

A Computer Simulation for Motorcycle Rider-Motion in Collision

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ABSTRACT

Through computer simulation of the motion of a motorcycle rider, as a result of a collision between a motorcycle and car, we have validated the computer simulation results in two cases. In each case a motorcycle hits the side of a running car, one at an angle of 45 degrees and the other at 90 degrees. The simulation software of explicit finite element method (FEM) was selected because of its capability for expressing accurate shapes and deformation. The mesh size was determined by considering the simulation accuracy and calculation time. Then, FEM models of a motorcycle, airbag, dummy, helmet and passenger car were built. To shorten the calculation time, a part of the model was regarded as a rigid body and eliminated from the contact areas. As a result, highly accurate dummy posture and head velocity at ground impact time were simulated in the two cases of collision. Calculation time of the two cases was about 50 hours using a computer with a performance of 14.4 Gflops.

1. Introduction

Honda has been researching studies on protection of motorcycle riders since the 1960's⁽¹⁾. A recent study described one of the rider protection techniques, a motorcycle-mounted airbag system⁽²⁾. In this research, airbag systems including sensors were developed and installed on the GL1500, a large touring model, for actual vehicle collision tests. Such tests require exclusive use of a test facility for long periods of time and are very expensive. It has, therefore, long been desired to develop computer simulation techniques that are usable in motorcycle airbag research. The goal of this study was to establish a collision simulation method that permits behavior estimates until the moment the dummy contacts the ground within a practical length of calculation time.

This report describes the results of two test cases. The reliability of computer simulations of rider motion in collisions with opposing vehicles was examined. The two

cases were collisions of a motorcycle moving at 13.4 m/s into the side of an opposing vehicle moving at 6.7 m/s at angles of 45° and 90°. Figures 1 and 2 show the impact configurations. The accuracy of the simulations were assessed by observing the rider motion parameters of head velocity and torso angle. Methods for reducing calculation time were also investigated while pursuing simulation accuracy.

2. Selection of Simulation Software

Simulation software for collision analysis can be roughly classified into two types: the Multibody type and the FEM type. The software of Multibody type is advantageous due to its short calculation time. The FEM type is more suitable for more accurate crash simulation until the dummy's ground hit, because it can generate the accurate shapes easily,

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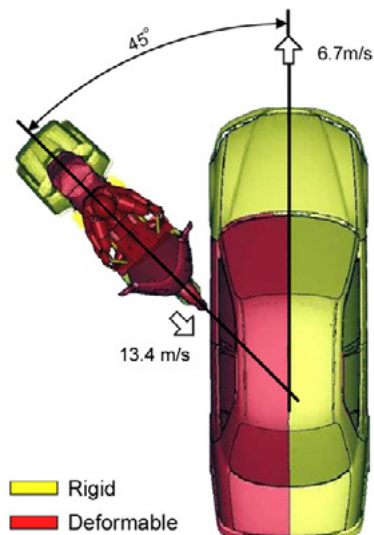


Fig. 1 Impact configuration of 45-degree

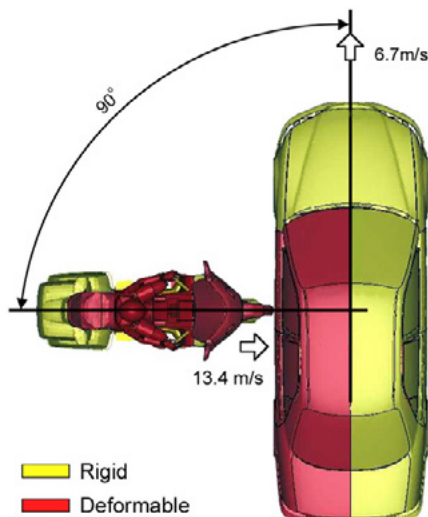


Fig. 2 Impact configuration of 90-degree

deformation and reaction force direction resulting from a deformation. Based on the above reasons, the finite element method, i.e., the explicit FEM software (LS-DYNA), was used for this study.

3. Creation of Model

3.1. Principles on Mesh Size and Model

Models of the motorcycle, airbag, dummy, helmet and the passenger car were handled simultaneously in the computer simulation in this study. Since the number of elements can be very large in this kind of simulation, the mesh size has a large influence on the calculation accuracy and the time needed for the calculation. A finer mesh is desirable for higher calculation accuracy, but the smaller the mesh size, the longer the required calculation time. It is also necessary to avoid having meshes of very different sizes where the models interfere with each other, to obtain the best stability and

accuracy in the calculation. Thus, the mesh size is a critical parameter. The mean mesh size in the dummy model was set as the standard size in this study; meshes were never created smaller than this. The sizes of the various models created are shown in Table 1. The validity of each model was verified in unit tests before the simulation of the motorcycle-opposing vehicle collision.

