A STUDY FOR FAST ANALYSIS METHOD OF VEHICLE STRUCTURE FOR OFFSET CRASH

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ABSTRACT

A fast analysis method of vehicle body structure for offset crash test was investigated from the various parameters such as section properties, vehicle mass and crushable length in the engine compartment.
Some practically useful relationship between these parameters and the vehicle crashworthiness was found out. This method seems very effective to implement “better birth” structure from the initial design stage before initiation of FEM simulation and to decrease iteration cycles by FEM simulation.

INTRODUCTION

In recent development of the vehicle, FEM analysis is widely and effectively utilized to investigate vehicle performance.
However considerable time is necessary to make model and get simulation result even if the computer software and hardware has been growing. Therefore after simulation results, if some critical problem in the vehicle structure is found out, it is very difficult to modify the structure remarkably; especially to expand section size of structural members. It often causes more weight increase for increasing stiffness to achieve the certain level performance.

Therefore, if the structure performance can be estimated roughly within short term before FEM, it seems to become very useful design tool.

From the above-mentioned viewpoint, a simple and fast analysis method of vehicle body structure under 64km/h offset crash test condition was investigated as follows:

- The effect of vehicle mass and crushable length in the engine room were considered on the crashworthiness of the vehicle body with some assumptions.

- The relationship between section properties of structural members (front side member, side sill, side member rear and so on) and the rearward intrusion of the vehicle cabin after crash was investigated based on the actual test data

Some practically useful relationship was found out which can be used in early design stage to estimate rough performance of the vehicle body.

METHODOLOGY

This study includes some assumptions based upon the geometrical and mechanical consideration, verification of the assumption through the test data and the preliminary design guideline for the vehicle structure.

Vehicle acceleration curve

Vehicle acceleration curve is simplified as the two phase constant level as described in Figure 1. (a)
The total vehicle displacement is described as:

$$Lv = Lh + Le + Lc \qquad \text{-----} \quad (1)$$

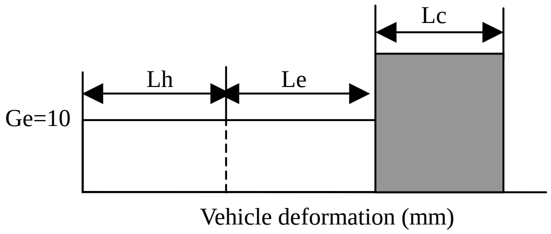
Lh: ODB honeycomb deformation (550mm)
Le: Crushable length in engine room
Lc: Vehicle cabin intrusion, determined from Some target

The acceleration level of the first portion during the deformation of Lh and Le is assumed 10G’s for all vehicles, based upon the average level of actual test results as shown in Figure 2.

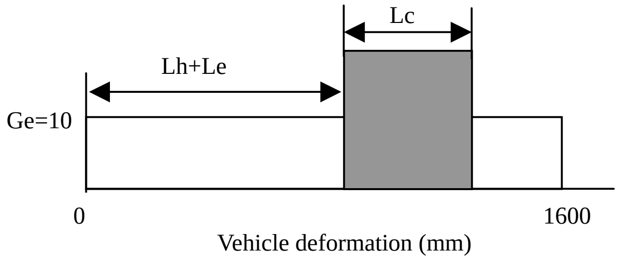
If the vehicle has sufficient crushable length, the constant level of vehicle acceleration 10G is acceptable to meet Lc target. In this case the total deformation of the vehicle is Lto=1600mm under 40mph ODB crash (Figure 1(b)).
However, the crushable length described in Figure 3 is usually limited and the permissible vehicle crash should be reduced by increasing the acceleration level of the cabin (Lc) to meet the Lc target (Figure 1(c)).
Then the required acceleration level ratio in phase 2 under the short crushable length is derived as,

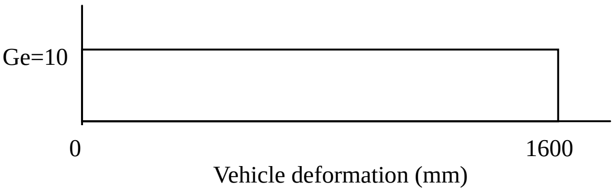
$$Kc = (Lto - Lh - Leo) / (Lto - Lh - Le) \qquad \text{-----} \quad (2)$$

Here, Leo is an arbitrary reference value and was set as 500mm in this study.



