Analysis SUV Vehicle Structure in Car to Car Frontal Impact

Nguyen Phu Thuong Luu and Ly Hung Anh

Abstract This study provides an analysis of the structural characteristics of an SUV vehicle in the context of a frontal impact. The results of the analysis provide an indication of the deformation magnitude and the capacity of the SUV vehicle structure to absorb the energy of the collision. This paper examines the structural characteristics of an SUV vehicle in the context of a frontal impact. Through simulations of the SUV vehicle structure model colliding with an object at various speed levels, the analysis seeks to identify the frame structures that can absorb the most impact energy and minimize deformation, thus safeguarding the occupants of the vehicle. The results of this study indicate that the A-Pillars and the longitudinal need to be improved to ensure the safety of the passengers.

Keywords Analysis · Simulate · SUV · Vehicle structure · Fontal impact

1 Introduction

Statistics from the Traffic Police Department of the Ministry of Public Security [1] show that more than 45% of cases involve traffic accidents with passenger cars, taxis, and cars caused by trucks, resulting in 52.1% fatalities and 80.5% injuries. These

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particularly serious traffic accidents are mainly due to drivers' lack of awareness while driving or using a device. The collision process can deform the side of the sport utility vehicle (SUV), putting the occupants in danger. Accidents can be frontal, side, rear, or overturn.

According to US-NCAP (United States New Vehicle Assessment Program), a hard-wall frontal crash test at 64 km/h is same as a car head-on collision at 55 km/h [2]. Some crash studies in Japan show that a head-on collision between two cars with a speed of 48.4–68.6 km/h is considered a speed hazard [3]. In a head-on collision, the height of the chassis greatly affects the deformation of the chassis [4]. The research [5] demonstrates that the impact force is divided, with half being taken up by the chassis and the other half spread across the engine and other parts.

The Insurance Institute for Highway Safety (IIHS) reported that SUVs with a Unibody frame decreasing the mortality risk by 18% compared to Body-on-frame vehicles [6], and that head-on collisions had a 51% risk of death [7]. Additionally, crash tests were conducted to measure the small overlapping collisions that occurred between 120 and 150 ms [8], and a simulated test of a collision between two SUVs and a sedan was conducted by adjusting the height, which resulted in different overlap rates [9].

This paper focuses on crash simulation and analysis of the deformation and collision absorption capacity of the vehicle sidewall. SUV is a sport utility vehicle with a larger size and payload than other large cars, built and simulated entirely on LS-DYNA software [10], in order to analyze and check problems [11, 12].

2 The Foundation of Collision Theory

When two moving cars collide with each other (collision at the center), an amount will appear, this is called a quantity and point. Energy and point depend on crash speed, chassis structure and vehicle design structure. With a constant speed, the maximum amount of energy and points when connecting the frame and making the material of absolute rigidity. However, when two vehicles collide, the structure and material manufacture are damaged and absorb some energy. This energy is known as absorbed energy.

Assume that two vehicles are moving on one coordinate axis Ox (Fig. 1).

v_1 is the car 1 speed
v_2 is the car 2 speed.
p is the pre-crash relative velocity.
p' is the post-crash relative velocity.

Based on Newton's second law, vehicle A and vehicle B interact with each other by applying forces on each other. These forces are known as relative forces and are equal in magnitude and opposite in direction. The force between car A and car B is denoted as F and it acts over a specific time interval from t to t'. In other words, the

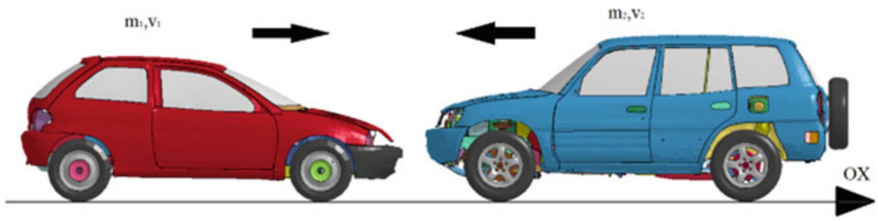

Fig. 1 Two vehicles are moving on one coordinate axis Ox

force exerted by vehicle A on vehicle B is equal to the force exerted by vehicle B on vehicle A.

