Simulation of shock absorbers behavior during a 9m drop test

Fabien Collin (TN International)

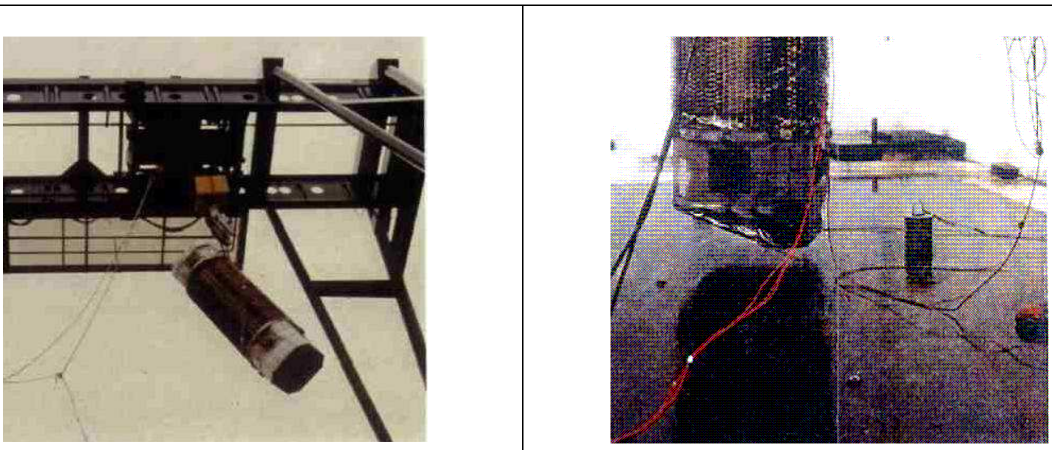
Abstract

TN International designs, manufactures and licenses packages for the transportation of radioactive materials. To justify the leaktightness and then insure the safety of a package during an accident event, a 9m drop test onto an unyielding target has to be considered. The corresponding kinetic energy is generally absorbed by shock absorbers filled with wooden blocks.
In order to improve the numerical simulation of those shock absorbers, a benchmark has been performed using a specific drop test exhibiting an important crushing. This study has led to the improvement of the wood material law, including shear damage effect. The welds failure was also implemented to improve results.
This paper will show the main results of this study.

1. Introduction

As requested by IAEA safety standards <1>, packages for the transportation of radioactive materials should demonstrate their ability to withstand accidental conditions of transport. For type B packages, used for the transportation of high activity contents, one of these events is a 9 m drop onto an unyielding target during which "the specimen shall drop so as to suffer maximum damage".

In order to fulfill this requirement, the TN® 17-2 package, used for the transportation of spent fuels, is equipped at each extremity by shock absorbers filled with wooden blocks (balsa and oak). During its licensing, several drop tests have been performed on a one third mock-up. In one drop configuration, where the center of gravity is aligned with the point of impact (see figure 1), high crushing of the top shock absorber has been recorded, geometrically higher than the bottoming strain of the filling wood.



TN® 17-2 mock-up before drop test

Shock absorber deformed shape after drop test

Figure 1: Pictures of the drop test

This drop test has been used to improve the numerical models developed to predict the behavior of wood shock absorbers.

Fine modeling of the wood material law (based on crush tests of cylindrical wooden specimens) was done with *MAT_MODIFIED_HONEYCOMB, but preliminary calculations carried out shown significant discrepancy and established that the law improvement was mandatory to fit tests results. In particular, the implementation of shear damage effects on wood was a way to improve significantly the benchmark results. In addition, since the wooden blocks were separated by steel gussets, the modeling of the failure of the welds of these gussets was also necessary to allow wooden blocks displacement inside the shock absorber.
Both modifications were then necessary to obtain the good behavior and good deformation shape of the shock absorber.

