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Algorithmic aspects in large deformation contact analysis using 'Solid-Shell' elements

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Abstract

A special application for the so-called 'Solid-Shell' elements are sheet metal forming problems with high stretching and large local contact pressure where standard 2D-shells fail to converge respectively do not give reasonable results. To describe such kind of problems besides a full 3D continuum discretization appropriate contact formulations are necessary to introduce the contact condition of the metal sheets against the rigid tools. In this contribution a velocity description is taken for formulation of contact conditions. A penalty as well as an augmented Lagrangian approach for frictionless contact is used as a first step in our developments. Special attention is paid to different numerical integration schemes of the contact integral and tangent matrices. As a result a series of different contact elements including various cases as "node-to-surface", "segment-to-segment" and "analytical rigid surface-to-segment" is considered under the unified description. For selected numerical examples the influence of the order of the quadrature formulae in a subdomain integration approach as well as the order of finite element interpolation used in the computations is discussed. The algorithms appear also to work well for friction type problems, which will be tested in a following paper.

Keywords: Higher order 'Solid-Shell' elements; Large deformations; Penalty method; Augmented Lagrangian method; Internal geometry of the contact surfaces; Contact problems; Sheet metal forming

1. Introduction

The so-called 'Solid-Shell' formulation as described in [10] and e.g. [19,17] is based solely on displacement degrees of freedom belonging to the upper and lower shell surfaces and thus the use of rotational degrees of freedom can be avoided. As no kinematical assumption is applied beyond standard 3D continuum theory also general three-dimensional material laws can be provided. In particular shell type problems with high stresses in thickness direction and considerable thinning due to stretching can be analyzed without further assumptions. Furthermore, to achieve a better geometric approximation beyond 'Solid-Shell' elements with bilinear in-plane shape functions also biquadratic in-plane shape functions are considered. To overcome the locking problems, which appear for both orders of interpolation, different schemes are used and finally as proposed for example in [9] almost locking free element formulations can be derived.

The main part of the paper focuses on large deformations contact problems. With standard nodal contact formulations the problem of weighting of the single nodal

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contribution occurs. As it is well known this is an effect of the under-integration of the contact integral and the corresponding tangent matrix. To overcome this problem a series of surface contact elements is investigated. These elements inherit the geometry of the surfaces of the 'Solid-Shell' elements. Therefore, instead of evaluating the contact conditions at the nodal points and determining the nodal forces directly, the contact forces are integrated numerically over the element area of surface contact elements as suggested in [15,24]. An improvement appears possible by using an integration in the subdomains of the contact element. A velocity description [14] is used for the formulation of the contact conditions and for the derivation of the contact tangent matrix as well. Both, penalty and augmented Lagrangian methods are used to enforce the contact conditions.

The contact forces are discontinuous over the contact surface and, therefore, the numerical integration gives a better result, if the number of integration points is increased. For further investigations a series of contact elements including a different approach for the evaluation of the contact integral is considered to check the effect of the numerical integration more closely. Contact between rigid analytically defined surfaces and deformable bodies is separately treated. Finally, after demonstrating the effect of various integration schemes on some simple examples, a sheet metal forming example with rather industrial content is taken to demonstrate various characteristics within this process.

2. The 'Solid-Shell' concept

In this section the basic features of the 'Solid-Shell' concept are briefly reviewed. For a detailed explanation we refer to [10] resp. [19,17] for similar elements. Two different types of 'Solid-Shells' have been developed, see Fig. 1, the bilinear element type with four nodes on the upper and lower shell surface each and the biquadratic element type with nine in-plane nodes on each surface. From the discrete nodal coordinates and displacements the geometry as well as the displacement field is approximated using the bilinear resp. biquadratic Lagrange shape functions for in-plane approximation and a linear interpolation in thickness direction.

As is well known the 'Solid-Shell' elements suffer from many locking effects. To avoid locking, methods of under-integrating the volume integrals (SRI [22]), an interpolation of transverse shear strains, resp. membrane strains and even thickness strains (ANS-method [2,4,3]) as well as mixed formulations (EAS-method [20]) are applicable. A complete discussion about these locking phenomena and different developed element versions is given e.g. in [9]. Finally, almost locking free 3D-shell elements are available. The nomenclature for the element versions relevant for the investigations in the following chapters is given in Table 1.

The use of non-linear material laws, necessary for the treatment of large deformation problems, is described in detail e.g. in [11]. It should be mentioned that in contrast to the degenerated shell concept strains and stresses in thickness direction are included in the 'Solid-Shell' concept. Thus general three-dimensional material laws can be used without any modification and general 3D stress and strain states can be treated directly.

3. Different contact algorithms in frictionless contact analysis

3.1. Velocity description

A specific derivation based on a velocity description [14] can be applied to describe contact conditions with

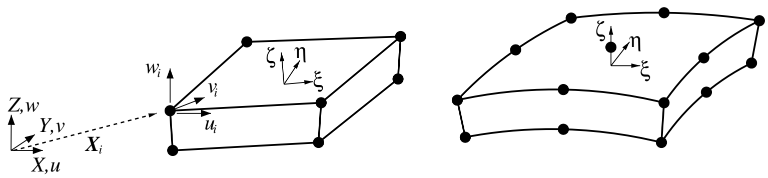

Fig. 1. 'Solid-Shell' elements with bilinear and biquadratic shapes.

Table 1
Nomenclature for 'Solid-Shell' element formulations

Element name	In-plane approximation	Membrane strain modification	Thickness strain modification	Transverse shear strain modification
ANS3DEAS	Bilinear Lagr.	–	EAS	ANS
EAS3DEAS	Bilinear Lagr.	EAS	EAS	ANS
MI9K3DEAS	Biquadratic Lagr.	ANS	EAS	ANS