Where: t is the starting crash time.

t' is the end time of crash.

Then impulses will be created:

$$I = \int_{t}^{t\prime} F(t)\mathrm{d}t \tag{1}$$

where: I is the linear pulse

F is the crash force.

Utilize the concepts of linear impulse and angular momentum to analyze the vehicles pre-crash and post-crash:

$$m_1 v_1 - I = m_1 v_1\prime \tag{2}$$

$$m_2 v_2 + I = m_2 v_2\prime \tag{3}$$

where: v_1, v_2 are the starting velocities of vehicle A and B,

$v_1\prime$, $v_2\prime$ are the post-crash speeds of vehicle A and B.

According to pre-crash and post-crash the conservation of kinetic energy as shown below:

$$\frac{m_1}{2} v_1^2 + m_2 v_2 = \frac{m_1}{2} v_2^{\prime 2} + \frac{m_2}{2} v_2^{\prime 2} + \Delta E \tag{4}$$

From Eqs. (2), (3) and Eq. (4), we rewrite:

$$\frac{m_1}{2}(v_1 - v_1\prime)(v_1 + v_1\prime) = \frac{m_2}{2}(v_2 - v_2\prime)(v_2 + v_2\prime) + \Delta E\prime \tag{5}$$

From Eqs. (2), (3) and Eq. (4), we rewrite:

$$\frac{I}{2}(v_1 + v_1\prime) = \frac{I}{2}(v_2 + v_2\prime) + \Delta E\prime \tag{6}$$

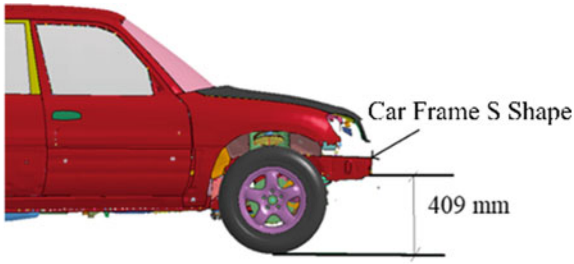

Fig. 2 The height of Car Frame *S* shape on Toyota RAV4

Table 1 Specifications of Toyota RAV4

Toyota RAV4	
Wheelbase	2410 (mm)
Width	1695 (mm)
Height	1660 (mm)

$$\Rightarrow \Delta E\prime = \frac{I}{2}[(v_1 - v_2) + (v_1\prime - v_2\prime)] \quad (7)$$

$$\Rightarrow \Delta E\prime = \frac{I}{2}(p + p\prime) \quad (8)$$

3 Analysis of Frame Structure

The Toyota RAV4 series, an SUV with a Unibody frame, was employed as the model for the study. The National Center for Incident Analysis (NCAC) utilized reverse engineering to construct a finite element (FE) model of the Toyota RAV4 (Fig. 2) based on its actual specifications (Table 1) and assessed by the US National Highway Traffic Safety Administration (NHTSA). The model was then tested in a crash simulation at 64 km/h with a solid barrier, which was enabled by the modeling aspect of the research.

4 Simulation

As previously discussed, there are two widely used types of frames for SUVs: Unibody and Body-on-frame. As a result, crashes at 55 km/h will be calculated in this study using 100% frontal collisions in accordance with NHSTA and IIHS guidelines. Create a crash simulation between car A (blue) and car B (red) to find the SUVs weakness areas. For Unibody chassis on Toyota RAV4 examples, adjustment of two crash models to a frontal collision is displayed [13]. The last case examines the deformation of both types of frames during impact. Set up a simulation using the LS-DYNA software with three collision scenarios (Fig. 3).

Case 1: Simulation of the finite element model (FE) between two Toyota Rav4 (SUV) vehicles in head-on collision with the same speed of 55 km/h, the model is taken from NHSTA and tested according to NCAC, simulating both vehicles collided with a speed of 55 km/h and the collision process on the LS-DYNA software (Fig. 4).

The process in Case 1 shows that both cars collide at the same speed, the chassis at this time is pinched inward and bent at the S position at 65–100 ms. Due to the large volume of the collision, the rear body was pushed up, causing the front of the vehicle to face down, and the frame was found to be bent in the downward direction.

