

Modelling of bolts under dynamic loads

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Summary:

Bolt connections are one of the main joining techniques in commercial vehicles. To capture the main effects of this connection type a new modelling technique is discussed and compared with conventional techniques. To describe the bolt material MAT_SPOTWELD-DAMAGE-FAILURE is used. Here failure strain is used as the criteria for bolt failure. In the framework of the present paper, test results are discussed and compared with simulation models.

Keywords:

Bolt modelling, crashworthiness, connection modelling, finite elements.

1 Introduction

Bolts are the most frequently used joining elements in machine construction. They are widely used in commercial vehicles. Here many parts are joined together with bolts because of better assembly and disassembly. To characterize this joining technique in simulation models for crash the requirements of the modelling technique have to fulfil many conditions. The modelling technique has to describe reality in the best way and Pre-/Post-Processing has to be practical.

2 Modelling techniques for bolts in LS-DYNA

There are different possibilities to model bolts in LS-DYNA [2]. Three modelling techniques will be described in detail to give an overview. All techniques have advantages and disadvantages depending on application. Nevertheless they can be distinguished in two main categories: modelling with 3d and 2d elements. The main focus in this work is the possibility to use the modelling technique in large models like full vehicle models for crash calculations.

2.1 Modelling of bolts with beam element and spider connection

This modelling technique is the most conventional way of modelling bolted joints because of easy pre- and post-processing. Here the bolt shank is represented by a beam and the connections to the clamping partners are made with a spider mesh (see Fig. 1). The spider mesh contains beam elements which have to be stiff enough for a strong connection. One advantage of this method is that setting contact between the bolt shank and the hole and the bolt head and the outside clamped parts is not necessary. The calculated normal force and the shear force in the bolt shank can be taken directly out of the e1 out file. Bearing stress can not be taken into account by this modelling technique because the load will be transferred circumferentially on the hole.

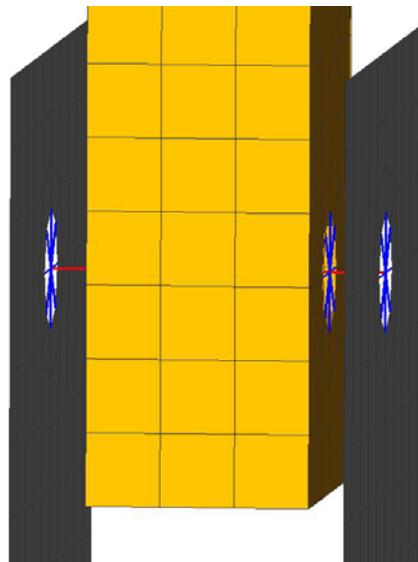


Fig. 1: Modelling of bolt with beams (elform=1) and connection through spider mesh

2.2 Modelling of bolts with solid elements

This modelling technique is the most realistic one because of a total 3-dimensional description of the bolt as shown in Fig. 2. Setting of contact between the bolt and the clamped parts is necessary. This is a problem when using shell elements for the clamped parts. Here the shell edge is extended by half of the shell thickness into the hole. Thus the hole diameter has to be increased or the hole edge on shell

elements has to be modelled with contact beams as it is done in this work. In the new version 971 of LS-DYNA the SHLEDG parameter in the *CONTROL_CONTACT card can now be set to assume that the hole edge of the shells is square. This option is only supported by the segment based contact. However a more realistic bearing stress on the hole edge is now possible with the solid modelling technique for the bolt. Another advantage is to insert a preload on the bolt shank with the keyword *INITIAL_STRESS_SECTION. To obtain the normal force or the shear force on the bolt shank for postprocessing is only possible by inserting a cross section which has to be normal to the bolt shank. This is quite difficult to realize. Furthermore it has to be known where the maximum forces will be expected which is also not user friendly. The modelling of the real circular cross-section for the shank is also mesh size dependent as presented in Fig. 3.

