

İSTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE
ENGINEERING AND TECHNOLOGY

**DESIGN AND DEVELOPMENT OF SIDE UNDERRUN PROTECTION
DEVICES**

M.Sc. THESIS

Didem AKKUŞ

Department of Mechanical Engineering

Mechanical Design Engineering Programme

Thesis Advisor: Prof. Dr. Hikmet KOCABAŞ

MAY 2016

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

YAN KORUYUCULARIN DİZAYNI VE GELİŞTİRİLMESİ

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**Didem AKKUŞ
503121206**

Makina Mühendisliği Anabilim Dalı

Konstrüksiyon Programı

Tez Danışmanı: Prof. Dr. Hikmet KOCABAŞ

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Didem Akkuş, a M.Sc.student of İTÜ Graduate School of Science Engineering andTechnology student ID 503121206, successfully defended the thesis/dissertation entitled “DESIGN AND DEVELOPMENT OF SIDE UNDERRUN PROTECTION DEVICES”, which he/she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Prof. Dr. Hikmet KOCABAŞ**

İstanbul Technical University

Jury Members : **Yrd. Doç. Dr. İsmail GERDEMELİ**

İstanbul Technical University

Prof. Dr. Ferhat DİKMEN

Yıldız Technical University

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To my family,

FOREWORD

Many people are to be thanked bringing this thesis and project to fruition. I would like to extend my sincerest thanks and appreciation to Prof. Dr. Hikmet Kocabaş who helped me accomplish this study.

Finally, I would like to thank my family and friends for their endless support in life.

May 2016

Didem Akkuş
Automotive Engineer

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ABBREVIATIONS

ADR	: Australian Design Rules
App	: Appendix
BITRE	: Bureau of Infrastructure, Transport and Regional Economics
ECE	: Economic Commission for Europe
EU	: European Union
FUPD	: Front underrun protection device
GVM	: Gross vehicle mass
OEM	: Original Equipment Manufacturer
SUP	: Side underrun protection
SUPD	: Side underrun protection device
UNECE	: United Nations Economic Commission for Europe
UK	: United Kingdom

SYMBOLS

e	: Exponent
kN	: Kilo Newton
N	: Newton
t	: Thickness

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DESIGN AND DEVELOPMENT OF SIDE UNDERRUN PROTECTION DEVICES

SUMMARY

The aim of this study is to review the existing literature and applications in side under-run protection devices and to submit new design proposals.

Every year, thousands of people are killed or injured by the crashes when heavy trucks are involved in. To prevent this problem, front and rear under-run protection devices are a requirement of law for heavy vehicles in many regions of the world and lateral under-run devices are also defined by most regions. This study starts with a review of literature on frontal, rear and side under-run accidents and statistics and continues with regulations in major world regions. The study points out that staying within the limits mandated by laws under-run protection design has significant effect on damage to vulnerable road users on potential crashes and the potential for creating economic efficiency through these devices are also of value for the future.

The current side under run protection device designs are reviewed and explained in detail. The advantages and disadvantages of them are compared. Besides safety factors, economy and environment friendly effects of side underrun protections are explained by several research results.

Finally, it is given the insights about the future direction of under-run protection design and what business implications are there for the industry in the future. The new honeycomb structure side under-run protection is designed in NX and tested under the loads by using finite element method in Ansys. According to the allowed deformation, weight optimization is applied on the design. Alternatively, other material and it's design is tested under the same loads. After that, the results are compared with each other to find out an optimum design for manufacturer.

In addition to mechanical improvement, weak points to improve on the visibility issues are investigated and integrated side marking system design was put forward, which can sense the approaching road users and warn the driver.

YAN KORUYUCULARIN DİZAYNI VE GELİŞTİRİLMESİ

ÖZET

Yerden yüksekliği fazla olan taşıtlarla gerçekleşen kazalarda korumasız karayolu kullanıcıları tekerler arasındaki boşluğa düşüp araç altında ezilebilir ve ölümcül yaralanmalar olabilir. Kamyon ve treyler yan koruyucuları; bu boşlukları kapatarak korumasız karayolu kullanıcılarını yan çarpma sonucu kamyonun tekerlekleri tarafından ezilmesini önlemek için tasarlanmıştır.

Bu çalışmanın amacı, yan koruyucularla ilgili mevcut literatürü ve uygulamaları gözden geçirilmesi; yeni yan koruyucu dizayn önerisi ile kamyon ve çekicileri daha güvenli bir hale getirmektir. Fabrika çıkışlı olarak, üst yapıcı tarafından ya da diğer üreticiler tarafından sonradan araca takılabilir.

Araştırma süresince incelenen yan koruyucuların kazalarda ölüm ve yaralanmaları büyük oranda azalttığı ve bu sebeple yan koruyucuların bahsi geçen araçlar için bir ihtiyaç olduğunu ortaya konmuştur. Mekanik dizayn iyileştirmeleri ile araç altına sıkışma ve sürüklenme sonucu yaralanma ve ölümler azaltılabilir. Kazaların olmasında diğer büyük sebep is görünürlük. Kamyon ve çekicilerin yer aldığı yandan çarpışma kazalarının büyük bir kısmı düşük hızla (30km/h altında) gerçekleşmektedir. Bu araçların tali yoldan ana yola çıkarken yetersiz aydınlatma sonucu görünmemesi, dönüş esnasında kör noktada kalan diğer karayolu kullanıcılarının farkedilmemesi ve yan reflektörlerden gelen ışınların yandan gelen araç tarafından geç farkedilmesi yan çarpışmalara sebebiyet vermektedir.

Avrupa Birliği ülkeleri başta olmak üzere birçok ülkede yan koruyucular yasal zorunluluktur. Avustralya, Amerika, Kanada gibi ülkelerde yasal bir zorunluluk olmamasına rağmen; bu konuda aktif çalışmalar ve öneri niteliğinde düzenlemeler mevcuttur. Türkiye’de ise Avrupa Birliği’nde kabul edilen kanunlar (ECE R73) geçerlidir.

Yan koruyucuların kaza güvenliğinin yanında, tasarımından ötürü diğer faydaları vardır. Düz yüzeyle yan korumaları, hava sürtünme katsayısı düşürür. Özellikle yüksek hızlarda ciddi yakıt tasarrufu sağladığı araştırmalar tarafından ispatlanmıştır. Yakıt tüketimini düşürmesi sonucu egzoz gazlarının salınımına da olumlu etki yapar. Bu sebeplerle çevre kirliliğinin azaltılmasında katkısı vardır.

Görsel etkiler de düşünülerek araca entegre yan tasarımları önem kazanmıştır. Bunun yanı sıra sensörler kullanılarak, sürücünün görüş mesafesi dışında (kör nokta) yaklaşan cisimler için uyarı sistemleri de dizayna eklenmiştir. Genellikle radar sensörler kullanılan bu sistemler cisimleri algılayarak sürücüye sesli/görsel uyarı yapar.

Ön ve arka korumaların aksine, mevcut yan korumalar, sadece korumasız karayolu kullanıcılarını korumak için kullanılmaktadır. Bu yüzden homologasyon testlerinde 1-2 kN'luk yüke dayanım yeterlidir. Tez çalışmasında, araba çarpışmasına da dayanabilecek bir yan koruma dizaynları NX'de yapıldı. Ağırlık optimizasyonu için doğadan esinlenerek tasarlanan bal petek yapısı kullanıldı. Bu yapının Ön ve arka korumalar için uygulanan test yükü 100kN uygulanarak sonlu elemanlar analizi ile Ansys programında test edildi. İzin verilen deformasyon limitleri arasında kalacak şekilde dizaynda ağırlık optimizasyonu uygulandı.

Alternatif malzemelerle aynı test koşulları için tekrar sonlu elemanlar metodu ile analizler yapıldı. Analiz sonuçları karşılaştırmaları ile optimum çözüm bulunmaya çalışıldı.

Görünürlük sebebiyle meydana gelen yan çarpışmalar incelendi. Yetersiz aydınlatma ve göz refleksleri nedeniyle geç farkedilmenin, çarpışmalardaki en önemli etken olduğu tespit edilmiştir. Bu nedenlerle meydana gelen kazaları önlemek için görünürlük iyileştirme dizayn önerisi sunuldu. Yan koruyucuların üzerine entegre olacak öneri dizaynda, yan işaret lambaları sensörlerle donatılmış olacak. Sensörler yaklaşan aracın aydınlatmasını (ön farları) algılar, yan işaret lambaları yanıp sönmeye farkedilirliği artırır. Normalde farklı ışığı algılamak için 0,5 saniyeye ihtiyacı olan insan gözü parlak yanıp sönen işaret lambalarını algılayabilecektir. Bu sayede

dönüşlerde kamyon ve treyler farkedilip yaklaşan araç da buna göre önlemlerini alabilecektir.

1. INTRODUCTION

A traffic collision occurs when a vehicle collides with another vehicle, pedestrian, animal or any other obstruction in the vicinity. Traffic collisions may result in injuries, fatalities or property damage.

There are several factors that contribute to the risk of collision.

- These factors include;
- Vehicle design
- Speed
- Road design
- Road Environment
- Driver skill
- Substance abuse

This thesis focuses on vehicle design aspect in collisions and in particular side under-run protection devices design, position in road safety regulations and future in business.

Road traffic safety refers to methods and measures for reducing the risk of a person using the road for being killed or seriously injured. Road users may include pedestrians, cyclists, motorists and all people in vehicles using the road network.

In most regions of the world front and rear under-run protection device regulations are well defined by road traffic safety regulations, and side under-run protection devices are also continually upgraded.

Side under-run protection, which can be seen in Figure 1.1, has been considered since the earliest cars and has been given bigger importance ever since.

Side collisions are vehicle crashes where the side of one or more vehicles is impacted.

Technically called a Side Under-run Protection System (SUPS), is a rigid assembly hanging down from the side of the vehicle, intended to provide some protection for passenger cars and other vulnerable road users such as motorcyclists, cyclists and pedestrians which collide with the side of the truck or trailer.

Additionally, side guards provides environmental benefit through fuels saving by aerodynamic drag reduction.

The requirements on side guards are legislated on certain vehicles as semi-trailers, tractors and trucks in various countries in the world. The requirements are continually upgraded and R&D investments in side guards are increasing in parallel. The designs are moving from simple mechanical structures to sensors systems and more integrated systems with the rest of the tractor and trailer.



Figure 1.1: Side protection devices

1.1. Purpose of Thesis

The purpose of this thesis is to review the existing applications of side under ride protection devices, with the view of drawing future prospects and valuable insights putting forward proposals for the development of side guards applications in the industry.

2. LITERATUR SURVEY

2.1. Accidents

2.1.1. Accident statistics

Several accidents happen because of heavy truck drivers or other road users/vehicles unawareness of others close to their vehicle (Figure 2.1 and 2.2). These accidents often happen when one of the vehicles is changing direction or at junctions and roundabouts. It is estimated that every year 400 people in Europe are killed in heavy vehicle involved crashes.



