Characterisation of cohesive soils under high-strain rate via split Hopkinson pressure bar

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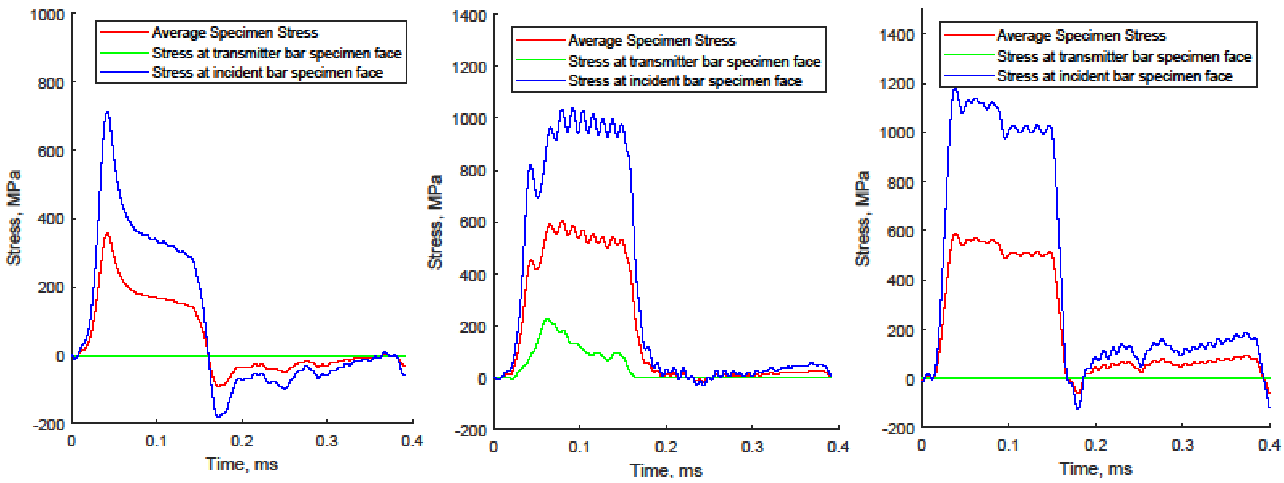
Abstract:

This paper presents the difficulties associated with high-strain rate testing on cohesive soils using the split Hopkinson pressure bar apparatus. Experimental testing reveals the intrinsic properties of cohesive soils like kaolin clay when subject to high-strain rate. Numerical approaches to modelling this behaviour is adopted using modern FEM techniques such as LS-DYNA. Various geometric techniques and material models have been investigated to determine the most suitable methods to simulate the high-strain effect on kaolin clay via split-Hopkinson pressure bar.

Introduction:

The response of soils when subject to extreme loading is vital in developing constitutive models that can be employed to evaluate the effect of blast and fragmentation. While characterisation of soils such as sands and gravel have been extensively investigated, there exists a gap in research in high-strain rate effects in cohesive soils [1]. Cohesive soils such as kaolin clay are found all over the world and are typically classified as being fine-grained, and easily subject to deformation. This paper focuses on the investigation of the behaviour of kaolin clay when subject to split Hopkinson pressure bar (SHPB) tests, the effect will be analysed and the properties of kaolin clay under high-strain rate loading will be properly characterised. This will be coupled with numerical modelling to investigate the existing approaches to modelling SHPB testing and kaolin clay under high-strain rates.



(a) Unconfined SHPB test result *(b) Confined SHPB test result* *(c) Partially confined SHPB test result*

Figure 1: Stress over time of unconfined, confined, partially confined SHPB test on kaolin clay.

Experimentation:

The split Hopkinson pressure bar (SHPB) is typically used to investigate material response at high-strain rates of up to $10^4 s^{-1}$ [2]. Experimental tests from unconfined SHPB tests reveal that upon impact, stress is transferred laterally rather than being propagated onto the transmitter bar as seen in Figure 1. The results show that it is an intrinsic property of kaolin to expand laterally rather than axially when subject to high-strain rate, this can be seen in Figure 2 which shows the moment the kaolin sample is ejected laterally from a SHPB test. This is due to the loading being taken via the pore water rather than the soil skeleton and hence behaving like a fluid when subject to compression.