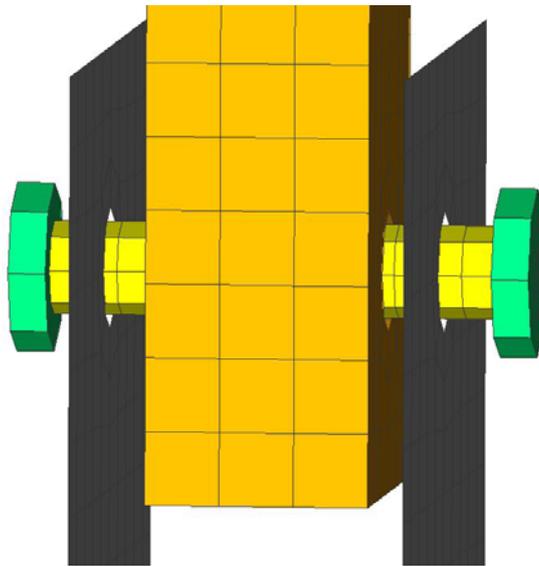


Fig. 2: Modelling of bolt with solid elements

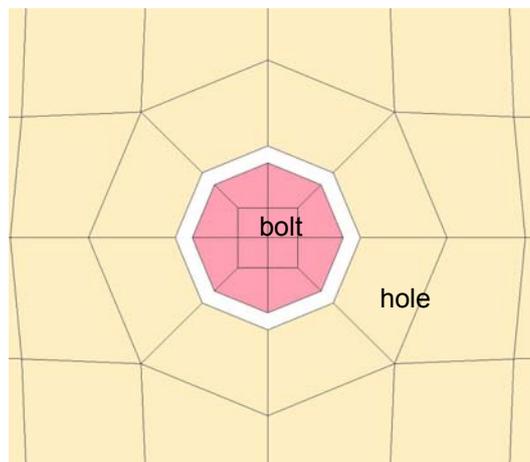


Fig. 3: Discretisation of solid bolt and hole

2.3 Modelling of bolts with contact beams (new modelling technique)

This modelling technique (see Fig. 4) combines the advantage of the beam with spider connection and the solid modelling technique. Here around the holes null beams are modelled and the bolt itself is modelled with a number of spotweld-beams (elform=9 which is a Hughes-Liu beam type). The bolt heads are modelled with shell elements. The contact between the bolt shank and the hole is set with the `*CONTACT_AUTOMATIC_GENERAL_MPP` contact. The contact between the bolt head and outer sheets is captured with the overall contact `*CONTACT_AUTOMATIC_SINGLE_SURFACE`. According to my suggestions, LSTC has implemented a new possibility of inserting a preload in the spotweld-beam. This can be done with the new keyword `*INITIAL_AXIAL_FORCE_BEAM` keyword which is available in LS-DYNA 971.R3. With that modelling technique a realistic bearing stress can be taken into account (see Fig. 6) and the circular cross section of the bolt shank is now captured correctly (see Fig. 5). The calculated normal force or the shear force in postprocessing can be taken directly out of the `e1out` or `swforc` file. With an automated postprocessing for each bolt it is quite easy to get an overview of the normal-, shear- and equivalent forces of all the beam pieces which belong to that bolt shank (see Fig. 7). Even for many bolts in a simulation model this approach is very efficient.