3.2. Motorcycle Model

The motorcycle model made for this study was exclusively for frontal collision simulations. It accounted for deformation of the front wheel, and the tire model reproduced a certain internal air pressure. Since the steering mechanism is forced to high steering angles at the time of the collision with the opposing vehicle, the model was constructed to reproduce steering. Some motorcycle component models were made deformable where interference with the opposing vehicle or dummy and deformation were expected, and other components were made rigid in order to save calculation time. The resulting motorcycle model is illustrated in Fig. 3. The red portions were deformable, and the yellow portions, rigid.

For validation of the motorcycle model, the results of a simulated collision with a fixed barrier at 13.4 m/s were compared with those of an actual model. Those are shown in Fig. 4. The pitching angle of the body and the deformation results around the front wheel and headlight resembled the actual model well. Figure 5 shows the predicted and test waveforms acceleration of the body center of gravity. Overall, the waveforms coincide well.

3.3. Airbag Model

The airbag is supported by the motorcycle body through a connection to the retainer box and two belts behind the airbag. There are several tethers inside the airbag to help maintain its intended shape. These structures are essential for a motorcycle airbag and were modeled in shapes faithful to those of the originals. Figure 6 shows the airbag model.

Table 1 Numbers of nodes and elements

	Motorcycle	Dummy	Airbag	Opposing Vehicle	Total
Number of nodes	25 618	34 962	4 768	178 329	243 677
Number of elements	34 821	35 567	4 692	168 916	243 996

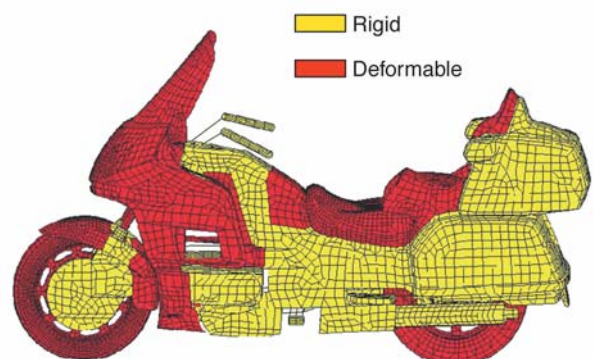


Fig. 3 Motorcycle model

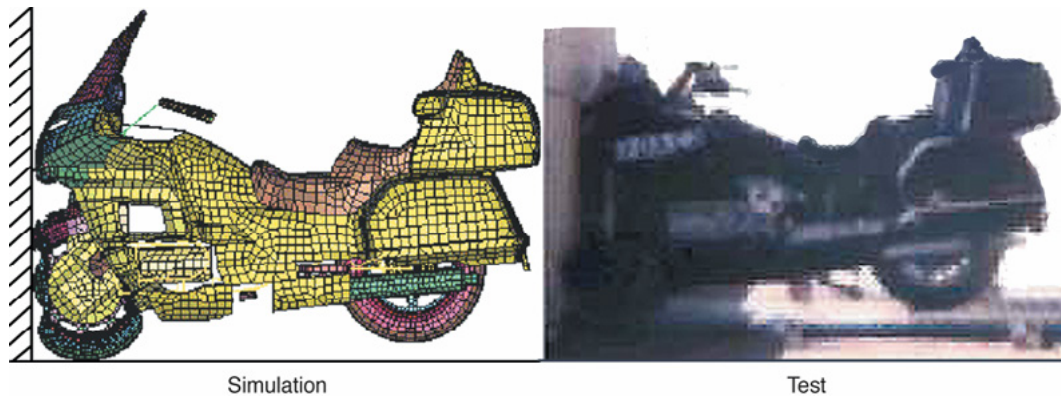


Fig. 4 Comparison of motorcycle motion between the simulation and the test in a rigid barrier collision

