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Research Article

Design and Structural Analysis of Trailer Sliding Underrun Protection Device Complied with ECE R58.03 Regulation

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Abstract

In this study, a new, innovative design and structural analysis of trailer sliding rear underrun protection device (RUPD) that complied with UN ECE R58.03 regulation has been made. The technical design norms that determined by United Nations (UN) were considered the key factor for the design parameters. Finite Element Analyses (FEA) were carried out considering the strength test standards specified in the UN ECE R58.03 regulation. Stress distribution was evaluated in the analyzes applied to RUPD. According to stress result of the P1 test condition analysis, the highest stress value was obtained as 839 MPa on hinge mechanism's pins and also during the P2 condition the stress level on same pins were above 1100 MPa. Considering the stress datas from FEA, it was concluded that the design had to be revised. After revision the stress levels decreased, but levels were close to the yield strength of materials that used. Based on all data obtained, authors decided that design is trustworthy enough to be produced and physical tested, but after the physical testing additional minor revisions may be needed.

Keywords: Trailer, Rear Underrun Protection Device (RUPD), Finite Element Analysis (FEA), Bumper, Sliding RUPD.

ECE R58.03 Yönetmeliğine Uygun Treyler Kayar Arka Koruma Donanımı Tasarımı ve Yapısal Analizi

Öz

Bu çalışmada, UN ECE R58.03 yönetmeliğine uygun treyler arka koruma donanımı içim yeni ve yenilikçi bir tasarım ve bu tasarımın yapısal analizi yapılmıştır. Birleşmiş Milletler (BM) tarafından belirlenen teknik tasarım normları, tasarım parametreleri kilit faktörler olarak kabul edilmiştir. Sonlu Eleman Analizleri (FEA) UN ECE R58.03 yönetmeliğinde belirtilen dayanım test standartları dikkate alınarak yapılmıştır. Donanıma uygulanan analizlerde stres dağılımı değerlendirilmiştir. P1 test durumu analizi stres sonucuna göre menteşe mekanizmasının pimlerinde en yüksek gerilim değeri 839 MPa olarak elde gözlemlenmiş ve P2 koşulunda aynı pimlerdeki gerilim seviyesi 1100 MPa'nın üzerinde hesaplanmıştır. FEA'dan gelen stres verileri dikkate alındığında tasarımın revize edilmesi gerektiği sonucuna varılmıştır. Revizyondan sonra stres seviyeleri azalma gözlemlenmiş, ancak seviyeler kullanılan malzemelerin akma dayanımına yakın olarak saptanmıştır. Elde edilen tüm verilere dayanarak, yazarlar tasarımın üretilecek ve fiziksel olarak test edilecek kadar güvenilir olduğuna karar vermişlerdir, ancak fiziksel testten sonra ek, revizyonlara ihtiyaç duyulabilineceği not edilmiştir.

Anahtar Kelimeler: Treyler, Arka Koruma Donanımı, Sonlu Elemanlar Analizi (SEA), Tampon, Kayat Arka Koruma Donanımı.

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1. Introduction

Since the very beginning of transportation vehicle's history, accidents involving casualties has been seemed as the most important case to be avoided. The risk of being killed in traffic rise people's attention due to survival instinct.

Owing to technological developments, global pandemic restrictions, legal obligations etc. the risk of being killed in traffic accidents has decreased in worldwide. Especially drop in traffic because of pandemic restrictions seems as the key factor for this decrease. According to WHO (WHO, 2021), in some countries, Netherlands and Australia, accidents with casualties has increased. This data allows inferences to be made that drop in traffic is not the sole factor for death rates, also current technological developments and norms may not be sufficient enough.

From the motor traffic safety point of view, two important goals should be considered. The first one is to reduce the probability of a crash (active safety) and the other one is to minimize the car crash effects (passive safety). (Gidlewski, Jackowski, Posuniak, 2022) Passive safety requirements of vehicles are mainly covered by safety standards. The vehicles must obey the rules that established by governments and standard organizations and must equip the safety devices. Otherwise, the transport that has been produced is illegal to be in the traffic.