2. Wood modeling

Wood was shown to be an orthotropic material with a strong direction (fiber direction) and two weak directions. Thus, TN International uses *MAT_MODIFIED_HONEYCOMB to model wood in shock absorbers. The material law was implemented using compression test results of cylindrical specimens confined in an unyielding jacket. Crushing stresses were deduced from test specimens and implemented in each material direction: LCA was filled with hardening curve provided from specimen crushed in fiber direction and LCB and LCC were filled using the one provided from specimen crushed perpendicularly to fiber direction. The major drawback of this modeling is that shear effects increased significantly the crush stress for an off-axis test, especially for small angles around fiber direction (see figure 2).

In addition, during drop tests of several packages, especially for drop angles around 30°, shear failure of wooden blocks was observed. The results analyses showed that this effect could modify significantly the deformed shape of some wooden blocks and then dramatically affect tests results.

Improvement of wood modeling using stress update model of *MAT_MODIFIED_HONEYCOMB was investigated to correct these drawbacks, using the negative option of LCA in *MAT-126 law described in <2>. This model allowed the shear damage effects to be taken into account; moreover this material model corrected the stress increase for an off-axis crushing test observed in current modeling.
In order to benchmark this new model, the former model and tests results, two types of calculations on wooden specimens were made: crushing test on cylindrical specimens confined in unyielding jacket (for several crushing angles) and traction tests of cut specimens. Results are shown in figure 3 below.

Validation of new wood model in crush test

Tests to obtain wood crush stresses were realized by TN International on 40 mm diameter cylindrical specimens confined in an unyielding jacket (see figure 2 below)

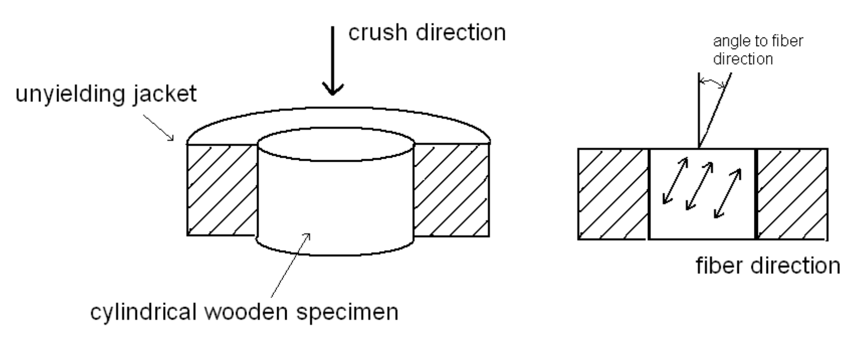


Figure 2: crush test description

To validate material model, simulations of these tests were carried out with both current and new modeling for crushing angles from 0° to 90° (by step of 10°). Mean crushing stress of each modeling was then compared for each orientation angle (see figure 3).

