Vehicle Roof Crush Modelling & Validation

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ABSTRACT

Real roof crush tests, quasi-static or dynamic, have been widely used to evaluate the safety integration of vehicle structure, especially in the USA, where there are specified standards such as FMVSS 208 and 216. Europe is endeavouring to reach the same target for vehicle safety taking into account the different road condition. However, carrying out full experimental tests is shown to be costly and in many cases unrepeatable. That is why the development of good reliable models can be the key to the solution of successful roof crush simulation that predict real world accidents.

For this particular paper, the modelling was partially carried out in Radioss FE model and then translated into LS-DYNA3D. The complete model was finalised in LS-DYNA3D, where it was made available for the roof crush simulations. To improve the structural integrity, spotwelds were remodelled and new Nodal_Rigid_Bodies were built-in manually due to the different definitions and interpretations in these two codes. Roof mesh refinements were done in order to remove roof stiff behaviour in some areas and therefore match the roof deformed pattern shown in real test. Local Cartesian coordinate system was established for rigid planes' spatial position. In addition, time integration algorithms in LS-DYNA3D were also discussed for roof crush prior to performing quasi-static and dynamic simulations on a small European car. Thereafter the results were verified against the real tests which showed very good agreement, especially in the time history crush characteristics. However, despite the force peak values to be nearly the same there is still a small discrepancy between the quasi-static roof crush simulation and its real test characteristic.

INTRODUCTION

Real roof crush tests, quasi-static or dynamic, have been widely used to evaluate the safety integration of vehicle structure, especially in the USA, where there are specified standards such as FMVSS 208 and 216. Europe is endeavouring to reach the same target for vehicle safety taking into account the different road condition. However, full experimental tests are shown to be very costly and in many cases unrepeatable.

With the development of computer technologies, several crash codes such as LS-DYNA3D, Pamcrash and Radioss, are used for vehicle impact simulations. These codes have been developed mainly based on explicit time integration, special shell elements specific to analyses, and modelling assumptions regarding the dynamic behaviour involved. But successful roof crush simulations published [1-4] are hard to come by although it is well known that there are no problems with frontal, side and rear impact simulations. The most difficult of the simulations is still the quasi-static roof crush simulation despite enormousf experience obtained over the last years. If a higher speed is used for the quasi-static simulation, it will result in inertia effects which smooth out the nonlinearities and deficiencies in the solution algorithms. While implicit solver could address quasistatic impact scenarios, the large deformation of parts surrounding roof and pillar areas, and contact involving multiple vehicle parts make the convergence of the solutions very difficult and sometime unstable within implicit solvers. At present two element types are employed in LS-DYNA3D for roof crush simulation, Belytschko-Tsay (Type 2) and Fully Integrated Shell (Type 16). The later is more computational costly and the roof behaves stiffer. Of course the finer the meshing and the smaller the time step size, the more stable the solution becomes but all these are computationally expensive.

In this paper a Radioss FE partial vehicle body model was translated and manually modified into LS-DYNA3D due to the differences that exist between the two algorithms. Modification of the model and new complete spotweld redefinition

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were made plus corrections to elements. Fine meshing was done to the roof, roof rail and roof support. An equation was set up for the impact direction on the vehicle body, following by the outlining of the time integration algorithms. For the work, the static and dynamic roof crush models were built separately and validated to the experimental work.

MODELLING OF VEHICLE BODY-IN-WHITE

Finite Element Model Descriptions

Ford Werke AG, Germany [5], one of the partners in the European rollover project, developed the original finite element model in RADIOSS FE model. After further processing, the fundamental finite element model was translated and made available for the roof crush simulations in LS-DYNA3D based on FMVSS 216 (Shown in Figure 1). The total number of elements and nodes for the vehicle body with windscreens are 80307 and 82774 respectively; while 70746 elements and 73555 nodes for the vehicle body without windscreens. The basic material models are all type 24 (Piecewise Linear Plasticity).