Standard safety equipments differ from each other based on the vehicle that being used or where they are being used on vehicles. In this paper, the rear underrun protection device (RUPD) at the rear of trailers is reviewed.

Rear underrun protection (RUP) aims to reduce the injury severity for the occupants of passenger cars that collide with a heavy goods vehicle (HGV). (Smith, Grover, 2008) When a smaller vehicle respect to trailers collide to the rear of trailer, the vehicle tends to slide under the trailer chassis due to gap between the chassis and ground. As shown in Fig.1, the collusion causes catastrophic damage to the vehicle and passengers in vehicle.

Fig. 1 2010 Chevrolet Malibu Front into 2007 Hyundai Trailer Rear Crash Test (Wegmuller, von der Weid, 2011)

As demonstrated in Fig. 2, RUPD is commonly made of two main components. The firs one is cross members and second is support member. The structure consists of devices that are fixed to chassis components or other structures on the vehicle. (Feng, Liu, 2018) RUPD components can be manufactured from different materials and different production methods, provided that they remain within the safety regulations. The most common materials that has been used are steel, due to their strength, and aluminum, owing to light weight.

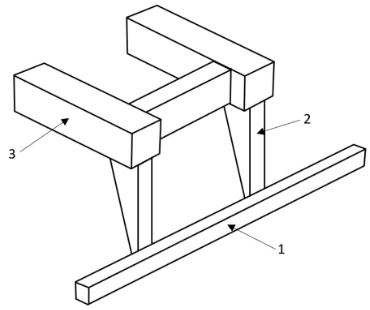

Fig. 2 Standard Rear Underrun Protection Device Representation. 1-Guard Bar, 2-Support Member, 3-Chasis (Gidlewski, Jackowski, Posuniak, 2022)

Depending on the working environment in which they used and the good they made to transport, trailers have different types of structures. Based on trailer variables and their requirements rear underrun protection devices must also have variants. Mainly RUPDs have two types. One of them is fixed, and the other one's adjustable.

Fig. Kässbohrer Container Chassis (Kässbohrer, 2022)

Adjustable RUPDs are largely used on non-extendable fixed container chassis. Fixed container chassis, demonstrated in Fig. 3, have robust frame system. Because of loading trailer with containers that have different dimension, displayed in Fig. 4, the dimension between rear end of container and RUPD changes. Even though in accordance with the regulations, dimension between containers' tail end and RUPD doesn't have to be in a range that set by regulations, due to traffic safety, the rear underrun protection is adjusted to the regulation dimension range.

Fig. 4 Container Chassis Loaded with 40 ft. (left) and 45 ft. (right) Containers.

Even though the safety regulations on RUPD differ among themselves, they are based on the same foundations. These regulations contain restrictions, requirements, classification, and approval for RUPD design, the vehicle categories that can be used in, installation on vehicles, test conditions etc. Also, penalties for non-conformity of production can be found in these regulations. In this paper, UN ECE R58.03 (UN) was used as the reference for evaluating the capability of the RUPD.

According to UN ECE R58.03 norm, there are basic design requirements for the RUPDs for the rear underrun protective device (RUPD) to function as required.

At the rear of a motor truck there is a big ground clearance under the trailer's load bed, which makes it possible for a passenger car to run into the space under the trailer. (Gidlewski, Jackowski, Posuniak, 2022) Thus RUPD's placement is very significant. Protection devices' the ground clearance cannot exceed 450 mm or departure angle up to 8˚ with a maximum ground clearance of 550 mm is deemed to satisfy the requirements, demonstrated in Fig. 5.

