Automobile Collison Behavior Usinga Mechanism CAE Analysis

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***Abstract*—This paper presents a method of a short multi-body mechanism CAE analysis during the development time as substitute for collision CAE analysis, which is widely used in the automotive industry, because of its high influence on improvement of passengers' safety. The time spent for collision CAE analysis to obtain accuracy requires a long time. Therefore, it is impossible to carry out an analysis using a lot of parameter settings in a limited development time. For this reason, the necessity of an effective, new analytical method in the preliminary design is requested. First Order Analysis (FOA) is proposed as one of the solutions. Because FOA through the use of mechanism CAE analysis can be done in a short time, the frequency of a necessary collision CAE analysis can be decreased. Thus, it is possible to contribute to the cutback during the development period of vehicles.**

Keywords—CAE Analysis; Simulation; Energy absorption; Crashworthiness optimization

I. INTRODUCTION

The cutting back of time spent during development by the accuracy improvement of CAE in recent years has been performed. A significant part of this effort has been concerned with the use of structures in energy absorbing systems of vehicles. To absorb the initial kinetic energy during the impact and to keep the force levels sufficiently low and consequently to prevent damage to the engine cooling system and other high cost components, aluminum columns are used. Such effort greatly contributes to the safety of the car's body etc., and to the reduction of the stroke of assessment from the collision model experiment that needs a large scale simulated system and that uses collision CAE analysis to examine a dynamic nonlinear behavior. However, a very long time is needed for analysis so that such a collision CAE analysis may obtain accuracy. Therefore, it is impossible to carry out an analysis using a lot of parameter settings in a limited development time.

Crash boxes are the passive safety systems preventing the excessive deformation of the automobile chassis against the frontal crashes. The crushing behaviors of tubular structures have been subjected to extensive experimental and numerical investigations. Various geometries including cylindrical [1], [2] and [3], square [4], [5] and [6] and hexagonal [7] and [8] cross-sections, multi-cell structures [9] and [10] and light-weight foam filling [11], [12], [13] and [14] have been investigated for improving the crushing behavior of tubular structures under quasi-static and dynamic loads. However it takes much time for experimental and numerical investigations.

For this reason, the necessity of an effective, new analytical method in the preliminary design is requested. First Order Analysis (FOA) is proposed as one of the solutions. In the present study, it is used to perform a short mechanism CAE analysis as a substitute for collision CAE analysis during the period of vehicle development. Because FOA uses mechanism CAE analysis for a short time, the frequency of a necessary collision CAE analysis can be decreased. Therefore, it may contribute to the cutback during the development period of vehicles.

II. VERIFICATION OF ACCURACY OF MECHANISIM CAE ANALYSIS

A. Experimental Details

First, to prove the ability of crash simulation analysis using collision CAE analysis in the mechanism CAE analysis, the accuracy of mechanism CAE analysis was verified. The crash simulation using the collision model experiment and the mechanism CAE analysis of the vehicle was proven through the verification method, which is by comparing condition and the measured impact acceleration and by comparing the displacement magnitude of the vehicle based on collision.

In the present study, the collision model experiment for the crash simulation and the case where a vehicle whose gross weight is 300kg and which was collided on both sides at 25 km/h are assumed. The fall type collision model using the simple vehicle model shown in Fig.1.to measure the impact acceleration that the vehicle obtained in the condition was examined. However, 1/10 models of a real vehicle was used in the experiment to evaluate the hazard when the vehicle model of 300kg fell and collided. The weight of 30kg and the crash zone made of urethane foam were installed in the vehicle model. The specification of urethane foam was: Density 43.5kg/m^3・25% compressive load 1.8×10^4 kg/m^2・Impact area 30cm^2. The impact acceleration was measured with a laptop PC using a small-type acceleration converter (AS-1000A) and using a sensor interface (PCD-300A), both made by Kyowa Electronic Instruments. The sampling frequency was 1000Hz. Moreover, a picture of the motion image of 1200 FPS was taken at the same time as the measuring of acceleration to compare the displacement of the crash zone.

To obtain the fall velocity at 25 km/h in the experiment, based on the principle of conservation of energy, the experiment was carried out from the height of 2.5 m. The result of the experiment is shown in Fig. 2. The greatest value of impact acceleration, -100.3 G in the experimental apparatus and the experimental condition, is shown in Fig. 1.

The impact acceleration value of -100.3 G was obtained based on the experiment carried out on 1/10 models even when the vehicle of 300 kg had the side collision at 25 km/h before it fully stopped. Although the collision model experiment used 1/10 models, the same acceleration as 1/1 model was obtained based on similarity rule.