Figure 2.1: Trailer car accident



Figure 2.2: Trailer-Cyclist accident

According to a research of BITRE (Bureau of Infrastructure, Transport and Regional Economics), 15% of all road crash fatalities has been in accidents involving heavy

vehicles. And 74% of fatalities in these crashes are the other vehicle occupants and vulnerable road users.

Otte (1987) found 22% of the injuries to cyclists and 27% of pedestrians resulted from being overrun by the wheels due to underrun.

In a 1987 study by Langweider and Danner on 110 accidents with pedestrians, it was found that 42% were with the front of the truck and 33% with the side. An interesting finding from the same study is that 2/3 of heavy vehicle crashes happens at speeds below 30 km/h.

In a study by Rechnitzer, heavy vehicle crashes with other vehicles and vulnerable road user are classified as below given fatality and injury rates (Table 2.1).

Table 2.1: Crash accidents statistics

Crashes with other vehicles	Fatalities	Serious injuries
Front of the truck	66%	68%
Side of the truck	13%	10%
Rear of the truck	9%	17%

Crashes with vulnerable road users	Fatalities
Front of the truck	42%
Side of the truck	40%
Rear of the truck	12%

According to below statistics the severity of the crashes can be ordered as below by deceleration forces:

- Worst case – Head on crashes
- Truck into side of a car
- Swipe crashes
- Rear and side crashes

Underrun will dramatically effect the outcome of these crashes by severity as below:

- Excessive rear underrun
- Side underrun in side swipe crashes
- Excessive front underrun

2.1.2. Side design and damage relation

2.1.2.1. Mechanical design

Besides the fact that vehicle mass is highest for heavy vehicles among road users; vehicle design can drastically reduce the damage on other vehicles and vulnerable road users involved in accidents with the heavy vehicles.

Most commercial vehicles have large open areas between the cab and rear wheels, and due to the height of the tray being 850-1100mm.

In these vehicles there are basically no structures to prevent pedestrians, cyclists or motorcyclists or vehicles from falling under the tray and being crushed by the rear wheels and hitting the under structures of the vehicle.

The lack of side underrun protection on trucks poses a double hazard for two wheelers as fall under the truck and be crushed, or they are exposed to severe head collosion with the rigid structures of the truck. These are likely to happen during lane changing or turning of the truck while the other is beside the vehicle.

For example; a 1986 research in Sweden at Volvo, (Hogstrom and Svensson,1986) studied on 1000 truck involved crashes implies that side skirts would have a positive effect in 35% of crashes involving cyclists and motorcyclists.

BITRE 2014 study with indept analysis of crashes and review of literature impls that lack of compatibility and agressiveness of heavy vehicle design is a major factor causing serious injuries and fatalities in crashes involing heavy vehicles.

A 1966 study in Australia on 59 crashes involving trucks suggests that fitting rear and frontal underrun protection devices and side skirts would significantly reduce the injury potential in these crashes.

In a 1981 study in Britain (Riley) on 700 accidents researchers found that side skirts could have saved the life of 39 cyclists and 14 pedestrians involved in these accidents.

Studying accidents in Switzerland Waltz in 1990 has proposed fitting flat panel side guards to all vehicles in use.

Langweider and Danner proposes in a 1987 study that side-underrun protection would influence around 50% of serious and fatal injuries for two wheelers and recommended that flat side panels should be designed instead of rail type side protection.

2.1.2.2. Visibility design

Side underride collisions usually happen at night and under poor lighting, when a truck is crossing or turning on to another street, highway, U turning or backing.

Although the truck driver may assume that their vehicle is properly visible to oncoming traffic, this sometime is not the case. This may both depend on attentiveness of the other road users or the visibility of the truck or trailer itself.

Conspicuity of the vehicle depends on several factors as;

- **Color:** Resemblance of the colors in the background and colors of the vehicle itself. An object with similar colors to the background is harder to see. Dark colors are harder to see. Multiple colors may make an object blend in into the background easier.
- **Movement:** An object at standstill or moving slowly is harder to notice on the background compared to a moving object.
- **Brightness:** An object with high reflectivity compared to its background is easier to notice compared to an unreflective object on an unreflective background.
- **Contrast:** An object with contrasting colors or a color contrasting with the background is easier to detect.
- **Shape:** The patterns or markings on a vehicle can effect visibility, random markings makes a vehicle less visible by erasing its silhouette.
- **Size:** A small object is harder to detect than a large object.

Several types of truck collisions may happen due to low conspicuity of the vehicles. It is a misconception that the large truck size by default makes these vehicles easily visible. Under day lighting conditions of the most of the trailers have features that will make them visible on the background. However, at low sun angles and darkness these features become useless to visibility.

For instance, loads protruding out of the truck body is a common cause for underride collisions (Figure 2.3). These loads are mostly low contrast with the trailer itself and small items. Therefore, these loads and trailers are at higher risk for underride also on daytime.



Figure 2.3: A truck with protruding loads

At night time, the trailers standard features are not enough to make the vehicle visible. A trailer crossing the road is invisible to oncoming traffic until the headlights of the coming vehicle illuminate the trailer, which may be too late (Figure 2.4).

The side markers placed on the trailer side are reflective and can improve visibility, however these side markers are easily mistaken for road side markers or other distant low headlights.

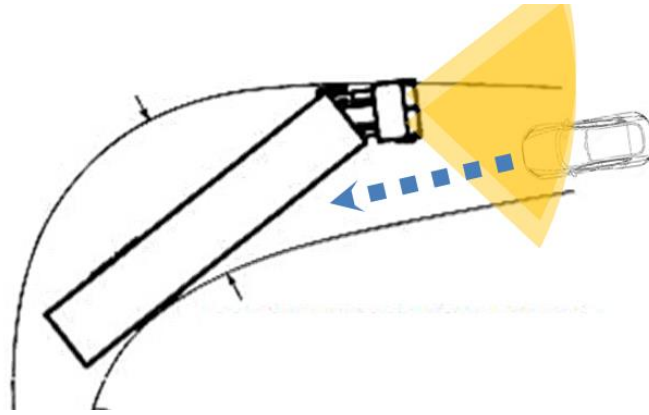


Figure 2.4: Visibility during cornering

For example; during a truck is turning a corner at night time, the head beams of the tractor truck will blind the eyes of driver of the oncoming vehicle. The side marks of the trailer will be invisible to the drivers eyes caused by the brightness of tractor head lamps. Only when the vehicle is past the tractor beam then the driver can see the trailer body, which will be too late at higher speeds.

2.1.2.3. Additional underride factors

There are also factors other conditions that effect underride:

- Inoperative side lights/markers
- Bright surrounding lights in the vicinity
- Very slow moving truck at crossings

Inoperative side lights or dirty markers obviously contribute to side underride risk, when these functions are absent the trailer becomes invisible to other road users until very close.

Another condition is when there are bright lighting in the vicinity and the truck is in a dark area nearby. When other road users are passing by the bright area the human eye adjusts to light conditions and the oncoming road becomes a black hole. When the driver enters the dark area there is an adaptation period in which the eyes must adjust to the new condition. During this period dark objects, hence trucks are invisible for the driver. Specific to this situation is when a truck leaves a gas station with bright lighting, in this situation the truck driver may assume that the vehicle is

visible due to lighting, however it is the opposite, adjacent to a very bright area the truck is less visible than usual.

Trucks may move very slowly, which makes them a greater hazard to road users especially when crossing roads or maneuvering, backing on oncoming traffic etc. However moving slow may create a sense of safety to the truck driver, it increases the risk of collision during a crossing.

2.2. Review of Current Sideguard Regulations and Standards

In this section, sideguard regulations and regulatory trends are reviewed, compared for in this section, sideguard regulations and regulatory trends are reviewed. The most defined specifications are from EU, GB, Japan, Austria, The US and Brazil. Therefore these are reviewed in detail.

2.2.1. European Union

In the EU, sideguards are required on most trucks in the European zone since 1989.

EU regulations are based on the United Nations (UN) and Economic Commission for Europe regulations which contain mainly technical requirements and are often adopted by the EU directives.

Council Directive 89/297/EEC, adopted on April 13, 1989, defines the legal framework for lateral protection (side guards) for certain motor vehicles and their trailers.

ECE Regulation No. 73 defines the requirements concerning the approval of goods vehicles, trailers and semi-trailers with regard to their lateral protection. This Regulation applies to complete vehicles of categories N2, N3, O3 and O4 with regard to lateral protection.

Sideguards can consist of horizontal rails or continuous flat surface. The side guards shall be essentially rigid and be able to withstand a horizontal static force of load of 1 kN applied perpendicularly to any any point along the guard by the center of a ram the face of which is circular and flat, with a diameter of 220 mm \pm 10 mm. The side guard can be considered suitable if the deflection under load measured at the centre of the ram is then not more than:

- (a) 30 mm over the rearmost 250 mm of the device; and
- (b) 150 mm over the remainder of the device

The maximum ground clearance cannot be more than 550 mm. It shall be positioned at a maximum of 30mm away from the outermost edge of the rear tires over at least the rearmost 250 mm and 150mm over the rest of the guard. Top of side guard shall not be more than 350 mm below lower edge of vehicle body.

On a vehicle of category N2 or N3, the gap between tires and side guards can be max 300 mm.

Figure 2.5 and Figure 2.6 shows the basic dimensions of the lateral protection device.

