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Modelling Complex gas flow-fractured solid interaction by a finite/discrete element method

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ABSTRACT

Extreme pressure and temperature, shock waves, high velocity fragments and gas-solid interactions complicate any numerical solution for modelling a blast problem. In this paper, a two-mesh strategy based on a combined finite/discrete element (FE/DE) methodology is proposed for modelling the complex phenomenon of gas flow-fractured solid interaction. Existing techniques include single-mesh procedures proposed by Munjiza et al. [1,2] which was based on gas dynamics formulation to simulate the gas flow through a cracked medium (uniform pipes), and the non-uniform isentropic gas flow models, proposed by Mohammadi et al. [3]. In a different approach Mohammadi et al. [4] developed a two-mesh coupled model based on the flow of gas through an equivalent porous medium. Independent gas and solid meshes were used to solve the governing equations of gas and solid media, respectively. In this paper, the method is further extended to adaptive general quadrilateral elements.

Simulation starts by detonation of the explosive material and its conversion to a high pressure and density gas, based on definition of an equation of state. The next step is to apply the pressure to solid medium and to let it deform and fracture using a combined FE/DE procedure. Expansion of the borehole and creation of cracks allow for gas expansion and flow through the openings which will consequently reduce its pressure and density. This coupled procedure continues until the gas overpressure vanishes.

In order to simulate gas flow in a blast induced cracked medium, the discontinuous medium is replaced by an equivalent porous medium based on definition of a permeability parameter. The weak form of governing equations of conservation of mass and momentum in an Eulerian description is adopted for gas flow analysis [1]:

$$-\int_{\Omega}(\nabla\mathbf{W})^T\left[\frac{k\rho^g}{\mu^g}\left(-\nabla P^g\right)\right]d\Omega+\int_{\Gamma}\mathbf{W}^T\left[\frac{k\rho^g}{\mu^g}\left(-\nabla P^g\right)\right]^T\cdot\mathbf{n}\,d\Gamma+\int_{\Omega}\mathbf{W}^T\frac{\partial(n\,\rho^g)}{\partial t}d\Omega+\int_{\Gamma_g^q}\overline{\mathbf{W}}^T\left\{\left[\frac{k\rho^g}{\mu^g}\left(-\nabla P^g\right)\right]^T\cdot\mathbf{n}-q^g\right\}d\Gamma=0$$

and the discretized form of variations of mass with respect to time can be derived in terms of the permeability matrix $\mathbf{H}_t^P$,

$$\mathbf{M}_{t+\Delta t}=\mathbf{M}_t-\Delta t\,\mathbf{H}_t^P\,\overline{\mathbf{P}}_t^g$$

$$\mathbf{H}_t^P=\int_{\Omega}(\nabla\mathbf{N})^T\frac{k\rho^g}{\mu^g}(\nabla\mathbf{N})\,d\Omega$$

In order to verify the proposed approach, the problem of fracture and fragmentation of a $0.75 \times 0.75m$ square concrete block subjected to an explosion in its central $0.25 \times 0.25m$ hole, is considered. Material properties of concrete and explosive materials are:

E_c	ν_c	f_{ct}	G_{cf}	ρ_c
$2.8\times10^{10}\ N/m^2$	0.1	$50\times10^{6}\ N/m^2$	$250\ N\cdot m$	$4200\ Kg/m^3$

$M_{\exp}$	$\rho_{\exp}$	$T_{\exp}$	$P_{\exp}$	$\gamma_{\exp}$	$a_{\exp}$	$b_{\exp}$
$10\ Kg$	$160\ Kg/m^3$	$3300\ ^{\circ}K$	$0.18\ GPa$	1.15	$10.99e-10$	4.0

The proposed two-mesh model, as depicted in Figure 1, is used to simulate the fracturing process and to evaluate blast pressures. An unstructured mesh of triangular elements is used to model the solid block, while the second adaptive quadrilateral mesh is used for modeling the gas governing equations.

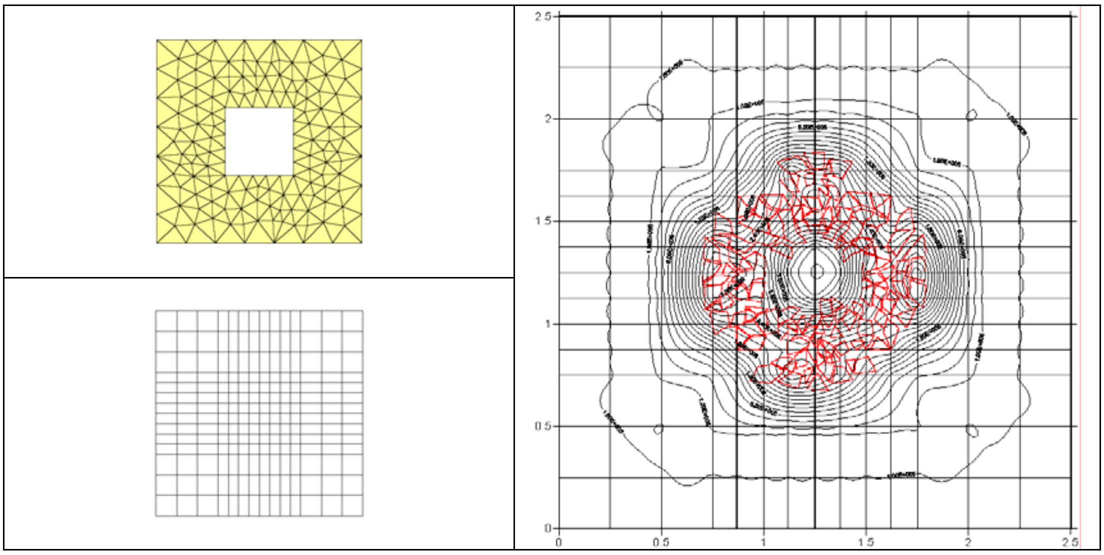

Figure 1- Solid and gas meshes and the final fracture pattern and gas pressure contours.

Due to the closed domain of blast, the rate of reduction of thermodynamics quantities of mass, density, internal energy and gas pressure remain low. However, following the expansion of blast gas and creation and propagation of cracks, these rates increase, reducing to low values in a short period of time. In conclusion, the proposed two-mesh FE/DE approach is found to be accurate and efficient for modelling the complex phenomenon of interaction of gas flow and progressive fractured solid media.

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