

A Computer Simulation for Motorcycle Rider Injury Evaluation in Collision

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ABSTRACT

Honda has been developing computer simulation technology, capable to predict the injury levels, in tests from the start of a collision until the point where the dummy strikes the ground. This research shows the correlation between the computer simulations and full scale impact tests as specified in ISO/CD 13232. The results validate that computer simulation can predict the injury levels, from the start of collision until the point where the dummy strikes the ground. The performance and effectiveness of the airbag system for the GL1800 were evaluated in 200 impact configurations using the computer simulation specified in ISO/CD 13232. The results showed that the total average benefit was 0.048 and the total average risk was 0.004. The relative impact speed which demonstrated the highest effectiveness was 20-25 m/s.

1. Introduction

Honda has been conducting research since the 1960s⁽¹⁾ on enhancing motorcycle rider protection at the time of collision. In recent years, research has been proceeding on the feasibility of a motorcycle airbag as a way of reducing injury levels. In this research, Honda has test-produced an airbag system with impact detection sensors and mounted it on the GL1500, a large touring model. This motorcycle has been used in collision tests. Results of these tests were reported at the ESV conferences in 1998⁽²⁾ and 2001⁽³⁾. One of the findings of this research was that there are many cases in which the dummies' measured injury level influenced by airbags when the dummy struck the ground.

ISO 13232⁽⁴⁾ is for Motorcycles Test and Analysis Procedures for Research Evaluation of Rider Crash Protective Devices Fitted to Motorcycles. It specifies that evaluation of rider protection device performance shall be done by computer simulation, in addition to impact tests using actual motorcycles (hereinafter referred to as

full scale impact tests). It is specified that computer simulation shall cover a 0.5 second time period, from the start of impact to the point where the dummy hits the opposing vehicle (hereinafter referred to as the primary impact sequence). However, after consideration of the aforementioned results, it was decided that when evaluating an airbag's rider protection performance by computer simulation, it is necessary to evaluate injury indices up to the point when the dummy strikes the ground.

It was decided, therefore, to establish a computer simulation technology capable of evaluating injury indices from the start of collision to the point where the dummy strikes the ground (hereinafter referred to as the entire impact sequence). Explicit FEM software, chosen for the analysis, could easily express shapes and reproduce deformation of vehicles. Mesh sizes, which greatly affect calculation time and accuracy with FEM software, were examined and decided upon. Using the selected mesh size, models were created of the motorcycle, airbag, dummy and opposing vehicle, and computer simulation calculations were performed. From these

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calculations, the compliance of dummy motion, up to the point of striking the ground, was evaluated using dummy head velocity and torso angle.

As a result, a computer simulation technique, capable of reproducing test results with high accuracy, was successfully created. At the same time, a very effective technique for reducing calculation time was contrived. These results were reported at the 2003 Small Engine Technology Conference⁽⁵⁾. This research endeavored to use the previously described computer simulation technology to make it possible to evaluate injury indices up to the point when the dummy strikes the ground. The correlation of results of computer simulation and full scale impact tests were investigated for 12 cases in seven impact configurations, as specified by ISO/CD 13232. The results confirmed that this computer simulation technology is capable of evaluating injury indices, from the start of collision to the point when the dummy strikes the ground.

2. Evaluation of Injury Indices to When the Dummy Strikes the Ground

The research attempted to further develop the computer simulation technology capable of reproducing dummy motion, up to the point of striking the ground with good accuracy, and create a computer simulation technology that can be used for evaluating injury indices, up to the point when the dummy strikes the ground. This project, and the tests to verify accuracy, covered seven basic impact configurations specified by ISO/CD 13232. These impact configurations are shown in Fig. 1.

Simulations were performed with and without airbags. However, impact configuration No. 1 and No. 4, with airbags, shown in Fig. 1, were not included in the scope of correlation because the airbag did not deploy in the full scale tests in these configurations. Therefore, the computer simulation correlation scope included 12 cases in seven impact configurations.

Full scale impact test speeds were set somewhat higher than the speeds defined by ISO/CD 13232, and evaluation was done under these more severe conditions. The computer simulation impact speeds were the same as those of the full scale impact tests.