Case 2: Simulation of the finite element model (FE) between two Toyota Rav4 (SUV) cars in 100% head-on collision, car A (blue) moving at 55 km/h and car B

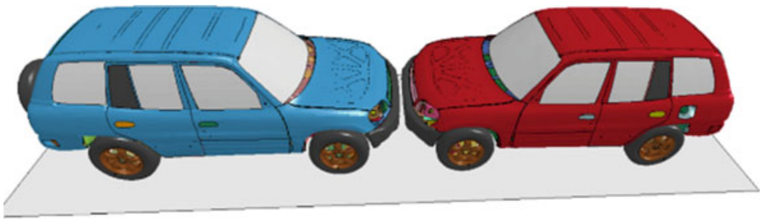

Fig. 3 Simulation of a head-to-head collision between two Toyota Rav4 (SUV) vehicles

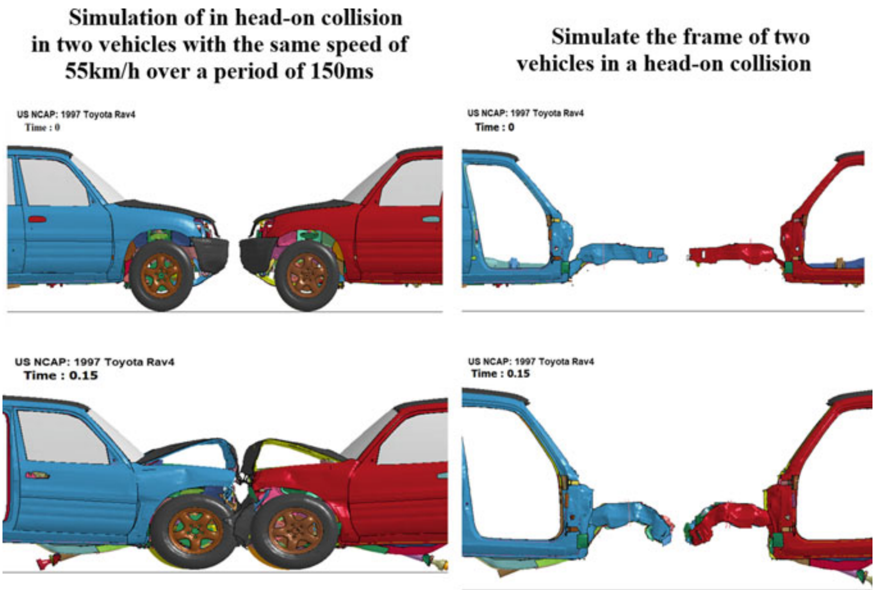

Fig. 4 The simulation a collision between two SUVs at the speed of 55 km/h

(color red) is stationary, simulating both the frontal collision and the collision process on the LS-DYNA software (Fig. 5).

The collision process in Case 2 of a direct collision between vehicle A with a speed of 55 km/h and vehicle B at rest shows that the elements of the front chassis of vehicle A are less deformed, showing that when the collision occurs collision with a stationary vehicle of similar height.

Case 3: Simulation of finite element (FE) between two Toyota Rav4 (SUV) frontal collision 40%, both cars collide at the same speed of 55 km/h, model is taken from NHSTA and tested according to NCAC, simulate both frontal collision (Fig. 6) and crash process on LS-DYNA software (Fig. 7).

Through all 3 cases, it was found that the Toyota Rav4 chassis was pinched if it collided with a vehicle with a horizontal frame size or larger, in Case 3, both the frame and the body were compressed quite a bit. In case of 100% head-on collision at the