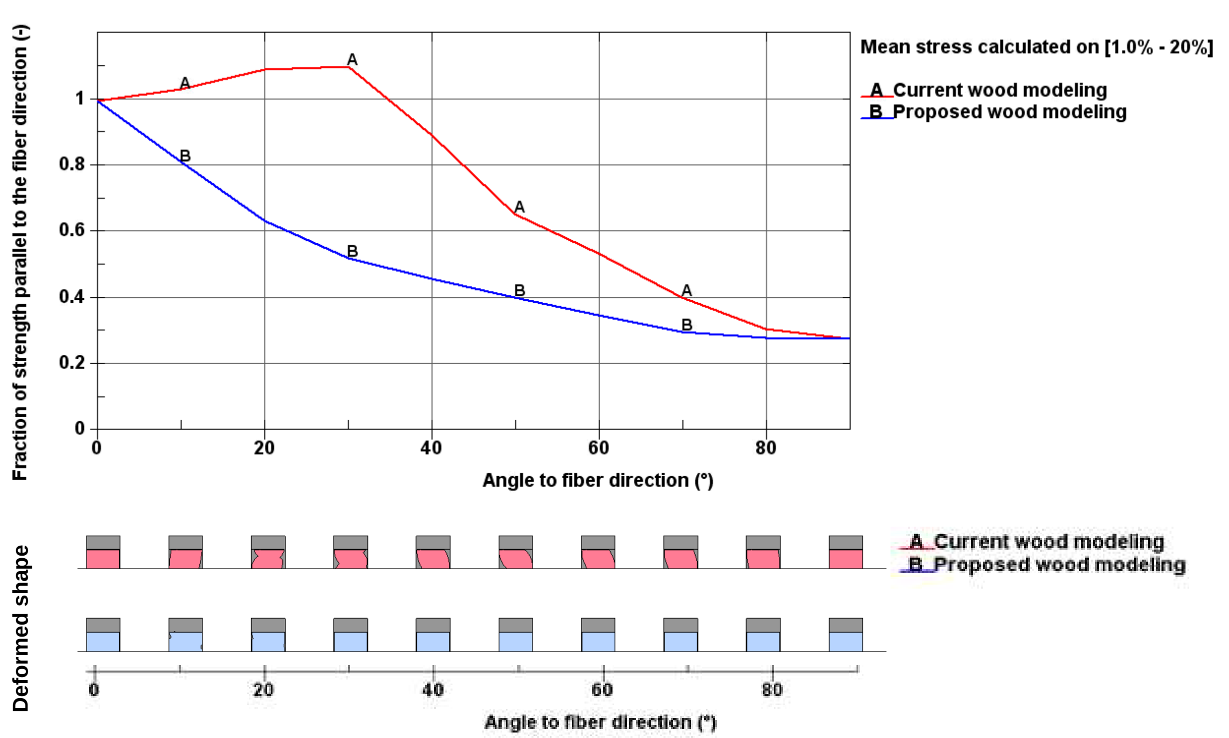
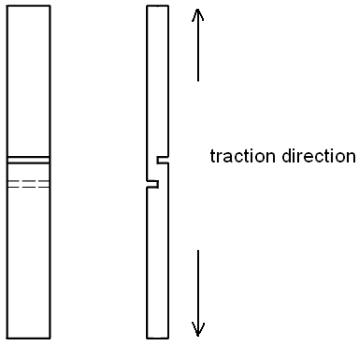


Figure 3 : Benchmarking of crush tests on cylindrical specimens confined in an unyielding jacket

Simulations performed showed that new wood modeling insured a more realistic strength evolution through crush angle direction (avoiding a stress level at 30° higher than parallel to fiber direction as observed using current modeling). Thus, as seen for real wood specimens, a decrease of mean stress was obtained with new modeling when crush angle to fiber direction increased. Furthermore, deformed shapes obtained were more realistic.

Validation of new wood model against test results for shear tests

Unlike the new wood model, shear damage effects were not taken into account in the former wood model. In order to obtain the ultimate force at which wood can resist in shear stresses, tests were performed on cut specimens (see figure 4).



Tests were performed using normalized oak specimens following French standards <3>. Contrarily to standards, tests were carried out using solid specimens in order to evaluate shear strength of oak at failure.

Figure 4: shear test description

Test results gave a maximal force at failure around 4 kN using such a specimen at room temperature. Then, simulations were carried out in order to compare numerical and test results. Results of this benchmark (presented on figure 5), shown a dramatic improvement of correlation between test and simulation using new modeling.