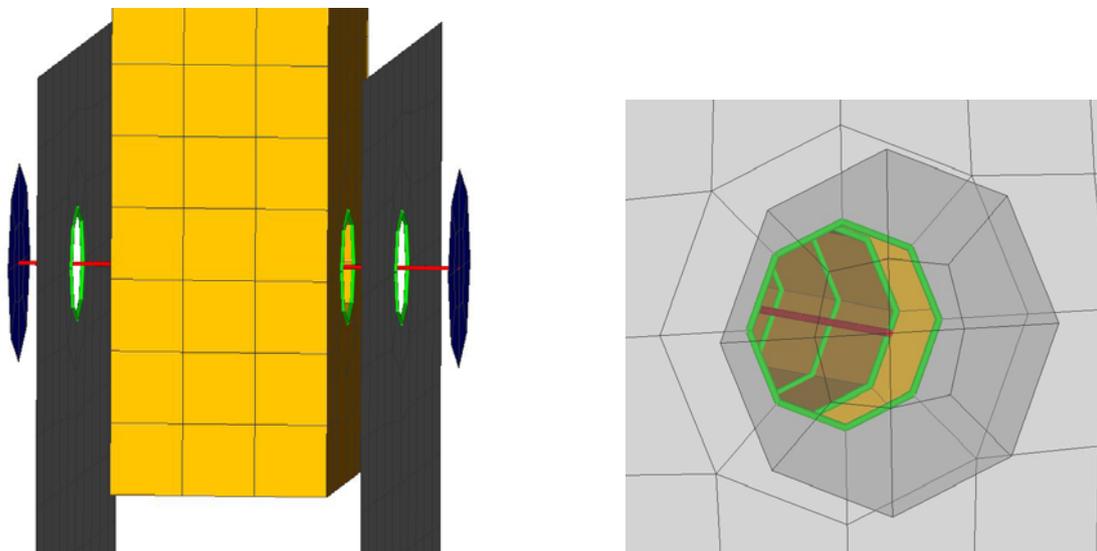


Fig. 4: Modelling of bolt with spotweld-beams and contact beams on hole edge

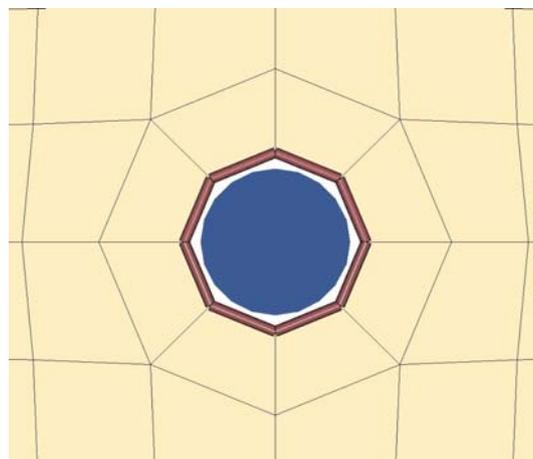


Fig. 5: Discretisation of beam bolt (3d-illustration) and contact beams around the hole

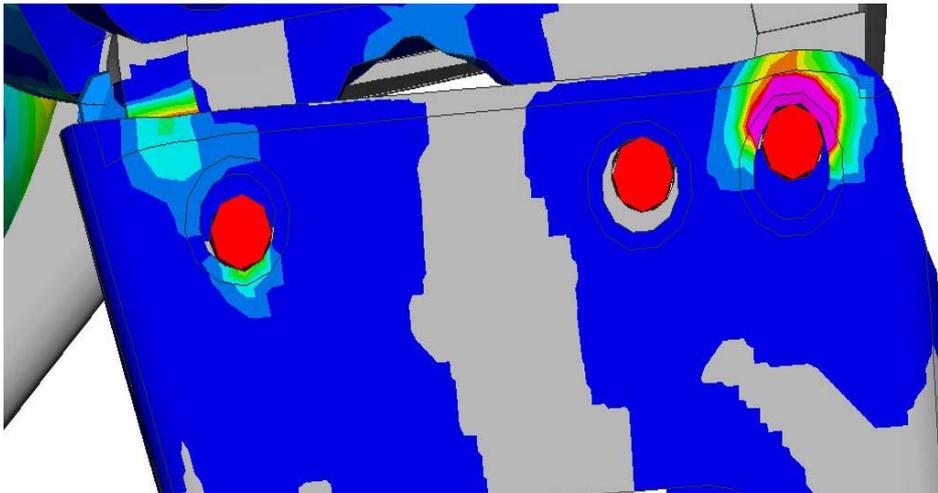


Fig. 6: Bearing stress with spotweld-beams for bolt-shank and contact beams around the hole