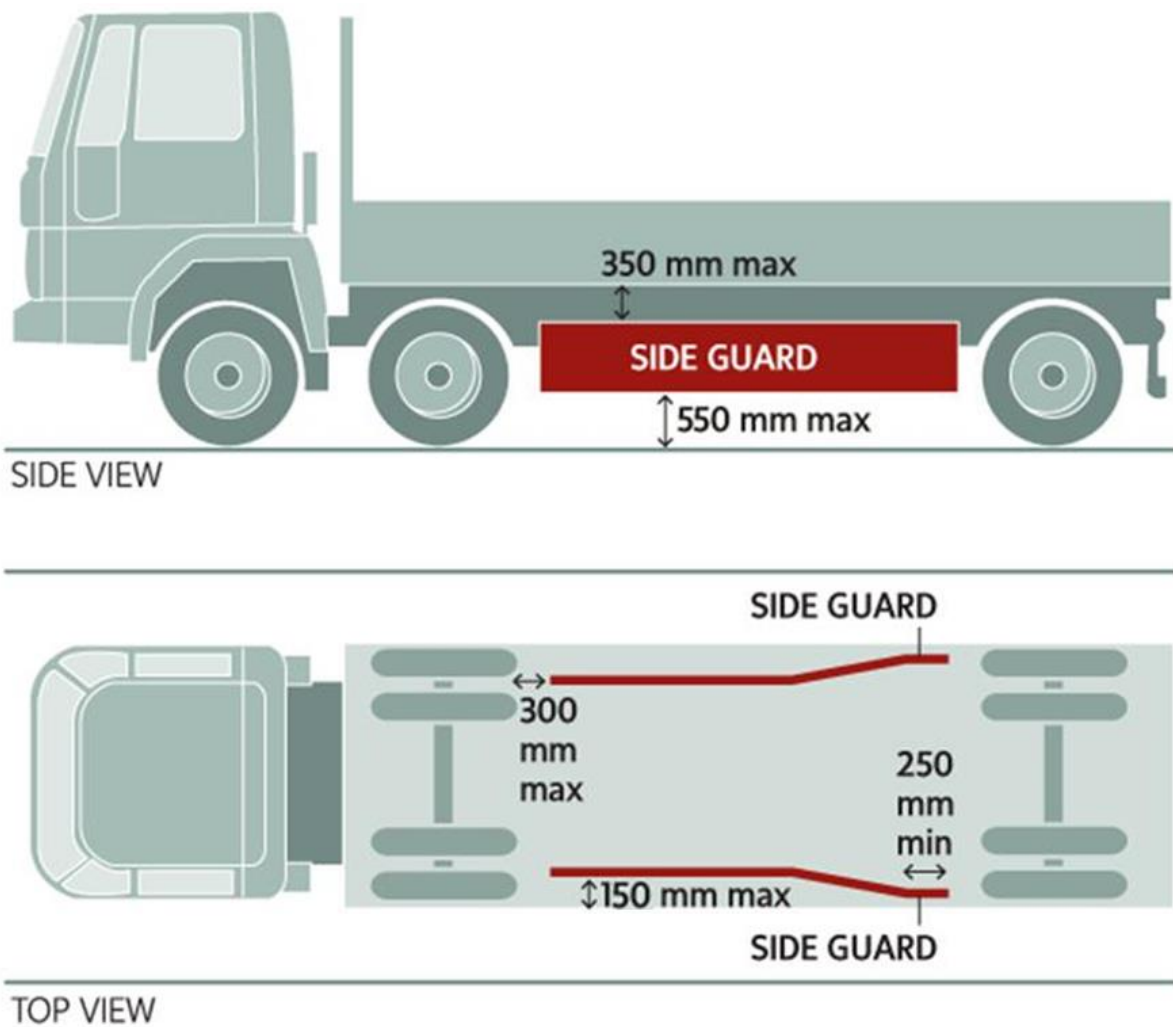


Figure 2.5: Dimensions of a truck sideguard

On a drawbar trailer, the distance between the device and the wheel immediately forward of the device can not more than 500 mm.

On a semi-trailer; the distance between the device and the support legs is max 250 mm to if support legs are fitted. However, the distance from the front edge to the transverse plane passing through the center of the kingpin in its rearmost position may not exceed 2.7 m.

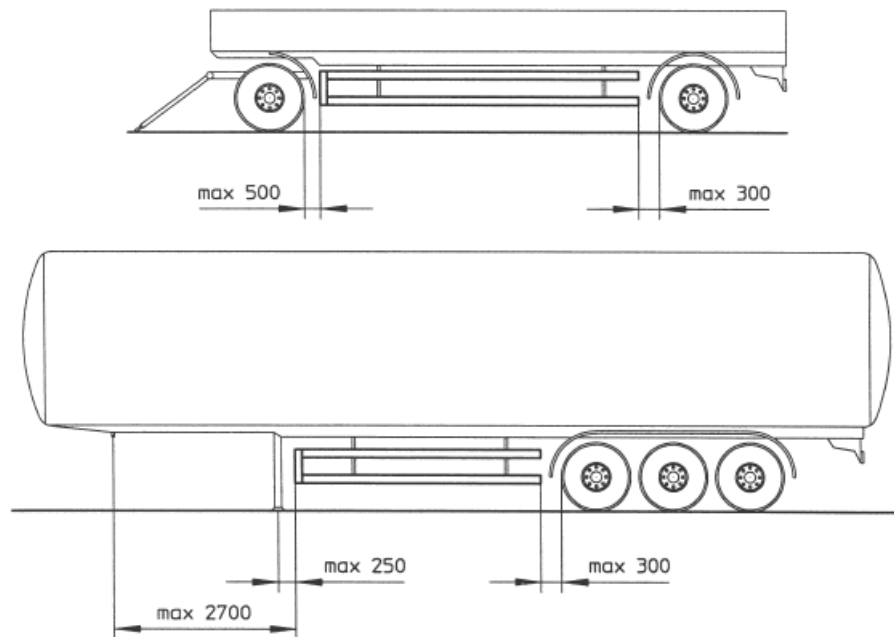


Figure 2.6: Dimensions of a trailer sideguard

The EU sideguard regulation does not apply to:

- Tractors for semi-trailers
- Trailers specially designed and constructed for transporting “very long loads of indivisible length, such as timber, steel bars, etc.”
- “Vehicles designed and constructed for special purposes where it is not possible, for practical reasons, to fit such lateral protection.”

Also, there are four specific exemptions in the EU regulation:

- An extendable trailer shall comply with all the dimensional and strength requirements when closed to its minimum length; when the trailer is extended, however, the gap between the sideguards and either the forward or rear tire can be greater than normal.

- Cargo tank trucks provided with hose or pipe connections for loading or unloading must be fitted with sideguards “which comply so far as is practicable with all the dimensional and strength requirements; strict compliance may be waived only where operational requirements make this necessary.”
- On a vehicle that has extendable legs, for example a crane, to provide additional stability during loading, unloading or other operations, the sideguard can have additional gaps to permit extension of the legs.
- On a vehicle equipped with anchorage points for roll on-roll off transport, gaps are permitted within the sideguard for fixing ropes. In addition, the regulation mentions that “if the sides of the vehicle are so designed and/or equipped that by their shape and characteristics the component parts together meet the requirements, they may be regarded as replacing the sideguards.” (Figure 2.7).

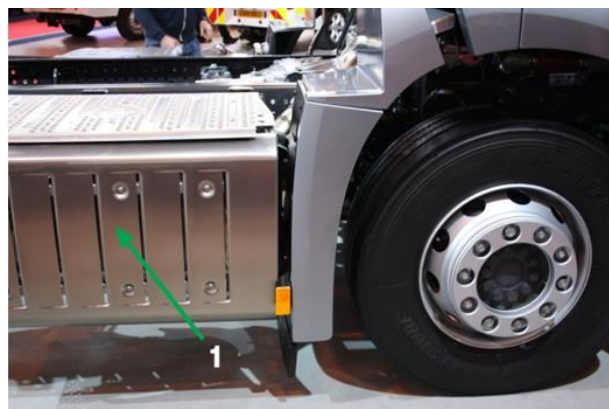


Figure 2.7: An original fitting exhaust shield can be considered sideguards

2.2.2. United Kingdom

There are significant differences regarding sideguard requirements between the Construction and Use Regulations (UK) and EU legislation. The Construction and Use Regulations also allow for many more exemptions from sideguard requirements compared to EU legislation.

Sideguards began to be implemented in the UK since 1983 and were nationally mandated by the Road Vehicles (Construction and Use) Regulations of 1986. According to The UK Freight Transport regulation the test load is specified as 2 kN, with the same requirements for deflection of the structure.

EU member countries can impose further exemptions for vehicles which do not have to comply with side guard regulations and currently UK provides exemptions for

approximately 20% of its heavy vehicles, including side and end tipping vehicles and trailers, naval, military and airforce vehicles, refuse trucks and vehicles designed solely for street cleaning.

2.2.3. Australia

Australian government has investigated the case for regulating underrun protection on heavy vehicles and accidents involving heavy vehicle. According to the statistics, about 75% of the fatalities occurred as a result of a frontal impact, 10% of rear impact and %15 them per year from side impact. However, the government decided not to adopt UNECE R 93 in Australia and still does not have a regulation for SUPDs. On the other hand, The Australian Trucking Association has published an Advisory Procedure to assist manufacturer on side guards. Its requirements are in accordance with the Regulation 73. The advisory procedure is only a guide, and is to be used voluntarily (Figure 2.8).

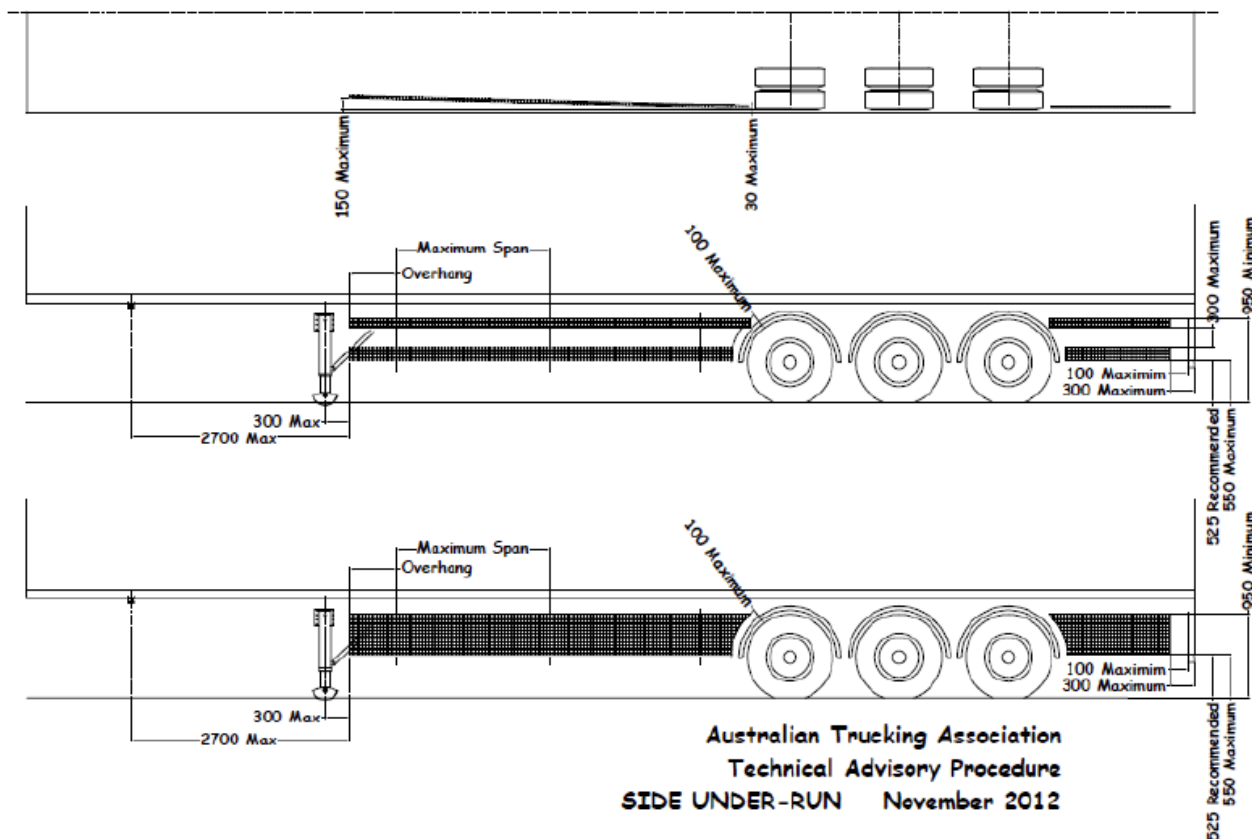


Figure 2.8: Dimensions of a trailer side guard (Australain Trucking Association Technical Advisory Procedure)

2.2.4. Japan

However Japan promotes international integration of vehicle homologation requirements, currently there is not a decision whether to introduce UNECE R 73 or not and how the process is to be implemented.