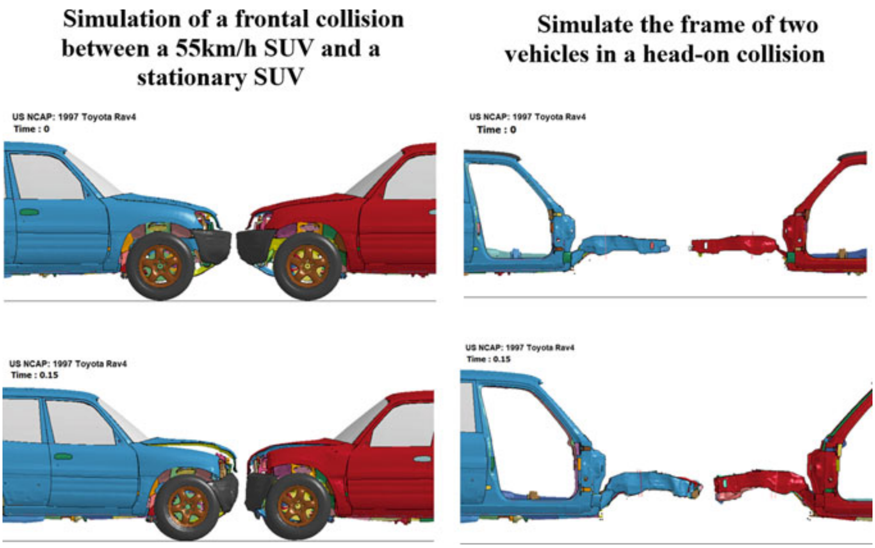

Fig. 5 The simulation a collision between two SUVs with different speeds

Fig. 6 Simulation of a collision between two SUVs with a 40% deviation

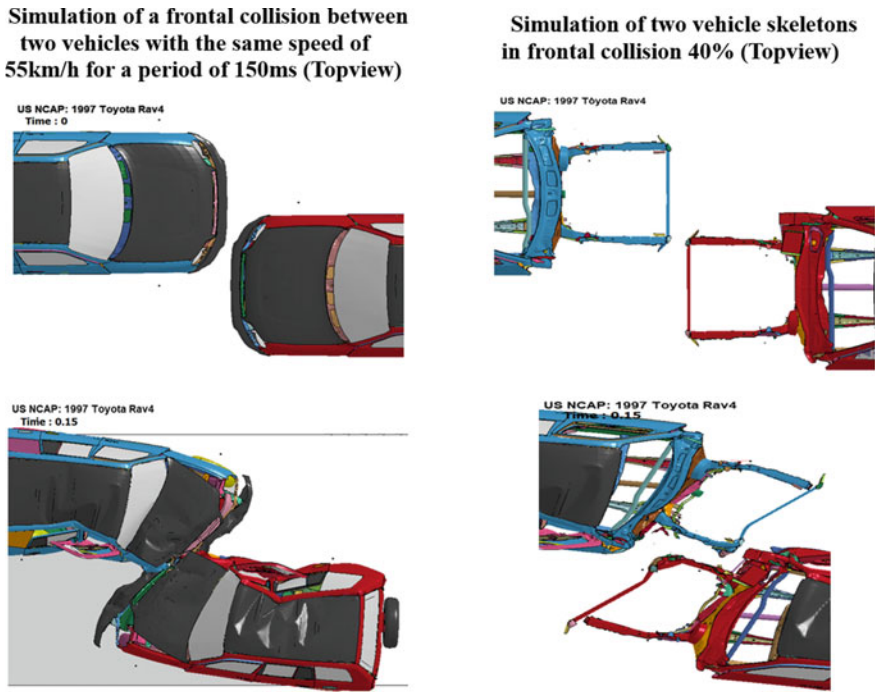

Fig. 7 The simulated collision process between two SUVs collides with a 40% deviation at a speed of 55 km/h

same or different speeds, the safety of the driver and occupants in the vehicle is still ensured in Case 1 and Case 2. But in Case 3, it is noticed if the collision is deflected. 40% leads to deformation of both the chassis and the passenger compartment (Fig. 7), endangering the occupants on the impact side and the rear passengers.

5 Conclusion

In this study, the finite element model (FE), which shows the deformation of the chassis structure of the SUV, uses the unibody frame type on the LS-DYNA software. The car has not yet shown full crash compatibility. Frontal crash simulation focuses on the front frame to improve inadequate energy absorption, while too much penetration into the dashboard easily injures the front occupants. Simulation results only when the collision at the same speed finds that the front frame of the vehicle is bent and pressed inward at the connection position between the frame and the passenger compartment. In a crash simulation that was not representative of actual conditions, the passenger compartment was observed to suffer significant deformation, thus posing a risk to the safety of the passengers. Consequently, it is imperative that the safety features of

SUVs be enhanced in order to guarantee the protection of the driver and passengers in the event of a collision.

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