Advantages and limitations of multi-degree-of-freedom models to simulate impact behaviour of concrete structures

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Summary

The present contribution deals with the behaviour of reinforced concrete beams under impact load. Moreover, the paper is intended as a discussion of advantages and limitations of different numerical models according to the degree of complexity. Two types of models are used. On the one hand, a simplified approach is presented, consisting of a three-degree-of-freedom model that reproduces the response of simply supported reinforced concrete beams subjected to an impact load at the midspan. The three degrees of freedom represent: 1) the contact between the beam and the projectile, 2) the flexural behaviour of the beam, and 3) the development of a critical shear crack. Nonlinear behaviour and damping are introduced into the three degrees of freedom. On the other hand, a comprehensive finite element model (Ansys LS-Dyna) has been used, which includes a concrete damage model with strain rate effect. It is discussed how the failure mode and the main physical behaviour are reproduced, comparing advantages and disadvantages regarding the reproduction of nonlinearities or strain rate effects, as well computational time required to perform parametric analyses.

Keywords: impact; reinforced concrete; numerical models; dynamic behaviour.

1. Introduction

Design of concrete structures subjected to impact loading is still a research issue due to the complex nature of resisting mechanisms mobilized under high strain rate. Empirical formulations have been used by design codes (e.g. Swiss or Japanese codes, [1][2]) in order to help practice engineers to make decisions without large computational efforts. Nevertheless, empirical models may be either conservative or unsafe when they are applied beyond the scope of the experimental works they are based on. Since impact tests of concrete structures are difficult, expensive and require large space, numerical models have been developed for the last decades.

Numerical models for concrete structures should properly reproduce the phenomenological experimental response. Existing experimental results have shown that concrete structures subjected to impact loading have a high tendency to fail in a brittle way with a shear failure mode. Even elements designed to have a ductile failure by yielding of the steel reinforcement under a static point load have failed by shear when the load is substituted by an impact at the same point [3]. Shear failure of concrete is not easy to be reproduced by numerical models and further difficulties arise in the dynamic regime [4]. Therefore, numerical models require significant refinement to get both the nonlinear behaviour of structural concrete and dynamic effects. Such models require large computational efforts and their use is out of the routine of design offices. Accordingly, it is challenging to develop more simplified but still rational models to analyze the influence of impacts on structural concrete. Many attempts have been done so far regarding the possibilities of simplified spring-damper models to study concrete structures under impact or explosive loads. Single-degree-of-freedom (SDOF) models have shown to be appropriate for elements having a ductile failure mode with yielding [5][6]. In such models, the impact (or explosive) load is known in advance and the degree-of-freedom reproduces the flexural behaviour of the structure. When the impact load is not known in advance, two-degree-of-freedom models can be used by simulating the projectile-

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