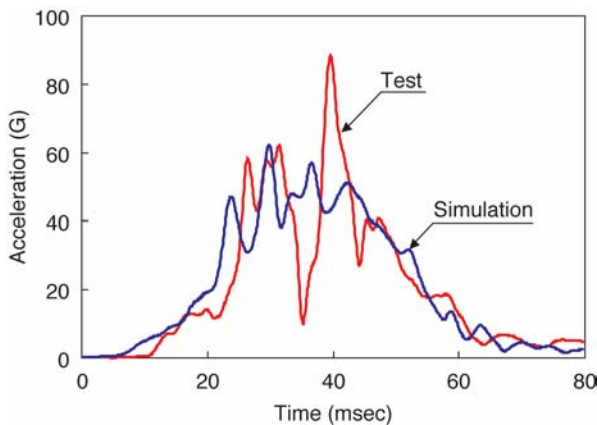


Fig. 5 Comparison of acceleration of motorcycle's center of gravity

For validation of the airbag model, the pressure waveforms during a static inflation of the test and simulation were compared; the waveforms are shown in Fig. 7. A high pressure spike occurred at the beginning of the test, but this was not indicated in the simulation. This is because folding

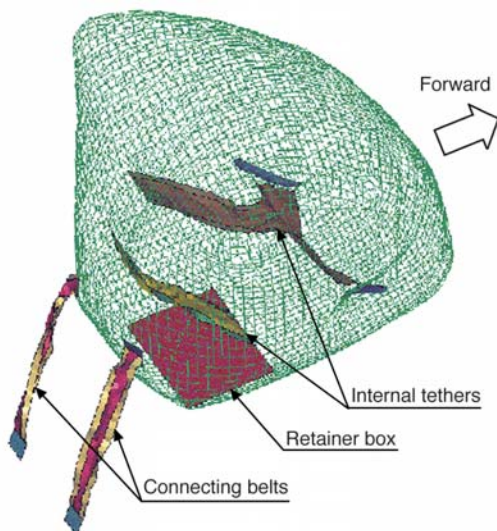


Fig. 6 Airbag model

of the airbag was not expressed in the model. Reproduction of this phenomena at the initial stage of inflation was not necessary in the present airbag model, which was made for assessing its effect on the rider after unfolding. Thus, folding of the airbag and the pressure spike at the initial stage of inflation were not included in the model.

3.4. Dummy

The dummy model has to be a deformable model because any part of the dummy body is subjected to a potential impact. Therefore, the LS-DYNA hybrid III 50th percentile model was selected as the base. It was created identically with the MATD dummy specified in ISO 13232⁽³⁾. The dummy model is shown in Fig. 8. The parts that were modified are shown in red; these were the head, neck, chest, abdomen, pelvis and legs. The model characteristics met the ISO 13232 criteria. The dummy also wore boots meeting ISO 13232.

3.5. Helmet Model

The helmet consists of a shell and a liner. The shell is a hard exterior and the liner is a shock-absorbing interior. Both the shell and liner were modeled with deformable elements. The helmet model is depicted in Fig. 9.

The helmet model was checked for validity according to JIS T8133-2000⁽⁴⁾ for the pileum, temporal, forehead and occipital regions. As an example of such verifications, both acceleration determined by test and simulation when the pileum of the helmet was dropped from a height of 1 m are compared in Fig. 10. The peak acceleration and the timing match well; the reaction forces of the shell and liner were well reproduced.

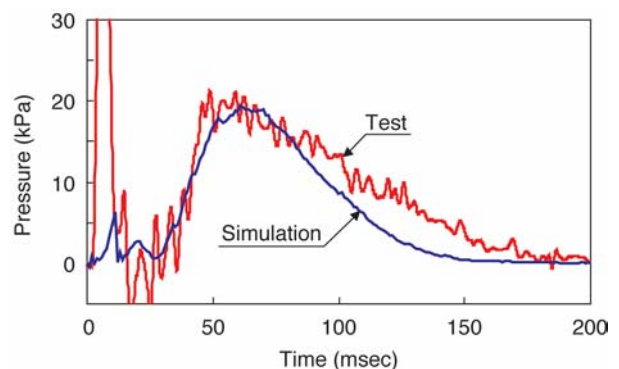


Fig. 7 Comparison of pressure in airbag inflating test

3.6. Opposing Vehicle Model

Rigid models were used for the portions of the opposing vehicle body where no impact with the motorcycle, deformation due to impact with the motorcycle, or contact with the dummy was expected. This was in order to reduce calculation time, as in the motorcycle model. Since this study concerned collisions with the side panel of a moving passenger car, the portions of the frontal part of the vehicle body and half of the vehicle body on the opposite side from the motorcycle were rigid models. The red portions of the model illustrated in Fig. 11 were deformable and the yellow portions were rigid. The results of the simulation and the test were compared to verify validity of the opposing vehicle

