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### ► To cite this version:

Jessica Rousseau, Emmanuel Frangin, Philippe Maurice Marin, Laurent Daudeville. Some aspects of DE/FE combined method: Model identification and combined method: Coupling DEM and FEM. IX International Conference on Computational Plasticity COMPLAS IX, 2007, Barcelona, Spain. hal-00468950

**HAL Id: hal-00468950**

**<https://hal.science/hal-00468950>**

Submitted on 20 Feb 2024

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## **SOME ASPECTS OF DE/FE COMBINED METHOD: MODEL IDENTIFICATION AND COMBINED METHOD**

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**Key words:** Discrete Elements, Finite Elements, Concrete, Impacts.

### **1 INTRODUCTION**

This study deals with impacts on reinforced concrete structures. Its aim is to predict local damage in the vicinity of the impact as well as the global response of the structure. The Discrete Element Method (DEM) seems particularly convenient for the modeling of fractures. The chosen Discrete Elements (DE) are rigid spheres of different sizes. The identification of the DEM material parameters from macroscopic data (Young's modulus, compressive and tensile strength, fracture energy...) will be presented in the first part.

The modeling of a large structure by means of DE may lead to prohibitive calculation durations. A refinement is required in the vicinity of the impact whereas the structure can be modelled by means of a coarse FE mesh far away from the impact area, where the material behaves elastically. Thus a coupled discrete-finite element approach is proposed: the impact zone is modeled by means of DE and elastic FE are used for the rest of the structure. The proposed approach will be described. Finally, an application of this coupling method will be shown by means of the response of a concrete slab impacted by a rocky block.

### **2 IDENTIFICATION OF THE DISCRETE ELEMENT MODEL PARAMETERS**

#### **2.1 Discrete Element Model**

The used Discrete Element method is fully described in Hentz<sup>1</sup>. Interactions between two spheres are defined with normal  $K_n$  and tangential  $K_s$  stiffness characterizing the elastic behavior of concrete. "Micro-macro" relations (1) are supposed in order to compute the stiffness  $K_n$  and  $K_s$  between elements a and b from Young's Modulus and Poisson's ratio. Parameters  $\alpha, \beta, \gamma$  of these relations were identified for a given average number of interactions per discrete element.

A modified Mohr-Coulomb criterion associated with softening is used to model the non-linear behavior of the material. Local parameters, as local tensile strength  $T$ , cohesion  $C_0$  and softening factor  $\zeta$  need to be identified from global parameters as compressive and tensile strength  $\sigma_c$  and  $\sigma_t$  and fracture energy  $G_f$ . A classical friction constitutive behavior is used between elements in contact.

$$\left\{ \begin{array}{l} E = \frac{D_{init}^{a,b}}{S_{int}} K_n \frac{\beta + \gamma \frac{K_s}{K_n}}{\alpha + \frac{K_s}{K_n}} \\ \nu = \frac{1 - \frac{K_s}{K_n}}{\alpha + \frac{K_s}{K_n}} \end{array} \right. \text{ or } \left\{ \begin{array}{l} K_n = E \frac{S_{int}}{D_{init}^{a,b}} \frac{1 + \alpha}{\beta (1 + \nu) + \gamma (1 - \alpha \nu)} \\ K_s = K_n \frac{1 - \alpha \nu}{1 + \nu} \end{array} \right. \quad (1)$$

## 2.2 Parameters identification of linear elastic constitutive behavior

Simulations of a compressive test with a DE sample are realized with different values of  $K_s/K_n$ . Numerical values of  $E$  and  $\nu$  are computed and values of  $\alpha, \beta, \gamma$  are then identified with (1) in order to fit numerical points of  $E$  and  $\nu$  versus  $K_s/K_n$ .

Tests have been carried out with 15 different samples (10 of them have identical sizes but different disorder and the 5 others have different geometries). The main assumption of this approach is that samples are representative of modelled concrete material in further simulations of impact on concrete structures. Samples have to be isotropic. With the identified values of  $\alpha, \beta, \gamma$  parameters, average uncertainty is about 2% (maximal error is 7%) for Young's modulus and about 3% (maximal error is 6%) for the Poisson's ratio.