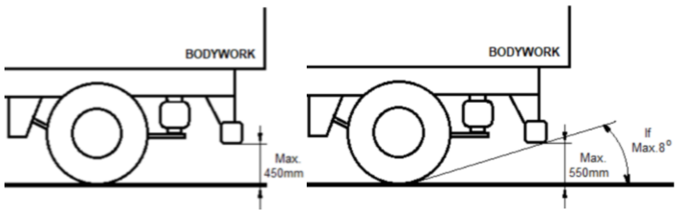

Fig. 4 Dimensional Limits of Ground Clearance of RUPD According to UN ECE R58.03 (UN)

Similarly ground clearance, the dimension between RUPD and trailer's tail end has to be in limit values. ECE R58.03 requires that during rear impact the distance between RUPD and rear extremity of trucks not more than 400mm, but there is no specific energy absorption requirement (Abid, Roslin, 2019) unlike other regulations from world, i.e., FMVSS 223/224 (USA), CMVSS 223 (Canada), GB 11567-2017 (China).

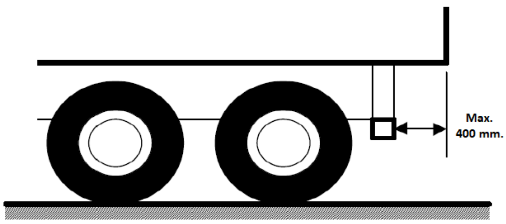

Fig. 5 Dimensional Limits Distance Between RUPD and Trailer Tail End According to UN ECE R58.03 (Pooudom, 2018)

RUPD's width (Y from Fig. 6) cannot exceed the vehicle's widest rear axle width, measured from the outer edge of the wheels, excluding the tire bulge near the ground, and cannot be shorter than 100 mm on either side.

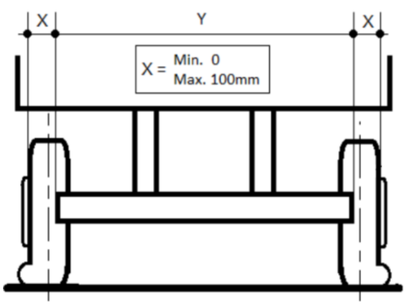

Fig. 5 Dimensional Width According to UN ECE R58.03 (UN)

RUPD Guard bars' shape, material and production method can be changed due to technical requirements. But bars' section height cannot be less than 120mm.

In order to design a RUPD that is convenient with ECE R58.03 regulation, device must meet all the above-mentioned requirements. Nonetheless relevance to basic design requirements is not sufficient enough, it also must pass the strength test. In strength test, protection devices are applied to different loads, Table 1, from different points of guard bar, as shown in Fig.6. When the loads are applied separately, under test load, the maximum total deformation can be 100 mm on the guard.

Table 1. UN ECE R58.03 Strength Test Conditions (UN)

Points	Force [kN]
P_1	100
P_2	100
P_3	180

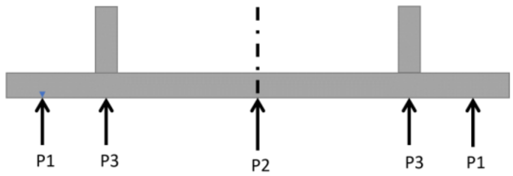

Fig. 6 Force Application Points R58.03 (Gidlewski, Jackowski, Posuniak, 2022)

In article named "Design and Structural Analysis of Trailer Sliding Underrun Protection Device Complied with ECE R58.03 Regulation", authors' aim was to design a new trailer sliding underrun protection device that lighter, cheaper, able to replace the current sliding RUPD and fully compatible with Tırsan and Kässbohrer trailers.

2. Material and Method

In this study, sliding rear underrun protection device design for trailers was made using S700 structural steel and finite element analysis (FEA) was performed on the design. To begin with, 3D computer aided design (CAD) model was designed in CREO. The created model was analysed using the finite element method under UN ECE R58 strength test conditions in the ANSYS program. The data obtained from FEA were interpreted and revisions were made.

2.1. Geometric Model Construction

By using Creo Parametric software, the geometric model of RUPD was created. In the design phase of this study, the existing fixed RUPD and hinge mechanisms were considered, and focus of this project was combining hinge mechanism and RUPD.