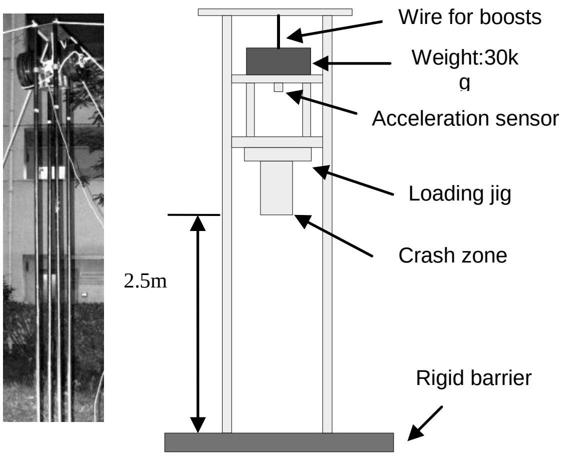


Fig. 1. Collision experimental apparatus

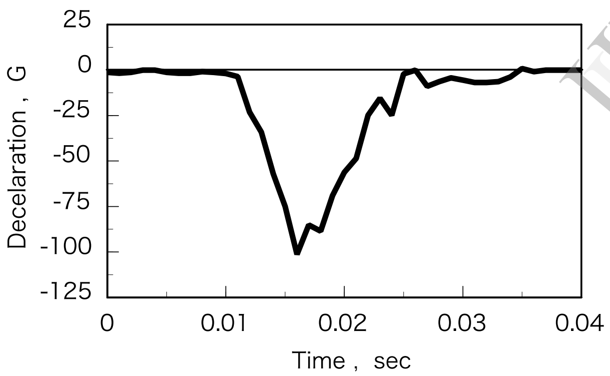


Fig. 2. Relationship between time and deceleration

B. Crash CAE Simulation

The crash simulation under the same condition as that previously mentioned was done by using the mechanism CAE analysis. In the present study, MSC.Visual Nastran of the MSC SOFTWARE Co. was used as mechanism CAE analysis software. This analysis software can be used for linear static analysis and linear buckling analysis etc., intended for a wide range of application from single-item level to complex-structure level. However, it controlled the rationing of the linear spring set to the same impact absorption power as the crash zone that was used for the nonlinear response, and it was used for a nonlinear dynamic analysis similar to the crash simulation in the mechanism CAE analysis software.

For the First Order Analysis, the spring constant and the natural length of a linear spring with the impact absorption power only of the crash zone were decided. For the crash zone used with the collision model experiment, a value of 0.037 N/mm was obtained for spring constant and 124 mm for natural length. The crash CAE simulation model is shown in Fig. 3. The impact acceleration result is shown in Fig. 4. In this Figure, the acceleration value measured by the crash simulation is shown with solid line and the collision model experimental result is shown with broken line. Both experiments corresponds to that time that the acceleration became the greatest at t=0.014s, and the impact acceleration value during that time was -100 G, although neither the crash simulation consequence nor the collision model experimental result completely corresponded Fig. 3.

Moreover, the solid line in Fig. 4 shows the change until the crash zone of the collision model experiment is displaced by 100mm, and broken line shows the change until the crash zone of the crash simulation is displaced by 100mm. It is understood that the change in the displacement magnitude, as seen in [Figure-3], to the crash zone of both experiments is near. It is judged that the mechanism CAE analysis has enough accuracy to simulate the nonlinear crash from Fig. 4.