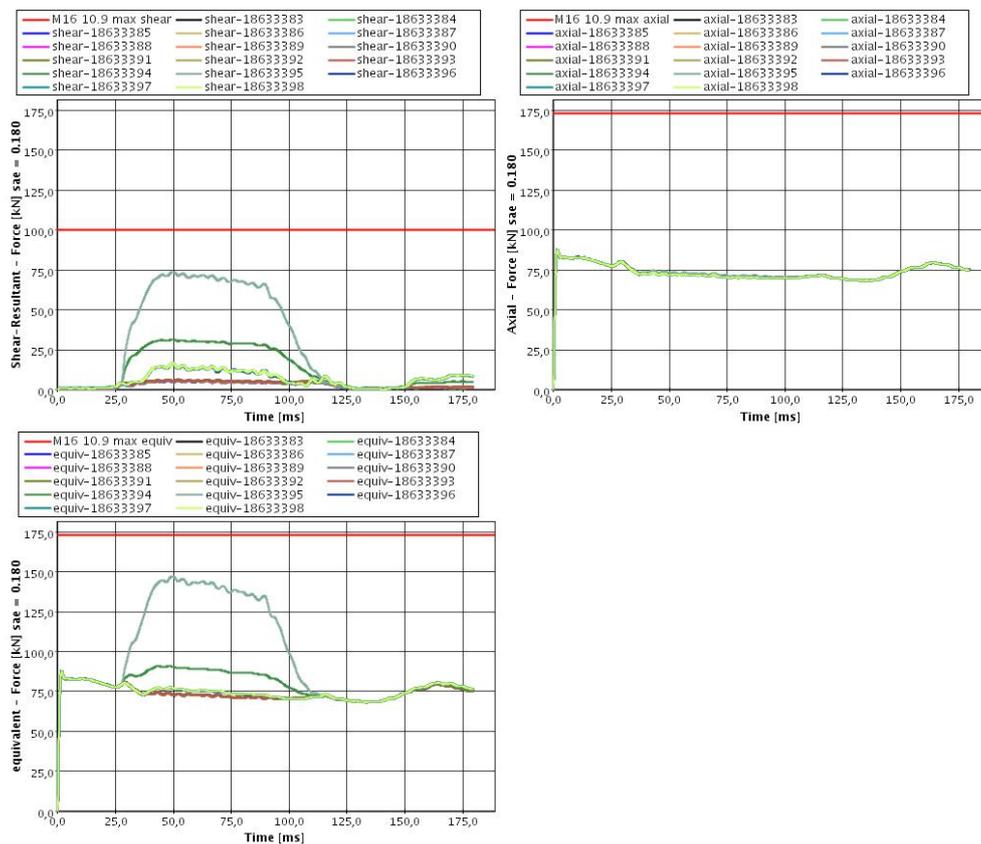


Fig. 7: Example for postprocessing of a bolt which is modelled with beam pieces

3 Numerical investigation

3.1 Basis model

For the numerical investigation a double shear model is used. In the following the influence of the modelling technique will be discussed. The solid and the beam contact model are using preload. In all calculations a mass is dropped on a middle block which is clamped between two sheets as outlined in Fig. 8. The reaction force is measured with SPCs on the ground. For a better comparison, the material behaviour for the bolt is set to elastic. The reaction force is filtered with an SAE 1000 filter because of high frequencies.

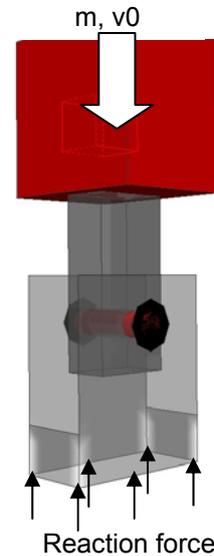


Fig. 8: Basis model for numerical investigation

3.2 Comparison of the described modelling techniques

As shown in Fig. 9 the beam with spider connection gives the highest reaction force (blue dotted line). The force increases very early which can be explained by the connection to the sheets with the spider mesh. The solid model is much weaker and the slope of the reaction force in the beginning is lower. The reaction force for the beam with contact model is higher than the solid model. It has to be taken into account that with the solid model and specific element length a perfect circular-cross-section for the bolt shank is not possible. With the beam in contact model the bolt shank is represented with a circular-cross-section. This will lead to the difference between the solid and the beam in contact model.