Basically, model consist of "C" cross section shaped guard bar bumper, hinge mechanism and support members that carry bumper.

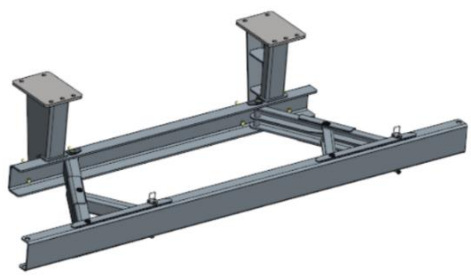

Fig. 7 Sliding Rear Underride Protection Device 3D Design

The bumper, shown in Fig.8, is the part that directly collide with external factors; thus, bumpers must have a rigid structure. In this design a "C" cross section bar was used as a bumper. In order to increase endurance of general structure, additional support brackets were also added. Especially hinge connection regions and the middle part that located between the hinges were predicted to be the most vulnerable zones of structure. Because of this prescience, the support brackets were added to these areas.

According to regulation, the bumper high must be above 120 mm. Taking this regulation account, bumper high was chosen as 140 mm and the thickness of sheet metal as 5 mm.

Fig. 8 Left, Bumper Cross Section. Right, Bumper

Demonstrated in Fig. 9, the hinge mechanism was based on 2-bar hinge mechanism. One short and one long arm are pinned to bumper and support member for each hinge. Pin connections allows the fix the bumper on open and close position, also rotating on the pin shaft that connects the support member and hinge, it enables the bumper to slide. Similar to bumper, "C" shaped cross section also was used for hinge arms. For long arm 8 mm, for short arm 6 mm thickness was chosen, since mainly the long arm bears the load coming from the bumper.

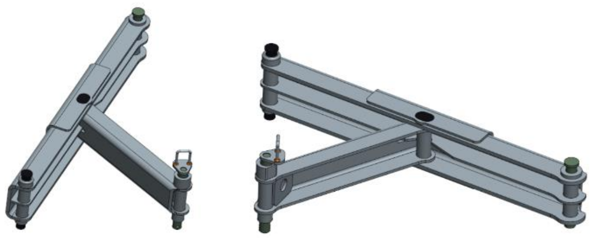

Fig. 9 Sliding RUPD Hinge Mechanism

The support members as name suggests, they're the parts that carry bumper and support its stiffness. This parts' stiffness is also very important due to the fact that they're the main frame that fix the bumper to the chassis. A failure on support members causes a dysfunctional protection device. The support members consist of "C" shaped cross and carrier support legs. C cross is very similar to bumper, but there aren't any support parts, also its thickness is 8 mm. As for carrier legs, it was made of from different shape of sheet metal parts.

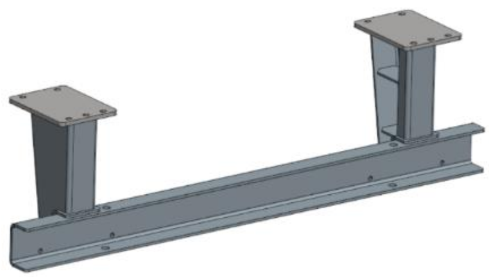

Fig. 10 Sliding RUPD Support Members

2.2. Materials

Table 2. Material's Mechanical Properties

Materials		**Rm** Tensile Strength (Mpa)	**Re** Minimum yield strength (MPa)	v(%)	E Elastic Modulus
Standard	Grade				
EN 10149-2	S700MC	900	700	27	200000
EN 10083-2:2006	C45	510	260	27	195000

The mechanical properties of S700 and C45 steel were used in the simulations are given in Table 2. In the rear underride protection device design, S700 steel is used for the overall structure and C45 steel is used for the pins.

2.3. Finite Element Model

As mentioned before, 3D model designed in Creo Parametric. In order to begin the finite element analysis in Ansys, the CAD data must be imported to ANSYS. Design in Creo was exported as ".step" file and then imported to the ANSYS, as shown in Fig. 11.

