Capturing complex nonlinear failure of bolt connections with simple Multibody System models

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Abstract

The main goal of system optimization is always to determine the key parameters that drive the system response. This is true for all areas of engineering, and for instance can be observed for that particular example of vehicle restraint systems (VRS) acting under vehicle impact. Although classification procedures according to the European standard EN 1317 [1] require physical tests, this is however quite inefficient for the new development of such complex systems. Experts with long experience may sometimes estimate in the forehand how specific system changes (e.g. higher steel grade, different bolt diameter or use of slotted holes) influence the behaviour of failure, but it will always be only a guess. In these cases numerical simulations on the other hand are rather powerful and allow detailed parametric studies to detect in the forehand how specific system changes influence the behaviour of failure.

Currently the European standard EN 1317 [2] is under revision. The corresponding technical report CEN/TR 16303 [3] contains guidelines for computational mechanics of crash testing, referred to as „virtual testing", of vehicle restraint systems. However these guidelines only give general advice and criteria, because there are a lot of possibilities for defining appropriate simulation models.

Multi-body system (MBS) modelling for crash testing simulations is one successful option [4], [5]. In the following, a method to define MBS models is presented which allows rapid and efficient simulation runs. It is demonstrated that rather simple parametric studies on for instance different bolted connections, e.g. a guardrail-beam connection to a post, enables to qualify the decisive parts of the system by considering all relevant nonlinearities of failure mechanisms. Thus, it may enable to achieve a higher performance (i.e. containment) level for an existing VRS by changing the decisive part or mechanism of failure.

The complete MBS model can be separated into two parts, the vehicle and the road restraint system. Furthermore it is possible to reduce the complexity of each of these by separating it into simple subsystems. A demonstration example shows the connection of the guardrail-beam to a post of the steel guardrail system, the so-called GS2 hard shoulder barrier via a spacer-element (see Figure 1).

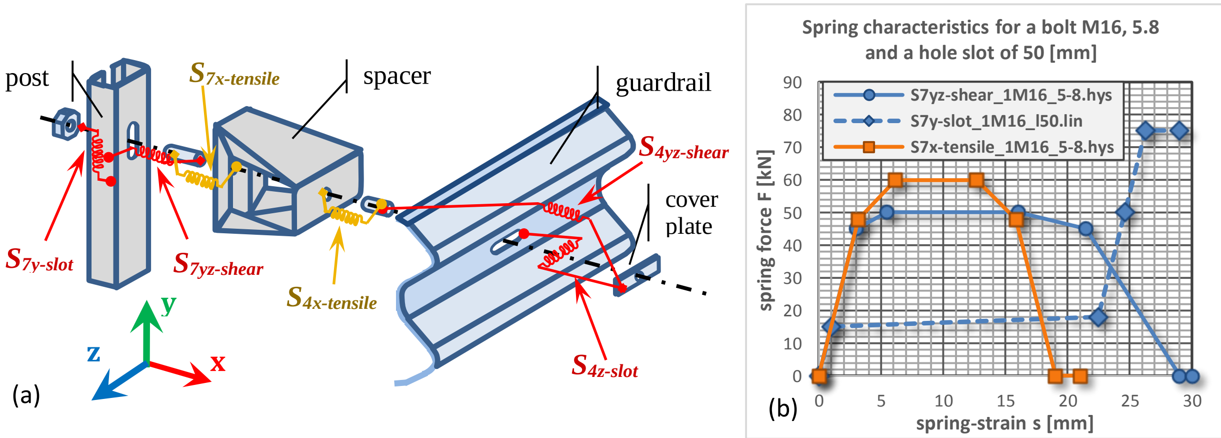

Figure 1: Steel guardrail system GS2 hard shoulder barrier – connection to a post.
(a) Schematic depiction of bodies and springs of the bolted connection.
(b) Spring characteristics to capture the shear of a bolt M16 and the slip of a slotted hole.

For multi-body systems, a bolted connection can be defined very comfortably by internal force elements, which are acting in hinges allowing specific degrees of freedom. This offers a separate view on each

single limit state. For instance, the dilatation of the slotted hole can be captured and modelled exactly and independent from bolt shearing as well as decoupled from bolt tension failure. Between post and spacer as well as between spacer and guardrail there are six degrees of freedom (three translational and three rotational) in case of bolt failure (see figure 1). Spring and damper elements with non-linear characteristics are introduced to describe the kinetic behaviour. By separating the kinematic movements, an internal force element can act separately for each kinetic property. For instance, defining a hinge between guardrail and cover plate allows to provide only one degree of freedom with free translation in horizontal direction parallel to the guardrail length axis. To represent the slotted hole at the guardrail, a spring with a linear elastic characteristic but following two levels, may be used. The first level describes the friction during free movement of the bolt in the hole. The second level then provides resistance to ultimate failure, see dotted curve in figure l (b). To consider shear in vertical and horizontal translational direction, then an additional hinge between the cover plate and the right bolt of the spacer is defined, with a non-linear hysteretic spring characteristic, see persistent line in figure l (b).
So the use of such models for the mapping of bolted connections therefore offers ideal conditions to capture the failure behaviour close to reality, in particular in view of parametric investigations, even for complex joining constructions.

References

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