Various forms of confinement methods were employed in SHPB tests to determine the effect under different scenarios. A ring confinement to prevent any lateral deformation, and a partially confined confinement method was utilised where a water reservoir was used to envelop the sample.

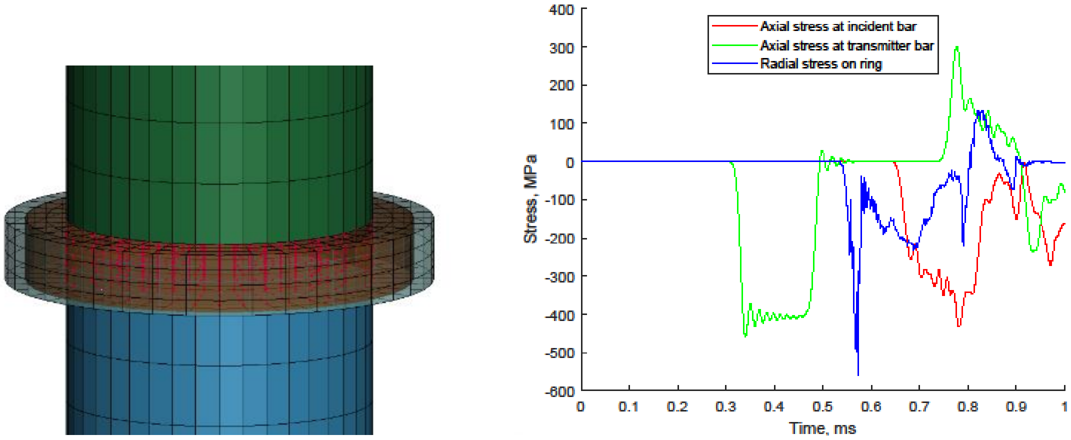
(a) Unconfined SHPB *(b) Confined SHPB*

Figure 2: Images from high-speed camera of SHPB tests on kaolin clay samples.

Numerical modelling:

The difficulties with accurately modelling the SHPB tests on kaolin clay are intrinsically linked to the fluid-like properties exhibited by kaolin clay when subject to high-strain rates as revealed from experimental testing. Numerous material models have been employed in existing research to model soil behaviour using LS-DYNA such as Soil and Foam, Pseudo-tensor etc. [3]. Subsequently, the Mohr-Coulomb material model was found to be the most appropriate due to the accessibility of the relevant parameters via triaxial testing and the material model not requiring an associated equation of state.

Various geometric techniques were tested and adapted to validate the Mohr-Coulomb model in modelling high-strain behaviour of kaolin clay in SHPB testing. Modelling the ring confinement setup proved difficult as the kaolin clay behaves like fluids upon impact, causing the sample to deform laterally and extrude from the ring confinement. Techniques such as use of arbitrary Lagrangian-Eulerian (ALE) elements, and smoothed particle hydrodynamics (SPH) methods to model the sample were tested (seen in Figure 3).



(a) Model in generated in LS-DYNA *(b) Results from LS-DYNA model*

Figure 3: LS-DYNA model displaying sample confined SHPB model and stress results recorded from the model.

Conclusion:

The characterisation of kaolin clay when subject to high-strain rates have been presented through SHPB experiments and further investigated by developing numerical models capable of simulating the behaviour under those conditions. The experimental tests reveal that kaolin clay tends to deform laterally when subject to immense loading, with behaviour comparable to fluids when placed under similar conditions. Subsequent numerical modelling using LS-DYNA was performed to validate the experimental results and to further investigate the effect on kaolin clay.

References:

[1] Sobczyk, K., Chmielewski, R., Kruszka, L. and Rekucki, R. (2021). Strength Characterization of Soils' Properties at High Strain Rates Using the Hopkinson Technique—A Review of Experimental Testing. Materials, 15(1), p.274.
[2] Kolsky, H. (1964), 'Stress waves in solids', Journal of Sound and Vibration 1(1), 88–110.
[3] Busch, C.L. and Tarefder, R.A. (2016). Evaluation of Appropriate Material Models in LS-DYNA for MM-ALE Finite Element Simulations of Small-Scale Explosive Airblast Tests on Clay Soils. Indian Geotechnical Journal, 47(2), pp.173–186. doi:https://doi.org/10.1007/s40098-016-0196-4.