PERFORMANCE ANALYSIS METHODOLOGY BASED ON CRASH PULSE SEVERITY AND VEHICLE OCCUPANT PACKAGING FOR FULL FRONTAL CRASH EVENT.

Bo Pil Seo
Sung Jun Han
Won Chul Kim
Si Yeol Kim

Hyundai Motor Co. & KIA Motors Corp
Korea
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ABSTRACT

Under full frontal crash events, major factors affecting occupant injury are crash pulse severity, restraint system, and vehicle occupant packaging space. The crash pulse severity represents the total performance of collision energy absorbed by vehicle structure during the crash event. The pulse severity also has a close relationship with the energy absorbed by restraint system out of the occupant's total kinetic energy induced by crash event. The capacity of energy absorption by restraint system is affected by the vehicle occupant packaging space. Thus, it is important to perform both restraint system and packaging space optimization simultaneously to manage the energy transfer under given severity of crash pulse.

In this study, severity function is defined to represent the regression curve of resultant energy absorbed by occupant, based on G-D curve and occupant packaging space. To build the regression curve, US NCAP top rated vehicles were analyzed and the relation between crash pulse severity and severity function is derived for various vehicle grades. Based on the result, target requirements of crash pulse severity and severity function are determined to satisfy occupant safety performance goals. This methodology is very useful to evaluate the crashworthiness performance of vehicle body design concept efficiently at early development stage.

INTRODUCTION

Under the condition of full frontal crash events, major factors affecting occupant injury are crash pulse severity, restraint system, and vehicle occupant packaging space.

Since crash pulse that is shown as a type of deceleration represents crash performance of vehicle body, the vehicle crash pulse plays an important role to understand and analyze behavior of the vehicle structure during the crash event.

The vehicle crash pulse is usually measured at the rear sill, near the vehicle CG, or near occupant seat, and this pulse data is often used to assess the severity of crash event. Many technologies have developed to predict the severity in a view of occupant injury risk from the data itself.

In general, the vehicle crash pulse represents the total performance of collision energy absorbed by vehicle structure during the crash event. Those have foundation on the factors having close relation with the energy management absorbed by the structure.

So, several studies have been made on the characterization of vehicle crash pulse which affects occupant response. [1-5]

Recently, theoretical studies on the pulse severity which affects occupant response have been developed using SDOF (single-degree-of-freedom) mass-spring systems which characterizes restraint system as a simple linear elastic spring model which consists of acceleration versus displacement of dummy. [3]

In this study, we defined severity function as a type of mathematical equation through linear curve fitting about net energy absorbed by occupant. Developed severity function is based on G-D curve and vehicle occupant packaging space. To build the regression curve, this study analyzes top-rated vehicle in US

NCAP and derives the relation between vehicle crash pulse severity and severity function for various grades of vehicles. Using the result, we will find target requirements of severity for crash pulse to satisfy occupant safety performance goals.

SEVERITY FUNCTION

The kinetic energy of an occupant during a vehicle crash is transformed into work in deforming the restraint system and vehicle structure.

Even if restraint systems in the vehicle were same, different the vehicle crash pulse severity or occupant energy absorption space results in a different occupant injury.

In order to guarantee same occupant injury performance, much more restraint space is required for the vehicle which has higher crash pulse severity.

RTE(ResTraint Energy) is used to evaluate the crash pulse severity in this study. Also, we introduce the concept of Severity Function. Severity Function contains RTE and layout parameter of occupant packaging as its independent variable. Using this Severity Function, this study derives interrelation from these two independent variables. The relationship between RTE and occupant injury has been presented in previous research. [5]

Severity Function is an integral in regression curve of occupant chest acceleration-displacement.

SF(Severity Function) can be represented as like

$$SF(S,F_g,MCT)=F_g\times[(MCT-10)-\frac{1}{2}\times\frac{F_g}{S}] \qquad (1)$$

In Figure 1, MCT is a maximum chest travel, S is the slope during elastic restraining, and Fg is an average acceleration during plastic restraining stage.