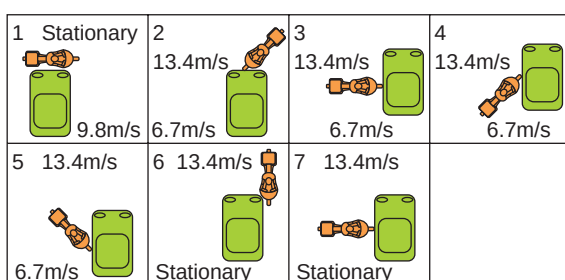


Fig. 1 Full scale impact test configurations

3. Model Creation Methods

3.1. Motorcycle Model

The motorcycle model previously used to validate the motion of dummies striking the ground was the GL1500, a large touring motorcycle. In subsequent airbag research, the GL1800 replaced the GL1500 as the motorcycle model. Therefore, a GL1800 motorcycle model was also created for the computer simulation. The model was created using a procedure reported in 2003 SETC⁽⁵⁾. The motorcycle model was to be entirely deformable, in order to enhance calculation accuracy. The motorcycle model is shown in Fig. 2.

3.2. Opposing Vehicle Models

Models of the opposing vehicle were additionally created in accordance with the diversity of impact configurations. Because local rigidity of the opposing vehicle model is very effective for reducing calculation time, rigidity was given to parts that would not come into contact with the motorcycle or dummy, and would not deform. This resulted in the creation of four different opposing vehicle models, each with different rigid parts. The model used was chosen according to the impact configuration. The opposing vehicle models created are shown in Figs. 3 to 6. The 1998 - 2001 Honda Accord four-door sedan with Japanese market specifications was used as the opposing vehicle model; Table 1 gives the specifications.

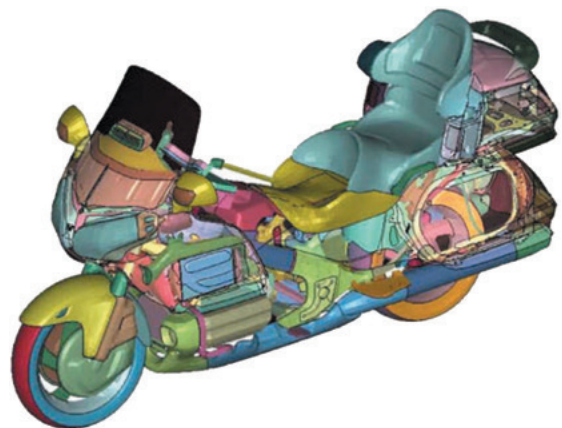


Fig. 2 Motorcycle model

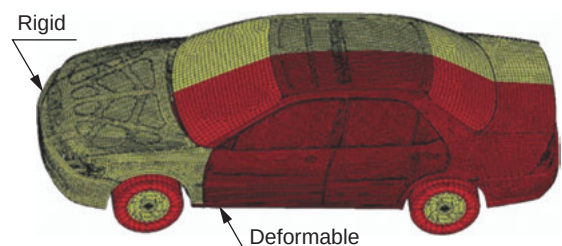


Fig. 3 Opposing vehicle model for side impact case



Fig. 4 Opposing vehicle model for front-side impact case

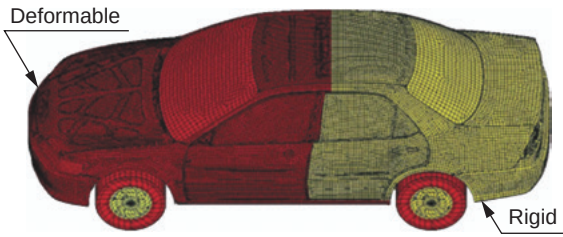


Fig. 5 Opposing vehicle model for front impact case

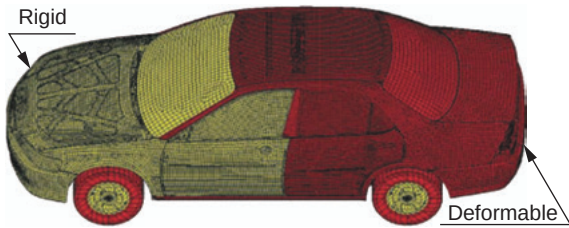


Fig. 6 Opposing vehicle model for rear impact case

Table 1 Specifications of opposing vehicle

Manufacturer		Honda
Model		Accord, Japan
Year		1998-2001
Mass (average)	(kg)	1300
Overall length	(mm)	4635
Overall width	(mm)	1695
Overall height	(mm)	1420
Wheelbase	(mm)	2665
Engine displacement	(cm ³)	1997