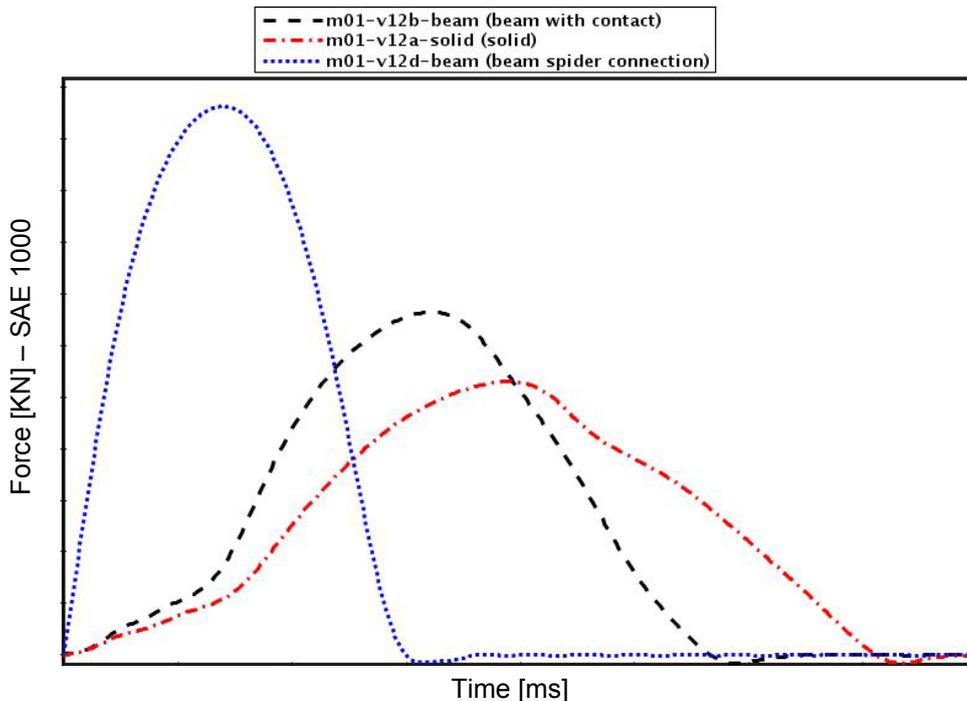


Fig. 9: Comparison of the reaction force for three modeling types

3.3 Influence of preload

With the possibility of introducing a preload in the beam in contact model it is possible to clamp parts together before they will be loaded. Especially if the contact partners do not touch; this is typically possible if the optional thickness is reduced in the *PART_CONTACT card so as to prevent initial penetrations between parts. In such cases it is quite important to introduce preload. In Fig. 10 it is shown that the axial force increases and the shear force decreases.