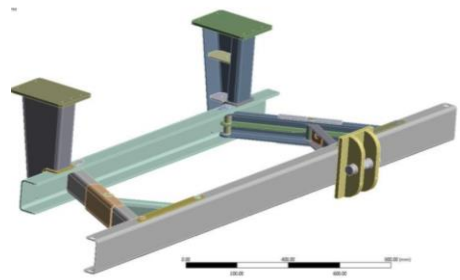

Fig. 11 RUPD Design Imported in ANSYS

The all components of RUPD design were meshed. Total 310798 nodes and 390561 solid elements were created in model.

2.3. Test Conditions

According to the requirements of the ECE R58.03 static strength test conditions, the loads that demonstrated in Table 1. applied to the bumper surface of RUPD design. Every load on different points were applied to the surface separately.

The worst case for this kind of sliding rear underrun protection is the opened position. Because mostly all load is caried by the hinge mechanism, device's strength decreases. Thus, in this case all the loads were applied to the wide open position of sliding device.

The study focused on the stress displacement in the RUPD. As an analyse output, the study focused on the stress distribution on RUPD design.

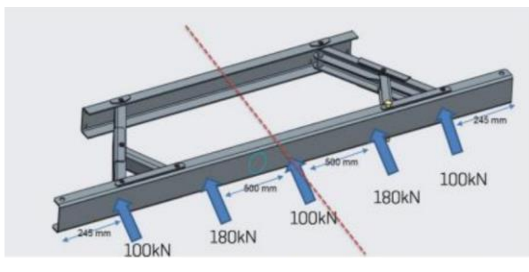

Fig. 12 Force Application Points and Loads on RUPD Static Strength Test

3. Results and Discussion

3.1. Results

Finite Element Analysis completed separately according to ECE R58.03 regulations static strength test loads that applied to the different points in ANSYS program. The result stress data was obtained from analysis as follows:

Analysis of results of stress distribution was not homogeneously distributed. In many case the stress occurred on pins caused the pins fail and stress spread other components local areas that connects with pins.

P1 case, shown in Fig.6, the stress levels of all the pins that connects hinge arms to the bumper and support member were above the yield strength of C45 steel, above 839 MPa on some parts, demonstrated in Fig14.

Overall, as can be seen in Fig. 13, for P1 case, problematic parts were that the hinge mechanism connections. Because of stress intensity on them, the bumper's, support members' and hinge arm connection zone's stress levels were also above the S700 steel's yield strength, 700 Mpa.