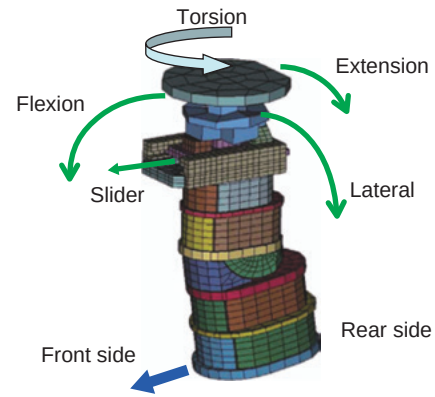


Fig. 7 Neck model of MATD (ISO/CD13232)

Table 2 Neck static characteristics of MATD model

Characteristics	Load	Required value	CAE model
Flexion angle	20 kgf	17.6 ± 2.6 deg	15.9 deg
Slider displacement	20 kgf	14.0 ± 3.0 mm	13.8 deg
Extension angle	20 kgf	30.9 ± 4.6 deg	27.7 deg
Lateral angle	20 kgf	28.7 ± 4.3 deg	25.8 deg
Torsion angle	3.2 kgf	41.5 ± 6.2 deg	43.6 deg

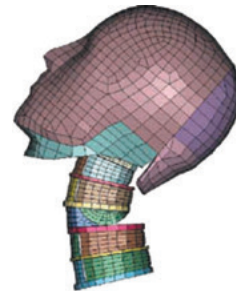


Fig. 8 Dynamic extension position

3.3. Dummy Model

The dummy model was based on the hybrid III 50th - percentile model for LS-DYNA⁽⁶⁾ and conformed to the MATD dummy specifications as defined in ISO 13232. The neck injury evaluation method, undefined in ISO 13232 (1996), has been defined in ISO/CD 13232 (2002), so the model followed ISO/CD 13232 (2002). The model created is shown in Fig. 7. The bending characteristics of the neck model were conformed to both the static and dynamic characteristics defined in ISO/CD 13232 (2002). The results of static correlation are shown in Table 2. Figures 8 to 18 show the correlation results for each of the dynamic characteristics, which are extension, flexion, lateral and torsion. Based on the above results, it was decided that the computer simulation neck model created for this research was usable.

3.4. Airbag Model

An airbag model was created based on the airbag designed for the GL1800. The V-shape of the back of the airbag to hold the rider, and the connecting and supporting belts from the back of the airbag to the motorcycle frame, were modeled. The computer simulation model of the airbag mounted on the GL1800 is shown in Fig. 19.