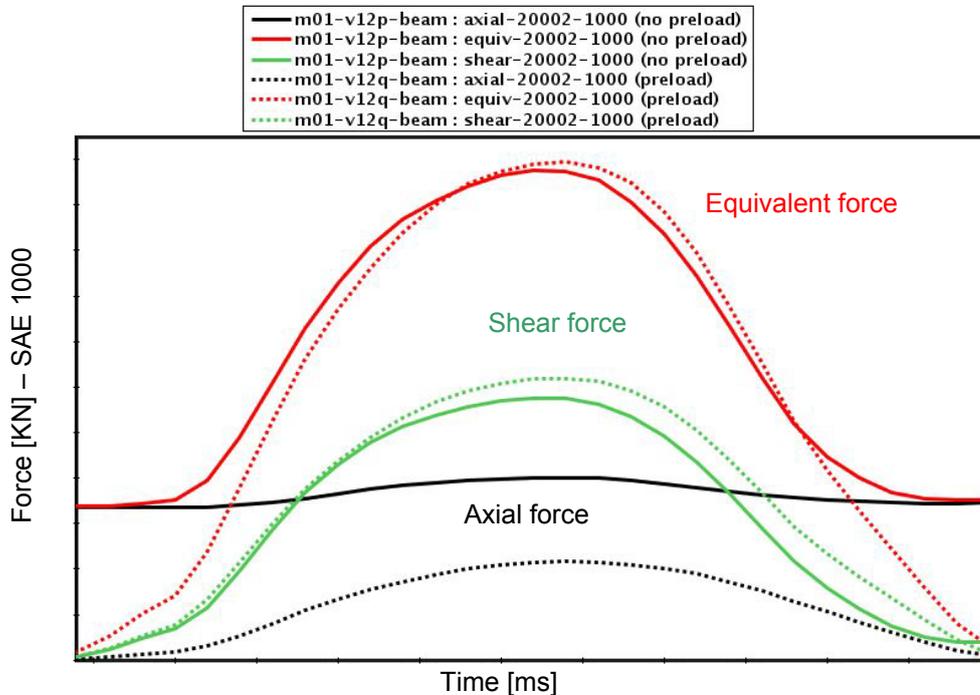


Fig. 10: Influence of preload in double shear model

4 Example

4.1 Motivation

There are many experimental data available for static tests with bolts [3]. In the dynamic case these data are not available; thus, this test was made for better comparison with finite element models. A bolt is primarily designed to withstand tensile loading. Shear load is very critical for bolts because of lower resistance against failure. In crash situation the slip resistance between the bolt and the clamped parts is not high enough to avoid the movement of the bolt in the hole. As a result high shear loads occur and a failure of the bolt is possible.

4.2 Test setup

To realize the critical shear load case in a test environment a double shear load test setup was chosen (see Fig. 11 and Fig. 12). Here two cross sections are effective in resisting the load. To test the bolt and not the clamped parts bearing failure in the clamped parts have to be avoided. Thus strong clamped parts were chosen. The bolt clamps the three parts together with a preload. The reaction force of the dropped mass which impacts the middle clamped part is measured on the ground with load cells. This reaction force is filtered with an SAE 1000 filter because of high frequencies.

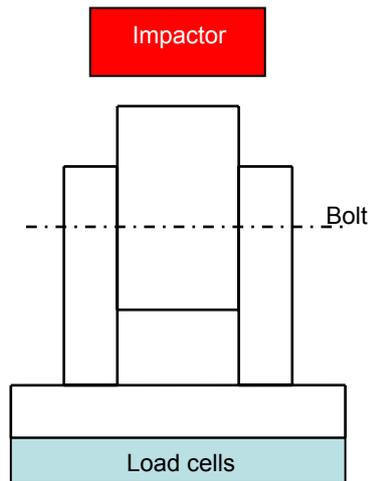


Fig. 11: Test configuration

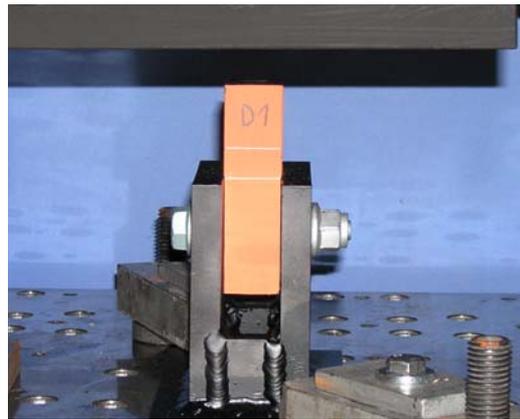


Fig. 12: Real test setup

4.3 Material model for the bolt

For the material model the *MAT_SPOTWELD_FAILURE-DAMAGE is used. The material model is a bilinear elastic-plastic type which is based on the classical vonMises-criteria (see Fig. 13). The description of the plasticity region is very limited with a bilinear model but including preload this is currently the only possibility to describe the bolt material. The description of post failure is also possible with a damage function. After exceeding a failure strain E_{fail} softening begins and continues until the rupture strain RS is reached [1]. The evolution of damage can be set by a parameter which qualifies the exponential function for damage growth.