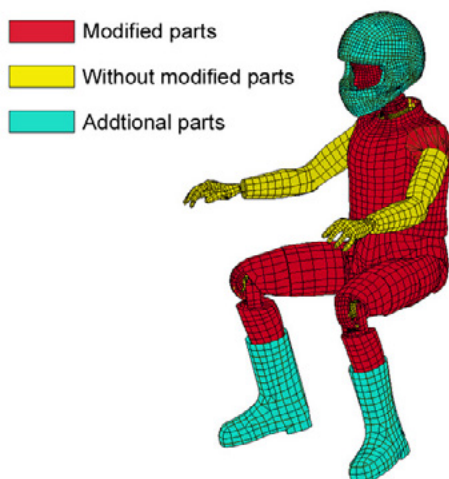


Fig. 8 Dummy model

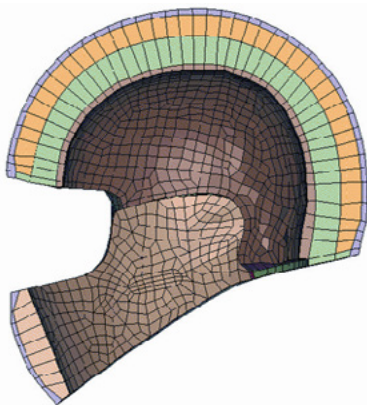


Fig. 9 Helmet model

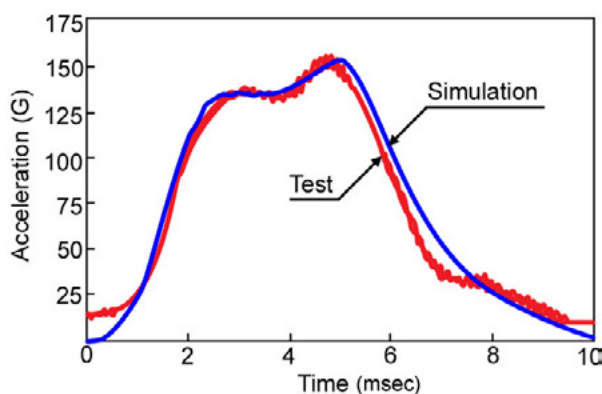


Fig. 10 Comparison of acceleration in helmet drop test

model. Figure 12 shows the comparison of velocity on the side of the vehicle body that moves while deforming. The value of peak speed and the timing were well reproduced in the simulation.

4. Method for Reduction of Required Calculation Time

Several investigations were carried out on methods for reducing required calculation time. It was found that the locations with the highest weights of required calculation time were the locations searched for object-to-object contact (impact) and the locations undergoing deformation⁽⁵⁾. These *contact search* and *deformation* calculations are carried out at every step for every model where they have been defined, whether or not there actually has been contact or deformation. Thus, an effective way to reduce required calculation time without degrading calculation accuracy is to eliminate the *contact search* and *deformation* calculations for locations which see no contact or deformation throughout the collision and for time domain where, temporarily, no contact or deformation occur during collision. A limited definition of contact and changing to rigid modeling were used as these methods in this study.

The limited definition of contact was performed in two stages. First, contact was not defined between locations and components that had no possibility of contact. In other words, contact was only defined between locations where it was expected. The second stage was to limit the time domain where contact was defined. For example, contact was not defined for internal components of the opposing vehicle from

