

STUDY ON STEERING COLUMN COLLAPSE ANALYSIS USING DETAILED FE MODEL

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ABSTRACT

EASC(Energy Absorbing Steering Column) is a kind of Steering Column which minimizes the injury of the driver during a car accident by collapse or breaking particular part of system. Up to now, Steering Column in Crash Analysis had no way to describe these 'Collapse' or 'Slip' by the Axial and Lateral Forces from driver. In this paper, we have created a new Steering Column using a Detailed FE Model which can describe such collapse behavior.

INTRODUCTION

EASC (Energy Absorbing Steering Column) is a type of Steering Column which minimizes the injury of the driver during a car accident by collapse or breaking particular part of system. Up to now, it has been difficult to assess the Collapse behavior and energy absorption of the Steering column in frontal impact analysis because of the rigid body FE joints of column model. Also, in cases of occupant analysis model, the loading characteristics of the column are described using a F-D Curve from the static axial compression test, but the reliability of the load in the arbitrary direction is low except for the load in the axial direction.

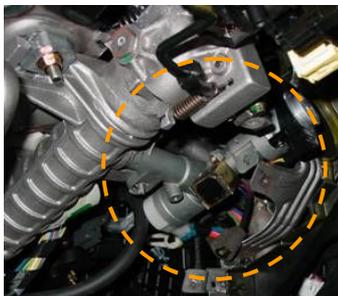


Fig.1 Key Set-Knee Bolster MT'G interference

Therefore, in case of Steering Column Collapse, it's impossible to check interference of the surrounding parts (Fig.1). It is also impossible to predict or respond

to Collapse test distribution (Fig.2).

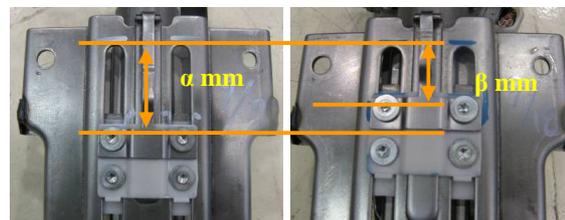


Fig.2 Column Collapse distribution of sled test

Thus we need to develop an analysis model that can describe the collapse behavior of the steering column under the arbitrary loading condition.

Accordingly, in this study, we have developed a detailed FE model that can describe the collapse behavior to cope with FE-Occupant Full vehicle analysis and FE-Multi body coupling analysis that will progress from hereafter.

The condition for the Steering Column analysis model developed in this study is as follows

- It should be able to describe the Collapse movement of load in the arbitrary direction.
- It should be able to describe the static compression test result.
- It should be adaptable to the Full car frontal impact analysis (US NCAP full frontal, EuroNCAP offset etc.).

In this study, we have selected 4 types of representative Steering Column (type A, B, C, D) to develop an FE model that satisfies the above terms. Using this, we established a Steering column analysis method through the following procedures.

- 1) Steering column static compression test correlation
 - Build capsule pin fracture model and correlation.
 - Build curling plate model and component correlation.
 - Fastening load and friction component correlation
- 2) FMVSS203 Body Block Test Correlation.
- 3) Verification of detailed column model using Madymo Input and Sub-Structure analysis.

All analysis was progressed using LS-Dyna Version 971 Revision 4.

BUILD DETAILED FE MODEL AND STATIC COMPRESSION TEST CORRELATION

The steering column developed through this study was made to apply to FE-Occupant Full vehicle analysis and FE-Multi body coupling analysis. For this, it should show a practical behavior in arbitrary loading condition that can be delivered through a test dummy. Therefore, in composing a model, we focused on the following concept and tried to exclude any non-practical collapse behavior.

- 1) Avoid rigid body modeling: Actual joint modeling for kinematical locking.
- 2) Friction and deformation form contact forces.
- 3) Following actual geometry and tolerance.

After analyzing the 4 selected steering columns, we could confirm 4 factors that had direct influence on collapse load.