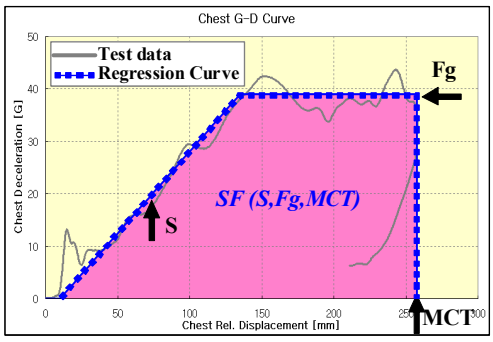


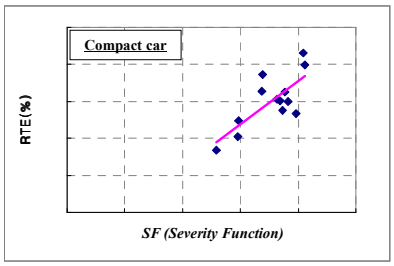
Figure 1. SF (Severity Function)

DERIVATION OF SEVERITY FUNCTION-RTE RELATIONSHIP

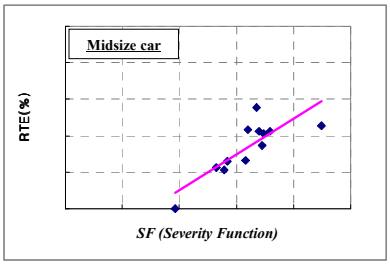
First of all, we analyze top-rated vehicles in US NCAP so as to find the relationship between RTE and SF. Table 1 shows linear regression relationship derived by analyzing test data for various grades of vehicles.

Table 1. The relationship of SF and RTE

Vehicle Class	Correlation Coefficient	Linear Regression	
		Equation	R-squared
Compact car	0.80	Y = 0.0048X + 18.790	0.65
Midsize car	0.82	Y = 0.0049X + 15.347	0.67
SUV	0.85	Y = 0.0059X + 18.597	0.57



(a)



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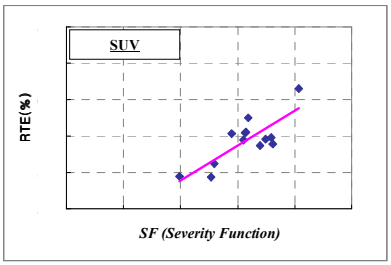

(c)

Figure 2. The relationship of SF and RTE for various vehicle grades. ((a) compact car, (b) midsize car, (c) SUV)

DERIVATION OF CS-RTE RELATIONSHIP

As for occupant package, CS is an horizontal distance between steering wheel center and occupant chest skin. It is affected by MCT. CS is defined in Equation 2.

A reference point and variable used to described the driver package as shown in Figure 3. All analysis was performed in two dimensions (side view). A is the horizontal distance between chest acceleration sensor and chest skin, B means the distance between chest acceleration sensor and steering wheel center when dummy reaches its maximum travel range with respect to the vehicle. C is a space obtained by column collapsing along a vehicle moving direction and C can be obtained by column setup angle and collapsed length along column axis.

$$CS = MCT + B - (A + C) \qquad (2)$$

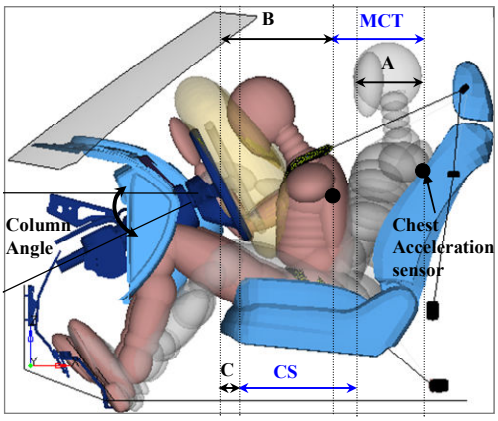

Figure 3. Dimensions in occupant package layout

Substituting Equation 2 for Table 1, we obtain interrelation between Severity Function and RTE as shown in Table 2. S and Fg are major variables in these interrelation and obtained by averaging test data.

Table 2. The relationship with CS and RTE

Vehicle Class	Average Value		CS-RTE Relationship
	S [G/mm]	Fg [G]	
Compact car	0.30	38.0	RTE=0.1824*CS-0.8540
Midsize car	0.27	37.0	RTE=0.1813*CS-3.4209
SUV	0.28	36.3	RTE=0.2142*CS+2.7818

Based on this result, target requirements of RTE and CS are determined so as to satisfy occupant safety performance goal as shown in Figure 4 and the following information can be drawn:

In order to improve performance in US NCAP

1) A Minimum requirement of CS when we know RTE about a specific vehicle.

2) A Maximum limit of RTE when CS is fixed. Here, CS and RTE concern an occupant package layout condition and an energy absorbing efficiency of vehicle respectively.