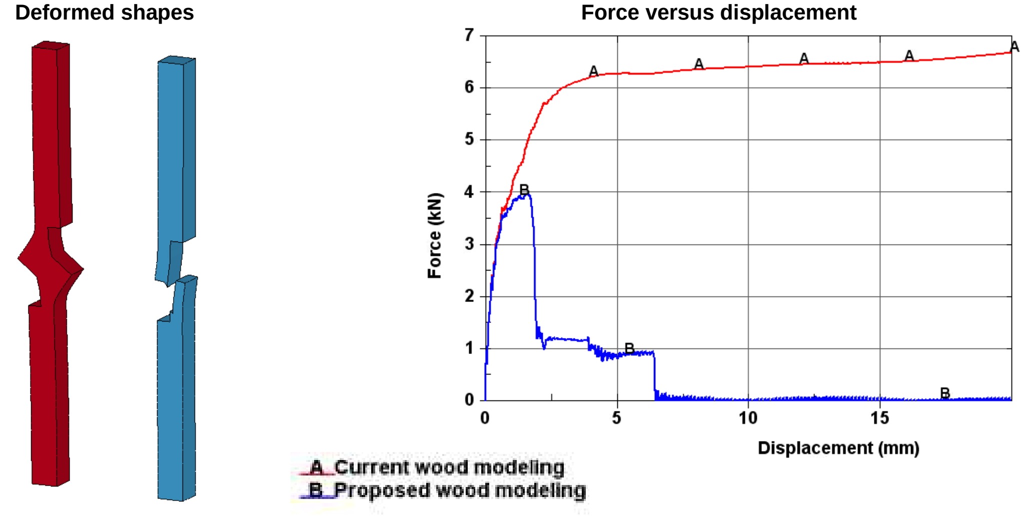
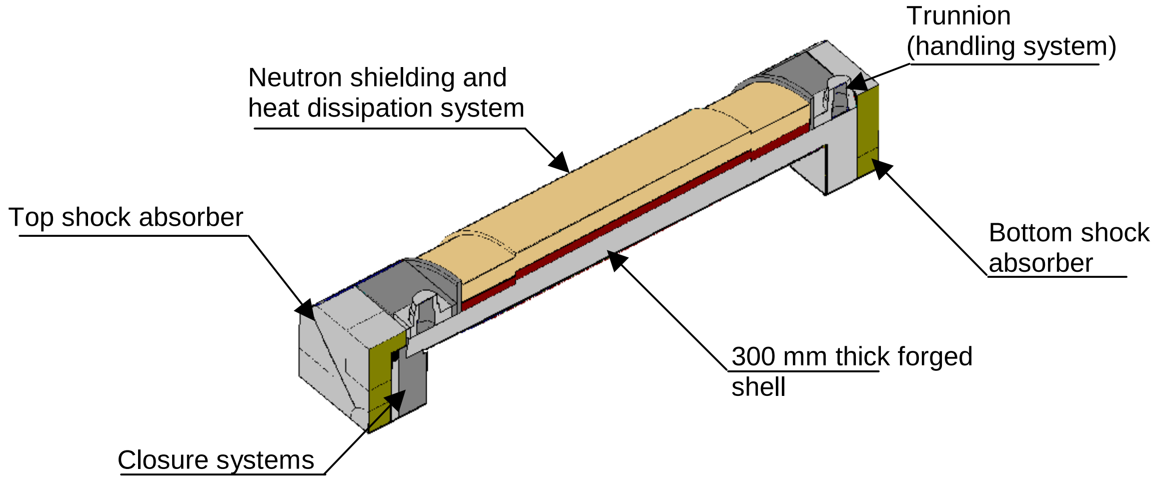


Figure 5: Benchmarking of shear test on solid oak specimen

Results from new modeling were close to test data. Furthermore, crush and shear deformed shape were greatly improved using new modeling.

3. Benchmark of the TN® 17-2 package drop test

After the validation of this new wood modeling, a comparison of simulations and drop test results of TN® 17-2 mock-up was carried out. This helped to evaluate improvement of such modifications on the predictive model used to benchmark test data. A schematic description of the package and its shock absorbers is given on figure 6.

