

Deformability Switching in LSDYNA®

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Introduction

Among several simple yet powerful techniques available in LS-DYNA, switching of bodies that affects their deformability (at run time) is certainly one of them. Switching of bodies with negligible internal strains to a rigidbody at user's specification can be useful to eliminate the calculation of element-centered variables such as stresses, which in many applications could dominate the total computation time. Additional benefits of using this feature could include the reduction of new model development time where regions of non-importance can be treated as a rigidbody for faster turnaround time. This paper presents an overview of how the switching works in theory and how they can be invoked in LS-DYNA which is supported both in SMP and MPP versions for both implicit and explicit solvers.

Need for Switching

Though today's average computer's performance has improved dramatically, the use of switching presents additional benefits to reducing the total computational time, especially for new model development where the model's kinetics could be quickly evaluated before considering a detailed model. This is due to the fact that the cost of rigidbody treatment in LS-DYNA is very small when compared with the cost of a deformable-body treatment. The ability to switch a deformable component to a rigidbody with minimal changes to the original model enables the user to quickly recover his original model by simply removing a few keywords related to switching. Switching can be used on any body whose motion is purely either a rigidbody translation/rotation or both with little sacrifice to the accuracy of the simulation model. A body in motion with negligible presence of internal strains can be expressed using rigid body mechanics where the computation of internal stresses may be ignored. A good example of bodies undergoing such a motion is a vehicle rollover event. Once the vehicle is off the ground, the total vehicle can be safely assumed to undergo a rigidbody translation/rotation prior to making contact again with the ground. During this time, calculations related to the computing of the internal stresses can be eliminated with no sacrifice to the accuracy of the model.

Merging Rigid Bodies

Prior to understanding deformability switching, a quick review of rigid body merging is presented here. Rigidbody treatment in LS-DYNA uses either the given finite element mesh or the user-specified parameters to compute the rigidbody's initial configurations such as translational mass, center of gravity and inertia tensor. When several rigidbodies are defined in a model, LS-DYNA allows "merging" of such independent rigid bodies to form a "master" rigidbody definition. The initial configurations of the master rigidbody will then be recomputed based on all the slave rigidbodies. This is illustrated in Figure 1.2. Merging of rigidbodies can be defined using **CONSTRAINED_RIGID_BODIES* keyword, where the user can specify any number of "slave" rigidbodies to form one "master" rigidbody. Switching capability in LS-DYNA allows merging of rigidbodies created on the fly to a "master" rigidbody which will be beneficial to combine several newly formed rigidbodies to be treated as one master rigidbody like the entire vehicle as mentioned before.

Invoking Deformability Switching in LS-DYNA

The keyword to use in LS-DYNA for deformability switching is **DEFORMABLE_TO_RIGID*. When using the default keyword, the only required parameter is the part (PID) that needs to be switched to "rigid" and the switching occurs at time zero. Switching invoked using this default keyword is irreversible which means that the component will be treated as an independent rigidbody for the remainder of the simulation time. Optionally the user can specify a master rigid body (MRB) to which the newly created rigidbody component can be merged to. There are two optional keywords, AUTOMATIC and INERTIA, that can be added to the default keyword **DEFORMABLE_TO_RIGID*. The option AUTOMATIC allows greater flexibility by providing a reversible switching process where one body can be switched between "rigid"/"deformable" any number of times with the requirement that the body's initial definition is deformable. It should be noted that bodies that use **MAT_RIGID* material law, are permanently rigid and cannot be converted to become deformable again. AUTOMATIC option allows the internal deletion/activation of the constraints that are attached to the body that is being switched. The option INERTIA allows the user to specify a user-defined mass/center-of-gravity/inertia-tensor when a deformable body is converted to a rigid body. Values specified using the INERTIA option will override all values computed using the finite element mesh. LS-DYNA allows any number of switch definitions (each associated with a unique id using SWSET) and each one can be associated to the other so they can be triggered in a desired sequence.