Current side guard regulations in Japan are outlined in the documents: Safety Regulations for Road Vehicle (Ministerial Ordinance) and its announcements. According to these documents, side guards are viewed as pedestrian protection devices. The ordinance defines that the transport of goods or ordinary-sized motor vehicle with a gross vehicle weight of 8 tons or more (except motor vehicles with a passenger capacity of 11 persons or more and motor vehicles having a shape similar to the motor vehicles with a passenger capacity of 11 persons or more) shall employ side guards on both sides. Sideguards design must comply with the requirements prescribed in the announcement. Some types of vehicles are exempted from the enforcement, the provision does not apply to motor vehicles having a structure which readily can prevent pedestrians, bicycle rider, etc., from being caught by the rear wheels of the motor vehicle.

2.2.5. Canada

According to the Motor Vehicle Safety Act of Canada; All new and imported vehicles sold in Canada must comply with measures that enforce the requirement for a minimum level of safety of vehicles. The regulations are aimed at making vehicles safer for road users in Canada.

While manufacturers and importers must certify that their vehicles sold in Canada meet the regulations safety requirements, provincial and territorial governments are responsible for establishing regulations and enforcement strategies for road use, vehicle and driver licensing, as well as operation and maintenance of vehicles.

There are currently no federal requirements to equip heavy trucks and trailers with side guards in Canada.

Many factors must be considered in order to evaluate the effectiveness of sideguard requirements in Canada and North America. Truck travel patterns in North America are different than in Europe, because a number of road transport lines are operating in both Canada and United States. Transport Canada would therefore need to determine which type of trucks and trailers would benefit from side guards, and

Transport Canada would need to align its requirements with trading partners across borders.

Furthermore, while side guards may provide environmental benefits on certain types of vehicles that operate on highways at higher speeds, they also increase overall vehicle weight which may increase fuel consumption at lower speeds. In addition, operational aspects specific to weather conditions in Canada such as, ice build-up on side guards must be evaluated.

Nevertheless, Transportation Association of Canada (TAC) in collaboration with Transport Canada, is working on a project aimed to quantify the magnitude and characteristics of the problem regarding collisions between vulnerable road users and commercial vehicles in selected major Canadian urban areas. This study will also identify any solutions that are already available and implemented in other jurisdictions in order to reduce these types of collisions.

2.2.6. United States

There is not an enforcing regulation for SUPDs on heavy vehicles in the US. However, there are several initiatives across the country to introduce legislation for enhanced protection of vulnerable road users such as cyclist and pedestrians. For instance, Bill 17-981 known as the “Bicycle Safety Enhancement Act of 2008” has been introduced in October 2008 in the District of Columbia. It requires that all District-owned heavy duty vehicles are to be equipped with blind spot mirrors, reflective blind spot warning signs and side underrun guards to prevent bicyclists, other vehicles or pedestrians from sliding under the rear wheels.

Besides that, a DC Council document explains that funds are not sufficient from 2009 to 2012 to implement the requirement to equip all District-owned heavy duty vehicles with side-underrun guards.

In the U.S., Federal Motor Vehicle Safety Standard (FMVSS) 223 applies to Rear Impact Guards and there are no corresponding Side Impact Guards. The National Highway Traffic Safety Administration (NHTSA) has rejected adding sideguard requirements to the FMVSS in 1991.

2.2.7. Brazil and other countries

By January 1st, 2011, trucks in Brazil are required to install sideguards. Based on the fact that Brasil has a large population of cyclists, there are differences in sideguard regulations in Brazil compared to other regions. Brazilian vehicles side guards must withstand 500 kg load, while the European and UK sideguards must only withstand a load of 100 or 200 kg.

China also requires sideguards on large trucks. Side guards are also common in other Latin American countries.

The Australian Trucking Association published a recommendation to help manufacturers comply with EU Regulation 73, however manufacturers are not forced to implement side protection devices.

2.2.8. Recommendations

Although, SUPDs are mandory to be mounted on the vehicles in many countries, there are still no regulations on it in other countries.

Current SUPDs are strong enough to save vulnerable road users. On the other hand, there is no side guard to prevent injuries and death on side accident with small vehicles. Therefore, the regulations should increase the load the load which SUPDs must withstand.

3. DESIGN

The main function of side underrun protection devices mentioned in homologation relevant regulations worldwide are preventing pedestrians, cyclists or motorcyclist from running under the vehicle body hence decreasing injuries, fatalities and damage.

SUPD vendors and OEMs must meet legal regulations, customer expectations and maintain low cost at the same time which might be contradicting.

Mechanical lateral underrun protection device designs are reviewed within the scope of this study.

In terms of design concept, side underrun protection devices fall into one of the two categories mentioned in the EU regulations, rail type and smooth type.

3.1. Rail Type

The guard rail type design is the lightest design among the other designs reviewed in this study (Figure 3.1 and 3.2). However, due to the construction it is easy for pedestrians and cyclist to get caught between the rails, therefore the protection ability of the device is questionable.



Figure 3.1: Rail type side guard



Figure 3.2: Rail type side guard

3.2. Smooth Type

The regulations for side guards define the minimum requirements. Some vehicles maybe have sideguards that exceed the requirements mandated by the regulations. One of the commonly used alternative to rail design is flat panel surface side guard design (Figure 3.3).



Figure 3.3: Smooth type side guard

This design provides a flat surface between the side structure of the vehicle preventing pedestrian, cyclists and other vulnerable road users underrunning by the vehicle. Furthermore, the flat design increases fuel efficiency. This is accomplished by smoothening the side construction of the vehicle hence reducing drag effects. The fuel efficiency increase is estimated in literature as 4-7%.

When trucks wheels are spinning, they create an airflow vortex which should be pushed towards outside of the trailer. For decades, they have been incorporated on trailers to the reduce aerodynamic drag by deflecting the air coming from the rear axle and obstructions under the trailers.

Air drag increases with speed, therefore fuel efficiency created by flat panel SUP is increased for vehicles that travel at higher speeds for longer periods.

According to a research by Transport Canada, a transport fleet of 57 trucks has achieved 6.4 % decrease in fuel consumption by 7134 lt saving and 19475 kg green house gas per month of testing period.

In addition to above, due to its construction flat panel surface blocks the airflow towards the brakes and therefore reduces brake cooling, the piling of snow, ice an mud is bigger compared to rail design, also the flat panel surface obstructs access to underbody of the vehicle for inspection or maintenance purposes.

Aerofficient claims that when the tractor's wheels are spinning, they create a vortex air flow which needs to be pushed outside of the trailer. If the fairing is simply a flat drop down, the turbulent air coming from the driving wheels will remain under the trailer and cause drag until it exits the rear of the trailer.

3.3. Integrated Design

The side underride protection may be provided by a rail-style sideguard, a solid panel-style sideguard, or by an integrated vehicle design (Figure 3.4). Integrated design concept implies that the side walls, wheel covers, toolboxes are combined as SUP (Figure 3.5). This application is mainly implemented at OEMs or installed aftermarket as retrofit.

In mass production applications, there several sideguard designs which exceeds the standards required by current laws.



Figure 3.4: Integrated design



Figure 3.5: A side guard integrated in toolbox

3.4. Other Designs

Some utility vehicles operate on city streets but also need off road access. These vehicle types may be; dump trucks, cement truck, sanitation vehicles and snow plowers. Due to the trucks operating environment SUPs may be inconvenient at times. A solution for these types trucks is to install a foldable or removable lower side guard under a fixed side guard, or totally foldable or removable side guard (Figure 3.6 and 3.7). When higher clearance from ride surface is required the side guards are folded or stowed off for operations (Figure 3.8, 3.9 and 3.10).



Figure 3.6: Foldable side guards



Figure 3.7: Foldable side guard (Wabco)



Figure 3.8: Side guard with other security measures



Figure 3.9: Steel mesh side guard



Figure 3.10: Frame mounted rail side guard

3.5. Materials

The Most common materials used for sideguards are steel and aluminium. There are several studies in literature investigating the use of alternative materials for side guards. The alternative investigations must take into account the following; weight, strength, cost, recyclability.

The materials mostly considered as alternative are:

- Magnesium alloys
- Titanium alloys
- Glass fiber reinforced plastic
- Carbon fiber reinforced plastics

The purposes of alternative material use are to:

- Decrease vehicle tare weight to increase payload staying within road regulations
- Decrease manufacturing cost
- Increase fuel efficiency
- Decrese repair costs
- Increase strength

3.6. Future

The application of SUP devices are continually increasing as governments become more aware of the potential benefits in reducing injuries, and material and production technologies makes it possible to create lighter and less costly designs.

In Figure 3.11, it can be seen a new concept example from large OEMs in truck manufacturing. These designs show an obvious bias towards increasing fuel economy through better aerodynamics and also better underrun protection.



Figure 3.11: European Experimental Truck EXT-92, smooth side guard which redesign which diminishes the harm potential to vulnerable road users (Mercedes-Benz Australia)

MAN turning assistant project uses radar sensors for object detection in the right side of the truck. When an approaching pedestrians, cyclists or stationary vehicle is detected, the system warn the driver by an optical signal on it (Figure 3.12).

