Stability and Uniqueness in Dynamic Analysis of Metal Structures Accounting for Anisotropic Damage

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The stability of the finite element solution of highly dynamical deformation (strain rates in range \(10^{-4}\) - \(10^{-7}\) s\(^{-1}\)) of a solid body (metal) with explicit time integration scheme is under consideration. The solid body is described in terms of continuum mechanics in the framework of thermodynamics [1], [2]. One of the key property of the constitutive model is the ability to describe the intrinsic anisotropic micro-damage in the metal structure whose evolution induces the anisotropy and may lead to macro damage.

The importance of the discussed subject, omitting its cognitive value itself, lays in a growing interest of the industry in the field of (continuum) damage mechanics. It is because avoiding or utilisation of a damage in today’s designing (e.g., cars, trucks, cranes, bridges, naval surface vessels, submarines) becomes the fundamental task - the past challenges in designing like covering elastic, plastic or viscoplastic ranges are nowadays standard.

We focused on our attention in adiabatic conditions in which limits the answer of the material (metal) depends on the interaction of the elasto-viscoplastic waves [1]. Thus, we are interested in the phenomena whose time duration are shorter than 100μs.

It can be proved, that to assure the stability of the explicit time integration scheme in finite element framework, for the discussed class of problems, at least the following must be satisfied:

(i) mathematically problem must be well-posed (the solution exists end is unique),
(ii) time increment must be chosen to fulfill stability condition and material model properties,
(iii) mesh should not degenerate significantly the elasto-viscoplastic wave character.

Fig.1. Dynamic testing metal specimen: shape, dimensions and discretisation; view of failure after experimental test; example of computational result of dynamic anisotropic visco-plastic simulation.
In the presented formulation the requirement (i) is fulfilled due to the definition of the model in the framework of the visco-plasticity theory (cf. [2] and cited therein). According to the condition (ii): stability is fulfilled by keeping the time increment smaller than transit time needed for a dilatational wave to cross any of the elements in the mesh and simultaneously smaller that relaxation time of mechanical disturbance (regularization parameter of the material model). The requirement (iii) is fulfilled by keeping the finite element mesh regular with size corresponding to the maximal allowable time increment.

The specimen, taken into consideration for numerical example, that is presented in Fig. 1. has the dimensions 36.8 mm and thickness 0.8 mm (notice that the analysis of anisotropic bodies can be led on only a 3D models). Boundary conditions are applied at the shorter bounds: one is fixed and the velocity 60 m/s is imposed on the opposite side - thus the global strain rates are around 3000 s\(^{-1}\). The aim of the numerical examples is to present the influence of the (i), (ii), (iii) criteria on the solution of localisation phenomena with damage in sheet steel (HSLA-65 steel) under adiabatic conditions. The parametric analysis comprise: 8 mesh densities (average element dimension in range 0.1-0.8 mm, with step 0.1 mm) and simultaneously two element types (linear with reduced and full integration).

The results confirm that not properly defined space and time discretization lead to nonphysical solutions. It was observed that for some cases of a reduced integration elements with coarse meshes damage was not reached. The general result is that full integration elements gave better predictions for damage. The comparison of selected global responses i.e. the reaction at fixed end in time with magnification of initial response showing different wave speed in proposed meshes with variable mesh size and standard or reduced integration method. Differences in calculated wave speeds are compared and theoretical time of elastic wave needed to reach fix end is the value verifying computations. Only definition of the analysis with the defined criteria leads to theoretical (unique) solution - cf. solution for average mesh density 0.1 mm.

References


Fig. 2. Examples of different failure mode, resulting from non-physical reasons.