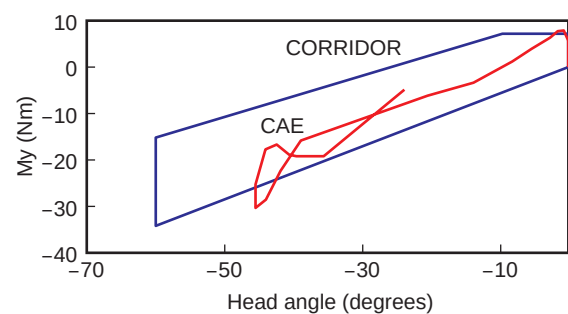


Fig. 9 Dynamic extension moment vs. head angle

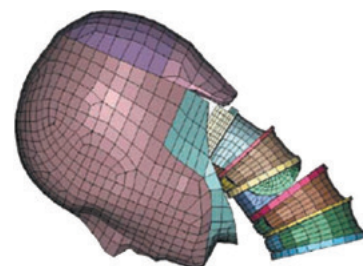


Fig. 10 Dynamic flexion position

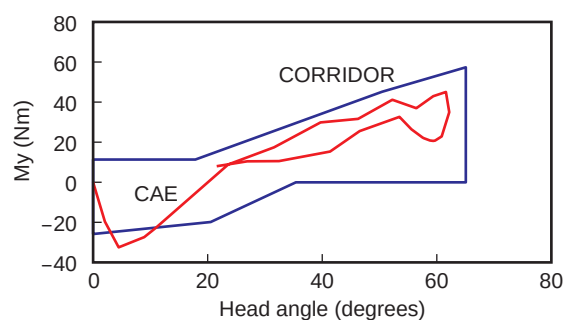


Fig. 11 Dynamic flexion bending moment vs. head angle

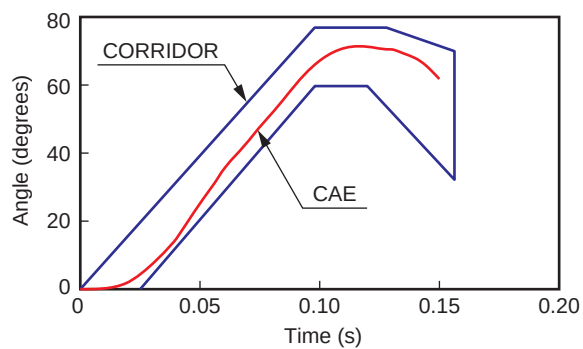


Fig. 15 Dynamic lateral head angle vs. time

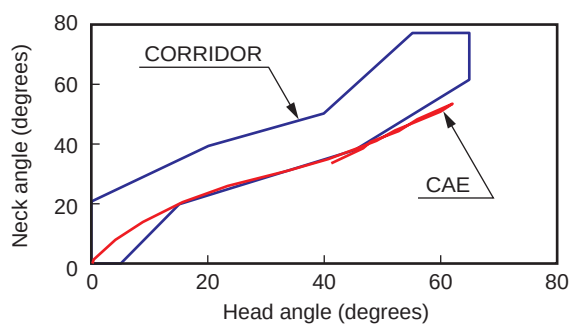


Fig. 12 Dynamic flexion neck angle vs. head angle

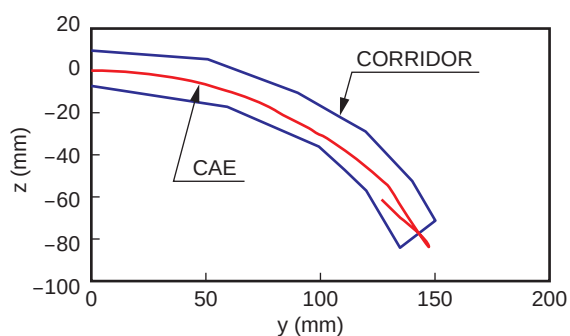


Fig. 16 Dynamic lateral head center of gravity position

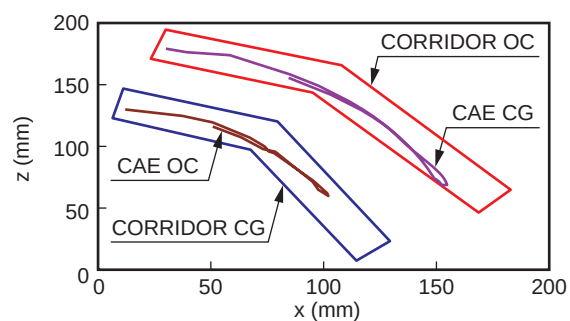


Fig. 13 Dynamic flexion occipital condyle and head center of gravity position



Fig. 17 Dynamic torsion position

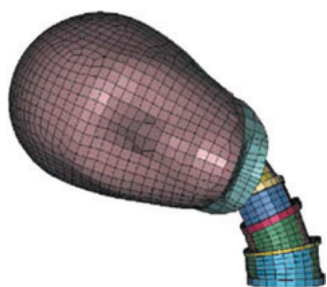


Fig. 14 Dynamic lateral position

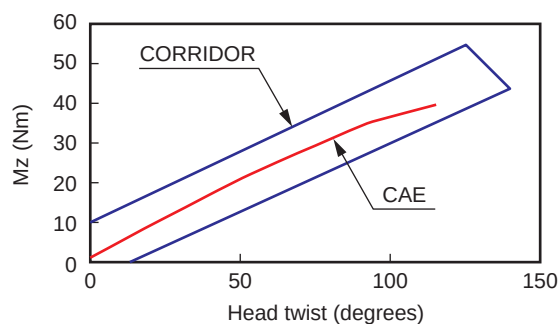


Fig. 18 Dynamic torsion stiffness

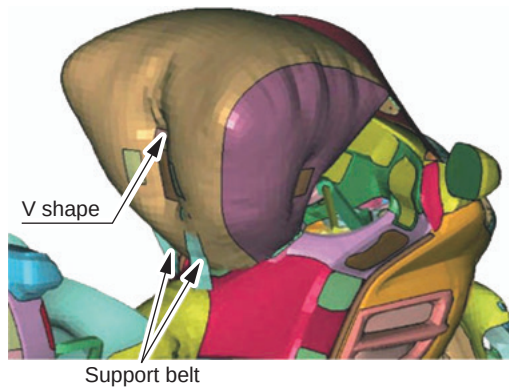


Fig. 19 Airbag model

4. Methods of Enhancing Model Accuracy

Each model created requires high accuracy to enable the evaluation of injury up to the point where the dummy strikes the ground. As the first step in this process, parts which can be predicted to deform during collision were faithfully modeled as far as possible. As the second step, tests were conducted to determine characteristics under simple conditions, such as the unit test defined in ISO/CD 13232 (2002), and rigid barrier impact tests using motorcycles and opposing vehicles. Simulation models and some calculation factors were adjusted so that the simulations would conform to the actual tests with high accuracy.