- Capsule Pin
 - Curling Plate
 - Friction force from fastening load of bolt
 - Friction Force from expending tube and collapse ring
- By analyzing the effect of such factors, we could progress static compression test correlation in each steering columns.

Capsule pin fracture model correlation

Capsule pin is a plastic injection pin connecting the Al capsule and column which was usually ignored in traditional analysis models. In this study, we assumed the Capsule Pin as a cubic element with 1mm height (Fig.3). Tied Contact method was used to bond to the basic material, and Stress Based Failure criteria was used to model the fracture of Pin through shear force. (Fig.4)

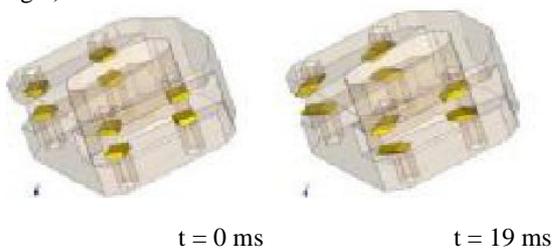


Fig.3 Capsule Pin modeling and Static Test

Using this Capsule Pin model, we conducted a Correlation about Capsule Pin component static test. Correlation was progressed by adjusting the following factors.

- Young's Modulus
- Hardening Modulus
- Failure Effective Strain
- Failure Shear Stress
- Rupture Strain

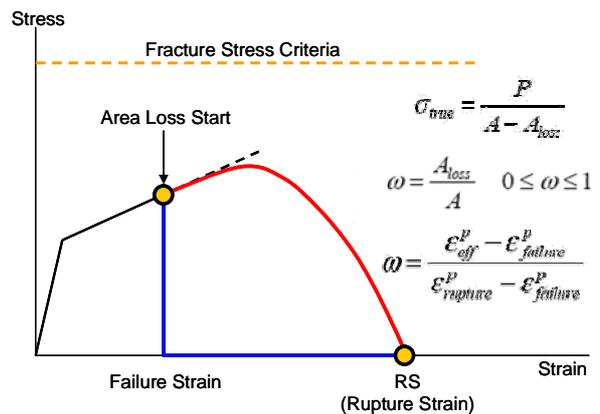


Fig.4 Fracture Stress Criteria

Fig.5 is the graph showing the result of the Static Test Simulation. We can see that the completed model has the characteristics of the actual Capsule Pin.

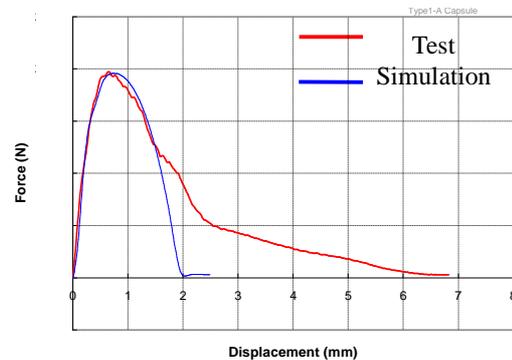


Fig.5 Capsule pin static test vs. Simulation

Curling Plate correlation

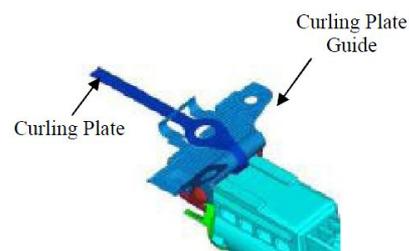


Fig.6 Modeling of Curling Plate

Curling plate is a component that controls collapse load of steering column. It is used to attain target collapse load through adjusting the thickness, width, and form. Change of collapse load by the design of curling plate is digressing from the main subject of this study, and therefore will not be handled. In this study, we tried to describe the given shape of the Curling Plate as detailed as possible, and conducted correlation with component test. (Fig.6) Fully Integrated Shell element

was used for FE model and integration point was set to 5 point at thickness direction to obtain bending stiffness. 1.5mm element was used to describe the Curling Plate and bending part of Guide. True Thickness Contact was used in every Contact related to Collapse, and to exclude the effect of friction between Curling Plate Guide and Column, the coefficient of friction was set at 0.0.(Fig.7)