(a) Dynamic F.E. Model with Windscreens (Elements: 80307; Nodes: 82774)



(b) Quasi-Static F.E. Model without Windscreens (Elements: 70746; Nodes: 73555)

Figure 1 Roof Crush F.E. Models

Remodelling Redefinition of Spotwelds

Spotwelds were the most difficult to translate from Radioss to LS-DYNA3D. In the Radioss model, a spotweld is a spring connected to the element meshing with an interface type 2 (tied contact), while in LS-DYNA3D model, the spotweld is a rigid beam that connects nodal points of the nodal pairs. The translating tool: ARUP's Oasys Primer 91, was used as a pre-processing software for LS-DYNA3D; but it couldn't correctly convert the spotwelds in Radioss model, instead it translated them as spring beams. This isn't a correct interpretation as LS-DYNA3D uses rigid beams as spotwelds. Coincident spotweld nodes in this case are handled by the Constrained_Nodal_Rigid_Body options that were converted manually. As with respect to the spotwelds that have two nodes in Radioss, these were manually redefined and translated into LS-DYNA3D, while the spotwelds that have more than two nodes were manually converted into Nodal_Rigid_Bodies because of a nodal pair required for one single spotweld.

On the other hand, Oasys Primer 90 cannot also process correctly the nodal_rigid_bodies from Radioss model. It translates them into massless rigid beams. Therefore, this part of the work was also done manually.

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Refine Meshing of Roof, Roof Rail and Roof Supports

With the original roof mesh, the roof behaved very stiff in the coarse mesh areas, and the locaitions of hinges in the simulation appear at different positions when compared to the practical test. So it was necessary to refine the mesh in the roof, roof rail and roof support for the quasi-static simulation as shown in Figure 2. With the refine meshing, a very good agreement was achieved between the simulation and the practical test (see Figure 5).



Figure 2 Refine Meshing of Roof, Roof Rail and Roof Support

Spatial Location of Tangential Plane on Vehicle Body Surface

For a spatial Cartesian coordinate system shown in Figure 3, the transformation equations between original coordinates and new ones are the following $x = x_2 \cos \beta - y_2 \sin \alpha \sin \beta - z_2 \cos \alpha \sin \beta$

 $y = y_{2} \cos \alpha - z_{2} \sin \alpha$ $y = y_{2} \cos \alpha - z_{2} \sin \alpha$ $z = x_{2} \sin \beta + y_{2} \sin \alpha \cos \beta + z_{2} \cos \alpha \cos \beta$ (1)
or $x_{2} = x \cos \beta + z \sin \beta$ $y_{2} = -x \sin \alpha \sin \beta + y \cos \alpha + z \sin \alpha \cos \beta$ $z_{2} = -x \cos \alpha \sin \beta - y \sin \alpha + z \cos \alpha \cos \beta$ (2)

So, the normal direction of the rigid plate downward the vehicle body is as follows $\vec{n} = \{\cos \alpha \sin \beta, \sin \alpha, -\cos \alpha \cos \beta\}$





Figure 3 Transformations of spatial Cartesian coordinate systems.

TIME INTEGRATION ALGORITHMS IN LS-DYNA3D

There are two solvers in LS-DYNA3D for time integration algorithms, explicit and implicit [6]. In the explicit approach, internal and external forces are summed at each node point, and a nodal acceleration is computed by dividing by the nodal mass. The solution is advanced by integrating this acceleration with respect to time. The maximum time step size is limited by the Courant condition, producing an algorithm which typically requires many relatively inexpensive time steps. While explicit is well suited to dynamic simulations such as impact and crash, it can become prohibitively expensive to conduct long duration or static analysis. In the implicit method, a global stiffness matrix is computed, inverted, and applied to the nodal out-of-balance force to obtain a displacement increment. The advantage of this approach is that time step size may be selected by the user. The disadvantage is the large numerical effort required to form, store, and

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factorize the stiffness matrix. Implicit simulations therefore typically involve a relatively small number of expensive time steps.

However, in real practical simulations the situation is rather different [1]. Often convergence, which is absolutely vital for implicit schemes, is very hard to achieve, and very small time steps are needed to obtain a solution at all. Often the condition number in pure static analysis is too bad such that a transient algorithmic treatment is necessary and also the active set of elements and nodes in the contact zones changes too rapidly such that permanent adjustment of time steps is needed to carry on in the simulation. Often, of course, a higher mesh resolution would have been required to avoid high mesh distortion and bad models such high mesh resolutions appear to be unacceptable for implicit algorithms due to limited computer resources and also due to the limitations of current equation solvers. In situations such as roof crush, computation of postbuckling loads, situations with high frequency response even under low velocity loading and many contact problems explicit schemes have shown their best. The storage requirements are small and the algorithms are fitting very well already now to parallel computers. Due to the simple forward marching scheme the programs deliver answers to the problems in a decent time frame, if the model is set up even with only reasonable care.