As the final step of validation, model accuracy and some calculation factors were modified when confirming the correlation with the test results in the 12 test cases using seven impact configurations defined in ISO/CD 13232. Some factors not included in the simple phenomena of the unit tests, or the rigid barrier tests, were included among the actual vehicle collision phenomena, which are more complex. These factors include friction properties as well as detailed structural parts of the motorcycle and the opposing vehicle, which had been eliminated in prior simulation, in order to reduce calculating time. The accuracy with respect to these factors was enhanced in the process of confirming correlation with the seven impact configurations.

The accuracy of component models of the side of the opposing vehicle and frontal part of the motorcycle were enhanced in the impact configurations No. 3, No. 5 and No. 7, shown in Fig.1, in which the motorcycle collides with the side of the opposing vehicle. Next, using impact configuration No. 2, shown in Fig.1, in which the motorcycle collides with the front of the opposing vehicle, the accuracy of the model of the front part of the opposing vehicle was enhanced. In impact configurations No. 4 and No. 6, shown in Fig.1, the accuracy of models of the front side part of the motorcycle and the opposing vehicle was enhanced, while in impact configuration No. 1, the accuracy of the model of the side of motorcycle was enhanced.

5. Correlation of Evaluated Injury Indices

The correlation was conducted using the dummy injury indices of 12 test cases of seven impact configurations. Figure 20 shows the head HIC injury index values in the primary impact sequence, while Fig. 21 shows the HIC values more than 0.5 seconds after the start of collision, up to the point when the dummy strikes the ground (hereinafter referred to as the secondary impact sequence). The r^2 correlation coefficient in the primary and secondary impact

sequences was 0.94 and 0.77, respectively.

Figure 22 shows the maximum compression ratios on the chest in the primary impact sequence. Because the airbag takes the primary impact, this is an important factor. The r^2 correlation coefficient was 0.62.

Table 3 shows a comparison between the simulation results and the full scale impact test results for leg fractures. The conforming rate of the simulation results and the test results was 96% for the femurs and 100% for the knees and tibias.

From the results above, it was decided that this simulation technology enables one to evaluate the dummy injury indices, from the start of impact to the point in time when the dummy strikes the ground. Therefore, we considered that this computer simulation makes it possible to evaluate the benefits and risks of the airbag system in the 200 impact configurations defined in ISO/CD 13232.

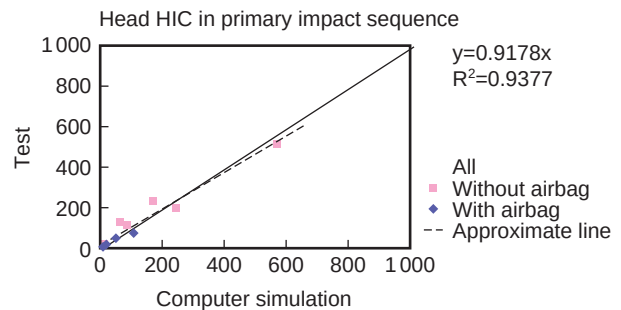


Fig. 20 Correlation of HIC at primary impact sequence

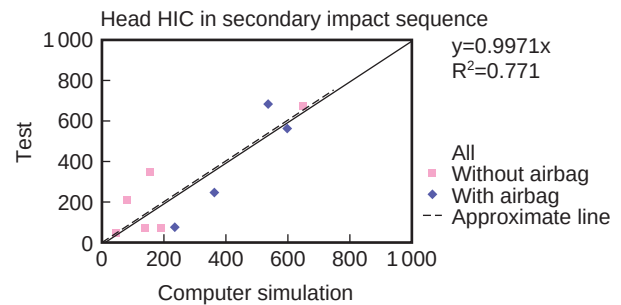


Fig. 21 Correlation of HIC at secondary impact sequence

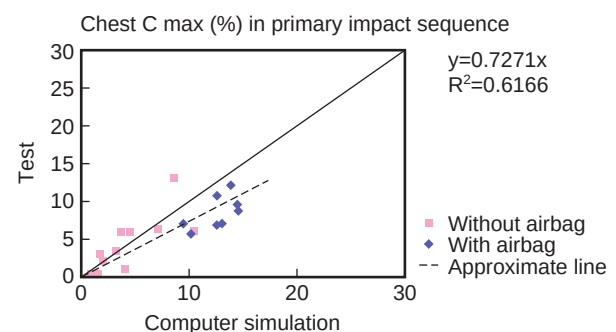


Fig. 22 Correlation of chest sternum compression at primary impact sequence

Table 3 Correlation of leg injury for entire impact sequence

Femurs		Full scale tests		Corrected percentage
		Fracture	No fracture	
Simulations	Fracture	0	1	96%
	No fracture	0	23	