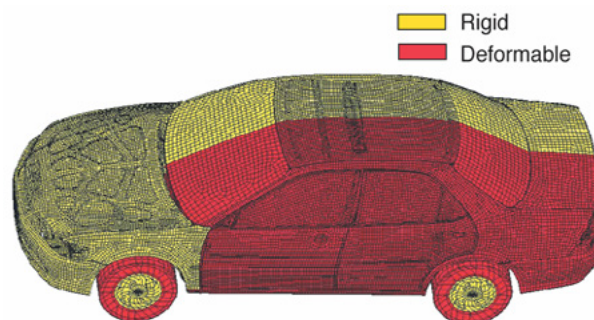


Fig. 11 Opposing vehicle model

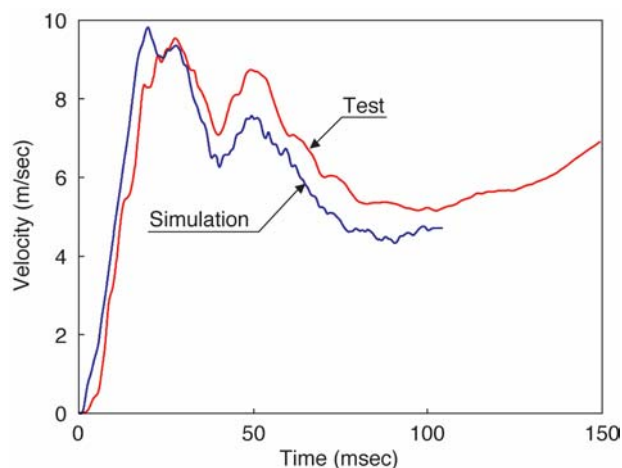


Fig. 12 Comparison of absolute velocity on the side of vehicle body in side impact test

0.300 s after start of calculation, i.e., after start of collision. Also, contact between the passenger car and the dummy was not defined until 0.050 s after the start of calculation. These two means were quite effective in shortening required calculation time.

The change from deformable to rigid modeling was also performed in two stages. In the first, prior to calculations, locations in the motorcycle and opposing vehicle, which were not expected to suffer collision or deformation, were modeled as rigid. Secondly, all the opposing vehicle models were considered as a rigid model after the halfway of the calculation process. This employment of a rigid model is applicable at the time both the motorcycle and the dummy disengage from the opposing vehicle. In the simulation of the two examples reported here, all the deformable portions of the opposing vehicle were changed to rigid at 0.300 s after the start of calculation. As the dummy does not disengage from the motorcycle until the very end of collision, a rigid model is not employed for the motorcycle in the process of simulation calculations. The employment of a rigid model for the opposing vehicle was very effective in the reduction of calculation time because the model size was large.

Overall, the calculation time was reduced by approximately 30% as a result of both the above mentioned secondary stages effects.

5. Simulation Results and Validation

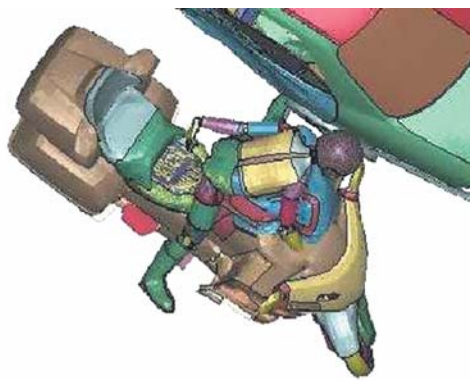
Simulations for the aforementioned two examples (Figs.1 and 2) were carried out on an identical model, and the head velocity and the torso angle from the simulation

were compared to those from the actual vehicle collision test. The coefficients of friction between the motorcycle and the opposing vehicle and between the rider and the airbag were investigated and selected during the validation of the correlation between the actual and numerical models. These characteristics are difficult to measure directly in real objects.

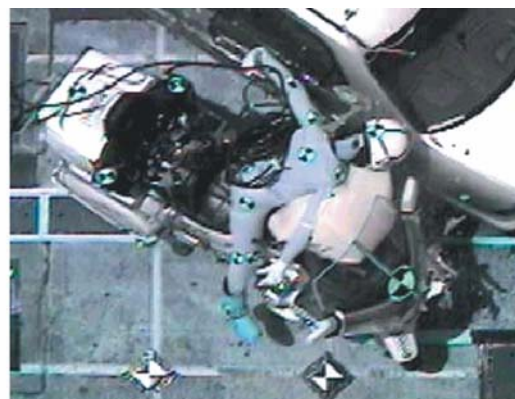
The results obtained in the simulations are explained below. Figures 13 and 15 show the test results and simulation results where the dummy is in contact with the airbag after the motorcycle has collided with the opposing vehicle at 45-degree and 90-degree angles. Figures 14 and 16 show the posture of the dummy just before falling on the ground in the same collision examples. The data from the simulation and actual test for the head velocity and torso angle at time of contact with the ground are shown in Table 2. Both in the 45-degree collision and in the 90-degree collision, the simulation results have coincided with the actual vehicle collision tests. Since the opposing vehicle model was changed to rigid after 0.300 s, the opposing vehicle behavior is not verified. A computer with a theoretical performance of 14.4 Gflops was used for calculation from collision until contact of the dummy with the ground; the required calculation time was 47 hours for the 45-degree collision case and 52 hours for the 90-degree case.