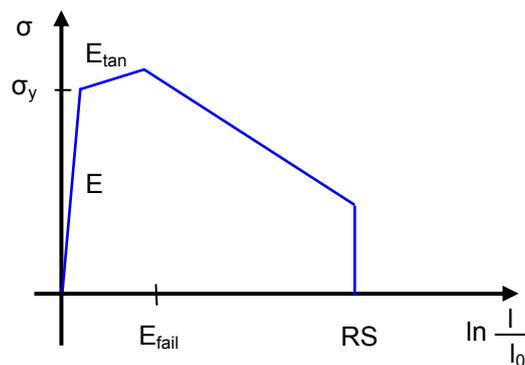


Fig. 13: Stress-Strain relationship for bolt material

4.4 FE-calculation and comparison with test

In the first test the bolt does not fail. Here the force characteristic differs in the first millisecond (see Fig. 14). This can be explained because of the thread on the bolt which does not exist in the simulation model. In the first millisecond the thread is deformed and leads to a lower force level. In Fig. 15 it is shown that the bolt has a plastic deformation. Also in the simulation model a plastic deformation was calculated.

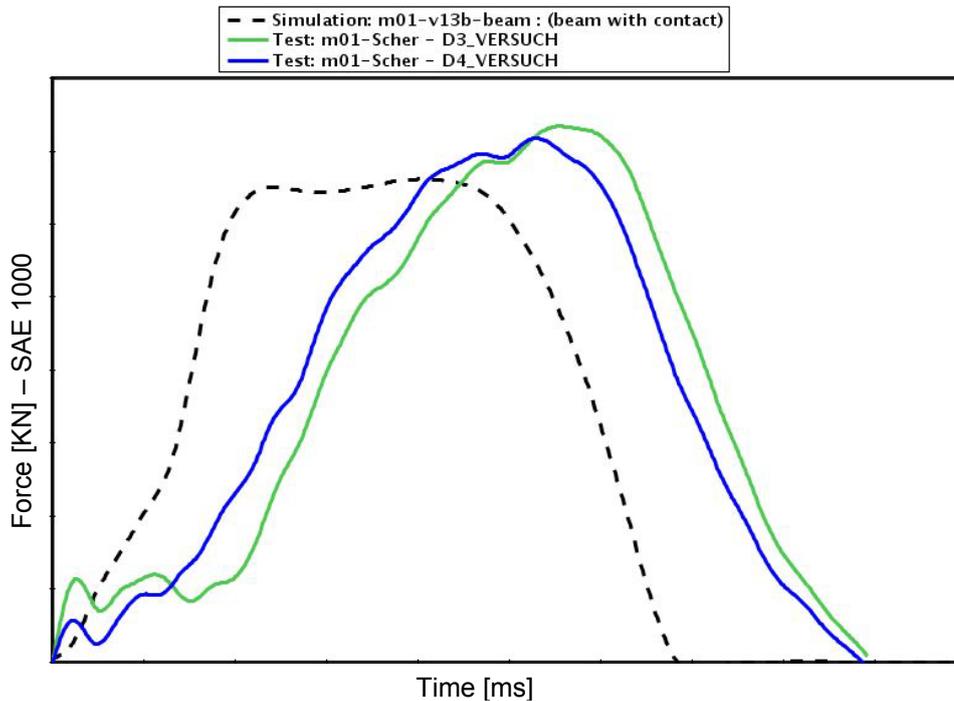


Fig. 14: Reaction force for dynamic test without bolt failure

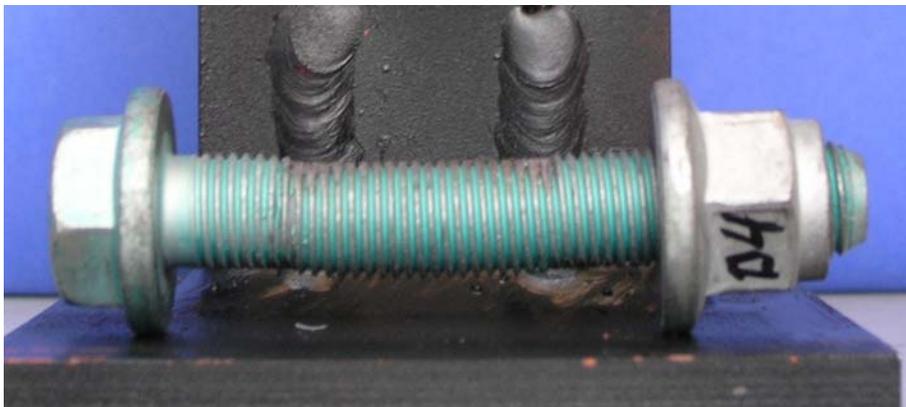


Fig. 15: Bolt after dynamic load without failure

In the second example given in Fig. 16 and Fig. 17 a test configuration where the bolt fails has been calculated. Here the energy of the dropped mass was increased. It shows that the force characteristics are equal and the failure in the bolt is calculated as well.