Knees		Full scale tests		Corrected percentage
		Fracture	No fracture	
Simulations	Fracture	0	0	100%
	No fracture	0	24	

Tibias		Full scale tests		Corrected percentage
		Fracture	No fracture	
Simulations	Fracture	1	0	100%
	No fracture	0	23	

6. Evaluation of Injury Reduction Effectiveness of Airbag for GL1800

ISO/CD 13232 defines the methodology for conducting the computer simulation of 400 impact cases, which are 200 impact configurations with and without the proposed rider crash protective device, and thereby determining the benefit and risk of that device.

Figure 23 shows 25 impact configurations defined by different combinations of relative heading angles and contact points. Additionally, the differences in impact speeds are defined in ISO/CD 13232. In combination, the number of impact configurations grows to 200.

Those of the 25 basic configurations that are marked with an X were omitted from simulation because it was judged that the airbag would not deploy, or it would deploy but did not influence the motion of the rider or the injury indices. Those configurations marked with a triangle were omitted from simulation because it was judged that the airbag would not deploy because of the impact speed. In the omitted configurations, the injury indices were defined as being the same, whether or not there was an airbag. Consequently, the final calculations used 121 impact configurations and 242 simulation cases.

7. Results of Airbag System Evaluation by Computer Simulation

Computer simulations were run for 121 impact configurations and 242 simulation cases.

The airbag's injury reduction performance was evaluated based on the methodology of ISO/CD 13232. The results quantified and characterized the effectiveness of the airbag system at reducing injury level in the various impact configurations.

7.1. Rider Injury Reduction Effectiveness

Figure 24 shows the influence the airbag has on injury during the primary and secondary impact sequences. The vertical axis represents NIC values, where an NIC of 0 indicates that there is no injury and 1 is the equivalent of one fatality. Figure 24 shows the total average benefit and total average risk in the primary impact