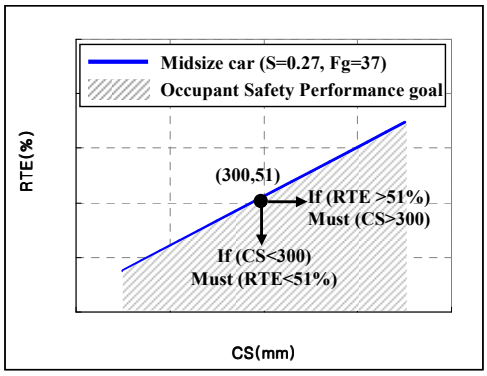

Figure 4. Requirement for occupant safety performance satisfaction (ex. Midsize car)

If CS is lower than its minimum requirement under given RTE, space to restrain occupant is insufficient. Excessive RTE results in increasing MCT and it can cause direct contact between chest and steering wheel. Moreover, to change a specification of the restraint system cannot solve these problems, since altering system specification has a possibility to increasing Fg in many case.

Figure 5 describes these phenomena.

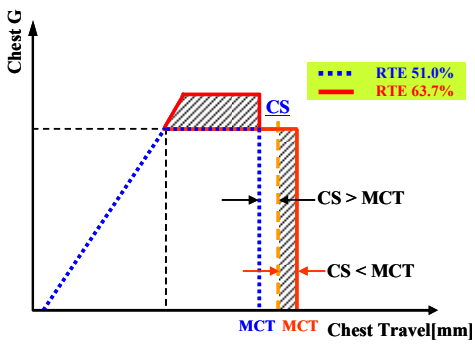

Figure 5. Effect of CS and RTE (S : 0.27)

DERIVATION OF BELT ANGLE(θ)-RTE RELATIONSHIP

One of many layout factors in occupant package, "belt angle(θ)" represents a horizontal distance from contact location between shoulder belt and upper torso to D-ring contact location as shown in Figure 6. This affects initial restraint efficiency of occupant.

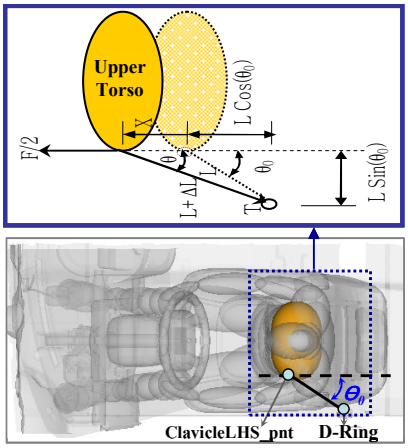

Figure 6. Dimensions in occupant package layout

In Figure 6, F is an inertial force of dummy upper torso and represented by dummy upper torso mass(m) and acceleration(a). T is tensile strength on shoulder belt, Shoulder belt length between D-ring and contact point on dummy upper increases from L to L+ΔL.

Standard Restraint Stiffness (K) is derived from Equation 3 and chest G-D Curve of test vehicles where belt setup location can be checked.

$$F = ma = \frac{2K\Delta L(LCos(\theta_0)) + X)}{(L+\Delta L)} \qquad (3)$$

$$\Delta L = \sqrt{(LSin(\theta_0))^2 + (LCos(\theta_0) + X)^2} - L$$

Interrelation between S and belt angle(θ) is obtained by Equation 3 and K. Finally, substituting this interrelation for Table 1, we obtain Table 3 as follows

Table 3. The Relationship of Belt angle(θ) and RTE

Vehicle Class	Average Value		Belt Angle(Θ)-RTE Relationship
	MCT [mm]	Fg [G]	
Compact car	245	38.0	RTE=-0.0034*Θ²+0.0457*Θ+52.884
Midsize car	252	37.0	RTE=-0.0033*Θ²+0.0449*Θ+50.931
SUV	286	36.3	RTE=-0.0039*Θ²+0.0526*Θ+68.319

Based on this result, target requirements of RTE and belt angle are determined so as to satisfy occupant safety performance goal as shown in Figure 7 and the following information can be drawn:

1) A Maximum limit of belt angle when we know RTE about a specific vehicle.

2) A Maximum limit of RTE when belt angle is fixed.

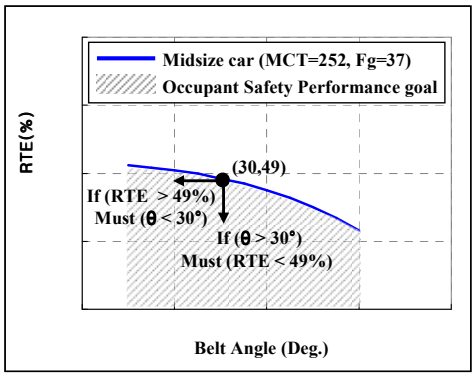

Figure 7. Requirement for occupant safety performance satisfaction (ex. midsize car)

If belt angle can not be guaranteed under given RTE, space to restrain occupant is insufficient by increasing. Excessive RTE results in increasing MCT and it can cause direct contact between chest and steering wheel because of MCT increasing. As mentioned, in many case we cannot solve this problems only by replacing or changing the specification of the restraint system.

