Developing FE-Tire Model Library for Durability and Crash Simulations

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ABSTRACT

We reported the development of a simple FE tire model at the DYNA international conference in ’00. Based on the techniques in that report, a FE tire library has been developed. We have developed the tire model to increase accuracy and robustness(Figure 1). In this report, we introduce the development of the tire library.

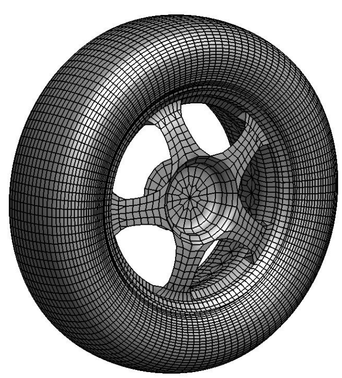

Figure 1. FE Tire Model

INTRODUCTION

Currently CAE is applied to each phase of vehicle development. And there is much demand for letting a vehicle model run, for example durability, handling or ride comfort.

Currently CAE is used in most areas of vehicle design. Accurate predictions of vehicle performance from computer simulations can reduce the use of prototype vehicles and the risk of late design changes. One area in which CAE is valuable is durability, handling and ride comfort.

When we analyze the vehicle FE model running, it is important to model the correct loading through the tires from the ground. For this reason, the tire model must be accurate. However, tires are made with complex materials, such as rubber, fabric, steel mesh and so on. If we attempt to model this explicitly, the FE model may include more than 100 thousand elements. To use 4 tire models like this in a vehicle model is beyond reality. This is the reason why we developed the simple FE tire models three years ago.

Many automobile makers produce a number of different types of cars, which have different sizes of tire. Also, it is popular to use different size tires for the one type of car. Scaling some base tire made to fit each car is one idea and this method is used widely. To scale the tire model may reduce the precision of the model. The tire structure and materials used in it depend on its size and aspect ratio.

The request for different size of tires made us decide to build the tire library. At the moment 20 sizes of tire model have been made. We think 20 sizes will cover more than 70-80% of the sizes automobile makers require.

The properties required for each size of tire were measured individually. The measurements included 3 types of static test and a cleat passing test. To get the static properties, tires were pushed by a plane plate, a step and an angled step. For the dynamic properties, a rotating drum with small cleat was used.

We started by making an original tire model as used by a tire maker. The original models are made by following our sequence to make a very complex model based on CAD data and our material database. After making the original models, we simplified the models to be suitable for durability simulations. We have previously reported the method we used at the international DYNA conference held two years ago.

We have been trying to simulate some scenarios with our simplified tire model. For example, we know that the robustness of the tire model during a calculation can be as important as it's precision. We had to improve the models for this reason. By adding solid elements and modifying the material models, we made the tire models suitable not only for durability simulation but also crash simulations.

APPROACH

Currently there are many kinds of specifications for a tire requested from automobile makers. Tire makers will have to perform tests to check their tires. It is natural for a tire model to be requested with the same specifications as the real tire. If we have 10 test results, we need to correlate the FE tire models to 10 test results. This will result in produce of complex original model.

We selected three types of tests as shown in figure 2. Those 3 tests were based on following specifications;

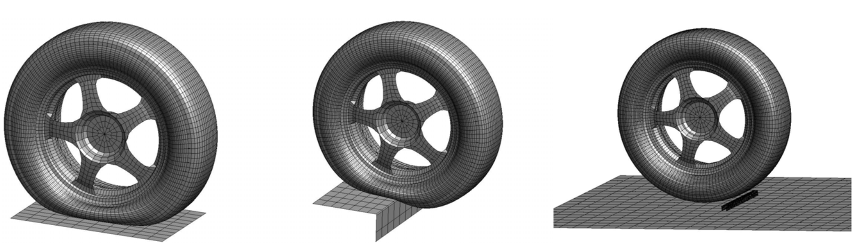

Figure 2. Correlation Tests

Pushing statically with a plane plate (vertical stiffness test) :

This is one of fundamental tests for tire models. After getting good correlation, lateral stiffness is usually inspected as well.

Pushing statically by step :
This test is to check the property of tire passing a step or hitting a curb.

Passing cleat test (drum test) :
This type of test was selected for correlating dynamic properties. The rotating drum test is popular amongst tire and automobile makers. The cleat size, which has a 20mm square section, is slightly larger than ones used by tire makers.

The tire model creation starts with making a complex original tire. Simple tire models were generated from these original tire models. We used the same method as we reported at DYNA conference held in 2000.

The tire model library will include more than 20 sizes of tires. We picked up one size and checked it with many tests to confirm the correlation and robustness. The tire structure is shown in figure 3 (Figure 4 is previous model we reported). The tire models showed good results for the 3 tests explained above, but there was an robustness problem which arose around the side wall and bead. The side wall of the tire was modeled using shell elements, which have a stiffness corresponding to the original tire. We checked the tire model robustness by impacting to an offset barrier model used in crash simulations. Of course this test is for the model’s suitability for ODB (offset deformable barrier) crash simulations. When the side wall is compressed and self-contact is activated, the shell elements deformed abnormally and the calculation dropped. Various contact definitions, material models, side wall/rim shape were tested one after another.