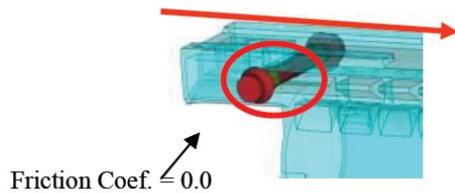


Fig.7 Modeling of Curling Plate

Fig. 8 is a graph showing the result of Curling Plate F-D test Simulation. It can be observed that the completed model is following actual characteristics.

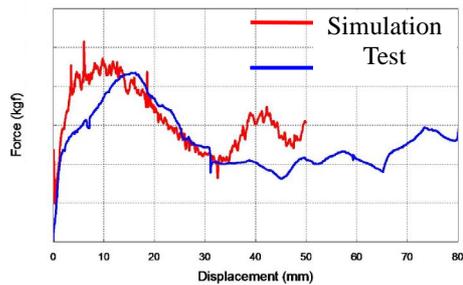


Fig.8 Curling Plate Correlation F-D Curve

Fastening load correlation

Fastening load is a friction load generated from fastening component, such as Bolt and Pin. In column FE model, fastening load of curling plate guide fastening bolt and tilt lever fastening bolt should be considered. If fastening load exists, normal force which is stronger than that of usual contact from geometry occur. Therefore, when realizing a collapse behavior according to friction and deformation, fastening load must be considered. In this study, Steering Column of A and C are relevant.

Friction from fastening load can be calculated by the following method.

- 1) Calculate the axial force of bolt from designed bolt torque.
- 2) Calculate the stress of bolt section.
- 3) Apply the calculated stress to the bolt section, using 'Initial Stress Section Card.
- 4) Check the stress contour during correlation analysis (Fig. 10)

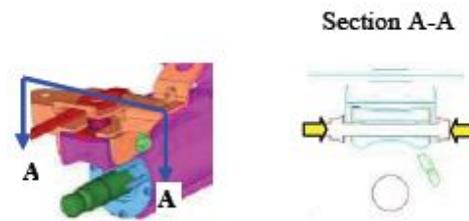


Fig.9 Normal force from fastening bolt

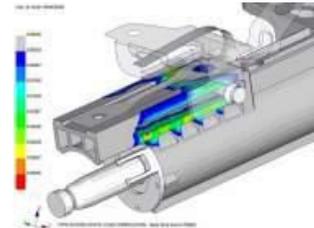


Fig.10 Stress contour from fastening load

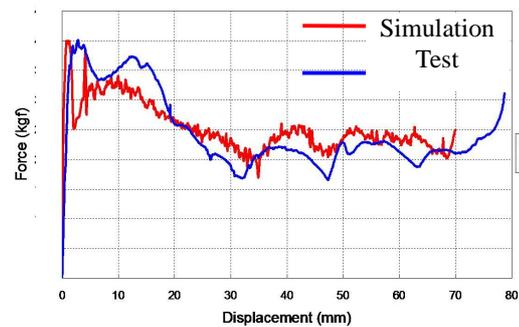


Fig. 11 Static compression test correlation of steering column type A

Fig.11 is a graph showing the result of static compression test of Steering Column type A. We can see that the completed model has the actual characteristics.

Of the 4 factors mentioned above, the ones that affected the Steering Column type A are the following three.

- Capsule Pin
- Curling Plate
- Friction force from fastening load of bolt

Friction component load correlation

Friction component load is the friction force that rises from collapse ring used in steering columns of expended tube type. Collapse Ring is a friction component that exists between the steering column housing and the main tube of the column. (Fig. 12)

In this study, the steering column of type B and D uses these friction components. Correlation was conducted under the assumption that all friction force of steering

column rises from the collapse ring.