Figure 8 describes these phenomena.

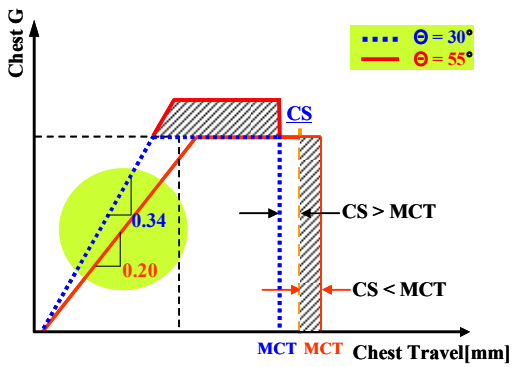

Figure 8. Effect of MCT and RTE (S : 0.27)

INITIAL CONCEPTUAL EVALUTION PROCESS

Up to now, we found the interrelation between SF and RTE and we proposed requirement conditions of each layout factor and RTE in order to satisfy occupant safety performance goal.

Based on this result, we set an initial conceptual evaluation process as shown in Figure 9. This process enables to evaluate crashworthiness performance for various grades of vehicles at early development stage.

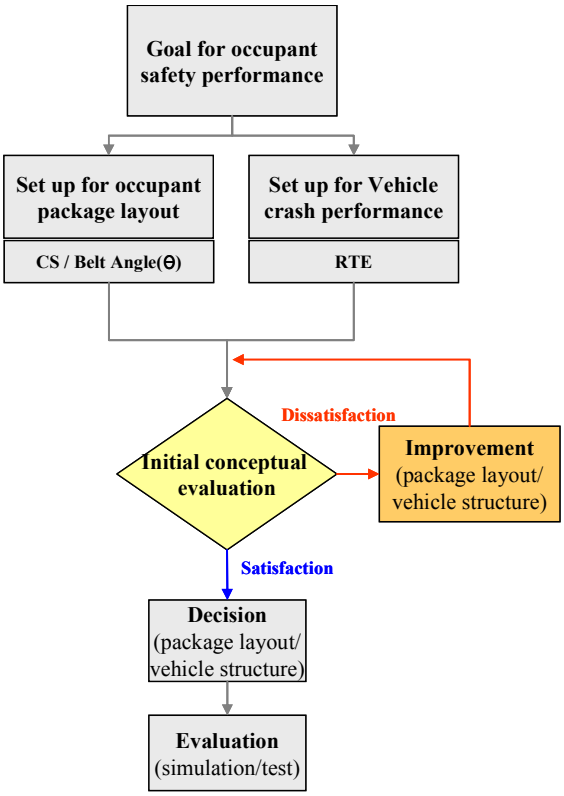

Figure 9. Initial conceptual evaluation process

When the occupant safety performance goal is set in the initial stage of vehicle development process, we can evaluate whether that is satisfied or not through given RTE, SF, and layout factors.

If given conditions be unable to satisfy performance target, vehicle developers improve layout and vehicle structure by analytical and practical method.

This study makes an initial conceptual evaluation sheet about each grade of vehicle in Figure 10. This sheet represents overall relationship among RTE, CS and belt angle and guides each requirement to satisfy performance target. This sheet helps vehicle developers to evaluate their vehicle.

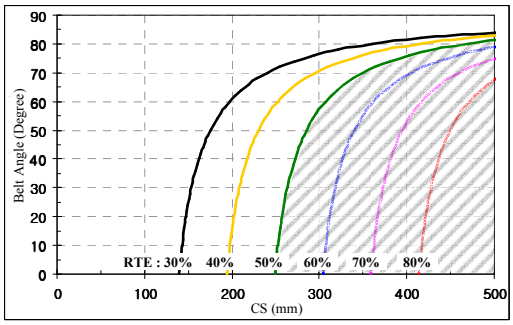

Figure 10. Initial conceptual evaluation sheet

CONCLUSIONS

In order to derive guideline about vehicle structure crash property and occupant package layout, this study analyzed top-rated vehicle in US NCAP.

Based on proposed severity function which depends on RTE and layout factors of occupant package, this study obtained results as follows

1) Through severity function, we find relationship among package space, belt angle, and RTE. Using these relationship, we suggest design guideline so as to achieve better safety performance in front NCAP

2) We propose the initial conceptual evaluation process in order to evaluate crashworthiness performance at early development stage.

We need to expand for additional layout parameter and have to construct data base about more vehicles. These data base can help vehicle designer to evaluate and obtain their required performance at early development stage.

In further study, we have a plan to analyze crash performance based on chest deformation for NEW NCAP.

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