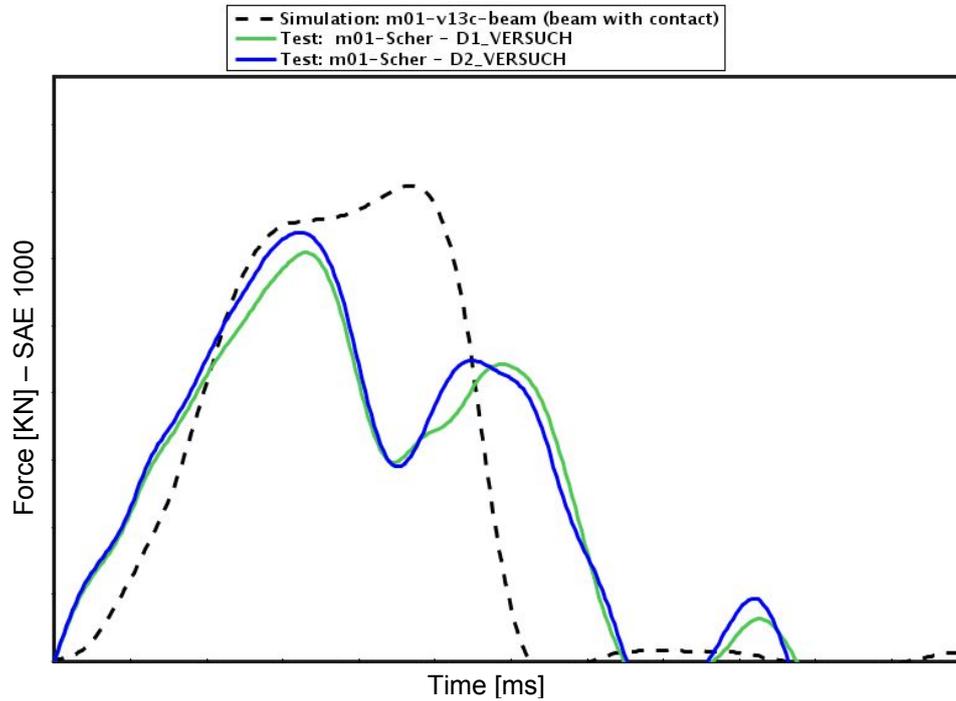


Fig. 16: Reaction force for dynamic test with bolt failure



Fig. 17: Bolt after dynamic load with failure

5 Summary

In this paper a new modelling technique for bolts is presented. This modelling technique presents a very simple method of introducing a preload. It can be used for a shell mesh as well as for a solid mesh. The post processing can be automated and the tracking of bolt loads within a large model with many bolts can be made very efficient. The introduction of a material model with failure can be made with the MAT_SPOTWELD_DAMAGE-FAILURE.

6 Literature

- [1] N.N.: LS-DYNA Nonlinear Dynamic Analysis of Structures, User's Manual, Livermore Software Technology Cooperation, Livermore, California, 2007
- [2] O'Tool B., Karpanan K., Fegghi M.: Experimental and finite element analysis of preloaded bolts under impact loading, 2006, AIAA 2006 1757
- [3] Steurer A.: Das Tragverhalten und Rotationsvermögen geschraubter Stirnplattenverbindungen, Institut für Baustatik und Konstruktion, ETH-Zürich, 1999