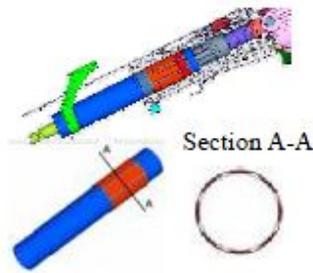


Fig. 12 Collapse Ring Modeling

Collapse ring uses rigid material. After analyzing the result of the static compression test results of column type B and D, we set the friction component load on α - β kgf to conduct the correlation.

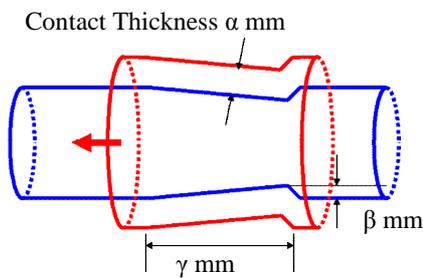


Fig. 13 Collapse Ring Modeling Concept

Fig.13 is the schematic diagram representing the modeling of friction component. As shown in the picture, the collapse ring (red line) and column tube (blue line) have a minute slant and step. This slant and step lead the tube's deformation when collapse progresses in the direction of the red arrow.

In order to compensate for the deformation at the initial state, we conducted a pre-analysis of moving the collapse ring forward from δ mm behind the original location. The stress of the tube can be adjusted by pre-stress condition using INITIAL STRESS SHELL card and you can attain the target friction force. (Fig. 14, 15)

Fig.16 is a graph that shows the simulation results from the static compression test of the steering column type B. We can see that the simulated results well follows the real characteristics.

Of the 4 factors mentioned above, the ones that affected the Steering Column type B are the following two

- Capsule Pin
- Friction Force from expending tube and collapse ring

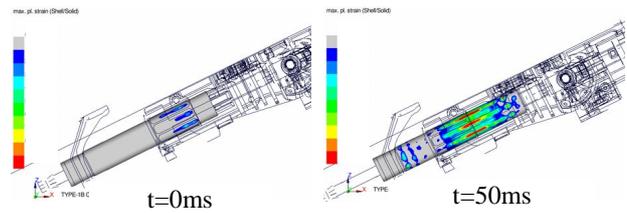


Fig. 14 Stress contour of column (before/after)

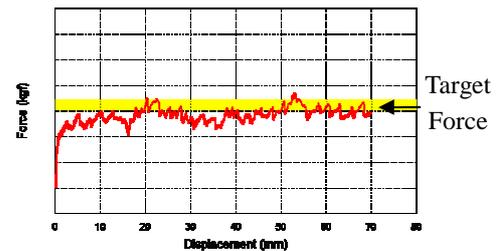


Fig. 15 Friction force F-D curve of steering column type B

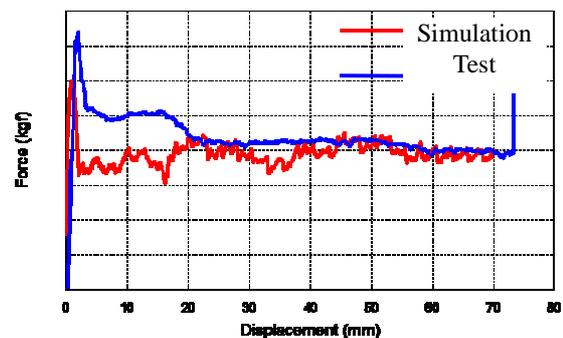


Fig. 16 Static compression test correlation of steering column type B

FMVSS203 BODY BLOCK TEST CORRELATION

FMVSS203 is a Steering Control System related regulation. The purpose of FMVSS203 is to minimize chest, neck, and facial injury in case of frontal impact. In FMVSS 203 test, a body block of approximately 36kg directly collides into the steering column with initial velocity of 15 Mph(24Km/h), and the maximum load of body block and steering column should not exceed 2500 lbs (11kN). Fig.17 describes the schematic diagram of the body block test.

In this study, body block test correlation is conducted with each 4 type of steering column and intermediate shaft.

