Discrete element modelling of penetration and perforation into concrete targets by ogive-nosed steel projectiles

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ABSTRACT

Reinforced concrete (RC) structures are widely used as shielding barriers to protect sensitive infrastructures such as nuclear power plants. The increasing demand for infrastructure security requires accounting the risk of severe loading due to natural or manmade hazards, such as aircraft or missile impacts. Because of the extreme severity of such a loading, assessment of the protective structures must go far beyond verification of the resistance to normal operating conditions: it is necessary to investigate the response of the structure until almost its complete failure to assess correctly its ultimate resistance capacity.

While continuous approaches such as the finite element method (FEM) are suitable for the nonlinear analysis of structures before failure, they reach their limits when trying to describe macro cracking and fragmentation mechanisms. The discrete element method (DEM) is a powerful alternative to FEM when advanced damage states and failure of concrete have to be studied. Indeed, DEM allows easily obtaining realistic macro-crack patterns and material fragments due to its discontinuous nature.

This paper presents a DEM approach implemented in EUROPLEXUS fast dynamics software able to predict damage of concrete and RC structures under severe impacts. The proposed DEM model for concrete relies on the original developments of Cundall and Strack for granular materials that was extended to cohesive materials such as concrete by introducing cohesive interactions in addition to contact ones. A geometric algorithm method based on a tetrahedral finite element mesh is employed for the discrete elements (DE) mesh generation. The mesh generation method uses a disordered assembly of rigid spherical elements of different sizes and masses although the elements do not represent the constituents of concrete. Each DE has 6 degrees of freedom (3 translations, 3 rotations). The behaviour of undamaged plain concrete is assumed to be linear, elastic, isotropic and homogeneous. Cohesive interactions are defined between neighbouring DE thanks to an interaction range that allows creating a sufficient number of links to get an isotropic constitutive behaviour at the macroscopic scale. Cohesive interactions are modelled thanks to beam-like elements with a non-linear constitutive behaviour to model damage and compaction (closure of porosity). The strain rate effect is taken into account in tension.

The elastic normal and tangential (shear) stiffnesses are identified with macroscopic elastic parameters, namely Young's modulus and Poisson's ratio, and a “micro-macro” relation inspired from homogenization models. The parameters of non-linear models are identified thanks to simulation of laboratory tests (unconfined compression, tension, confined compression).

In order to validate the DEM approach, the simulation results of three hard impact tests are presented. The tests were performed by CEA Gramat on plain concrete targets with a passive confinement given by a steel jacket surrounding the cylindrical specimen and submitted to the impact of ogive-nosed steel projectiles. The results of two penetration tests and one perforation tests are discussed.