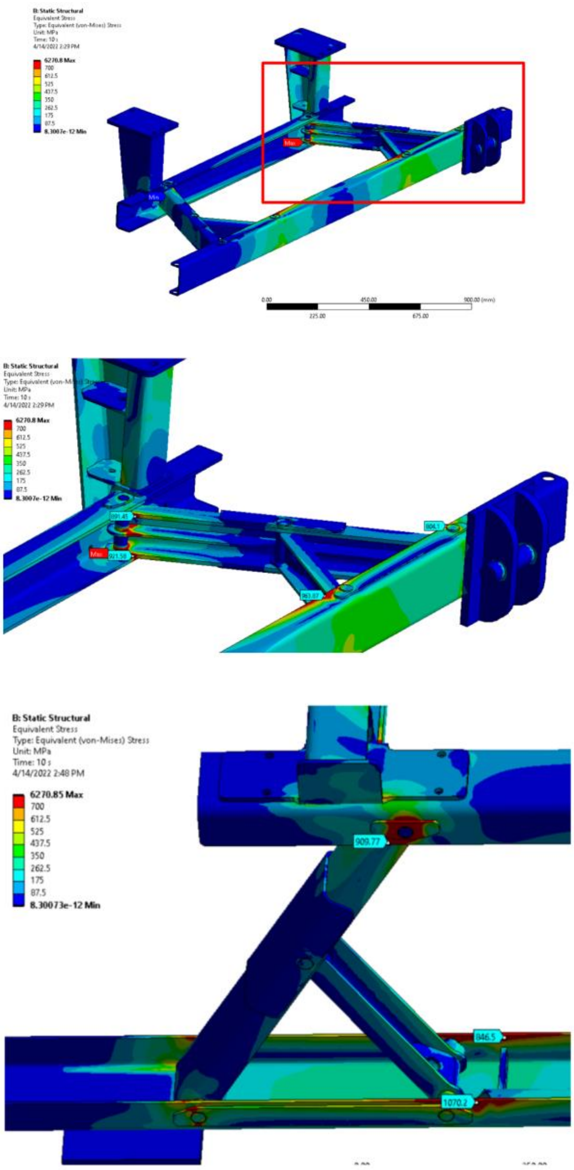

Fig. 13 RUPD Static Test, P1 Load Case Stress Distributions

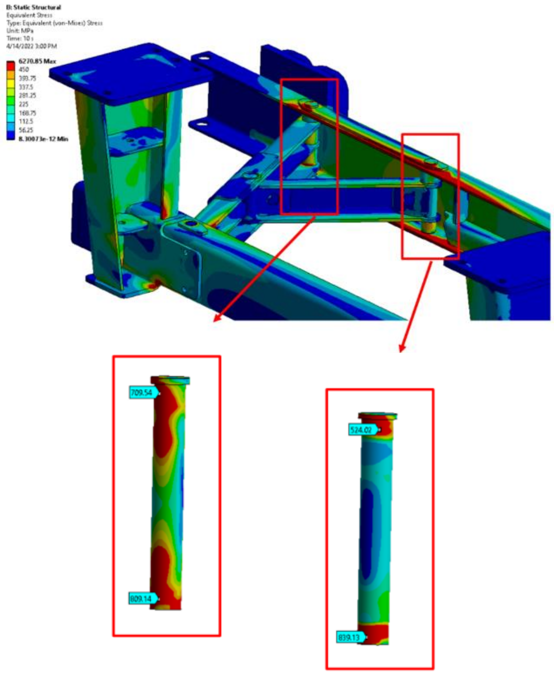

Fig. 14 RUPD Static Test, P1 Load Case Stress Distribution on Pins

In P2 case, after 180 KN load was applied to the bumper, similar to P1 case, stress levels on hinge mechanism's pins were above the yield strength. Due to the increase in load the stress levels were higher than the P1 case. The pin which was nearest the applied force has the highest level of stress that was above 1122 MPa, shown in Fig 15.

Also, the connection between hinge arms were seemed problematic. On the long arm stress level was above 1000 MPa and since this value was way above the yield strength of S700 structural steel, it is estimated that component's integrity would be broken.