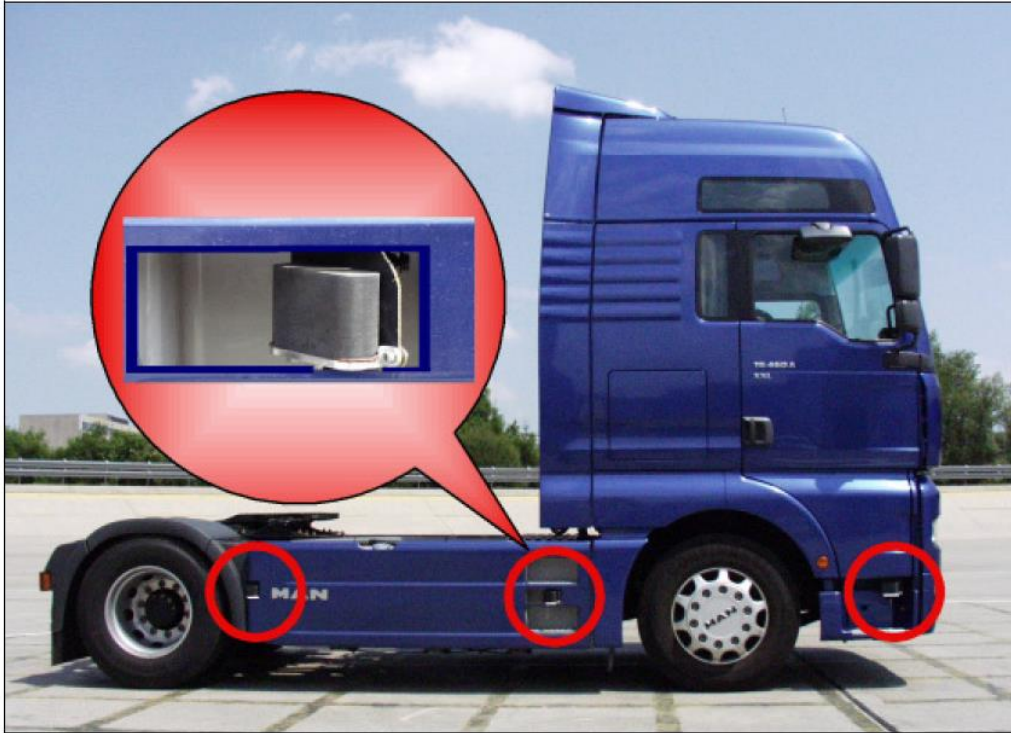


Figure 3.12: Turning assist system

According to the review of current design trends and regulations, the road map of the future is based on following ideas:

Safe: Increased underrun protection for both vulnerable road users and other road vehicles.

- Economic: Reduced air drag and reduced fuel consumption.
- Eco-friendly: Reduced fuel consumption and increased sustainability through reduced CO₂ emissions.
- Longer: An increase in length (0.5~1.0 meter) is needed for the integrated designs to create better aerodynamics and underrun protection.
- Ergonomic: Designs that create a better working environment for the driver.

All add-on solutions or designs changes have the same disadvantages – additional weight and/or additional costs. The solution to these problems can come from advanced material technology and reduction in manufacturing costs.

One alternative way of creating underrun protection is to redesign the tractor / trailer frame concept. A change in the topology of two centered longitudinal main beams to

a frame concept, in which the tractor and the trailer are both integrated and structure has the function to maintain durability and underrun protection besides other benefits to driver and other road users.

This will mean a complete redesign of current manufacturing processes to be able to support the radical design change. Also, the radically increased integration between the trailer and the tractor would possibly enforce changes in the tractor and trailer OEMs businesses. Trailer OEMs would need to come closer with tractor OEMs while making designs and new introductions which could also possibly lead to mergers and new businesses.

3.7. Design Proposal

Building upon the prior studies reviewed as a part of this these, a new design is proposed which will satisfy the current regulative requirements and align with the path to the future of under-ride protection devices.

The proposed concept design is focused on an improved mechanical design to improve safety for light vehicle side collisions onto heavy trucks and also electronic assist system to notify light vehicle drivers about a collision risk ahead of the road.

3.7.1. Mechanical design improvements

Unlike SUPDs, Front/rear underrun protection devices are designed to prevent the impacting vehicle from getting wedged under the HGVs.

In this study, it is aimed to design a new concept SUPD that prevent vehicle underrunning as well, besides light road users.

In this study, a new side guard was designed which can save car passengers as well from side accidents.

The proposed mechanical design has the manufacturability attributes to have the aesthetics and aerodynamic design attributes as implemented by the OEMs strategy. The difference from current applications is the honeycomb material design proposed which increases strength without increasing material weight much (Figure 3.13).

Honeycomb structures are structures that have the geometry of a honeycomb. Honeycomb design is a biomimic design that replicates the design of natural honeycomb.

Honeycomb structure realises the minimization of the amount of material used hence minimizes material cost. The geometry of honeycomb structures vary widely however the common feature is an array of hollow cells formed between thin vertical walls. The cells are often hexagonal in shape.

In addition to light-weight, a honeycomb shaped structure provides a material with minimal density and relative high out-of-plane compression strength and out-of-plane shear strength.

According to manufacturer specification honeycomb panel can achieve 37 times the stiffness, 9.2 times the strength of regular panels with a 4 times increase in volume and 0.06 times increase in weight.

Honeycomb structure is superior to solid structures in terms of weight and strength with a small increase in weight significant increase in strength is achieved.

According to the expectation, the strength and weight attributes will be found suitable as side under-ride protection on heavy vehicle - light vehicle collisions after a detailed analysis and experimentation.

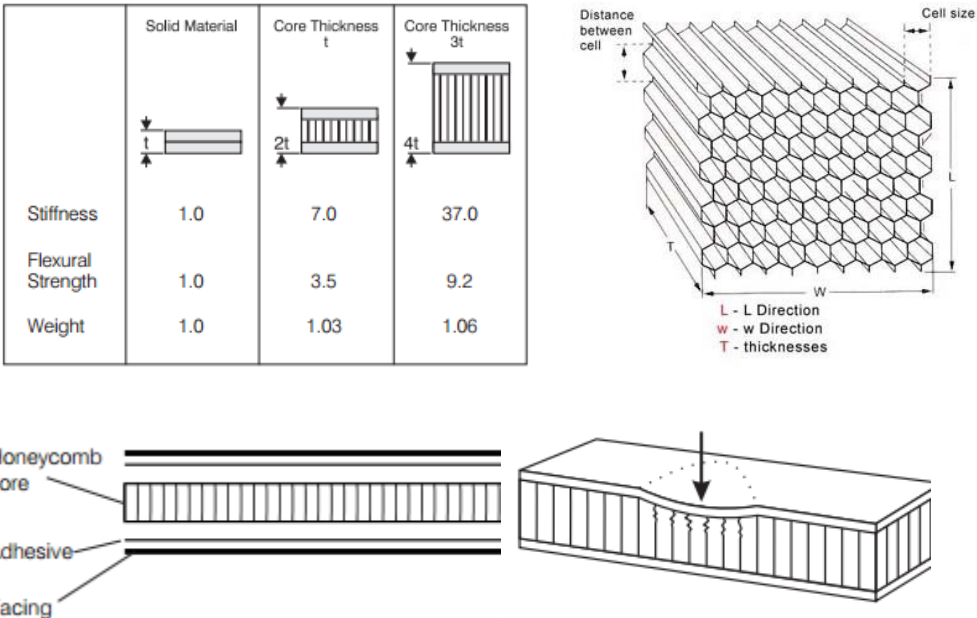


Figure 3.13: Honeycomb design (Hexweb)

The proposal design was designed in NX, to be mounted on a trailer chassis (Figure 3.14). From manufacturer’s product catalog, 5052 Aluminium and Steel Carbon 1017

were selected as honeycomb core and facing material respectively (Figure 3.15, 3.16 and 3.17). Mild Steel was used for the material of holding brackets. To represent supports, U Profile (30x30mm, t=5mm) were mounted to side guard (Figure 3.18 and 3.19). A simplified honeycomb structure (1000x400mm) was modelled as a solid body and orthotropic material properties was assigned to this body in Ansys 15.

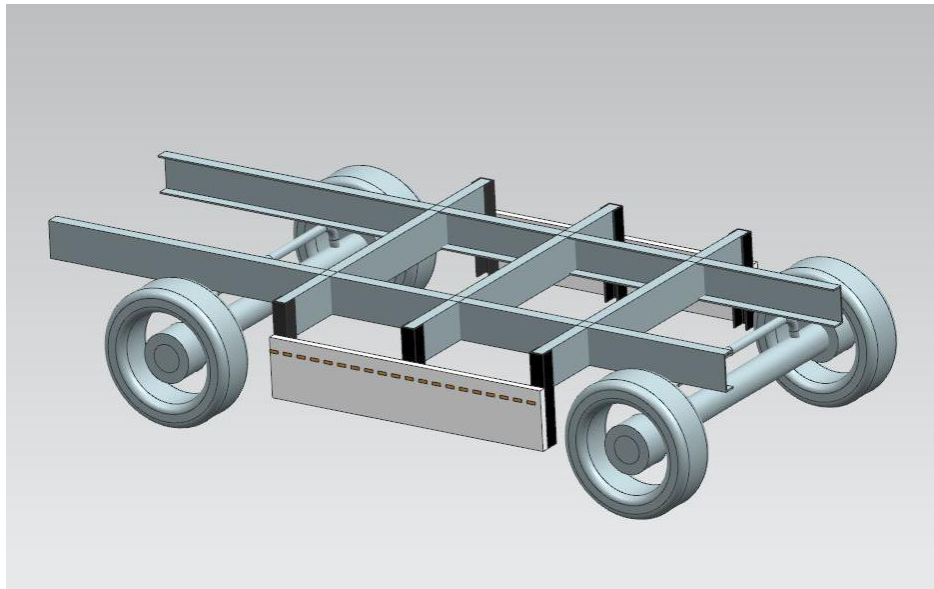


Figure 3.14: A sample trailer chasis with the proposed deisgn

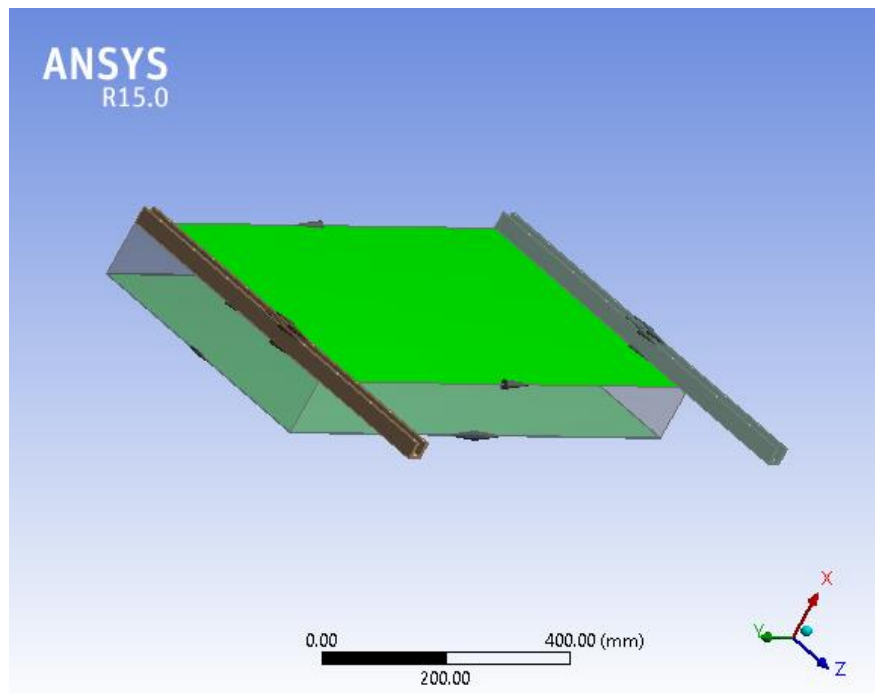


Figure 3.15: The model in ANSYS 15

Outline of Schematic D2: Engineering Data				
	A	B	D	
1	Contents of Engineering Data		Description	
2	Material			
3	honeycomb	<input type="checkbox"/>		
4	steel	<input type="checkbox"/>		
5	Structural Steel	<input type="checkbox"/>	Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1	
*	Click here to add a new material			