(a) Simplified model





(c) Actual condition

(b) Sufficient crushable length (ideal)

Figure 1 Vehicle acceleration curve

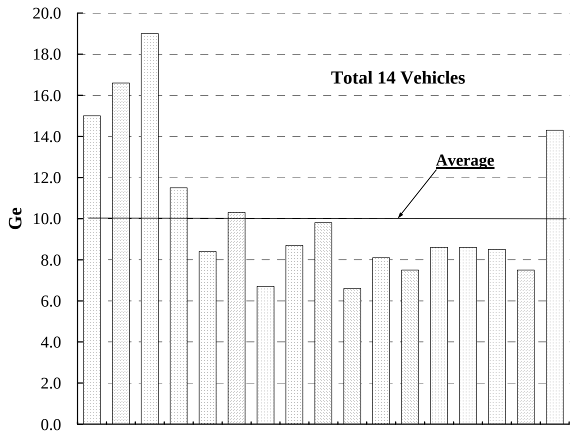
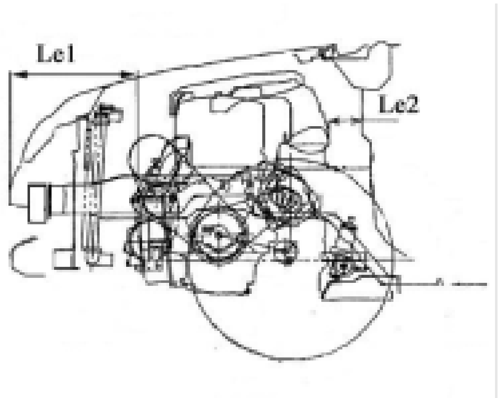


Figure 2 Ge level in actual test results

Engine room for energy absorption
Front side member

Cabin for reaction part
Under body Side member rear
Side sill

Upper body A-pillar upper
Side roof rail



Crushable Length = Le1+Le2

Figure 3 Engine room crushable length

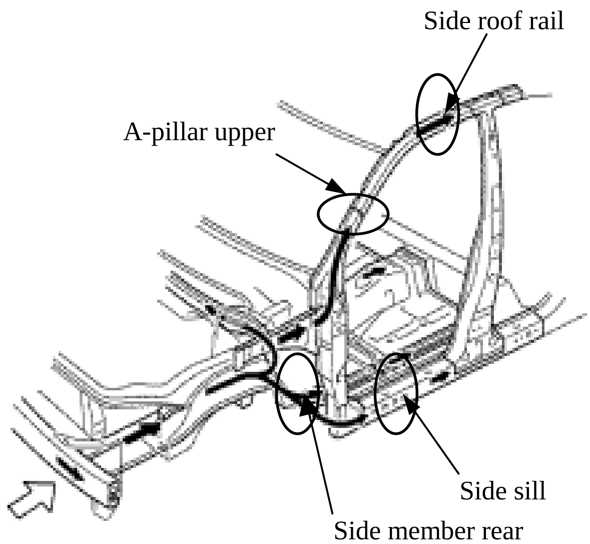


Figure 4 Related sections

Section Properties

The section properties of the following structural members were considered in this study (Figure 4).

The deformation of a front side member and a side sill seems mainly due to the compression force, and the section area at the weakest section of each member was selected as the representative section

property for these members.
The deformation of a side member rear, an A-pillar upper and side roof rail seems mainly due to the bending moment, and the section modulus at the weakest section of each member was selected as the representative section property for these members.
Each section property (section area and section modulus) was calculated from geometry of the section and material properties.

Combination of Section Properties

The side member rear and side sill are considered to activate as parallel springs, while the A-pillar upper and side roof rail are considered to activate as serial springs. Therefore the combination property for these regions was assumed to describe:

For side member rear and side sill:
(Upper cabin property) =
(Section area of side sill)
+ Ks*(Section modulus of side member rear)
----- (3)

Here, Ks are the coefficient and the constant value has been decided through FEM analysis results for various vehicles.

For A-pillar upper and side roof rail:
1/(Upper cabin property) =
1/(Section modulus of A-pillar upper)
+ 1/(Section modulus of side roof rail)
----- (4)

The representative section properties were divided by vehicle mass to neglect the effect of the vehicle mass. The cabin properties were also multiplied by the coefficient Kc in the equation (2).

