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Influence of SPH Regularity and Parameters in Dynamic Fracture Phenomena

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Abstract

The Smoothed Particle Hydrodynamics (SPH) method can be used with advantage in the field of fracture mechanics, which is especially true when quasi-brittle materials are involved. The advantages of the SPH method are more evident when loading speed increases and dynamic material fractures start to occur. Since the SPH method is a meshfree method, the large deformation and eventual fragmentation of material during simulations can be solved without major complications. This happens because of the phase of the SPH method in which a search is made for neighbouring particles and the constraints created between them within a chosen time interval. The number of neighbouring particles depends on the size of the area where the search takes place. This area – the support domain – may therefore be considered as one of the key control elements in simulations using the SPH method. The influence of the number of particles and their initial distribution on the results is also a question. Particle clusters (areas with increased particle concentration) may be formed in cases of poor regularity. Consequently, false (numerical) cracks which bypass these clusters may appear in the simulation. The article describes an experiment concerning the dynamic loading of concrete L-specimens simulated by the SPH method. Different density distributions and initial particle distribution regularities are chosen in the simulation. The results show that it is especially necessary for the initial configuration to exhibit regular particle distribution if simulations are to be executed successfully. False cracks tend to occur more frequently with increasing particle distribution irregularities. A certain degree of compensation can be achieved via the appropriate choice of support domain size with its variations during the simulation.

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1. Introduction

In 1977, Gingold and Monaghan [1] and Lucy [2] introduced the meshfree method, which was originally intended for the simulation of astrophysical problems. This method, which was later named Smoothed Particle Hydrodynamics (SPH), is based on assumptions regarding the flow of Newtonian fluid – most frequently described by Navier-Stokes equations. Even though the SPH method was developed mainly for the hydrodynamics field, e.g. multiphase flow [3], it has also been adapted for related fields, e.g. research into the quasi-brittle failure of materials [4-6]. The SPH method is particularly attractive in the area of high speed stress and large deformations [7, 8]. Thanks to the approach of the SPH method, in which links are built between particles at intervals occurring with a specified frequency (e.g. simulation time steps), a virtual mesh can be created even for very highly deformed areas. In this way, fragmenting matter can also be simulated without any numerical complications [9-12]. However, in cases when the distribution of SPH particles of the original geometry is not regular, the results do not correspond with those from experiments. The size of this problem is also influenced by the density of the discretization of the continuum. In order to evaluate these dependencies, the contribution focuses on dynamic loading issues concerning concrete L-specimens which are simulated using the SPH method. In the executed simulations, the regularity of the distribution of SPH particles and its influence on the type of failure are primarily examined. Results from FEM simulations and experiments are used for comparison.

Nomenclature

a_g	maximum aggregate size
d	number of dimensions
E_c	Young's modulus of concrete
f_c	cylinder compressive strength of concrete
f_t	tensile strength of concrete
G_F	fracture energy
h	smoothing length
m_j	mass of the particle j
N	number of particles
$\boldsymbol{v}$	flow velocity vector
v_c	Poisson's ratio of concrete
W	smoothing function
$\boldsymbol{x}$	position vector
ΔV_j	finite volume of the particle j
κ	smoothing function constant
ρ	mass density
ρ_c	mass density of the concrete
ρ_j	mass density of the SPH particle j
Ω	integration domain

2. Essential formulation of the SPH method and the size of the support domain

The formulation of the SPH method is often divided into two key steps. The first step is the *integral representation* of field functions, and the second is *particle approximation*. Assuming that the finite volume ΔV_j is assigned to SPH particle j, the following relationship applies:

$$m_j = \Delta V_j \rho_j ; \tag{1}$$