Activation of Switching

The default keyword, **DEFORMABLE_TO_RIGID* with or without the option INERTIA, activates the switching at initialization and cannot be modified by the user. When the AUTOMATIC option is used, switch definitions can be triggered by one of five methods shown below using the parameter CODE.

0. Time-based. This is the default option where the switching will occur at a specified time using the parameter TIME (default = 0, at the start of the simulation).
1. Rigidwall force is zero. This option will associate the switching to a rigidwall definition whose resultant force will be checked every cycle and when it reaches zero, the switching will be activated.
2. Contact force is zero. This option will associate the switching to a contact definition whose resultant force will be checked every cycle and when it reaches zero, the switching will be activated.
3. Rigidwall force is non-zero a user-defined magnitude at or in-between two time states. This option will associate the switching to a rigidwall definition whose resultant force will be checked every cycle and when it reaches a non-zero value, switching will be activated.
4. Contact force is non-zero a user-defined magnitude at or in-between two time states. This option will associate the switching to a contact definition whose resultant force will be checked every cycle and when it reaches a non-zero value, switching will be activated.

Numerical Treatment of History Variables in Switching

When a deformable body is switched to rigid or vice-versa, it is important to understand how the node-centered (displacement, velocity, acceleration...) and element-centered history variables (stresses, plastic-strain...) are treated particularly when the switched rigidbody is restored back to its deformability. When switching from a deformable to a rigidbody, the average node-centered variables of the deformable body are applied to the rigidbody. For example, if the deformable rigid body has a varying velocity field, then the average mass-weighted velocity magnitude and the vector are computed and are applied to the rigidbody. If there are non-zero element-centered history variables, they are internally recorded for every element with reference to the element's local coordinate system. When the rigidbody is switched back to its deformability, the stored element-centered variables are then re-applied to the respective elements. This way we regain back the stored internal energy and maintain energy balance. Since the element history variables are stored in the local co-rotational system when deformable parts are switched to rigid, elements such as Hughes-Liu based elements (shells/beams), which store the element history variables in the global coordinate system, are not supported to regain its deformability and so only a one-way deformable to rigid can be activated for elements based on Hughes-Liu formulations. Please see Fig 1.2 for more information on the process of storing and restoring element history variables for co-rotational based elements.

Numerical Treatment of Connections in Switching

When switching a deformable body to a rigidbody, the nodes on the deformable body used in a constraint definition such as **CONSTRAINED_NODAL_RIGID_BODY* **CONSTRAINED_SPOTWELD* etc, will prevent the formation of the new rigidbody or cause instabilities during the simulation. This is due to the violation of the single constraint requirement on rigidbodies. To overcome this, LS-DYNA allows the user to specify deletion/activation of constraints at the time of switching thereby making it seamless. By default, LS-DYNA internally deletes all constraints that are defined using the nodes of the deformable body before switching. Deleted constraints can be re-activated when the rigidbody is switched back to its deformability. When converting a deformable body to rigid, various types of constraints on the deformable body could exist as shown in Figure 1.3. For each case, LS-DYNA's internal treatment based on the flag values of NRBF and NCSF is illustrated. The flag NRBF is used to activate/deactivate nodal rigid bodies or spotwelds using either **CONSTRAINED_NODAL_RIGID_BODY* or **CONSTRAINED_SPOTWELD* or **CONSTRAINED_GENERALIZED_WELD* whose node set may use one or more of the deformable body nodes prior to switching. The flag NCSF is used to activate/deactivate constraint node sets defined using **CONSTRAINED_NODE_SET*. This mechanism of internal treatment of constraints during switching helps to define the switching process with almost no change to the original model where removing of the deformable to rigid keyword will result in complete recovery of the original model.

Timestep

In certain applications, the entire model may need to be switched to one rigid body. In such instances, the global controlling timestep may lead to infinity due to non-existence of any deformable element. In such cases, the parameter DTMAX can be used to place a limit on the global timestep such that a reasonable timestep is used for the explicit solution. DTMAX has no effect when implicit solution is invoked and is not in any way associated to the DTMAX that appears in **CONTROL_IMPLICIT_AUTO*.