Properties of Outline Row 4: steel					
	A	B	C	D	E
1	Property	Value	Unit		
2	Density	8300	kg m ⁻³	<input type="checkbox"/>	<input type="checkbox"/>
3	Isotropic Elasticity			<input type="checkbox"/>	
4	Derive from	Young's Mo...			
5	Young's Modulus	2.05E+11	Pa	<input type="checkbox"/>	
6	Poisson's Ratio	0.3		<input type="checkbox"/>	
7	Bulk Modulus	1.7083E+11	Pa	<input type="checkbox"/>	
8	Shear Modulus	7.8846E+10	Pa	<input type="checkbox"/>	

Figure 3.16: Material properties of the holding brackets

Outline of Schematic D2: Engineering Data				
	A	B	D	
1	Contents of Engineering Data		Description	
2	Material			
3	honeycomb	<input type="checkbox"/>		
4	steel	<input type="checkbox"/>		
5	Structural Steel	<input type="checkbox"/>	Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1	
*	Click here to add a new material			

Properties of Outline Row 3: honeycomb					
	A	B	C	D	E
1	Property	Value	Unit		
2	Density	130	kg m ⁻³	<input type="checkbox"/>	<input type="checkbox"/>
3	Orthotropic Elasticity			<input type="checkbox"/>	
4	Young's Modulus X direction	2.414E+09	Pa	<input type="checkbox"/>	
5	Young's Modulus Y direction	1	Pa	<input type="checkbox"/>	
6	Young's Modulus Z direction	1	Pa	<input type="checkbox"/>	
7	Poisson's Ratio XY	0		<input type="checkbox"/>	
8	Poisson's Ratio YZ	0		<input type="checkbox"/>	
9	Poisson's Ratio XZ	0		<input type="checkbox"/>	
10	Shear Modulus XY	9.3E+08	Pa	<input type="checkbox"/>	
11	Shear Modulus YZ	3.72E+08	Pa	<input type="checkbox"/>	
12	Shear Modulus XZ	1	Pa	<input type="checkbox"/>	

Figure 3.17: Material properties of side guard plate

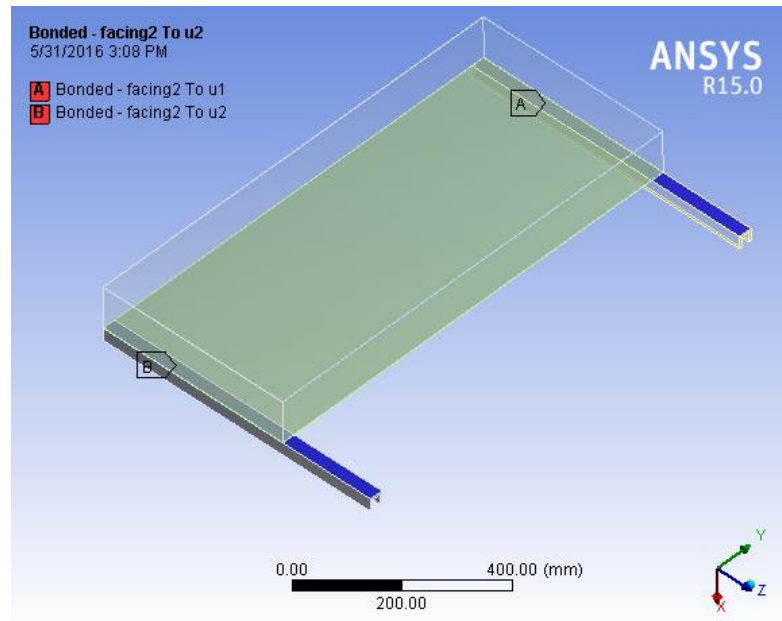


Figure 3.18: Contacts (Between U profile and body, bounded contact was defined.)

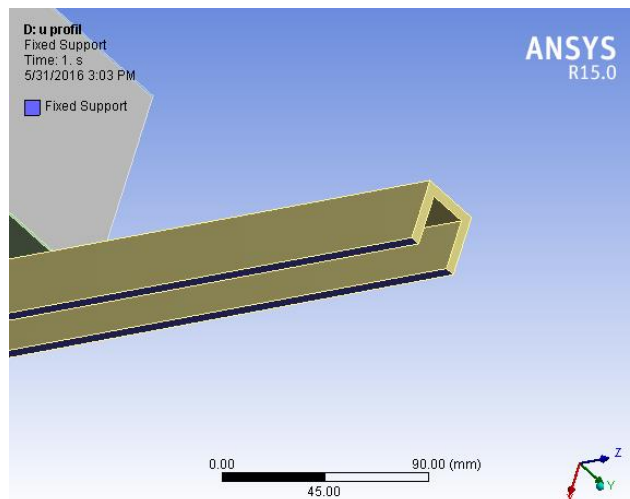


Figure 3.19: Supports (fix support were defined on the free surfaces of U-profile)

According to ECE test procedures for front/rear underrun protection, 100 kN or 50% of the maximum mass of the vehicle (whichever is the lesser) is applied and the maximum deformation should not exceed 400 mm. If the underrun protection device fulfil these requirements, it can be mounted to the vehicle.

Because the trailer chassis has enough strength, it was not counted in analysis. Honeycomb structure side guard and it's holding brackets were analysed under the

test load (100kN). The half of side guard was modeled of it was loaded in the middle with 100kN to test the worst case (Figure 3.20).

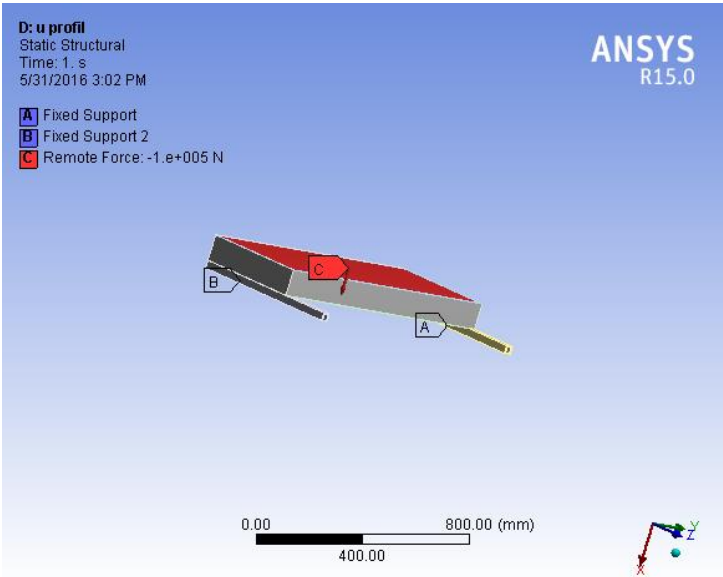


Figure 3.20: The loading force on side guard

After running the analysis, the following results were obtained for material thickness =100mm (Figure 3.21).

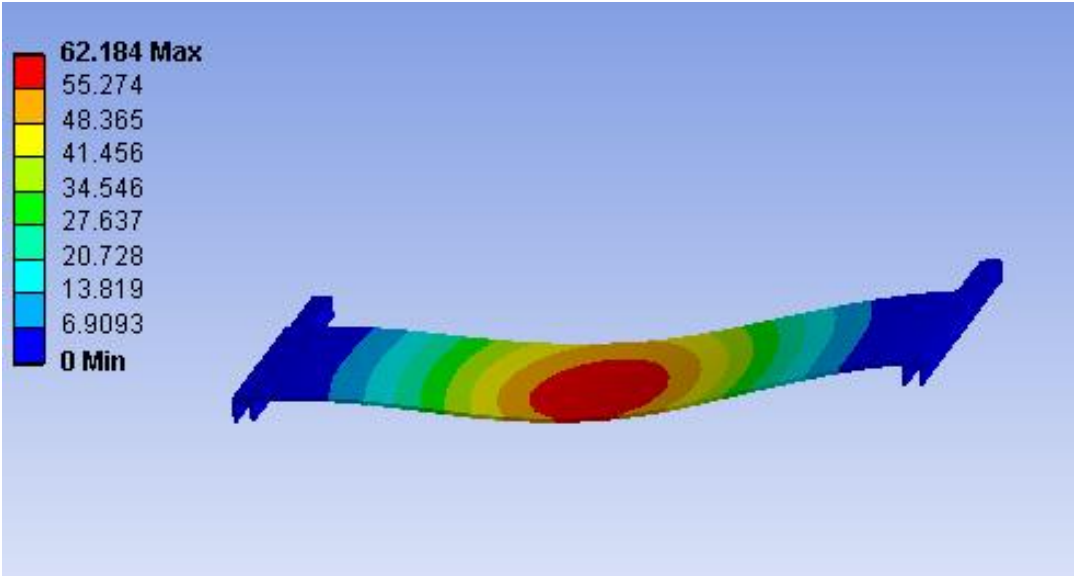


Figure 3.21: Deformations on the part (t=100 mm)

This deformation is too low compared to allowed deformation. Thus, weight optimisation was applied and thickness was decreased to 40mm (Figure 3.22).

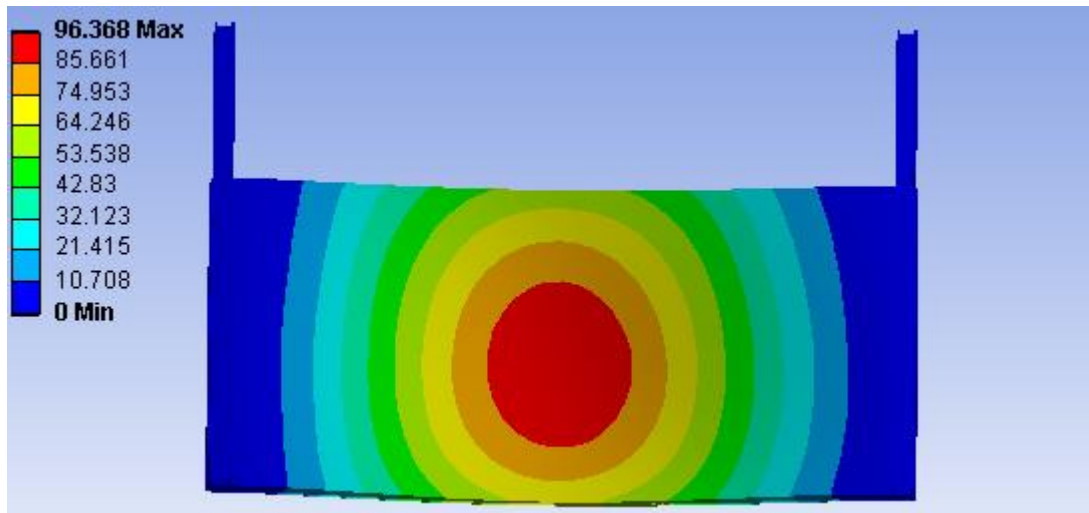


Figure 3.22: Deformations on the part (t=40mm)

However, the deformation was still very low. Then, thickness was decreased gradually (Figure 3.23).