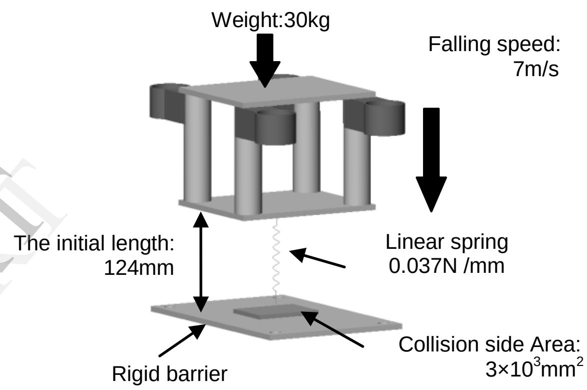


Fig. 3. CAE model of crash box simulation

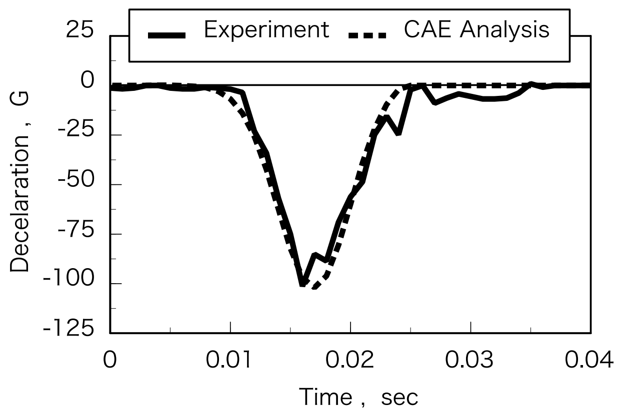


Fig. 4. Comparison of CAE and experimental result

III. FULL VEHICLE CAE ANALYSIS

Thus far, it was demonstrated that the proposed method is able to simulate non-linear CAE analysis. Additionally, in the present study, the seat belt structure was examined as a piece of the parametric study to increase level of safety in a motor vehicle accident and to upgrade protection against vehicle collision. The improvement of safety technology to a more advanced one will be requested in the future owing to the increasing number of vehicular accidents in recent years, although the number of fatality is decreasing tendency through the improvement of the collision safety technology of cars. Because the force of constraint doesn't change in lap and diagonal belts used in relation to the weight of the crew, although the seat belt is one of the most effective passive safety devices of a car, there is a possibility of fracture and visceral injury by the whip and the thoracic part and the pressure on the abdomen due to uncontrolled excessive force of constraint. This may happen when a crew who is heavier than the standard body weight meets with an accident or when a crew who is lighter than the standard body weight collides with the handle and the dashboard due to the shortfall in the force of constraint.

Using FOA to develop a seat belt structure, which changes the force of constraint according to the weight of the crew, was done in the present study through the crash simulation using mechanism CAE analysis.

A. Parameter Setting

The vehicle models with human body model seat belt model were used to carry out behavior analysis of the occupants of the car accident simulation. Full vehicle CAE model is shown in Fig. 5. The vehicle of 300kg was crashed in a full flap collision in rigid barrier at 25km/h. To measure the force of constraint suitable for weight, the weight of the crew was changed from 55 to 95kg, and analyzed. Then the most suitable force of constraint for the weight of the crew was measured. In the present study, it is assumed that the value of the force of constraint of the seat belt when the distance that the crew moved reaches 100 mm and that secondary collision is avoided with enough optimal force of constraint. The analysis was discontinued because there is a possibility that secondary collision happens when the quantity of movement of the crew exceeded 100mm.

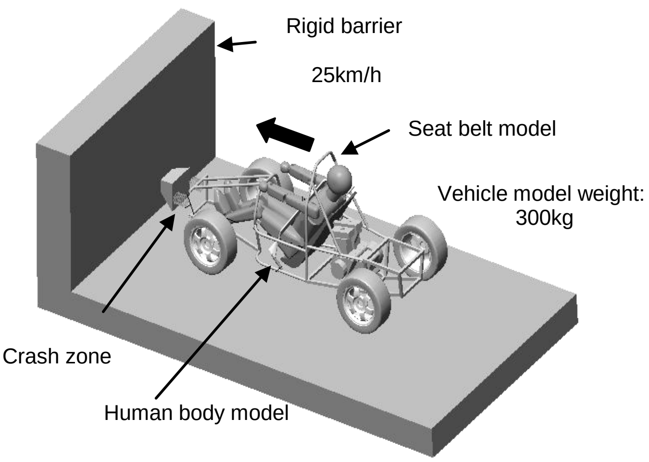


Fig. 5. Schematic of Full vehicle CAE model

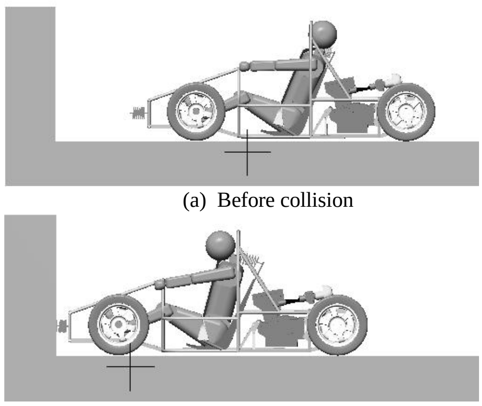
In order to represent a seat belt structure which can freely modify the restraining force of the seat belt, a linear spring in the belt anchor portion of the seat belt was attached to the seat belt. To change the spring constant of the linear spring, the power was varied. The crash simulation was done under the above-mentioned condition. An example of a crash simulation is shown in Fig. 6. Here, Fig. 6(a) and Fig. 6(b) show before collision and after collision, respectively. It is seen that the linear spring attached to the belt anchor portion of the seat belt which restrains the occupant after the collision Fig. 6(b) is elastic.