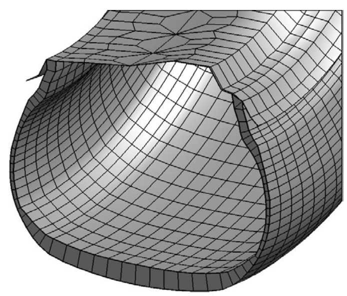

Figure 3. Section of Tire Model

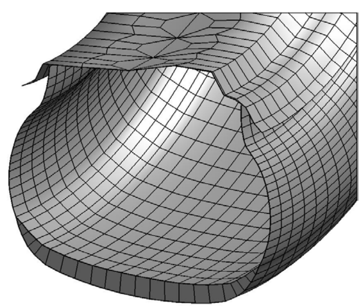

Figure 4. Previous FE Tire Model

We found it was necessary to prevent the side wall shell elements from deforming abnormally. The shell elements don’t have a high bending stiffness and are easily folded. Solid elements were added to the outside of the side wall shell elements using the same nodes. Mooney-Livlin rubber is used as the material model because the stress increases exponentially under high compression.

Now the side wall was modeled using not only shell elements originated in carcass and bead, but also solid elements representing the side wall rubber. The additional solid elements improved the non-linear characteristic of the vertical stiffness especially for the lower aspect ratio tires. The rim and side wall sometimes contact and vertical stiffness is slightly changed. To simulate this, the exact side wall shape is needed and the additional solid elements work well.

Tread, which does not have a tread pattern, also was modeled by solid elements. We did not take into account into the influence of the tread pattern because the pattern depends on the tire brand name, and we were not concerned with the small differences in deflection the tread pattern causes. Before ignoring the tread pattern, we compare the tire model with simple tread pattern to a tire with no tread pattern. Additionally, solid elements for the tread rubber with different stiffnesses were compared. We could not find a considerable difference in the tire model. If we are concerned with very small deflections of around a few mm, tread pattern will be very important. At the moment our target for our tire library is model validity for larger deflections.

We would like to move from tire related things to wheel modelling. Tire models are always used with wheel models. If the tire is deformed very much, the side wall will start to touch on the rim of the wheel. This contact is sometimes found in durability simulations as well as impact simulations. We intend to maintain the precision of our model under high compressions, so we carefully modelled the bead, rim and their connection.

Regarding the wheel model, an elastic-plastic material is used rather than a rigid material. In durability simulation, the spindle loading is measured because it is the starting point of the load path running into the vehicle body. We found that the rigid wheel causes a very spiky spindle load. So we changed the material.

We have tested our tire model for precision and robustness. For robustness, it is very important to remove the possibility of the calculation stopping because of large element deformations. On the other hand, small vibrations when the tire is rotating is one the problems for durability simulation. These requests make the tire models separate into two types of modeling. One is for durability simulation and the other is for crash simulation. They have slightly different material models and contact definitions specific for their use.

DISCUSSION OF RESULTS

Figure 5,6,7 shows one of the results picked up from the tire library. The crash model tire is loaded statically using a plate and a step. The durability model tire was loaded dynamically with the rotating drum and cleat. Good correlation is shown for both tests.
For the static test, loading speed affects the result. If the loading speed is too fast, the vertical stiffness looks higher than reality. So we found a loading speed which does not affect the result.

