THE EFFECT OF CRASHWORTHINESS PARAMETERS FOR VEHICLE BODY

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ABSTRACT

With the modernization and globalization of the world we live in, use of vehicles have become very important. Increasing number of vehicle on the road has led to an increase in accidents. Vehicle safety has become more paramount of an issue than it ever was and vehicle manufacturers strive to make their products safer for its occupants and other road users. One of the most important aspects of vehicle safety is the crashworthiness of the vehicle. Balancing the vehicle design, weight and crashworthiness features has become a dilemma for the safety engineers. This paper would review the core crashworthiness parameters and briefly discuss the effects of those parameters on a vehicle body.

Keyword: Crashworthiness Parameters, Effects On Vehicle Body, Vehicle Design

I. INTRODUCTION

Every year the amount of vehicle produced and the people using them have been increasing. Different types of drivers, some very careful and some very reckless, sit behind the wheels. With this increasing amount of vehicle usage, road traffic and reckless driving, the number of vehicle accidents and accident fatalities has also increased. Eventhough there are accident prevention guidelines and traffic rules, many fall victim to these life threatening accidents. According to the statistics from the National Highway Traffic Safety Administration (NHTSA) of the United States [1], after a decline in motor vehicle crashes and fatalities for 6 straight years since 2005, the number had increased again in 2012. In United States alone, 45,586 vehicles were involved in fatal crashes [2] from which 78 percent were passenger vehicles constituting a total of 21,667 deaths and an estimated 2.09 million injuries. Vehicle safety issues have been a topic of utmost importance for decades now. To minimize the accidents, more importantly the fatalities involved, extensive research has been made into areas of vehicle safety and protection. Active (primary) safety and passive (secondary) safety measures have been implemented.Active safety [3] refers to the systems, mostly automated, that are designed for accident prevention and accident mitigation while passive safety [4,5] refer to the features of the vehicle that prevents or minimizes the injury to the vehicle occupants without the driver or occupant action.

Passive safety includes crashworthiness of the vehicle. Crashworthiness [6] is the ability of a vehicle structure and its components to protect its occupants in case of a crash and maintain a survivable space for the occupants. This review paper would:

1. explore and discuss the corecrashworthiness parameters
2. briefly discuss crashworthiness in different directions of impact
3. discuss the effects of crashworthiness parameters on the vehicle body

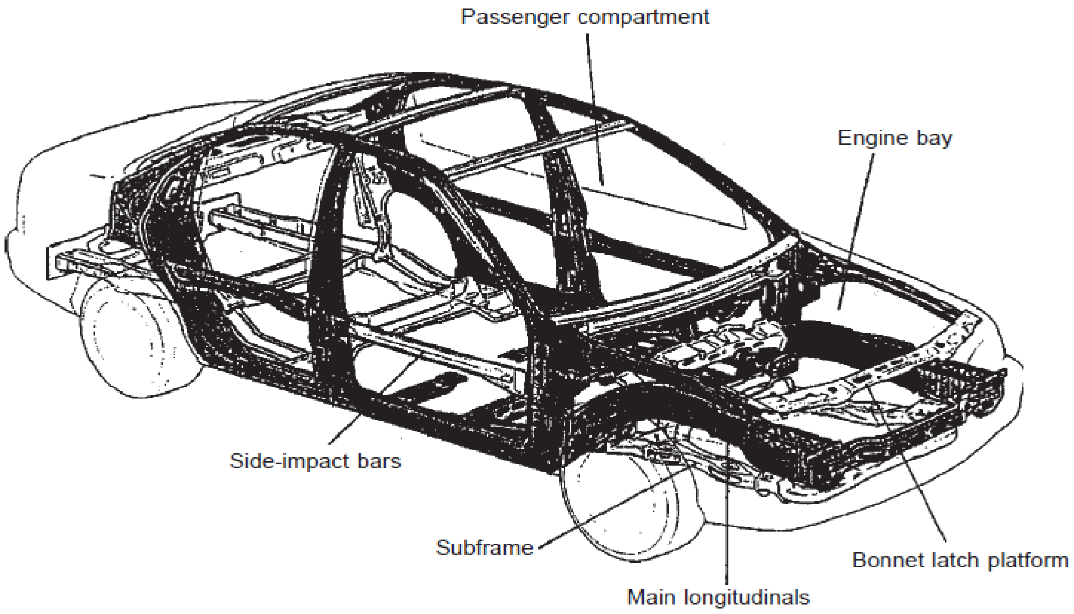

Figure 1: Basic Structure of Modern Saloon Car [7]

