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Study of contact algorithms influencing specimen response in numerical simulation of SHPB test

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ABSTRACT: This paper demonstrates the importance of a proper contact algorithm selection when a constitutive model is correlated and validated, especially in the case of brittle materials. A parametric study is carried out to study the influence of contact parameters on the outcomes of the numerical simulations of a dynamic compression test. The split Hopkinson pressure bar (SHPB) model is developed, and sandstone rock is considered as a representative material having considerably different properties compared to SHPB bars. The finite element method (FEM) and smoothed particle hydrodynamics (SPH) were used to simulate specimen behavior using a LS-Dyna solver. Two contact types based on the penalty method are analyzed: nodes to surface (FEM and SPH) and surface to surface (FEM only). Furthermore, three approaches of contact stiffness calculation are used for each contact type. The waveform data and failure patterns are then compared among all simulated cases and the corresponding experimental outcomes. It is found that the soft constraint stiffness (SOFT = 1) provides the best outcomes, especially in the case of one-way contact, and is nearly insensitive to stiffness scaling parameters. By contrast, standard (SOFT = 0) and segment-based (SOFT =2) approaches require a substantial effort in adjusting the stiffness scaling parameters to obtain satisfactory results. This paper provides valuable guidance for correlating and validating parameters of constitutive models for rock and other brittle materials in the SHPB test.

KEY WORDS: contact modeling, sandstone, rock, SHPB, LS-DYNA

1. Introduction

One of the basic experiments to investigate the dynamic brittle material properties is the split Hopkinson pressure bar (SHPB) test, which generates a high strain rate compression loading [1].

Considering the complexity of the dynamic conditions to which the tested material is subjected, numerical methods are extremely useful for providing better insights in the material be-haviour and associated failure processes during the SHPB test. However, a high-fidelity constitutive modelling and a validated numerical model are needed to provide information that will be useful for the understanding of material failure phenomena. Notably, the SHPB setup is a first-choice experiment to be reproduced using numerical tools to correlate the selected constitutive model in dynamic conditions, which is then used in subsequent simulations of a material subjected to complex dynamic loadings such as blasts or impacts. However, in mostly all of the studies the authors do not show any detailed information about the contact modelling. A basic data regarding contact type or friction properties is not enough since the numerical procedures responsible for contact calculations can have a drastic impact on the numerical simulation outcomes, which was demonstrated in this and previous study [2].

Two different numerical techniques are used for the study: Finite Element Method (FEM) and Smoothed Particle Hydrodynamics (SPH). Both methods are utilized to simulate rock be-haviour. For both methods, the Johnson–Holmquist ceramics (JH-2) constitutive model was used. The constitutive parameters were validated under various stress conditions using the simulations of single-elemental tests, SHPB test, drop-weight impact tests, blast tests and projectile impact tests.

The present study mainly aimed to demonstrate a need to correlate both constitutive model and contact procedure parameters, because both of these have a significant impact on the obtained numerical results.

2. SHPB setup and model definition

To achieve the goal of this study, a representative numerical model of the real-world SHPB setup was developed (Fig. 1)

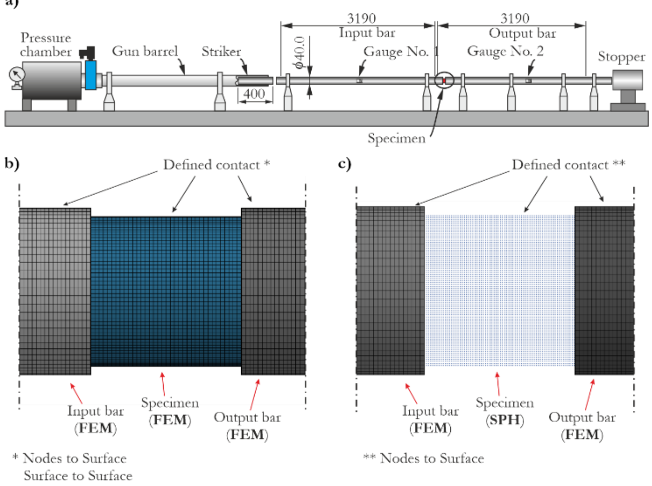

Fig. 1 (a) Scheme of the SHPB setup and corresponding numerical model with **(b)** FEM specimen and **(c)** SPH specimen

Only the bars with the specimen inserted between them were assumed while developing the numerical model. Moreover, frictionless interaction was assumed between the bars and the specimen since polyester foil and lubricant were used in the SHPB experiments. The effectiveness of this concept has already been demonstrated in previous studies [3].