Example Applications

Some of the applications that could take advantage of the switching process are listed here (However, it is not limited to these):

- **Seat cushion foam pre-stress calculation** In this model, the dummy can be prescribed to align to a design H-Point location. Since the determination of the seat cushion pre-stress is of important while the occupant's self interaction is not of much concern all the components of the occupant can be merged to form one occupant rigidbody which can be then prescribed to compress the seat cushion. It must be noted that all the individual component part ids needs to be used in the contact definition as opposed to using just one master rigidbody id as the contact definitions are independent of the switching definitions.
- **Wiper mechanism simulation** Simulation of the wiper sweep is dominated by rigidbody motion. The interested components such as the motor housing which undergoes straining only during the blade impact due to an obstacle on the windshield. During the rigidbody motion until impact, the motor housing can be conveniently switched to rigid until the contact force between the blade and the obstacle is zero.
- **Vehicle Rollover Event**

General Guidelines

When using the switch functionality, it is recommended to understand the connections of the body that is being switched. A time-zero one-way deformable to rigid switch is always recommended as an initial definition. If there are any errors associated with the switching, it can be caught and diagnosed quickly. If a reversible process is of interest, then a quick review of all the shell/solid/beam formulations of the bodies being switched should ensure that the supported element formulations are used.

References

1. LS-DYNA THEORY MANUAL
2. LS-DYNA KEYWORD USERS MANUAL

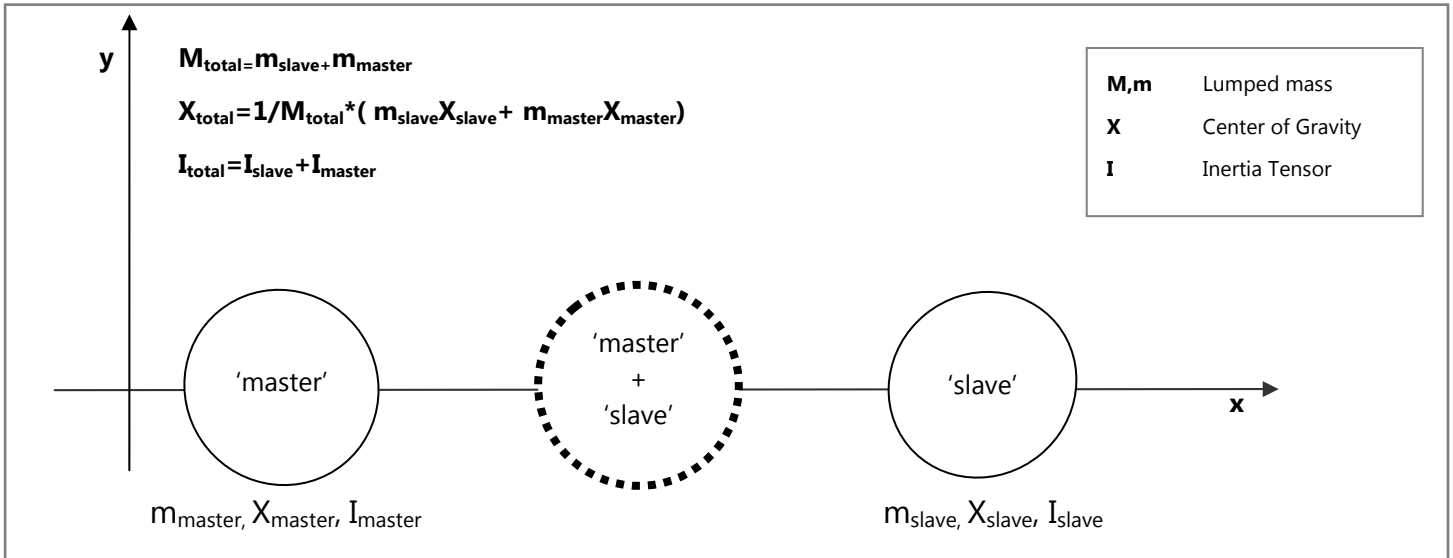


Figure 1.1: Merging of Rigidbodies

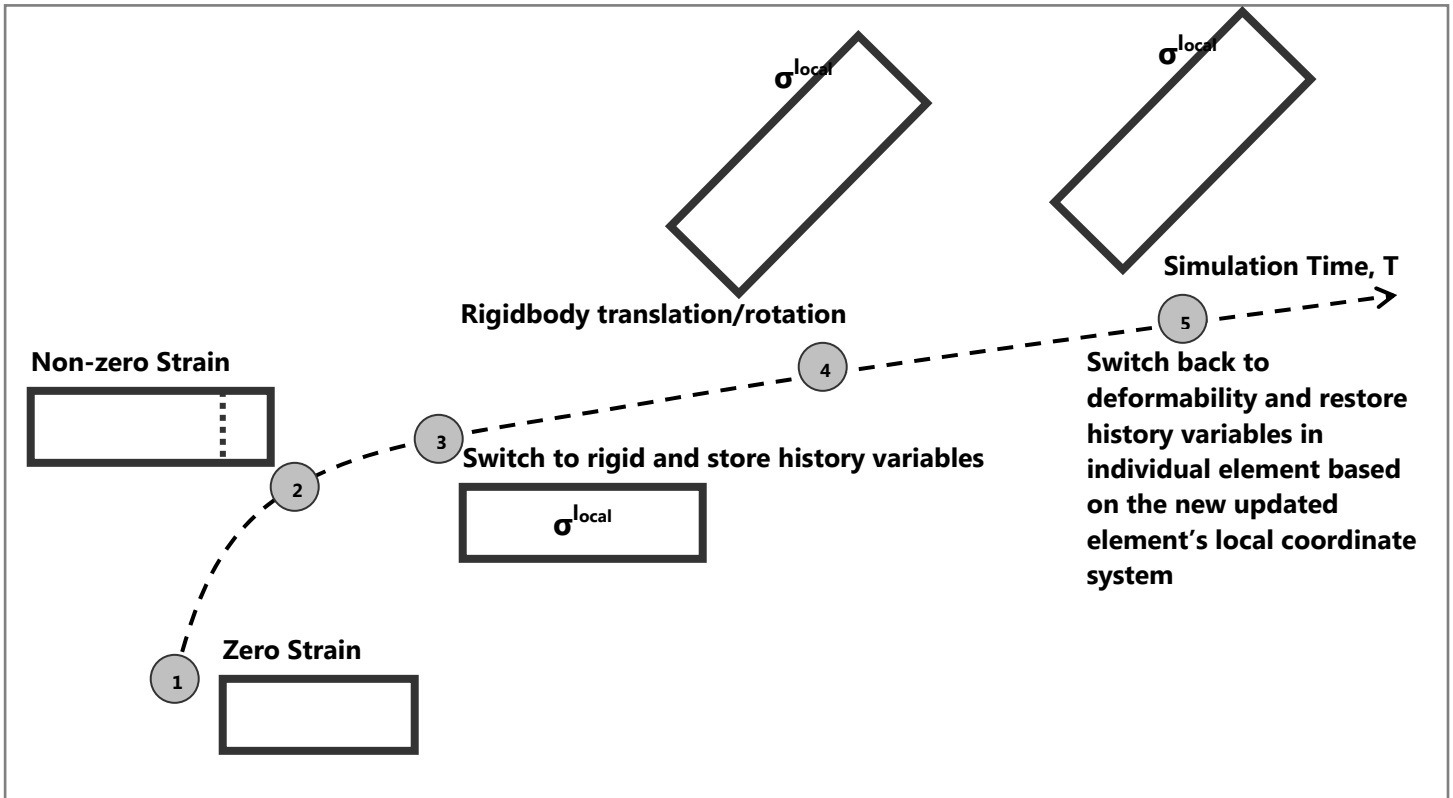


Figure 1.2: Treatment of History Variables During Switching

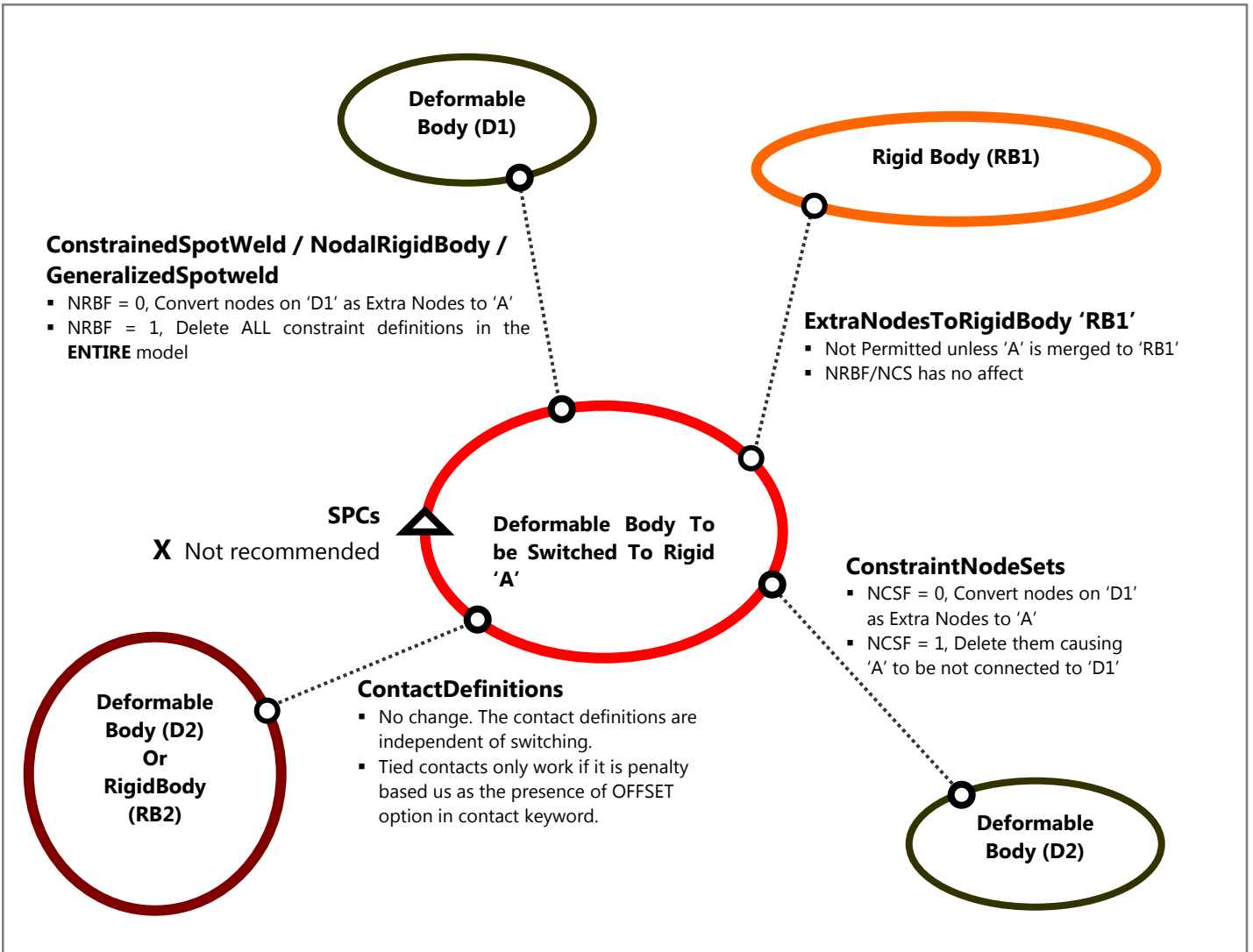


Figure 1.3: Treatment of Connections During Switching