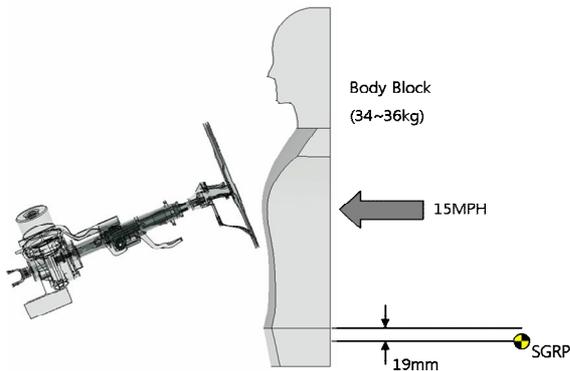
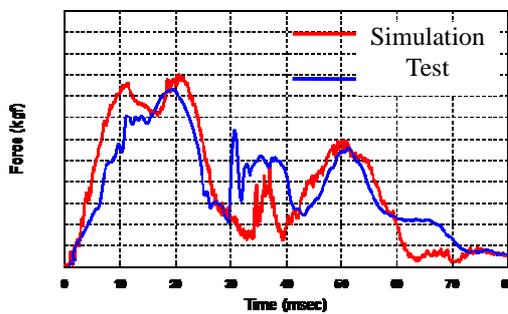
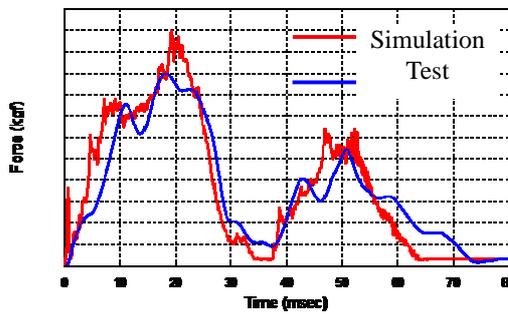


Fig. 17 Body Block Test



Load Cell Force



Body Force

Fig. 18 Type D Body Block Test Correlation

Fig.18 is a graph that shows the simulation results from the steering column body block test of column type D. It can be noted that static compression correlation models agrees with the actual characteristics of body block test

VERIFICATION OF DETAILED COLUMN MODEL USING SUB-STRUCTURE ANALYSIS

Final goal of this study is the development of steering column system which is available for FE-Occupant Full vehicle analysis and FE-Multi body coupling analysis. To do this, steering column model should have the following characteristics.

- 1) Description of the collapse behavior according to the

load applied in arbitrary direction.

2) No Time Step and Mess Scaling problems.

3) Rapid response for modifications of restraint system.

In order to satisfy 2) and 3), our study reviewed the possibility of steering column using sub-structure analysis rather than through full vehicle analysis.

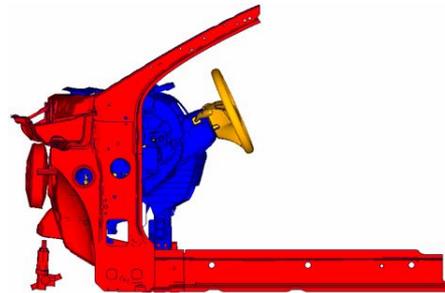


Fig. 19 Boundary condition of Sub-Structure analysis

Fig.19 represents boundary conditions of sub-structure analysis developed in our study. Procedural steps are as follows.

1) Extract sub-structure boundary condition data from the components which can influence column collapse behavior in US NCAP frontal analysis. (Fig.17 Red components)

2) Build sub-structure analysis model including crush pad, detailed steering column system, etc.

3) Input the x/y/z direction load extracted from occupant analysis (using MADYMO) as a curve according to time.

4) Run the sub-structure analysis and verify the collapse behavior of detailed steering column system.

Since our FE-Occupant Full vehicle analysis is not yet established, for the collapse behavior, we input the x/y/z direction load extracted from occupant analysis (using MADYMO) as a curve according to time.