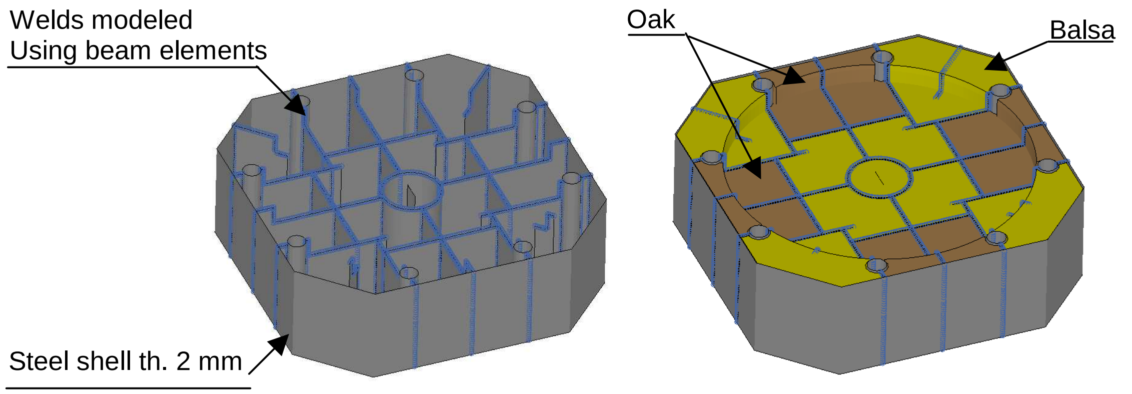


Schematic view of a quarter of package
(for full scale model : length around 6.15 m, total weight around 80 t)

Figure 6 : schematic description of TN® 17-2 full scale package

A 9.1m vertical drop test on the top shock absorber was realized. Mock up axe made a 15° angle to the vertical so that the center of gravity was aligned with a corner of the top shock absorber, in order to maximize shock absorber crushing. Mock-up accelerations were recorded on accelerometers located on the forged shell at the opposite of the impact and shock absorber crushing at the end of the drop was measured.

Mock-up model was realized using a deformable shock absorber and an unyielding body (as no damage was observed after drop test). A simulation of the drop test was performed using the current and the new modeling of wood in order to benchmark test results. Description of the shock absorber model is presented on figure 7:

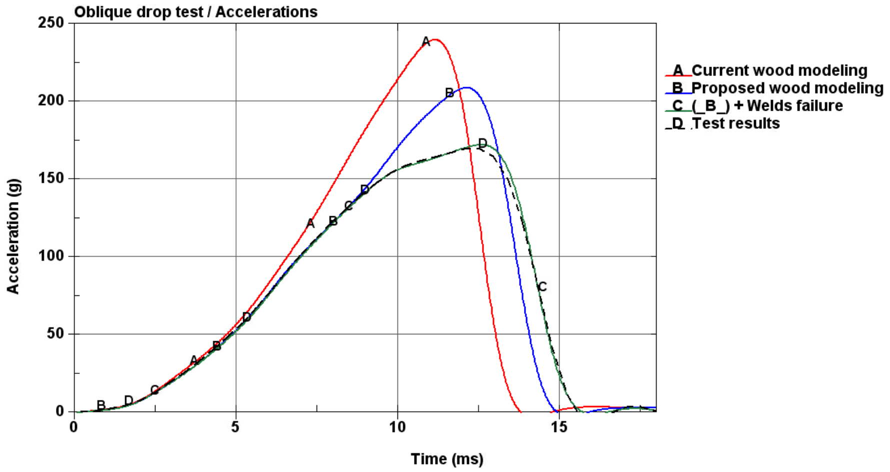


Steel shell is modeled with shell elements connected by “beam spotweld” elements type 9. Wooden blocks were modeled with solid elements.

Figure 7 : Modeling of the top shock absorber

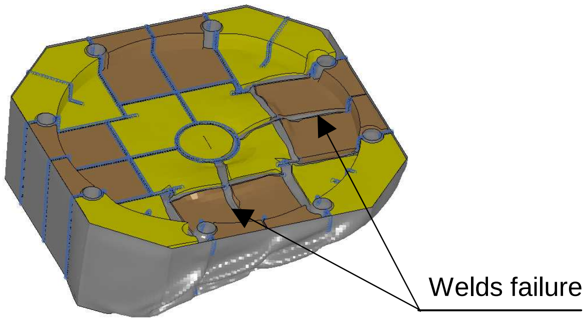
Implementation of new modeling on TN® 17-2 oblique drop test simulations