6. Conclusion

- Highly accurate simulations have been attained for dummy behavior (until falling on the ground) in the two cases of collision using the explicit FEM software.
- Rigid models and limited areas of contact were effective

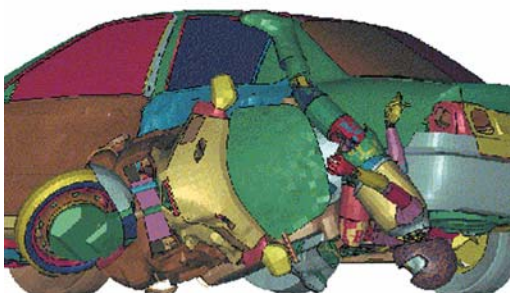


Simulation



Test

Fig. 13 Comparison of rider and motorcycle motion in 45-degree collision



Simulation



Test

Fig. 14 Comparison of rider motion during fall in 45-degree collision

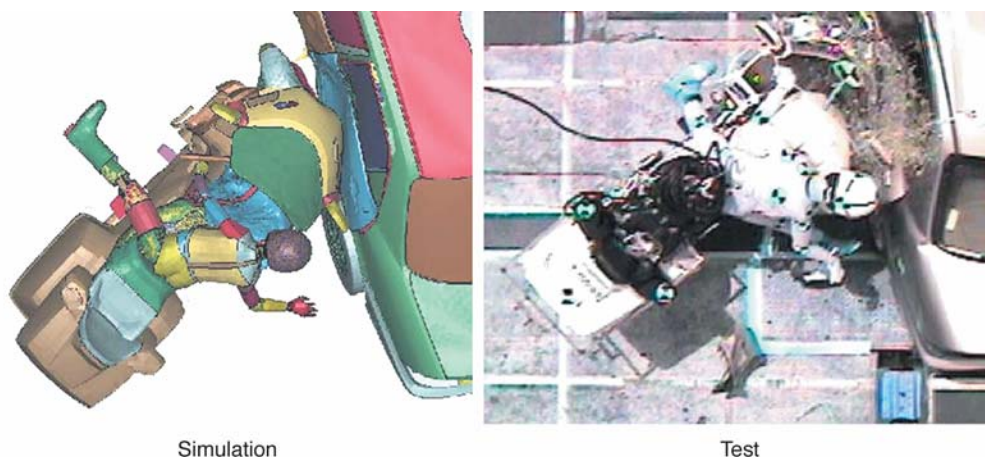


Fig. 15 Comparison of rider and motorcycle motion in 90-degree collision

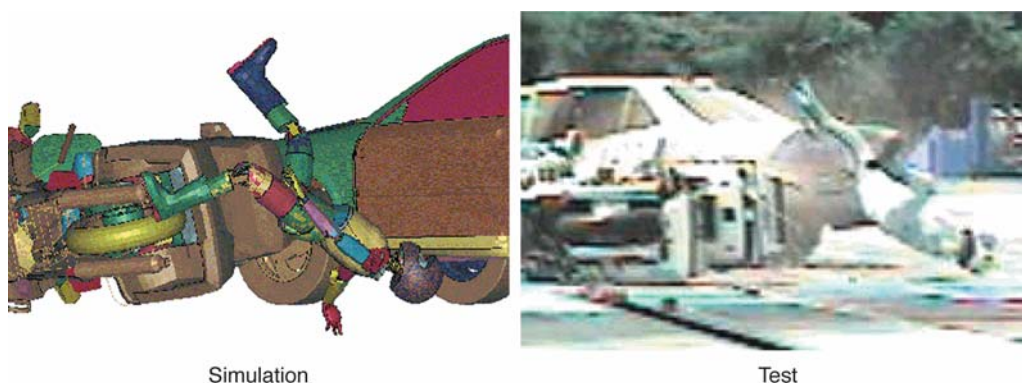


Fig. 16 Comparison of rider motion during fall in 90-degree collision

Table 2 Comparison of torso angle and head velocity of dummy

45 degree collision

		Test	Simulation
Torso angle	deg	41	48
Head velocity	m/s	7	6

90 degree collision

		Test	Simulation
Torso angle	deg	31	34
Head velocity	m/s	4	5

methods for reducing required calculation time.

- The required calculation times were 47 hours for the 45-degree collision and 52 hours for the 90-degree collision.

Future research will focus on establishing methods for assessing rider injuries and for reducing calculation time.

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