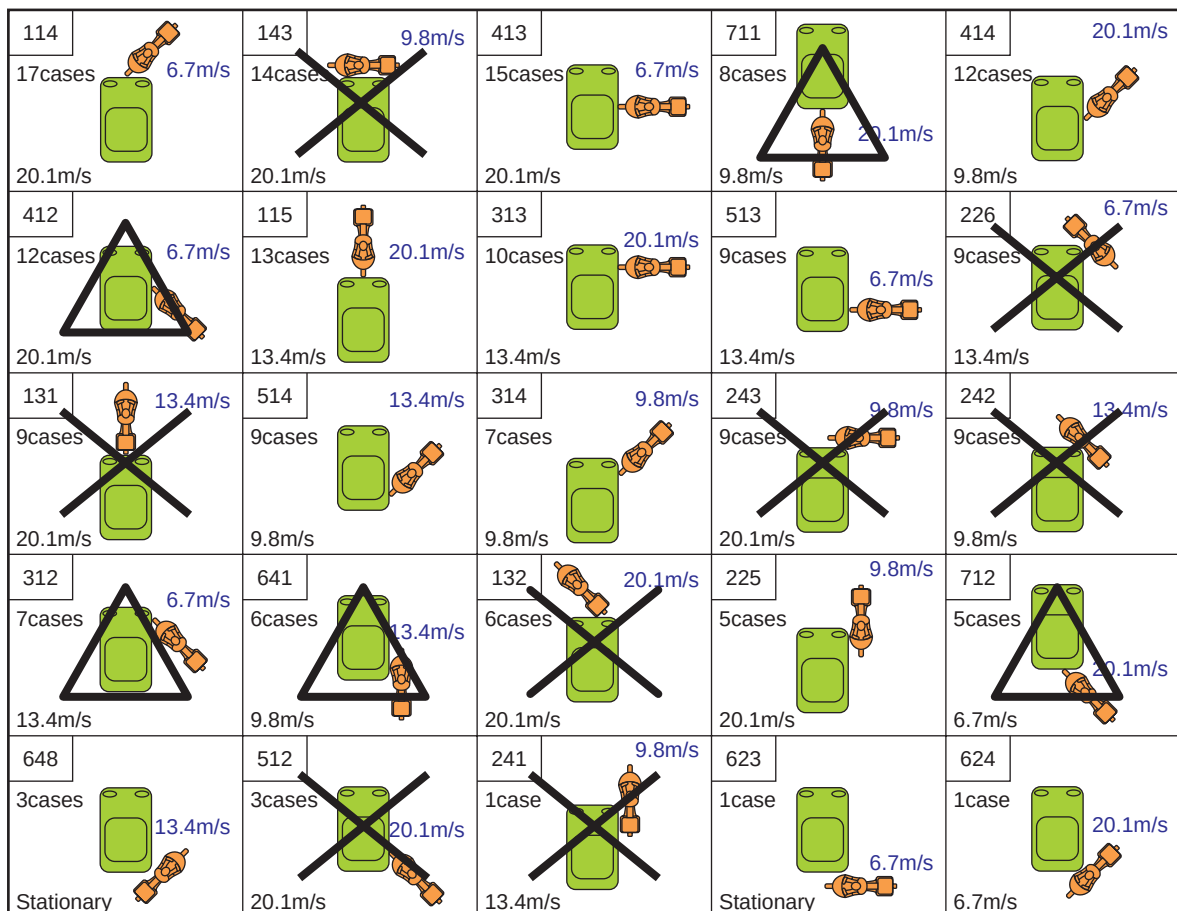


Fig. 23 Impact configurations for computer simulation

sequence. The total average benefit is 0.038 and the total average risk is 0.001. The ratio of risk to benefit is 0.026. The average net benefit is 0.037.

Figure 24 shows the total average benefit and total average risk in the secondary impact sequence. The total average benefit is 0.022 and the total average risk is 0.011. The ratio of risk to benefit is 0.500. The average net benefit is 0.011.

Thus, the injury reduction effect from the airbag is greater when the rider impacts the opposing vehicle than when the rider strikes the ground.

Figure 25 shows the total average benefit and total average risk in the entire impact sequence, encompassing both the primary and secondary impact sequences (i.e. from the start of collision until the point where the dummy strikes the ground). The total average benefit is 0.048 and the total average risk is 0.004. The ratio of risk to benefit is 0.083. The average net benefit is 0.044. From these results, it was judged that the airbag system has appropriate injury index reduction performance.

7.2. Influence of Impact Speed

The average net benefit values were compared by impact speed. Figure 26 shows the results. Impact speed in this case refers to relative speed. When the motorcycle collides with the side of the

opposing vehicle, the speed of the motorcycle is used as the relative speed. When it collides head-on with the front of the opposing vehicle, the combined speed of the two vehicles is used as the relative speed. When it collides with the rear of the opposing vehicle, the speed of the motorcycle minus the speed of the opposing vehicle is used. When colliding with the front or rear of the opposing vehicle, and the impact configuration is angled, the impact speed of the opposing vehicle is reduced in proportion to the angle of impact.

For instance, in configuration No.2 of Fig.1, the motorcycle collides with the front of the opposing vehicle at an angle of 45 degrees. The relative impact speed in this case was calculated as “13.4 m/s (motorcycle speed) plus 6.7 m/s (opposing vehicle speed) times $\cos 45^\circ$.”

Figure 26 verifies the benefit of the airbag for the GL1800 from the low to high speed ranges, demonstrating that the airbag was effective. The highest benefit appears at the relative impact speed range of 20 - 25 m/s. Therefore, the effect of injury reduction is significant at a high-speed range.

Figure 27 gives an example of an impact configuration where the effectiveness of airbags in a high-speed range is clearly demonstrated, as based on the above results. Dummy motion during collision of the baseline motorcycle (i.e. the one without an airbag) is shown in Fig. 28. Dummy motion during collision of an airbag-equipped motorcycle is shown in Fig. 29. In the case of the baseline motorcycle without an airbag, the head of the dummy impacts the roof of the opposing vehicle hard. In contrast, in the case of the airbag-equipped motorcycle, the head of the dummy softly impacts the opposing vehicle. The injury indices are shown in Table 4.

The dummy injury index is shown as AIS. Injury indices are expressed on a six-level scale, with AIS 1 being a minor injury level and AIS 6 a fatal injury level.

With the baseline motorcycle without an airbag, AIS for the dummy's head was calculated as 6, i.e. fatal, whereas the calculated AIS for the head with the airbag-equipped motorcycle was representative of no injury. Similarly, the AIS for the dummy's neck with the baseline motorcycle without an airbag was calculated as 4, whereas the AIS for the neck with the airbag-equipped motorcycle was equivalent to no injury.