The HIC (Head Injury Criteria) and the value of the acceleration of the thoracic part (hereafter breast G) are adopted from safety standard FMVSS208 that has been set to assess the side crash test occupant injury with NCAP (New Car Assessment Program) before finalizing the assessment of the analysis. The Head Injury Criterion (HIC) is a measure of the likelihood of head injury arising from an impact. It can be used to assess safety related to vehicles. The variable is normally derived from the acceleration/time history of an accelerometer mounted at the centre of gravity of a head. It is defined as below:

$$HIC = [(t_2 - t_1)\{\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)\,dt\}^{2.5}]_{\max} < 1000 \qquad (1)$$

where t_1 and t_2 are the initial and final times of the interval during which HIC attains a maximum value, and acceleration a is measured in standard gravity acceleration. Note also the maximum time duration of HIC, $t_2 - t_1$, is limited to 36 msec.

However, since HIC is representative of the damage of trauma when the head of an occupant collides secondarily with dashboards or the steering wheel, it does not give reliable results if second collision is not considered, as in this study. After performing collision CAE analysis using the method which we proposed above, when the weight is set at 75 kg and the amount of movement at 100 mm, the HIC obtained was 692. Thus, the evaluated HIC was used as the basis in this study (hereafter HIC <692).



(a) Before collision

(b) After collision

Fig. 6. Example of simulation result

IV. NUMERICAL SIMULATION RESULT

The CAE result is shown in Fig. 7. This shows the relationship between the spring constant of the seat belt and the weight of the crew. In order to keep HIC at 692 or less, it is necessary to change the spring constant of the seat belt portion in accordance with the weight of the crew. It can be seen in Fig. 7, as the weight of the crew is increased, binding of optimum seat belt increases.

The relationship between the weight of the crew and deceleration and HIC is shown in Fig.8. According to this Figure, when the weight of the crew increases, it can be seen that the HIC value increases. Furthermore, when the crew weighs 75kg, HIC is 260. HIC has declined to 62.4% compared with the case of 692 which is the evaluation criterion. That is, it is possible to reduce HIC value greatly by making adjustments according to the weight and rigidity of the seat belt.

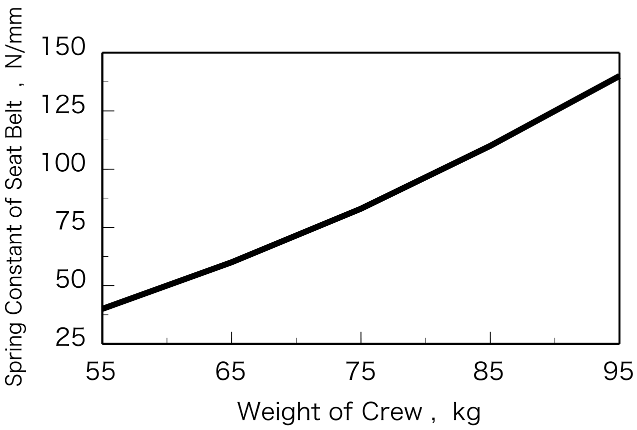


Fig. 7. Relation between weight of crew and spring constant of seat belt

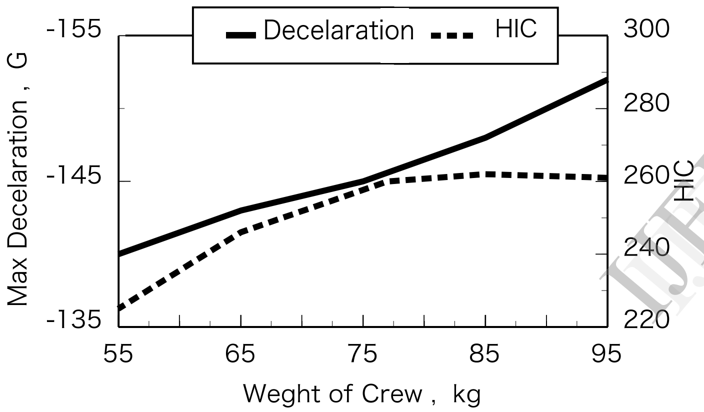


Fig. 8. Example of simulation result

Fig. 9 shows relation between the elapsed time and the impact acceleration value measured by the head of the crew of 75kg in weight. The solid line is a seat belt structure that vigor changes in proportion to the weight that the present study proposes, and the short dashed line is a past seat belt structure. From this figure, the maximum acceleration was -132.1G with the conventional seat belt structure, but was -93.3G with the seat belt structure that this study suggested. That is, the result that improvement of 29.4% of occupant protection ability was expected was provided.