3. Contact modelling

Although several kinds of contact kinematics procedure are discussed in the literature, all of them rely on the tools provided by differential geometry to ascertain the distance between a point on one body and the projection of this point on an opposite body. Knowing the distance between master and slave in the given point, it is possible to calculate stresses and forces in the point of contact. This can be done under the assumption that the following conditions are fulfilled on the contact surface (1)

$$g_N \geq 0; \quad \sigma_N \leq 0; \quad g_N \sigma_N = 0 \tag{1}$$

where g_N denotes the distance between the contacting bodies, and σ_N the normal contact stress.

The most popular way to solve this problem is the so-called penalty method, where the value of contact force in the given node is proportional to the value of the penetration of this node.

$$F_N = k_F g_N \tag{2}$$

where F_N denotes normal contact force, and k_F the penalty coefficient.

In the article authors investigate influence of the value of penalty factor on the results of SHPB test simulations, taking the commercial explicit code LS-Dyna as a testing environment. Considering both FEM-based and SPH-based specimen modes, 52 different configuration of contact parameters were compared.

4. Results

In the following figures (Fig. 2 - Fig. 4) some example results are presented. To estimate quality of the simulation results the following aspects were considered: correlation with the waveform data acquired during experimental campaign, failure pattern and compressive strength. In Fig. 2, the stiffness of contact was too small, resulting in inappropriate transfer of elastic wave in the specimen, which is clearly demonstrated in waveform data and specimen behavior. In Fig. 3, however, considerably better results are presented since contact stiffness calculation in this case gave higher contact forces resulting in a great correlation experimental result. Satisfactory reproduction of the failure pattern and wave-form data using SPH specimen can be also seen in Fig. 4, in which similar contact force was obtained compared to the FEM specimen presented in Fig. 3

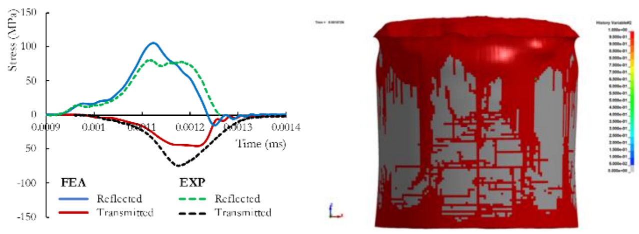

Fig. 2. Examples of incorrect results obtained for FEM

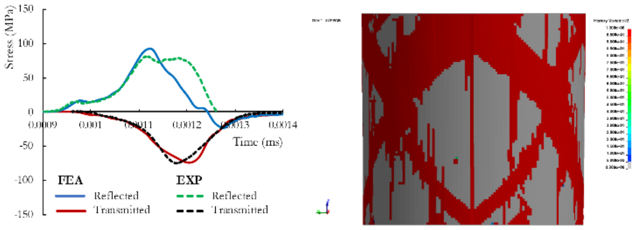

Fig. 3. Examples of correct results obtained for FEM

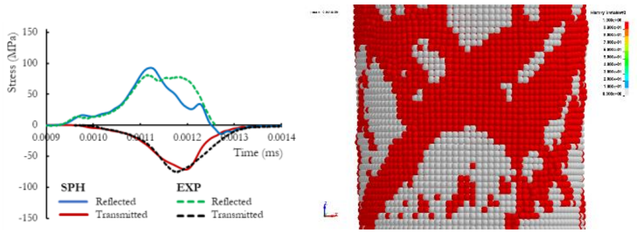

Fig. 4. Examples of results obtained for SPH

5. Conclusion

Based on the conducted study the following conclusions can be drawn:

- Differences in contact modelling led to completely different results of the SHPB test simulation, including divergent solutions or unphysical failure patterns.
- Default contact parameters, i.e., those set by the software provider, were found to give wrong outcomes, since they resulted in underestimated contact force value
- Evaluation of waveform data, failure patterns and pick values of stresses is required to efficiently correlate and validate the numerical model, including the constitutive model of a brittle material. Focussing on merely one of these aspects can result in some of the erroneous simulations going unnoticed

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