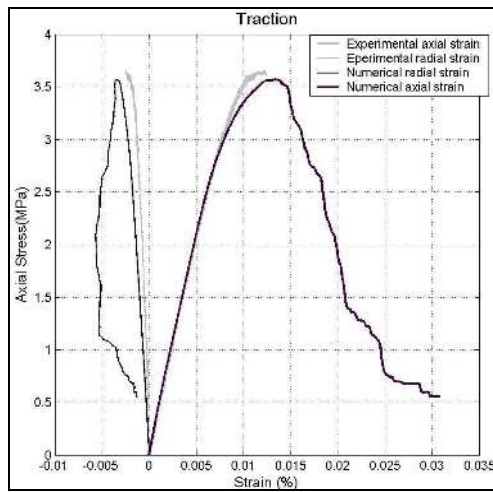


Figure 1 : Uniaxial Traction : Stress-Strain curve

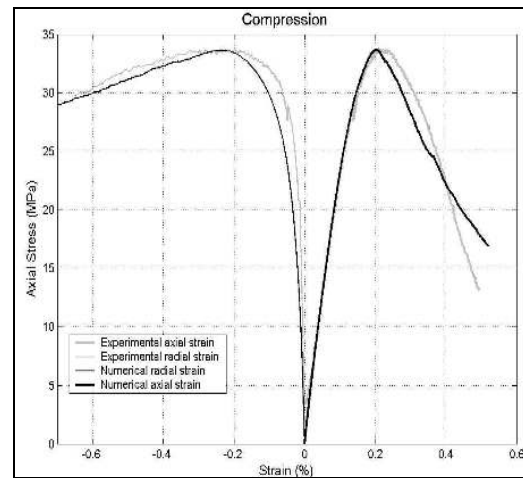


Figure 2 : Uniaxial Compression : Stress-Strain curve

## 2.3 Parameters identification of non-linear constitutive behaviour.

In this part, the point is to identify local parameters to model macroscopic values as compressive strength  $\sigma_c$ , tensile strength  $\sigma_t$  and fracture energy  $G_f$ . Only local tensile strength  $T$ , cohesion  $C_0$  and the softening factor  $\zeta$  will vary in this study, friction parameters will be fixed values.

The aim is to realize traction and compression simulations in order to simulate tests performed in 3S-R laboratory (Gabet<sup>2</sup>). We identified parameters according to Hentz's procedure. In Figure 1, we can observe the result of the traction simulation and the compressive tests on Figure 2.

### 3 IMPACT ON STRUCTURE WITH COMBINED DE/FE METHOD

#### 3.1 Description of the method

This third part concerns the coupling between continuum and discrete domains. Discrete element method is convenient for modeling discontinuities and fracture but it may lead to prohibitive durations of calculation with a large structure. During an impact, though the impact zone needs a refined mesh, the main part of the structure far away from the impact zone can be modeled by means of coarse finite elements. We propose to couple discrete elements in the vicinity of the impact with elastic finite elements in the rest of the structure. It is chosen to use a bridging domain in order to couple DE and FE degrees of freedom.

Many methods have been already developed for multi-scaled problems. Belytchko<sup>3</sup> proposed to use a bridging domain where the Hamiltonian is a linear combination of discrete and finite ones. Equation (3) shows DE and FE Hamiltonian are weighted by a parameter  $\alpha$  equals to 1 in the FE domain and equals to 0 in the DE domain.

$$H = \alpha H_{FE} + (1 - \alpha) H_{DE} \quad (3)$$

We link in the bridging domain DE displacements  $d_r$  with FE displacements  $u_r$ . DE rotations  $\omega_r$  are linked with the antisymmetric part of the FE displacement gradient. The solution is obtained by minimizing the Hamiltonien with introduction of the kinematics constrains by means of two Lagrange multipliers linked to displacement and rotation constrains. Details of the method are explained in Frangin<sup>4</sup>.

Due to the variation of discretization size between both models, we use a process based on the relaxation of Lagrange multipliers or on damping parameter to reduce the high wave reflection (Frangin<sup>4</sup>).

#### 3.2 Impact on a concrete structure

To quantify the efficiency of this method, we propose to compare damage and displacement response of a concrete slab under a rocky impact (Figure 3) between combined FE/DE method and the full DE method (Figure 4). Displacements and damage of the slab are very close at each part of the slab. The combined method is 10 times faster than the fully DE method without a multi-time step algorithm. Some computation on a reinforced concrete structure will be presented.

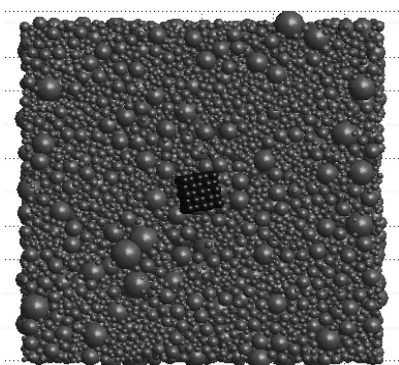


Figure 3: The discrete model

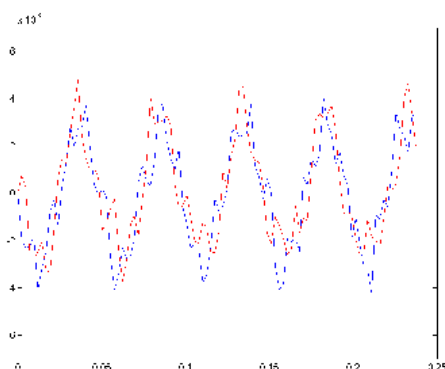


Figure 4: Comparison of displacement between DE (red) method and coupled method (blue)

### 3.3 Influence of the reinforcement

Main modification induced by the modeling of reinforcement concerns the random process where DE cannot move easily around reinforcement and the porosity of the media is higher near the reinforcement than in the concrete. Two different interaction radii are used to keep a number of contact equals to 12 for concrete DE and for steel DE. The FE domain and the bridging domain keep an elastic behaviour and so we do not take into account the reinforcement in the FE domain. The bridging domain is a way to regularize the displacement and there is no localization due to the reinforcement in this area.

## 4 CONCLUSIONS

- The identification of parameters for concrete behavior gives very accurate results. First, the elastic behavior seems to be reliable. And secondly, uniaxial tensile and compressive behaviors can be easily computed.
- This identification process combined with an efficient coupled DE/FE method give solution to simulate large RC structure under impact.

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