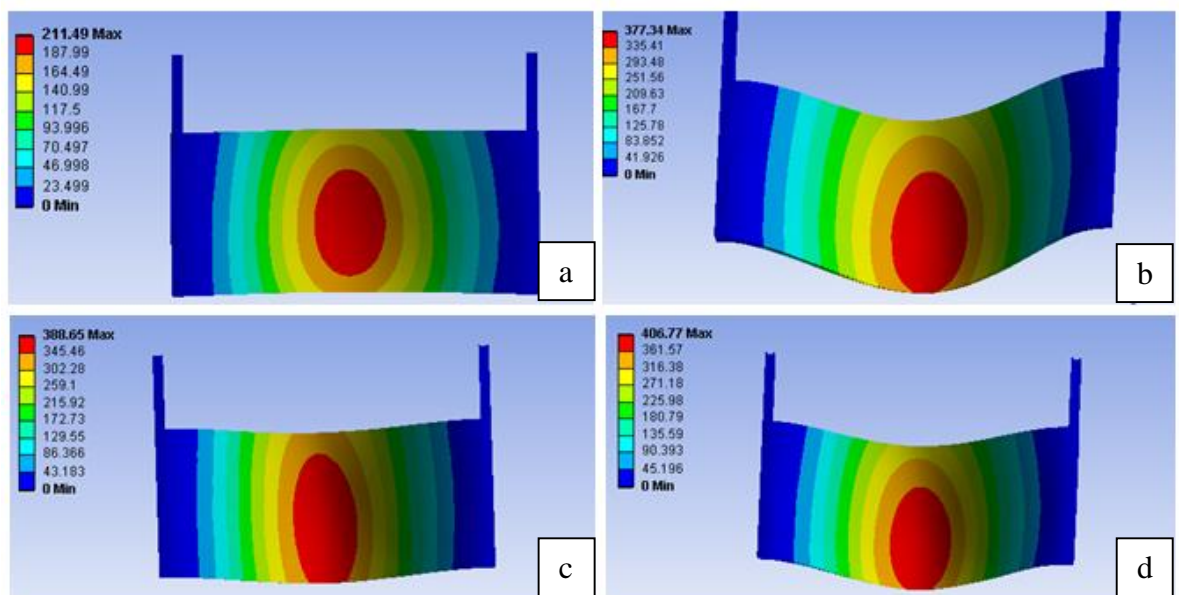


Figure 3.23: Deformations according to thickness: a) 20 mm, b) 11 mm, c) 10mm, d) 9mm

For the thickness of 10 mm, the deformation is in the allowed limits. Thus, this thickness was decided to use for the proposal design. The weight of side guard was calculated =2.12kg.

As an alternative solution to the honeycomb design, completely steel side guard side was tested under the same test conditions.

Firstly, the thickness of 20 mm was selected (Figure 3.24)

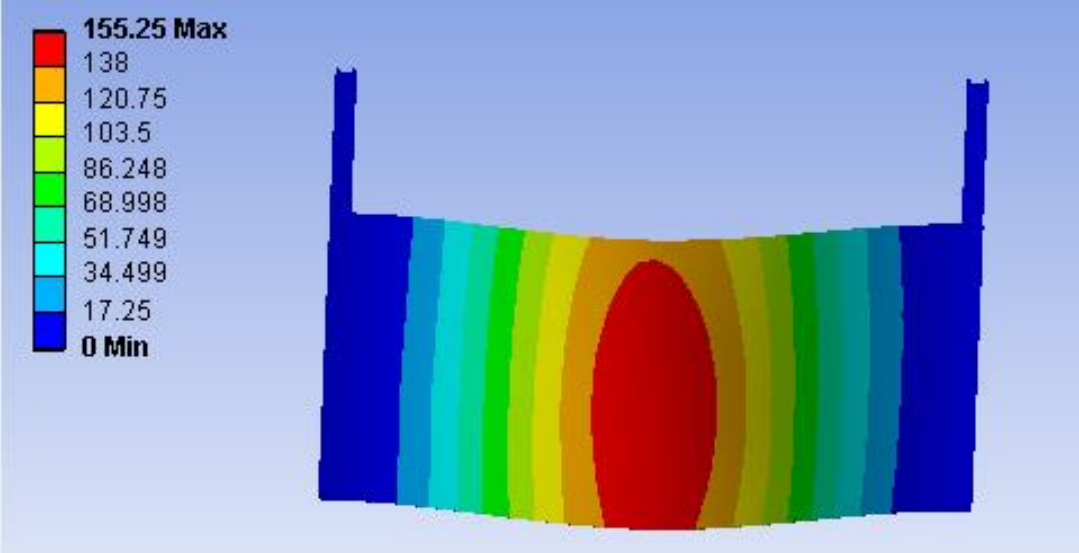


Figure 3.24: Deformations on the part (t=20mm)

Because, the deformation was extremely lower than the permissible deformation limit, the thickness was decreased gradually and analyzed (Figure 3.25).

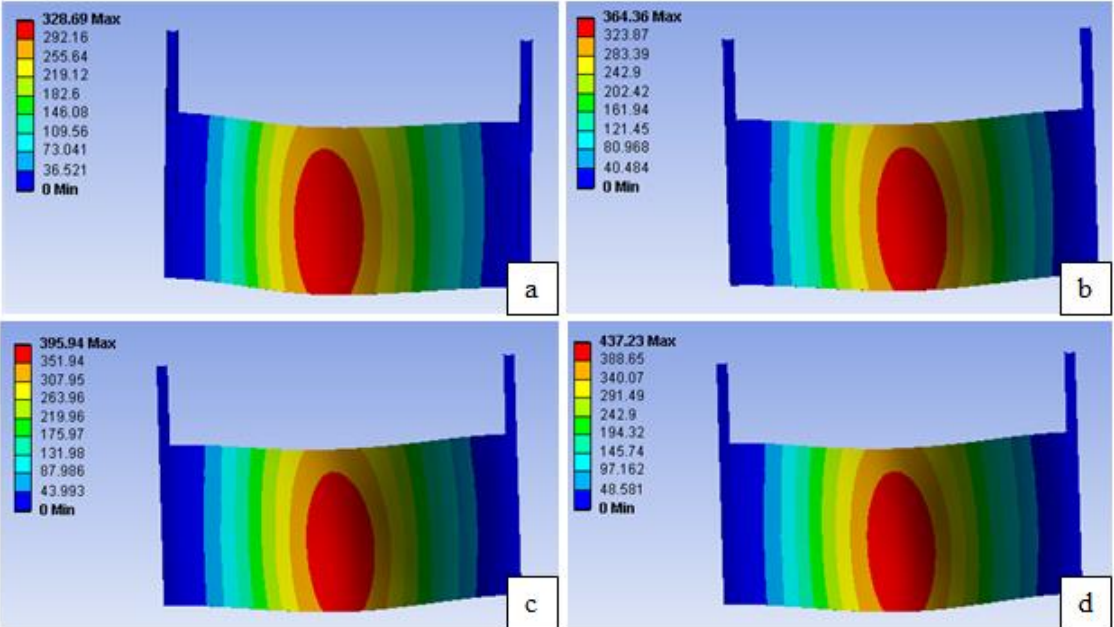


Figure 3.25: Deformations according to thickness: a) 9 mm, b) 8 mm, c) 7 mm, d) 6mm

According to the deformation limit of 400mm, the lowest acceptable thickness of 7 mm steel side guard was chosen as the alternative solution. The weight of side guard was calculated =43.4kg.

The honeycomb design is the light solution in weight compared to the steel side guard. However, the steel design has advantages due to its easeness of manufacturing and lower cost.

3.7.2. Visibility design improvement

As well as it is important to prevent under-ride in case of collision, of prior importance is to prevent collisions as possible.

Regarding above, it is of value to analyse the typical trailer crash scenario described below,

- A passenger car is travelling on the main road at night with head lights on.
- A heavy tractor with trailer attached is taking a right turn onto the main road.
- The tractor is fully on the lane and trailer is following
- Trailer is moving across the opposing lane
- The passenger car drivers eyes are dazzled by the blaze of the head lamps of coming tractor
- The tractor and trailer both have side markers, however they have become invisible due to the fact that the passenger cars drivers eyes pupillary light reflex adjusted for the bright blaze of on-coming head beam of the tractor (Figure 3.26).
- The passenger cars driver does not perceive the crossing trailer and has little time to stop her vehicle once the trailer comes in sight.

As described in pupillary light reflex causes the side markers of the trailer to become invisible due to pupillary light reflex. Even after the passenger car is past the tractor beam, the drivers' eyes need approximately 0.5 seconds to adjust for the new light condition and perceive the glow of side markers.

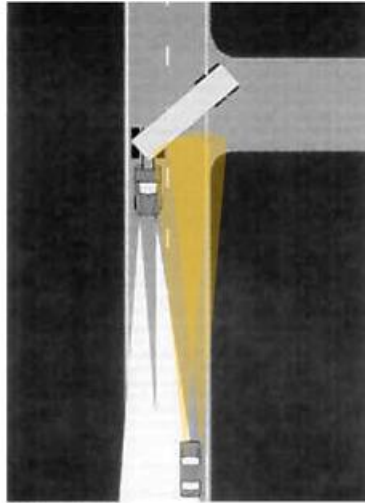


Figure 3.26: The visible area during cornering

It is suggested to implement active side markers that signal brighter when above conditions are sensed by vehicle sensors (Figure 3.27). These sensors however similar to standard vehicle signalling lights, will automatically sense for oncoming vehicles head beam lighting and turn on warning lights automatically as the vehicle is approaching the trailer.



Figure 3.27: Side markers

It is expected that active side markers have the potential to have a significant impact on reducing the number of trailer collisions described in above paragraph. Therefore, the industrial R&D in this area should be undertaken to implement these systems.

4. CONCLUSIONS AND RECOMMENDATIONS

The road transport in many regions of the world is ever-growing with the increase in specialized production work force and scale economies. This in turn day by day boosts the amount of trucks and trailers traveling around the world.

The increase in road transportation made road safety regulations gain higher importance for a sustainable society.

The study implies that side under-run protection devices have potential to reduce injuries and fatalities in road collisions involving heavy trucks and trailers.

The regulations are being upgraded with the advances in technology and as the governments and society are becoming more aware of side under-run and its relation with side design of trucks and trailers.

One of the important points focused in this study is that side protection devices can also function as a cost reduction device by reducing aerodynamic drag, especially for vehicles travelling at highway speeds. (i.e. long haulers.)