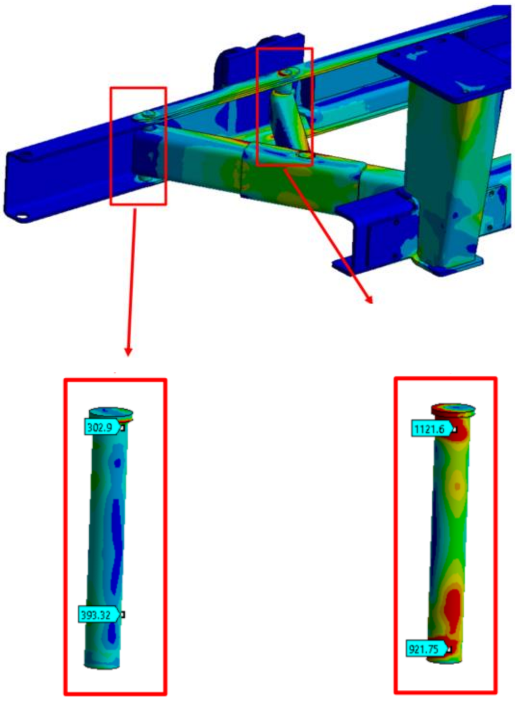

Fig. 15 RUPD Static Test, P2 Load Case Stress Distribution on Pins

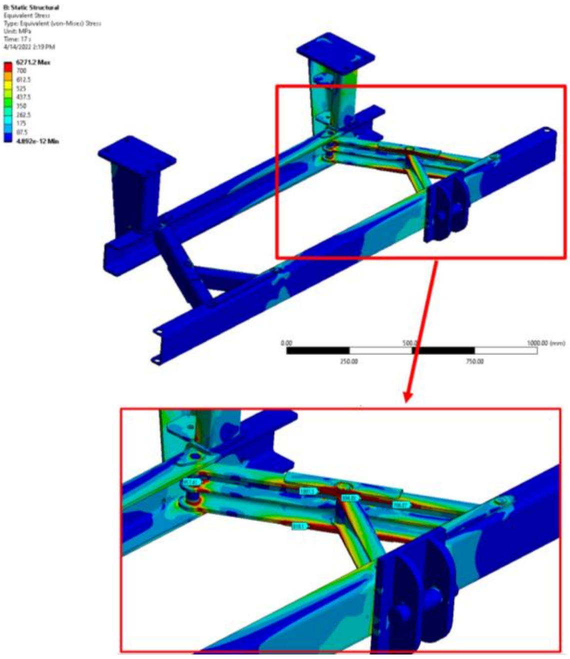

Fig. 16 RUPD Static Test, P2 Load Case Stress Distributions

Authors decided that revisions had to be made on the design, due to the regions that had stress levels above the yield strengths of their material.

The support bracket on the upper side of bumper, for each side of the bracket 80 mm, total 160 mm were extended. The bracket inside of short arm of hinge mechanism's length also increased 35 mm, as shown in Fig. 17.

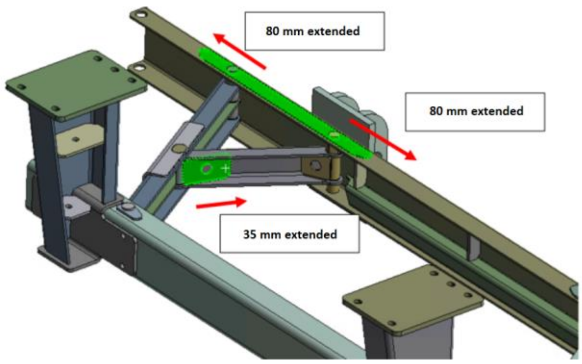

Fig. 17 Revised Parts on RUPD Design

The support bracket on the downside of bumper length, for each side of the bracket 80 mm , total 160 mm were extended. Also, the support part that placed under the support members thickness increased 2 mm.

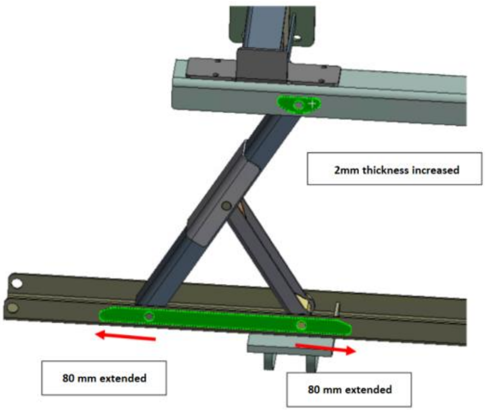

Fig. 18 Revised Parts on RUPD Design

After all revisions applied to the RUPD design, all analyses run again for each load cases and the result stress data obtained.

After analyses, critical problems were seemed in P2 case. After 180 KN load applied to the device, the stress levels that were close to the yield strength of materials observed.decided that revisions had to be made on the design, due to the regions that had stress levels above the yield strengths of their material.