STATIC ROOF CRUSH TEST AND SIMUALTION

Real Test Descriptions

An experimental static roof crush test was conducted at The University of Bolton in the UK. The setting was made so that it took consideration of roll angle changing depicting a real rollover accident. The movements of the loading rigid plate in the test rig constituted of a translation along its normal direction downwards onto the vehicle body and rotated along its longitudinal axis (shown in Figure 5(a)). The initial roll angle was 8°; while the pitch angle was 6°.

Simulation

Two simulations were carried out on the basis of the following loading conditions (Figure 4)

$$V_0 = 450 \text{ mm/sec} (1.006621 \text{ miles / hour});$$

$$\omega = \frac{V_0}{(1075 + 800/2)} = 450/1475 = 0.305085 \text{ radian/sec}$$

One is for the original meshing model and the other is for the fine roof meshing model. The initial roll angle and the fixed pitch angle are the same as the real test, 8° and 6° respectively.



Figure 4 Loading conditions for static roof crush simulation

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Results & Discussions

The outcomes of the deformed geometries between the simulations and real test are shown in Figure 5. The mode of the deformed geometry for the original meshing model is different from the real test mode due to the coarse meshing in the roof area, i.e. compared to the real test, a plastic hinge on the roof rail happens at a different location. The vehicle roof behaved much stiffer with the original meshing than with the refine meshing that showed results comparable to the real test in terms of the forces and the positions of hinges on the roof rails.



(a) Static roof crush test rig & Deformation



(b) Simulation with the refine meshing model



(c) Simulation with the original meshing model

Figure 5 Comparisons of deformed geometries between simulation and real test

The comparisons of force characteristics between the simulations and real test are illustrated in Figure 6, where a great difference exists between the original meshing model and the refine meshing model. Further, there is still a discrepancy between the quasi-static roof crush simulation and its real test characteristic, although force peak values are nearly the same. The main reason is the inertia effect of loading due to the high loading rate. In a crash analysis, the inertia effects generally "smooth out" the nonlinearities and deficiencies in the solution algorithms [3].

DYNAMIC ROOF CRUSH TEST AND SIMUALTION

Real Test Descriptions

An experimental dynamic roof crush test was carried out at MIRA [7] for the validation of the FE models. The vehicle body with windscreens, side glasses, doors and a tailgate, was rotated 40° roll (to LHS) and 10° pitch (front raised) and fixed on a sled (shown in Figure 7(a)). The sled impact speed was 5.64 m/s, while the total mass of the vehicle body, mounting frame, a ballast and the test equipment was 1134 kg.



---· Real Test

-A Refine Meshing -B Original Meshing

Figure 6 Comparisons of force curves between real test and simulation

Simulation

With reference to its simulation, the vehicle body was constrained to the floor and impacted by a rigid plate at 10° pitch angle and 50° roll angle. The initial impact velocity of the rigid plate was 5.64 m/s. Its dimension and weight are 4000×1211.54×30 mm and 1134 kg respectively. The rigid plate itself was constrained to prevent rotations and lateral movements, effectively providing a rigid wall.

Results & Discussions

The results of the real test and the simulation are in good agreement as shown in Figures 7(b), 7(c) and 7(d). All curves obtained from the simulation are original ones and no further processing was done to them. The maximum dynamic crush deformations are 254.4 mm for the simulation and 257.1 mm for the real test respectively. Both of them match very well. The discrepancy for the accelerations exists between 0 and 0.02 seconds, where the peak and trough values are a little bit different between the simulation and the real test. The only explanation is that the modelling of the windscreen models does not offer accurate representation, i.e. the employed material properties and the connection definition require further improvement.

SUMMARY & CONCLUSIONS

A Radioss FE model was successfully translated in LS-DYNA3D for conducting roof crush simulations with manually remodelling spotwelds due to the different definitions and interpretations in these two codes.

It is necessary for roof crush simulation to fine mesh roof area in order to match the real test.

Building a local Cartesian coordinate system functioned as pitch and roll angles can conveniently determine the impact orientation of a vehicle, which is required by LS-DYNA3D's input data.

Dynamic roof crush simulation showed very good agreement with real experimental test results, especially with respect to the time history crush characteristics.

But a discrepancy between the quasi-static roof crush simulation and its real test characteristic exists because of the inertia effect of high loading rate, despite that the deformed roof geometry patterns and force peak values are nearly the same.



(a) Real test rig (Mira, UK)



Dynamic Roof Crush

(b) Displacement time histories between the simulation and the real test







Dynamic Roof Crush



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