PFC (Figure 4). Figure 6 shows the complete displacement fields obtained by numerical method (left), and analytical method (right). Generally, the PFC2D results have a very similar pattern as the analytic solutions in terms of the polarity and shapes of the lobes. The main difference occurs in the center region. PFC2D results present more noise and irregularities in the central region wrapped by the lobes. Comparing the semi-analytical with the numerical results (Figure 5), the inner part of the region close to the center has noticeable noise and irregularities. However, in general, the numerical PFC results are in good agreement with the semi-analytical results in terms of the pattern, polarity and symmetry. Thus, the bonded-particle methods can reliably compute the displacements and stresses due to seismic wave propagation resulting from a single point force.

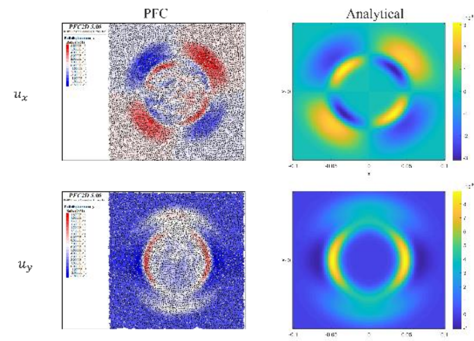

Figure 4 Comparison of the complete displacement fields of the analytical and numerical simulations at the time of 1e-5 sec. The top row represents the x-component of the complete displacement field, and the bottom row represents the y-component. The results on the left are the numerical results from PFC2D. The results on the left are the analytical solutions.

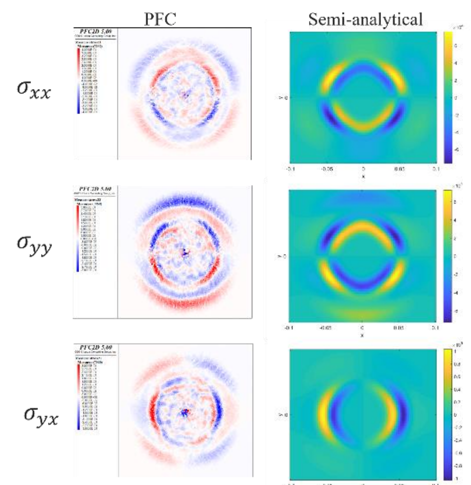

Figure 5 Comparison of the complete stress fields of the semi-analytical and numerical simulations at the time of 1e-5 sec. The top row represents the x-component of the complete stress field, and the bottom row represents the y-component. The results on the left are the numerical results from PFC2D. The results on the left are the semi-analytical solutions.

Compressive tests

The dynamic simulation, cracks and fractures can release energy in the form of seismic waves. The granite sample appears to be more brittle (Figure 6).

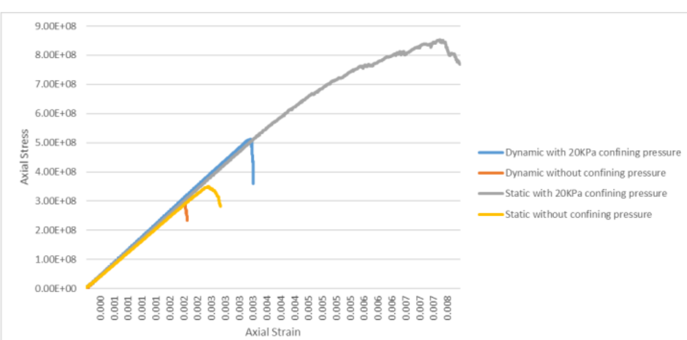

Figure 6 Stress-strain response under different conditions on the granite model.

However, in static runs, the granite sample appears to be more ductile. Also, without confining pressure, it requires a shorter time to reach the peak pressure, i.e. the failure status. Moreover, we also observe that the growth of cracks and microfractures are encouraged with confining pressure applied. The fracture pattern is significantly affected by the degree of damping (dynamic or static).

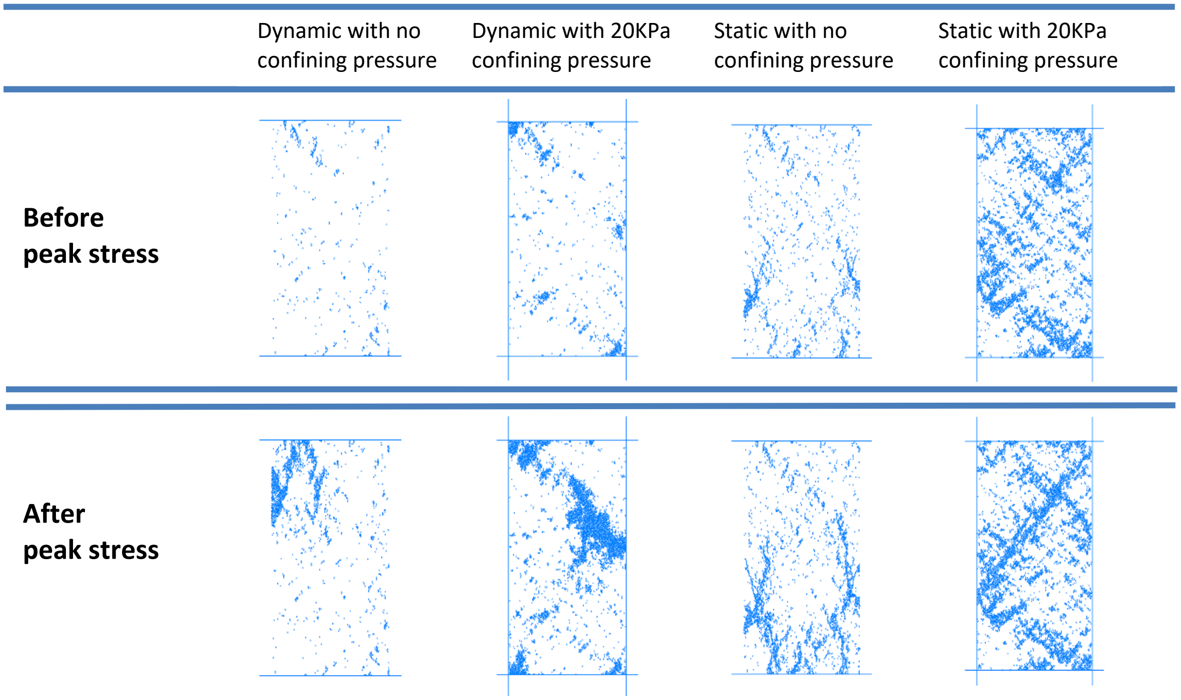

Figure 7 The crack and macrofracture formed before and after peak pressure in the granite under different condistions.

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