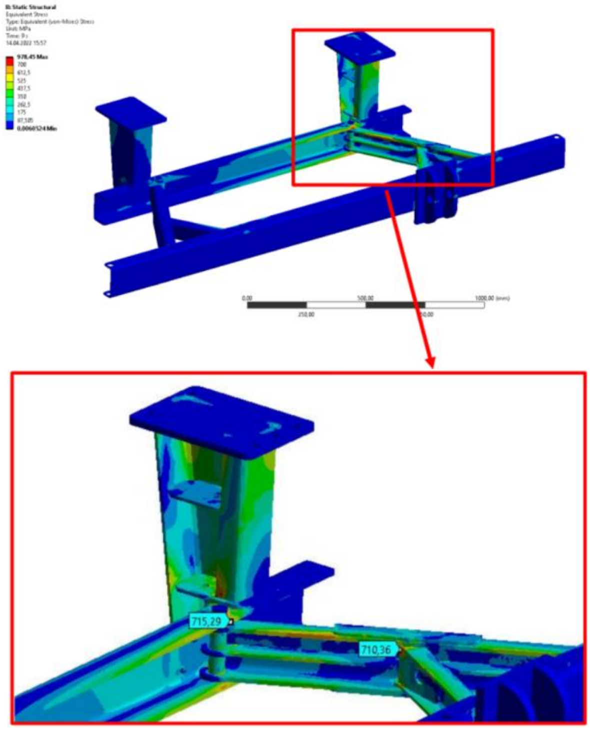

Fig. 19 Revised RUPD Static Test, P2 Load Case Stress Distributions

In P2 case, similarly to unrevised analyses connection zones stress levels were higher that rest of device. The stress levels on hinge arm and support members were almost same as the yield strength of S700, as can be seemed in Fig. 19.

After the revision, it can be seemed in Fig 20. that the pins stress levels also decreased. But still the stress levels were higher than yield strength of C45.

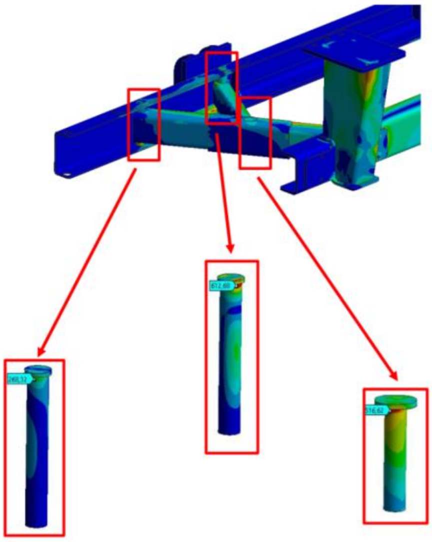

Fig. 15 Revised RUPD Static Test, P2 Load Case Stress Distribution on Pins

3.1. Discussion

The new design for rear underrun protection device had been completed considering the technical requirements of UN ECE R58.08 regulation. RUPD's width is the same as the rear axle width, bumpers cross section high is 140 mm which is above 120 mm min. requirement, etc. When examined in terms of design parameters, authors decided that there was no situation that violates regulatory requirements.

According to finite element analysis results, the first design for rear underrun protection device was not suitable for the strength test requirements. For both P1 and P2 test conditions, the stress levels on pins were above the yield strength of C45 steel. This result indicates that the pins were going to fail during the physical test conditions, and this would cause plastic deformation on other components of device. Thus, the RUPD would be not function, and it would not meet the needs of study.

After reviewing the first analysis, some revisions had made in order to improve the design. All the strength test parameters were applied to the devices ones more. The stress levels on hinge and support members for hinge and bumper decreased. The stress levels were under the yield strength, but still they were close to the yield strength level of material, Also the stress levels of pins were lesser than first design, the levels were still above the yield strength of material. Authors decided that the results were acceptable for physical test and the local zones that has higher stress levels will be reviewed during physical strength test.

4.Conclusions and Recommendations

After the finite element analysis of the new design for rear underrun protection device, the design meets the needs of UN ECE R58.03 requirements. Also, design must be tested physical conditions. Even though after the physical test some revisions may be needed to apply, the whole structure of design acceptable and it's estimated that the revisions will be minor.

The study demonstrated by analyses that design is trustworthy enough to be produced and tested.

5. Acknowledge

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