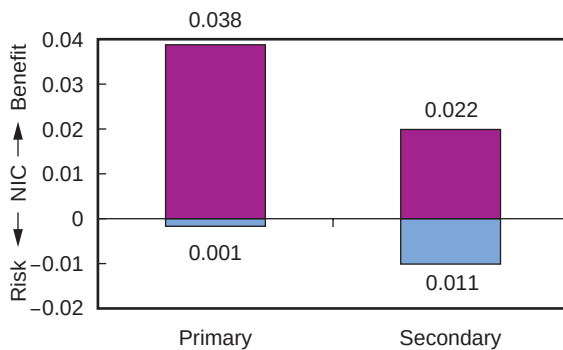


Fig. 24 Total average benefits and risks, primary and secondary impact sequence

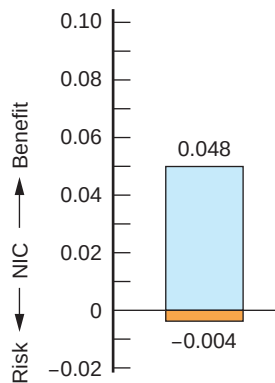


Fig. 25 Total average benefits and risks in the entire impact sequence

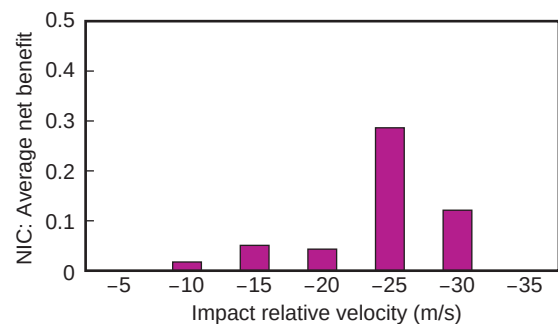


Fig. 26 Total average net benefits, by relative impact speed

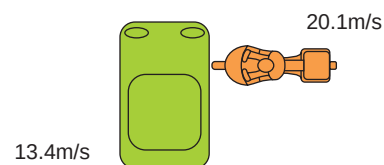


Fig. 27 Benefit impact configuration

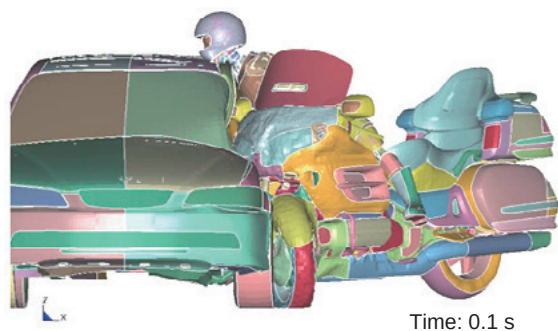


Fig. 28 Baseline impact case

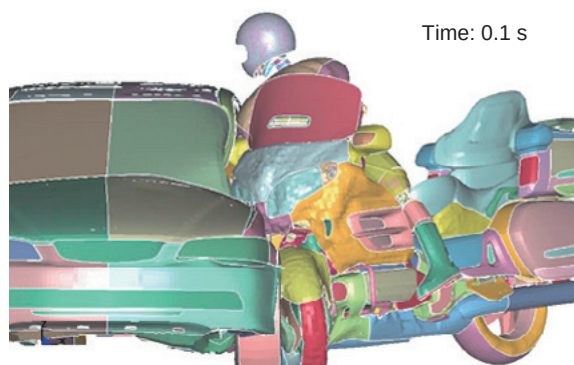


Fig. 29 With airbag impact case

Table 4 Comparison of AIS between baseline and with airbag

	Base line	Airbag
Head	6	0
Neck	4	0
Chest	1	1
Abdomen	0	0
Leg	3	3

8. Conclusion

- (1) Computer simulation using explicit FEM software enables the evaluation of the dummy injury index during a motorcycle collision up to the point where the dummy strikes the ground.
- (2) Using this simulation method, the injury reduction performance of an airbag mounted on the GL1800 was evaluated based on ISO/CD 13232.

The following conclusions regarding injury reduction are drawn from this research:

- The total average benefit of the entire impact sequence was 0.048 and the risk was 0.004. The performance of the injury reduction system is therefore appropriate.
- The highest average net benefit appears at the relative impact speed range of 20 - 25 m/s (72 - 90 km/h).
- The injury reduction effect is greater when the rider impacts the opposing vehicle than when the rider strikes the ground.

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