Cabin intrusion

The relationship between each section properties of the structural members and cabin intrusions was investigated and the best combination was found out.
The investigated cabin intrusions were toe-board intrusion and A-pillar rearward deformation.
The test data of used in this study were in-house test results including some competitor's vehicle with the model year range of 1998-2000. The test method was according to JNCAP[1] or EuroNCAP[2] test procedure.

RESULTS

Toe-board intrusion

Figure 5 shows the relationship among the representative section area of front side member (vertical axis), under cabin property (Equation (3), horizontal axis) and toe-board intrusion.
Each test results were classified into four categories according to toe-board intrusion value and were indicated by different symbols as shown in Table 1.

Table 1 Test result category (Toe-board intrusion)

Category	Toe-board intrusion range	Symbol in the graph
I	<RV1	No data
II	RV1< <RV1+50	○
III	RV1+50< <RV1+100	□
IV	>RV1+100	△

RV1: reference value

It can be said the area of the graph can be separated with different toe-board range, although some exceptional test results exists in the graph.
When the structure is week (left lower area in the graph), the toe-board intrusion will become large.
When the structure is strong (right upper area in the graph), the toe-board intrusion will become small.

A-Pillar rearward deformation

Figure 6 shows the relationship among upper cabin property (Equation (4), vertical axis), toe-board intrusion (horizontal axis) and A-pillar rearward deformation.
Each test results were classified into three categories according to toe-board intrusion range and were indicated by different symbols as shown in Table 2.

Table 2 Test result category (A-pillar rearward deformation)

Category	A-pillar rearward deformation	Symbol in the graph
V	<RV2	●
VI	RV2< <RV2+50	■
VII	>RV2+50	▲

RV2: reference value

A-pillar rearward deformation depends upon the deformation of under cabin, which is described by toe-board intrusion. Therefore toe-board intrusion was selected as the main parameter.
It can be said the area of the graph can be separated with different A-pillar rearward deformation range, although some exceptional test results exists in the graph.

Higher strength of upper cabin (upper side in the graph) indicates less A-pillar rearward deformation with same toe-board intrusion.

CONSIDERATIONS

Figure 5 and Figure 6 can indicate some design guideline for the vehicle structural member. For example, if some target of the toe-board intrusion is described, the necessary section property of structural member can be estimated roughly from Figure 5.

This guideline is not so accurate to skip FEM analysis. However, it is very simple and little time consuming, therefore it seems a practically useful design tool especially in very early design stage to estimate rough performance of the vehicle body.

This method seems very effective to implement "better birth" structure from the initial design stage and decrease iteration cycles by FEM simulation to meet the target level.

REFERENCE

1) New Car Assessment Japan
Offset frontal collision testing Methods

2) European New Car Assessment Programme
Frontal Impact Testing Protocol
Version 3.1.1 August 2002