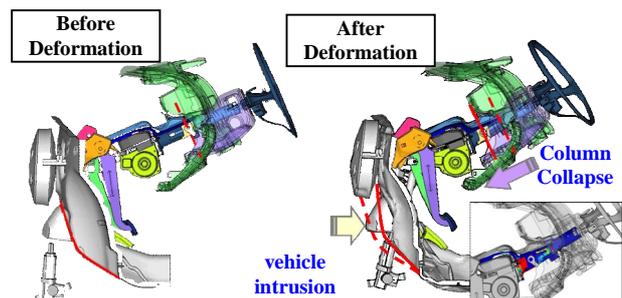


Fig. 20 Sub-Structure analysis result (Side View)

Fig.18, Fig.19 is the result of US NCAP frontal analysis using sub-structure analysis proposed by our study. A detailed model (type C) collapsible to load in the arbitrary direction that was developed by this study was used, and body and other data were extracted from the full vehicle model. The collapse behavior was well

described and interference between column and pedal mounting during collapse behavior was also well described. Therefore, the detailed column system is expected to be readily applied to the FE-Occupant full vehicle analysis.

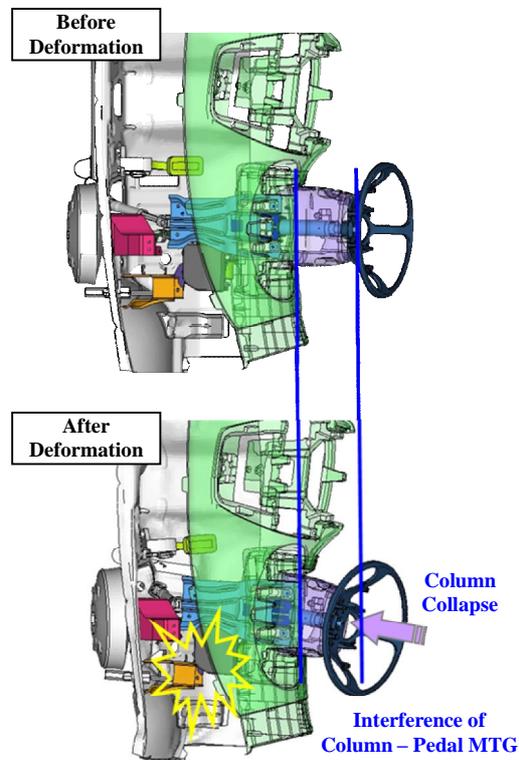


Fig. 21 Sub-Structure analysis result (Top View)

CONCLUSIONS

In our study, we developed a detailed model of a steering column that can be applied to the FE-Occupant full vehicle analysis. And using this, established a steering column collapse analysis method. The detailed model and analysis method developed in this study have the following characteristics:

Detailed modeling

- Deformable materials were used in defining most parts to consider the effects that can be caused from column bending and etc.
- Unusual behavior that can occur from rigid component was minimized by describing every mechanism in actual shape and not using rigid FE joint, except for on some bearings.
- Friction component and collapse load component, such as curling plate and collapse ring, contact thickness is defined as actual thickness, and by removing initial penetration, the contact was precisely

described.

- The collapse ring that is hard to describe as its original shape was realized through a simplified FE model that reflects the same concept.

Correlation

- By simplified model of the capsule pin, we developed a material that reflects failure properties of capsule pin.
- Correlation was performed by defining the initial stress at the parts where pre-stress exists by fastening load.
- When using the curling plate as the main collapse control part, we can identify the degree of contribution of the curling plate.

Sub Structure Analysis

- Substructure modeling methods that shows same behavior with full vehicle analysis was developed by inputting the crash results.
- The effects of the dummy, airbag and other restraint system could be evaluated by the results of occupant analysis.

The expected effect from proposed analysis method is as follows:

REFERENCES

- [1] NHTSA, "Laboratory Test Procedure For FMVSS 203 - Impact Protection for the Driver from the Steering Control System", 1990.
- [2] LSTC, "LS-Dyna Keyword User's Manual Version 971", 2007