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ADVANCED MODELLING OF THE REINFORCED CONCRETE STRUCTURES UNDER SOFT IMPACT

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ABSTRACT

To guarantee the safety of nuclear facilities in case of hypothetical accidents such as an aircraft crash onto the reactor confinement building, EDF develops and qualifies numerical methods and computational methodologies allowing to perform analysis with a progressively increasing degree of realism and to quantify thus the conservatism of the licensing methods. To this end, the EUROPLEXUS fast dynamics software is used [1].

A very efficient and computationally inexpensive methodology has been developed to simulate the whole dynamic response of large-sized reinforced concrete (RC) structures under impact: a highly non-linear short-time phase of the impact and a long-time phase of the impact induced vibrations are considered in the same simulation. The two key-points of this methodology are, firstly, a multi-domain multi-time step approach allowing to use non-matched meshes and different time steps per sub-domain and, secondly, a global-type material modelling of the reinforced concrete structures [2]. Our constitutive law, formulated in stress resultant variables, deals with damage and plasticity mechanisms and takes into account both membrane and bending behaviours of the orthotropic shell-type structural elements [3]. Being a powerful alternative to a very expensive 3D modelling, this methodology is transferred to EDF Engineering to be used in safety studies [4].

The proposed global RC modelling has been enriched and extended to study the ultimate behaviour of the RC structures under soft impacts. For the range of strain rates of the order of 1 s^{-1} and the impacts of deformable projectiles we consider here, failure of reinforced concrete slabs happens through a particular perforation mode by formation and detachment of a conical shear plug [5] delimited by oblique cracks, generated by structural bending and shear waves. To account for bending and shear failure modes, we derive a failure criterion in terms of stress resultant variables [6]. We apply the kinematical method based on the upper-bound theorem and obtain the global criterion as the lowest upper bound among all states of deformation compatible with the assumed failure mechanism. The criterion is constructed, first, for a reinforced concrete beam then extended to the case of plates. The first computations and comparisons with experiments show the capability of the proposed global criterion to predict perforation

of RC slabs under soft impact [7]. Since the membrane effect is also taken into account, this criterion can be efficiently used to study perforation of curved RC structures.

Until the instant of complete detachment of the shear plug from the slab, i.e. as long as some links between the plug and the slab exist (due to the presence of reinforcement), it is relevant to consider that the slab remains “continuous” and that its deformation is still compatible with the reduced plate kinematics. Because the safety rules do not allow the confinement shield to be perforated, the global approach based on section continuity is a priori sufficient to answer the question on whether local ruin takes place or not.

Despite the massiveness and an extremely high degree of reinforcement, the safety structures can undergo severe damage with detachment of fragments causing secondary impacts on the protected structures. This demands further investigation and understanding of the failure mechanisms, which cannot be described by a continuous approach. To model material discontinuities, mesh-free methods are very suitable because they do not rely upon any assumption about where and how a crack or several cracks occur and propagate. We use a Discrete Element Method (DEM) to obtain a detailed description of the fracture and fragmentation mechanisms in a local zone of the RC structure subjected to a damaging impact [8]. Both media – concrete and steel – are considered as discontinuous with intra-element interaction defined either through constitutive laws (before breaking) or through contact relations (after breaking).

At the moment, we are working to couple the DEM model of the impacted and severely damaged zone with a finite element model of the less damaged part of the structure, that will allow us to perform an efficient multi-scale analysis of large RC structures.

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