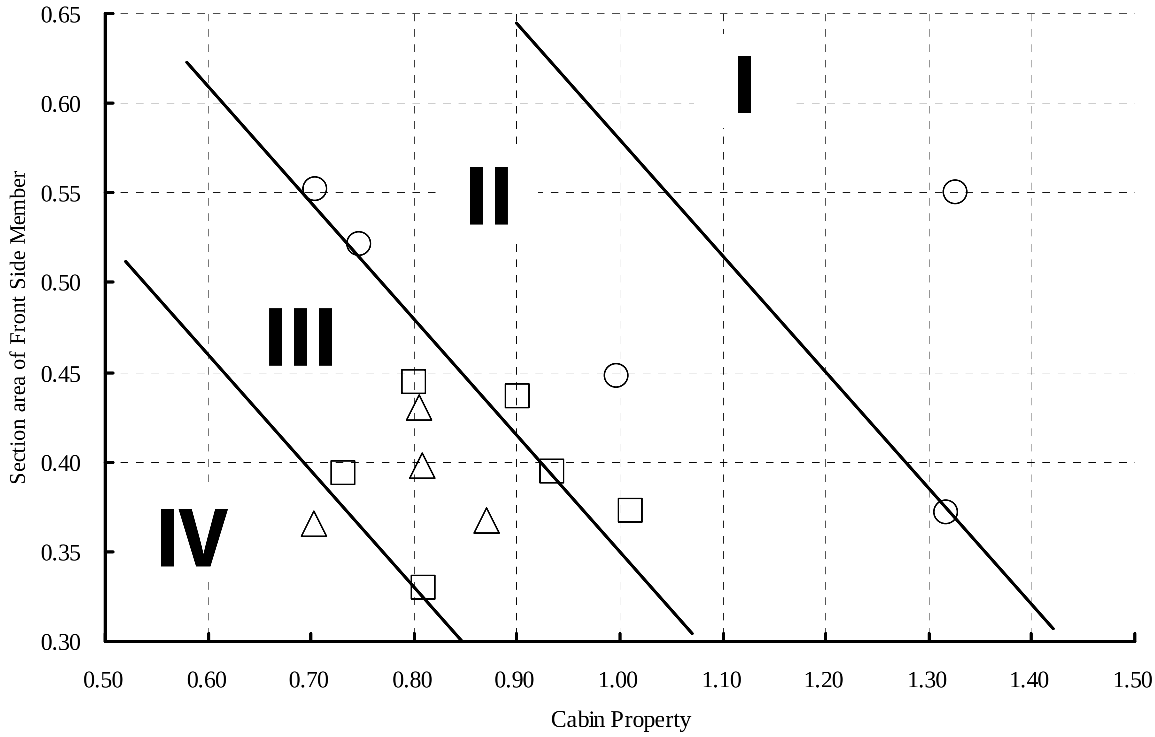


Figure 5 Relationship among the representative section area of front side member, under cabin property and toe-board intrusion

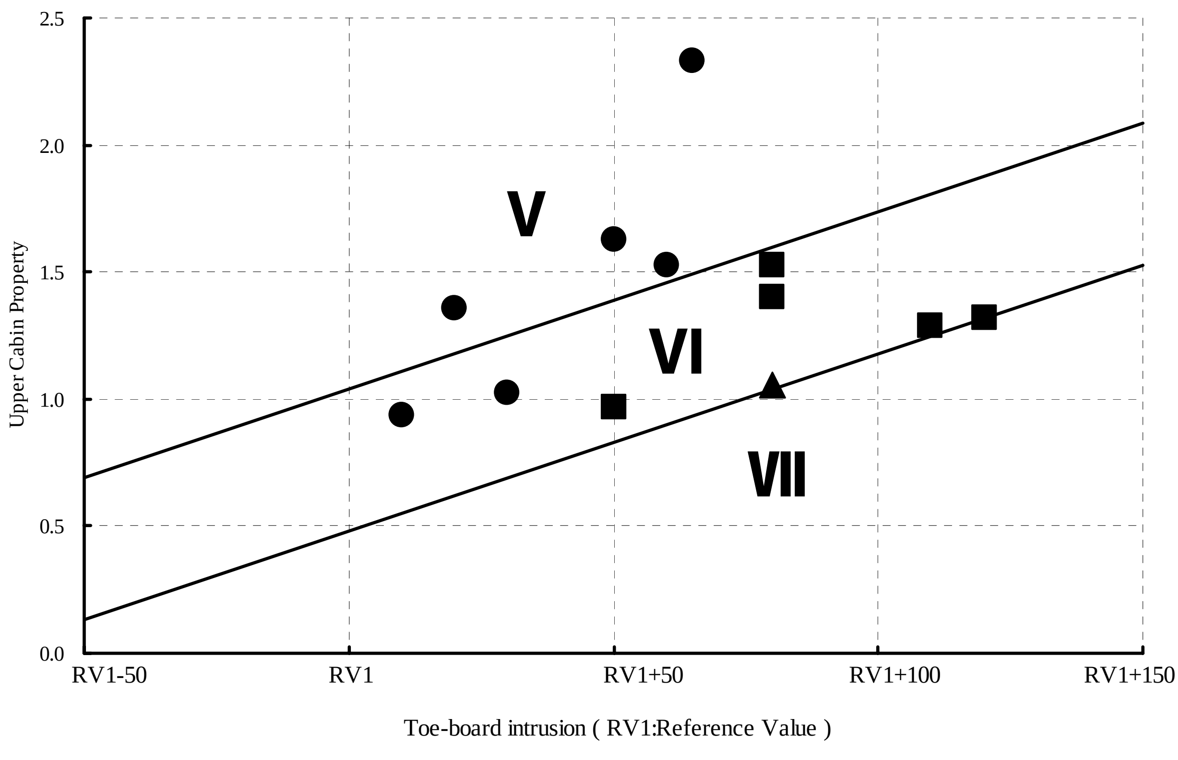


Figure 6 Relationship among upper cabin property, toe-board intrusion and A-pillar rearward deformation