Simulations were carried out first with the former and the new wood modeling without failure of welds (which was the usual modeling of the shock absorber shell)
Accelerations of the forged shell for both wood modeling are compared to test results on figure 8. The new wood modeling without failure of welds showed a significant improvement of benchmark but the discrepancy on maximal accelerations remain significant. Furthermore, compared to the 120 mm of crushing obtained after test, crushing reached 114 mm for the new wood modeling instead of 109 mm for the former modeling.



Comparison of the forged shell accelerations

During simulation, weld failures occurred due to tangential pressure of sheared wooden blocks. This phenomena led to a change of acceleration slope (observed during tests)



Deformed shape at the end of the drop test

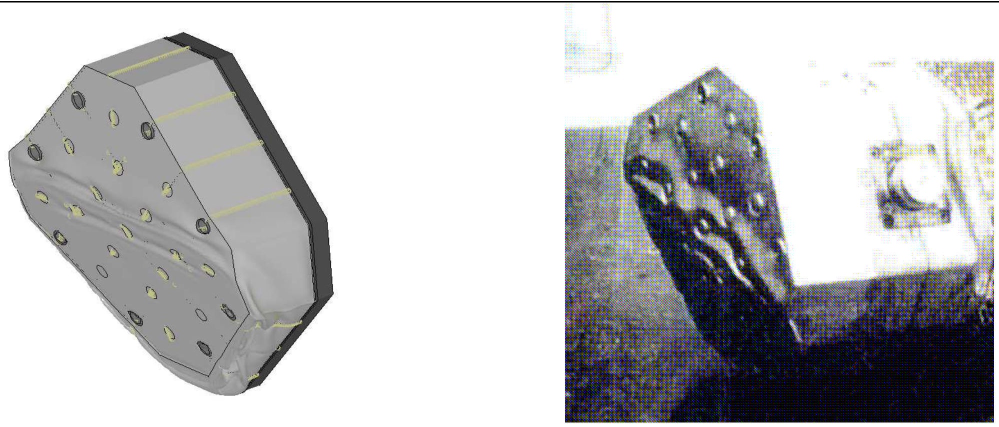
Figure 8: Results of the drop test benchmark

Welds failure implementation in drop test simulation

Since wooden blocks displacements inside the shock absorber shell seemed to affect accelerations results, welds failure of the shell gussets was investigated. Indeed, as the new modeling allowed the shear of the wooden blocks, pressure induced by wood on the gussets due to the drop angle increased compared to the former modeling and then welds failure became a decisive parameter to predict the true deformed shape. Welds failure was added to the model with new wood modeling by use of “spotweld beam” elements type 9. Results were added on the previous ones on figure 8.
Accelerations and maximal shock absorber crushing, which reached 125 mm, fitted then better test data.

4. Conclusions:

Results obtained from the combination of the new wood modeling and the welds failure shown a good correlation with test data: Accelerations were very close providing a discrepancy on maximal acceleration below 2%. Furthermore, deformed shapes were similar (see figure 9)
Thus, improving the use of honeycomb material law using the negative option and taking into account the welds failure allowed a successful representation of the behavior of package shock absorbers filled with wooden blocks. Simulations on other packages using wooden blocks in shock absorbers confirmed these conclusions.



model deformed shape

Mock-up deformed shape

Figure 9: Comparison of the deformed shape

5. References :

<1> IAEA Safety Standards, Regulations for the Safe Transport of Radioactive Material 2009 Edition
<2> Shigeki Kojima, Tsuyoshi Yasuki, Satoshi Mikutsu, Toshikazu Takatsudo, « A Study on Yielding Function of Aluminum Honeycomb », 5th European LS-DYNA Users Conference
<3> NF EN 205, Détermination de la résistance à la rupture des joints à recouvrement par l'essai de cisaillement en traction