Also current side protection designs defined in regulations and broadly used in the industry are focused on mechanical designs that prevent other road users from under-run; in addition to this, there is a growing trend for under-run protection devices that employ sensors and digital control systems that intervene with vehicle movement or notify the driver in case of an eminent collision.

The improvement potential for sensor systems and more aero dynamic designs requires that trailer and truck designs that are more integrated compared to current industry situation.

Therefore the author draws attention on the need for higher integration between vehicle OEMs and trailer, side under-ride protection vendors. Among the future prospects there are technology transfers and even potential mergers between vehicle and trailer OEMs.

Overall, the trend and potential of side under ride protection and saves several lives every year, therefore manufacturers will continue to invest in side protection device

R&D. And regulations will continue to be upgraded as the globalisation of the world is growing every day.

REFERENCES

- Aparicio, H. Puttenstein and F. Feist**, (2009), "Demonstration of Truck Side Design Improvements," Adanved Protection Systems (APROSYS).
- Abrah Alexander K E., Ph.D., Peirce S., Breck A., Cooper C., and Segev E.**, (2014), Truck Sideguards for Vision Zero Review and technical recommendations for Safe Fleet Transition Plan pilot deployment..
- Badger J.E.**, (1998), Trailer Underride – Deadly From Any Angle
- Bodapati V.K.K.**, (2004), Evaluation of Energy absorbing pliers Underride Guards For Rear and Side of Large Trucks
- Economic Commission for Europe** (1998), (2011), "Addendum 72: Regulation No. 73," United Nations, Geneva, 2011.
- Freight Transport Association**, (2010), FTA Compliance Guide Side Guards
- Galipeau-Bélaïr P.**, (2014), Design and Development of Side Underride Protection Devices For Heavy Vehicles, The Faculty of Engineering and Applied Science University of Ontario Institute of Technology
- Gogte S., Vijendran N.**, (2014), Conceptual design and development of movable rear underrun protection, Department of Product and Production Development CHALMERS UNIVERSITY OF TECHNOLOGY Gothenburg, Sweden.
- J. Lambert and G. Rechnitzer**, (2002), Review of Truck Safety: Stage 1: Frontal, Side and Rear Underrun Protection," Monash University - Accident Research Centre.
- Niewöhner W., Berg F. A.**, (2015), Gefährdung von Fußgängern und Radfahrern an Kreuzungen durch rechts abbiegende Lkw, Bundesanstalt für Straßenwesen.
- Rechnitzer G. & Grzebieta R.H.**, (2014). So yo want to increase cycling on roads: then we need side underrun barriers on all trucks Transport and Road Safety (TARS) Research, University of New South Wales (UNSW)
- Riley, B.S., Farwell, A.J. and Burgess, T.M.**, (2010), " Side Guards for Trucks and trailers Phase 1: Background Investigation " Ottawa.
- Road Safety and Motor Vehicle Directorate Transport Canada** (1987), "Front underrun guardsfor trucks" Eleventh International Conference on Experimental Safety Vehicles, Washington, May, 1987
- Robinson T. and Cuerden R.** , (2014), Safer Lorries in London: Identifying The Casualties Associated With Side Guard Rails and Mirror Exemptions., Transport Research Laboratory.

Sauerbrey J., MAN Abbiegeassistent: Ein System zur Unfallvermeidung beim Rechtsabbiegen von Lkw, MAN AG, München.

Schreck B., Seiniger P., (2015), Abbiege-Assistenzsystem für Lkw- Grundlagen eines Testverfahrens, Bundesanstalt für Straßenwesen.

T. L. Smith and Knight I., (2004), Review of Side and Underrun Guard Regulations and Exemptionsi TRL Limited.

Transport od NSW, (2013), Safety Technologies for Heavy Vehicles and Combinations., January 2013.

Welfers, T., Ginsberg, S., Funcke, M., Hamacher, M., Matheis, R., (2011) Design of a Tractor for Optimised Safety and Fuel Consumption., FORSCHUNGSGESELLSCHAFT KRAFTFAHRWESEN MBH AACHEN (FKA) BODY DEPARTMENT.

Url-1 <<http://bright-cars.com/photo/mercedes-benz-atego>>, date retrieved 9.04.2016.

Url-2 <<http://www.aerofficient.com/side-fairing-fixed-toe-in-or-gear-wrap.html>>, date retrieved 29.03.2016

Url-3 <<http://www.crashforensics.com>>, date retrieved 29.03.2015.

Url-4 <<http://www.elet.polimi.it/>>, date retrieved 10.01.2016.

Url-5 < <https://www.gov.uk/government/publications/side-guards-lateral-protection-device-guidance/side-guards-lateral-protection-device-guidance> >, date retrieved 29.03.2016

Url-6 <http://optiflow.com/fileadmin/user_upload/Brochures/OptiFlow_SideWings_Brochure_web__EN-lr.pdf>, date retrieved 29.06.2015.

Url-7 <<http://www.mohid.com>>, date retrieved 29.06.2015.

Url-8, < <http://www.kronosenergysolutions.com/FleetFairings/skirt-side-fairings.html>>, date retrieved 29.03.2016

Url-9 <http://www.unfallanalyse.de/unfallforschung/rechtsabbiegender_lkw.html>, date retrieved 29.03.2016

APPENDICES

APPENDIX A: Materials

APPENDIX A

Mechanical Properties of Honeycomb Materials - Typical Values at Room Temperature

PRODUCT CONSTRUCTION		COMPRESSION		PLATE SHEAR			
Density	Cell Size*	Stabilized		L Direction		W Direction	
kg/m ³ (lb/ft ³)	mm (in)	Strength MPa	Modulus MPa	Strength MPa	Modulus MPa	Strength MPa	Modulus MPa
3003 Aluminium							
29 (1.8)	19 (3/4)	0.9	165	0.65	110	0.4	55
37 (2.3)	9 (3/8)	1.4	240	0.8	190	0.45	90
42 (2.6)	13 (1/2)	1.5	275	0.9	220	0.5	100
54 (3.4)	6 (1/4)	2.5	540	1.4	260	0.85	130
59 (3.7)	9 (3/8)	2.6	630	1.45	280	0.9	140
83 (5.2)	6 (1/4)	4.6	1000	2.4	440	1.5	220
5052 Aluminium							
37 (2.3)	6 (1/4)	1.35	310	0.96	220	0.58	112
50 (3.1)	5 (3/16)	2.3	517	1.45	310	0.9	152
54 (3.4)	6 (1/4)	2.6	620	1.6	345	1.1	166
72 (4.5)	3 (1/8)	4.2	1034	2.3	483	1.5	214
83 (5.2)	6 (1/4)	5.2	1310	2.8	565	1.8	245
127 (7.9)	6 (1/4)	10.0	2345	4.8	896	2.9	364
130 (8.1)	3 (1/8)	11.0	2414	5.0	930	3.0	372
5056 Aluminium							
37 (2.3)	6 (1/4)	1.8	400	1.2	220	0.7	103
50 (3.1)	3 (1/8)	2.4	669	1.7	310	1.1	138
50 (3.1)	5 (3/16)	2.8	669	1.8	310	1	138
72 (4.5)	3 (1/8)	4.7	1275	3.0	483	1.7	193
HRH10 Nomex (Aramid)							
29 (1.8)	3 (1/8)	0.9	60	0.5	25	0.35	17.0
32 (2.0)	5 (3/16)	1.2	75	0.7	29	0.4	19.0
32 (2.0)	13 (1/2)	1.0	75	0.75	30	0.35	19.0
48 (3.0)	3 (1/8)	2.4	138	1.25	40	0.73	25.0
48 (3.0)	5 (3/16)	2.4	140	1.2	40	0.7	25.0
64 (4.0)	3 (1/8)	3.9	190	2.0	63	1.0	35.0
64 (4.0)	6 (1/4)	5.0	190	1.55	55	0.86	33.0
80 (5.0)	3 (1/8)	5.3	250	2.25	72	1.2	40.0
96 (6.0)	3 (1/8)	7.7	400	2.6	85	1.5	50.0
123 (7.9)	3 (1/8)	11.5	500	3.0	100	1.9	60.0
144 (9.0)	3 (1/8)	15.0	600	3.5	115	1.9	69.0
29 (1.8)	5 OX (3/16)	1.0	50	0.4	14	0.4	21.0
48 (3.0)	5 OX (3/16)	2.9	120	0.8	20	0.85	35.0
HRH78	Typical mechanical properties are similar to HRH10, however, the aramid sheet manufacturing tolerances are wider therefore minimum values may be reduced.						

Other foil thicknesses and cell size are available: see specific data sheet or Selector Guide, obtainable from Hexcel Composites on request.
 *Please note that the exact cell sizes for HexWeb core are the imperial measurements. The metric values are provided for reference only.

Properties of typical facing materials for sandwich panel construction.

FACING MATERIAL	TYPICAL STRENGTH Tension/Compression MPa	MODULUS OF ELASTICITY Tension/Compression GPa	POISSON'S RATIO μ	TYPICAL CURED PLY THICKNESS mm	TYPICAL WEIGHT PER PLY kg/m ²
Epoxy UD CARBON tape (0°) 60% volume fraction	2000 / 1300	130 / 115	0.25	0.125	0.19
Epoxy UD GLASS tape (0°) 55% volume fraction	1100 / 900	43 / 42	0.28	0.125	0.25
Epoxy WOVEN CARBON (G793-5HS) 55% volume fraction	800 / 700	70 / 60	0.05	0.30	0.45
Epoxy WOVEN ARAMID (285K-4HS) 60% volume fraction	500 / 150	30 / 31	0.20	0.20	0.27
Epoxy WOVEN GLASS (7781-8HS) 50% volume fraction	600 / 550	20 / 17	0.13	0.25	0.47
Phenolic WOVEN GLASS (7781-8HS) 55% volume fraction	400 / 360	20 / 17	0.13	0.25	0.47
ALUMINIUM Alloy 2024 T3 5251 H24 6061 T6	Av. Yield 270 150 240	Av. 70	0.33	0.50	1.35
STEEL carbon 1006 1017	Av. Yield 285 340	Av. 205	0.30	0.5	4.15
Exterior PLYWOOD Fir	30 / 35	Av. 9	0.1	12.7	6.3
Tempered HARDWOOD Teak	110 / 40	Av. 12	0.1	12.7	8.5

Figure A.1: Material properties

CURRICULUM VITAE



Name Surname : Didem Akkuş
Place and Date of Birth : Tarsus, 08.01.1990
E-Mail :
didemakkus@hotmail.com

EDUCATION :

- **B.Sc.** :2012, Hacettepe University, Automotive Engineering
- **M.Sc. (On going)** :2016, Istanbul Technical University, Mechanical Engineering

PROFESSIONAL EXPERIENCE AND REWARDS:

- 2015- Present : R&D Engineer, Mercedes-Benz Türk A.Ş.
- 2013-2014: Method Engineer, Ford Otosan A.Ş.