II. CRASHWORTHINESS PARAMETERS

This chapter would discuss the following parameters of crashworthiness:

1. The maximum load (Pmax)
2. Total Energy absorbed (E_a)
3. The mean load (Pm)
4. Specific Energy Absorption (SEA)
5. Crush Force Efficiency (CFE)

2.1. The Maximum Load (Pmax)

The maximum load (Pmax)[8], also referred to as peak crushing force[9], is the force required for the vehicle body to start the energy absorption process and initiate plastic deformation. In the design of a vehicle, the front of the vehicle is designed with a series of crumple zones [10], each of which would resist deformation until a certain load level is reached after which the zone deforms constantly until next zone is reached. This is sometimes true for rear of the vehicle [11] incase of any impact from rear. The higher the peak force/load, the higher the deceleration of the vehicle would be during the impact. Higher deceleration levels cause higher risk of brain injury[12]. The maximum load could also be defined as the compressive strength of the material.

2.2. Total Energy absorbed (E_a)

Total Energy absorbed (E_a) is the total energy absorbed during the crash or deformation. This could be calculated by calculating the area under the force-displacement graph [8,13] and can be mathematically represented as follows:

$$E_a = \int_0^{\delta_b} P \, . \, d\delta \quad (1)$$

In the formula P is the instantaneous crushing load and δ_b is the length of crushing specimen.

During energy absorption, kinetic energy is converted to other forms of energy as the material deforms. As the kinetic energy is lost during the process, the forces acting on the vehicle and its occupants will also decrease [14]. As such, the energy absorption parameter is very imperative for crashworthiness of a vehicle.

In the earlier vehicle designs, designers believed that stiff vehicles would provide the best safety in collisions [11]. Therefore the vehicles were designed with stiff, non-deformable front ends, rear ends and the occupant cell. However this proved to be fatal, as the vehicle's front and rear ends did not crush in collisions allowing all crush force to be directed towards the occupant cell [11]. This caused the occupants to experience high deceleration leading to brain injuries [14].

2.3. The Mean Load (Pm)

The mean load (Pm), also referred to as mean crushing load [8,15] could be interpreted as the average or specific energy absorption per unit crash of the structure [16] and can be defined by the following formula:

$$P_m = \frac{E_a}{\delta_b} \quad (2)$$

2.4. Specific Energy Absorption (SEA)

Specific Energy Absorption (SEA) is the energy absorbed per unit mas (m) of the material [8] and is an important factor while considering low weight objectives [16]. It can be calculated by the following formula:

$$SEA = \frac{E_a}{m} \quad (3)$$

	Material	Relative Density	Density	Energy Dissipation/ Unit volume (MJ/m³)	Energy Dissipation/ Unit mass (MJ/kg)
Aluminium Foam	Cymat Foam	0.2	560	6.3	0.01
	Alulight Foam	0.35	1000	11.2	0.011
	Alporas Foam	0.1	250	1.394	0.006
	ERG Foam	0.1	250	2.7	0.011
	Duracore Foam	0.35	1000	17	0.017
Ulra high strength steel	DP500	-	7800	70	0.009
	DP600	-	7800	66.5	0.009
	TRIP800	-	7800	132.3	0.016
	CP-W800	-	7800	64	0.008
	MS-W1200	-	7800	52	0.007

Table 1: Comparison of Energy Dissipation of Various Materials [17]

Table 1 shows that Carbon Fiber Reinforced Polymer (CFRP) has better energy dissipation with regards to unit volume and unit mass. However, in metals, Ultra high strength steel has better energy dissipation per unit volume whilst Magnesium has a better energy dissipation value per unit mass.

2.5. Crush Force Efficiency (CFE)

Crush Force Efficiency (CFE) [18] is the ratio of mean crushing force (Pm) to the maximum crushing force (Pmax). CFE can be used to categorize load consistency [19] and measure the performance of an absorber [20]. CFE can be mathematically represented by: $CFE = \frac{P_m}{P_{max}}$ (4)

III. ACHIEVING CRASHWORTHINESS IN DIFFERENT IMPACT DIRECTIONS

From the previously discussed parameters, we see that core components of crashworthiness parameters revolve around absorbing the impact energy by a controlled means of failure of the structure. The better a material absorbs energy, the safer the material could be in an impact. In automotive design, crashworthiness in frontal and side impacts are imperative to save the occupant fatality. For frontal impact, the crash structures are front end and long members that would go through progressive axial collapse during impact [17]. For side impacts, the door structures along with the components of the body dissipate crushing energy by deforming in bending [17]. The side impact beams or bars play an important role in providing the lateral stiffness of the side structure giving a survivable space for the occupants in an impact [21]. Door padding is also used to reduce the effects of a side impact [22].