Then, Fig. 10 shows the relationship between the impact acceleration and chest movement amount measured at the chest of the crew of 75kg.The solid line shows a seat belt structure of the present study, broken line shows the 3-point seat belt of the conventional type as in Fig.9.From this figure minimum shock acceleration is -56.2 Gwith the conventional seat belt structure, and is -22.1G with the seat belt of this study. So, 60.7% performance improvement is expected. In addition, it can be seen that the shape of the curve graph is also quite different. Withthe conventional seat belt deceleration value is going smaller among the chest displacement 18 mm to 40 mm.On the other hand, with the seatbelt structure of this research, the deceleration of a chest hardly fluctuates, while the load to a crew member has been it is kept constant low.From the results of both, the use of the seat belt restraining force that matches the weight of the crew, it is shown that the proposal method improves the crew protection performance.

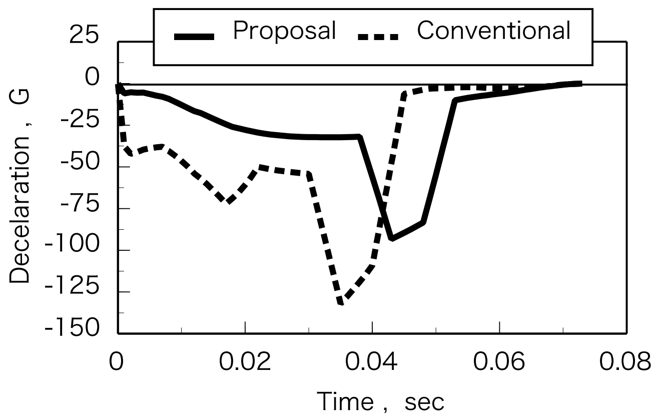


Fig. 9. Relation between the elapsed time and the impact acceleration

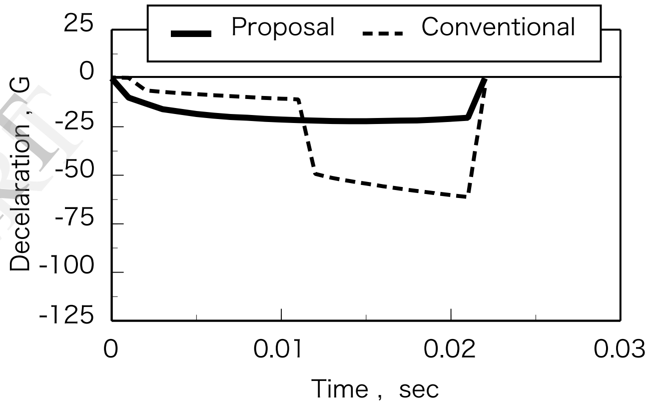


Fig. 10. Relation between the elapsed time and the impact acceleration

V. DISCUSSION AND CONCLUSION

Considering these findings, mechanisms CAE analysis may be used to replace collision CAE analysis as a method to reduce the time spent for analysis. This can contribute to the reduction of the time used in the development of a car's body. It was found that there is a possibility that, based on the parametric study example carried out in this study, setting the seat belt restraining force to suit the weight of the occupant improves safety better than the conventional one. When the seat belt mechanism is developed, by using the FOA results of this study, it is possible to reduce the number of crash tests and collision CAE analysis and achieve a reduction in development time.

An efficient numerical procedure was developed to study the behavior of seatbelt and crew. Interesting seatbelt stiffness behaviors are obtained from the numerical analysis. Some attractive results are as follows:

1. The collision model experiment is done and the consequence of the crash simulation can do a

nonlinear crash simulation by using the mechanism CAE analysis suitably well.

2. The spring constant value in which an optimal force of constraint is shown increases with the weight of the crew.
3. Damage to crew and passengers increases when the weight is heavily increased.
4. The damage of the impact acceleration value is a little in parallel like to the low value because the crew's weight and the seat belt structure combine and the force of constraint changes in proportion to the crew's weight.

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