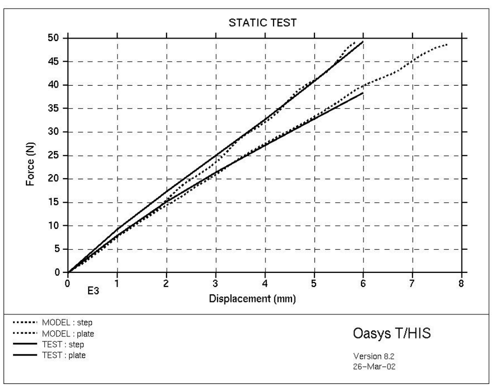

Figure 5. Static Test Result

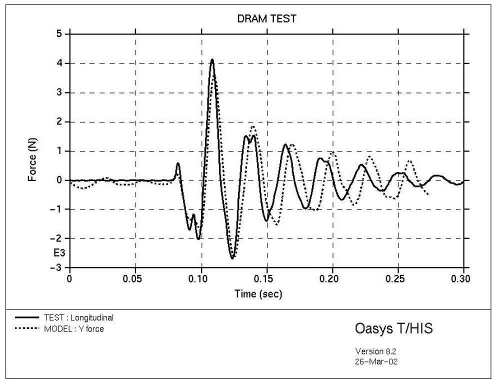

Figure 6. Dynamic Test Result

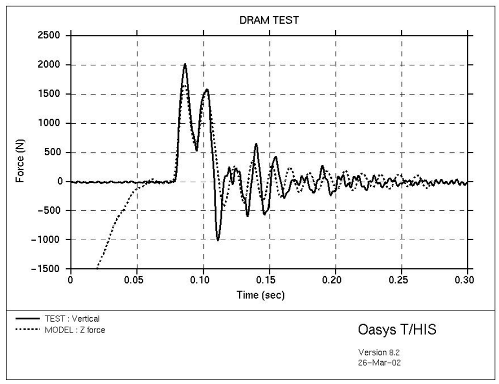

Figure 7. Dynamic Test Result

Our tire models will be used for crash simulations as well as for durability simulations. The robustness of our tire models has been checked by hitting the plate and deformable barrier, which is used for offset frontal crash. Figure 8 shows the results. The idea for using the offset barrier as a robustness test came after we tried to use the model in an ODB analysis. During this analysis, we found that hitting the barrier is a severe condition for the tire models. Our tire models now have the ability to pass those severe conditions.

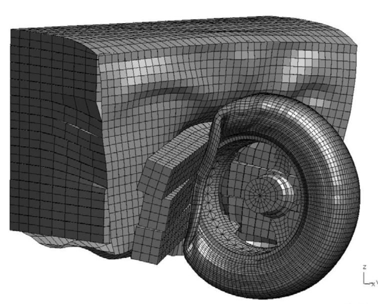

Figure 8. Robustness Test

We checked the influence of the wheel materials. In early durability simulations, FE models included many rigid parts to reduce calculation times. Recent developments in computer technology allow more complex models to be used. We have already noticed the difference between a rigid wheel and a deformable wheel. Figure 9,10,11 shows the difference. Using the deformable wheel, the second peak during longitudinal loading was reduced.

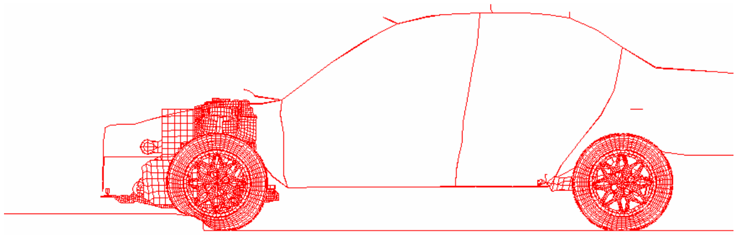

Figure 9. Curb Strike Test Using Rigid/Deformable Wheels

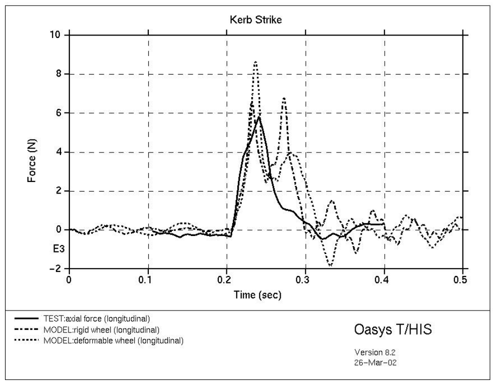

Figure 10. Result of Rigid/Defomable Wheel (Vertical Loading)

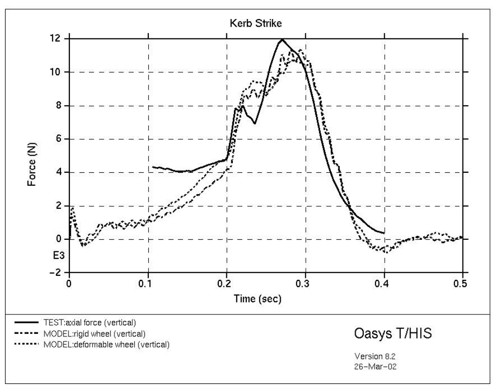

Figure 11. Result of Rigid/Defomable Wheel (Longitudinal Loading)

CONCLUSIONS

We have reported our development of the tire library. We think that continuous development will be needed to improve the model accuracy. At the moment our model is useful as a base model to improve a current FE simulation. The tire FE model library includes more than 20 sizes to help you to find a model without any scaling or additional correlations. Table 1 shows current 24 models.

165/80R13	**185/65R15**	**215/50R17**
175/60R13	**185/70R14**	**215/60R16**
175/60R14	**195/60R15**	**215/65R15**
175/65R14	**195/65R15**	**215/70R16**
175/70R13	**205/60R15**	**225/55R17**
175/70R14	**205/60R16**	**225/60R16**
175/80R14	**205/65R15**	**225/70R16**
185/65R14	**205/65R16**	**265/70R16**

Table 1. Current Tire Model List

As we have already mentioned in the abstract section, there are many types of test requests from our customers. As these tests are added, additional correlation will be needed. We would like to improve our tire models step by step in this manner.

Regarding tire size, not all sizes are represented, however we will be able to add other sizes using the same method as we have been using.

REFERENCES

Shiraishi M.,Yoshinaga H.,Iwasaki N.,Hayashi K., (2000), "Making FEM Tire Model And Applying It For Durability Simulation", 6th International LS-DYNA Users Conference, Detroit.