IV. EFFECTS OF CRASHWORTHINESS ON THE VEHICLE BODY

In 1951 Béla Barényi revolutionized car safety by developing the concept of rigid structure to prevent the collapse of the passenger compartment with crumple zones at the front and rear to absorb the crash energy [23, 24]. Generally, it is known that the design of a vehicle body structure should meet the following requirements:

- Passenger compartment/box should be rigid enough to allow a survivable space during a crash
- The deformation zone should be sufficient to absorb the impact energy
- Should be compatible with other road users

In a crash scenario, the longitudinal members have to absorb most crash energy with a progressive folding deformation [17, 25]. The energy absorption should be such that the amount of deceleration force should be as low as possible to decrease the occupant injury to an acceptable level.

4.1. Effect on Weight

In terms of weight of the vehicle body, it is generally understood that increasing or improving crashworthiness of a vehicle will add up to weight of the vehicle body. This is mainly due to the fact that stiff and stronger materials have to be used to achieve crashworthiness for both frontal and side impact scenarios. The materials used in the crumple zones should be stiff and strong enough to absorb the impact well while the side impact beams, safety cages and side pillars [26] should be strong enough to withstand an impact without allowing any intrusion or too much reduction in occupant compartment. Many academics also believe that heavier cars correspond to better safety [27]. On the other hand, the equation (3) suggests that inorder to have a better energy absorption factor, more of that material should be used. Hence, increasing the mass of the body.

4.2. Effect on Size and Thickness

The sizeof the vehicle body, in this context, refers to the dimensions ofthe car including crumple zones, engine compartment and the occupant compartment. Research in this field suggest that vehicle size is an important safety variable in collisions between similar vehicles [27]. The automotive designers adjust the crumple zones of the vehicle depending on the size of the vehicle [4]. Larger vehicles have a bigger and softer crumple zone while the smaller vehicles have small and stiffer crumple zone. At any case, having the crumple zones in the front and rear to absorb impact energy adds up to the overall size of the vehicle body. The size of the occupant compartment also adds upto the overall size. Since crashworthiness principles dictate that occupant compartment should retain a survivable space for the occupants during a crash [28], decreasing the cabin size would compromise occupant safety and increase the risk of the injuries or fatalities. In side impact crash scenario, the incident car hits the striking car from the side where there are no crumple zones and the occupants are directly involved. In such cases, the main objective is to minimize intrusion and divert the impact forces away from the occupants [4, 6]. To achieve this, the side beams, door designs and the side structure should be made of stiff material that would dissipate crush energy in bending [17] at the same time retaining a survivable space. Crashworthiness in side structure would be achieved by using thick and reasonably stiff material. The thicker the material would be, the better it is in crashworthy aspects.

4.3. Effect of Shape

The shape of the car should not be such that it would reduces the crumple zones to an extent that these zones cannot perform their function and the occupant cell is not able to protect occupants in a crash. Crashworthiness is significantly improved by a good body design and many researchers argue that bigger cars generally offer better crashworthiness than smaller cars [4, 27].

V. SUMMARY

Consumers are beginning to be more aware of the importance of vehicle safety and prefer vehicles with more safety features. With this demand from the consumers, manufacturers are left with no choice but to improve the safety features of the vehicles. Many researcheshave been done on improving the crashworthiness of the vehicle by optimizing the vehicle and impact absorbing structures. Fuel economy demand, safety demands and other demands from consumers, regulatory bodies and governments have driven the manufacturers to come up with designs that are lighter yet safer. The dilemma that safety engineers face at design stage is that crashworthiness parameters do not allow significant change to the body design and weight without compromising the safety of the occupants. Eventhough new composite materials have emerged in the recent years that would make the vehicle body lighter compared to the steel or metal bodies used now, research has still to be done on crashworthiness applications of such material and their cost-benefit analysis. Vehicles made up of strong composite material body structure that is as good as metals in crashworthy aspects would be much more expensive and unfeasible for consumer production. Further research has to be done on optimizing vehicle design, weight and size and retain an acceptable level of crashworthiness inorder to comply with the legislations and regulations to improve vehicle fuel efficiency and safety, and cater to the consumer demands to make vehicles modern, sportier and more crashworthy.

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