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STRUCTURAL STRENGTHENING OF SECOND ROW PASSENGER SEAT FRAME DEVELOPED FOR M1 CATEGORY VEHICLES

Semih ERKUL *
Semih BALCI *

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Abstract: The issue of security in the automotive industry is becoming more and more important day by day and intensive studies are carried out in this regard. It is vital that automobile seats have to meet security regulations to assure optimum passenger safety. This article investigates the design changes of a passenger seat required to meet and exceed the Economic Commission for Europe (ECE) R-14 regulation. ECE R-14 contains a lot of restrictions to secure adequate safety-belt anchorages endurance for vehicles. Various design scenarios have been created to improve the performance of the seat. The CAD models have been designed in CATIA V5 and validated using Hyperworks software. Then, physical tests were also conducted with prototypes to compare outputs with FEA results.

Keywords: Second row passenger seat, tube to tube welding, safety-belt anchorages, frame integrity, ECE-R14

M1 Kategorisi Araçlar İçin Geliştirilen İkinci Sıra Yolcu Koltuğu Karkasının Yapısal Güçlendirilmesi

Öz: Otomotiv endüstrisinde güvenlik konusu her geçen gün daha da önem kazanmakta ve bu konuda yoğun çalışmalar yapılmaktadır. Otomobil koltuklarının optimum yolcu güvenliğini sağlamak için güvenlik yönetmeliklerini karşılaması çok önemlidir. Bu makale; Avrupa Ekonomik Komisyonu (ECE) R-14 yönetmeliği ile uyumlu ve bundan daha ağır şartlara da mukavemet göstermesi beklenen bir yolcu koltuğunun tasarım değişikliklerini araştırmaktadır. ECE R-14, araçlarda yeterli emniyet kemeri ankraj dayanımını sağlamak için birçok kısıtlama içerir. Koltuğun performansını arttırmak için farklı tasarım senaryoları yaratılmıştır. CAD modelleri CATIA V5 kullanılarak tasarlanmış ve Hyperworks yazılımı yardımıyla analiz edilmiştir. Ayrıca, FEA ve gerçek testlerin sonuçlarını karşılaştırmak için prototiplerle fiziksel testler gerçekleştirilmiştir.

Anahtar Kelimeler: İkinci sıra yolcu koltuğu, borudan boruya kaynak, emniyet kemeri bağlantı elemanları, karkas bütünlüğü, ECE-R14

* Diniz Adient Oto Donanım San. ve Tic A.Ş., Organize Sanayi Bölgesi Sarı Cad. No:25, 16159 Nilüfer, Bursa
İletişim Yazarı: Semih ERKUL (semih.erkul@adient.com), Semih BALCI (semih.balci@adient.com)

1. INTRODUCTION

The automotive industry is consistently trying to decrease product development duration to reduce the high costs and meet the customer demands. In addition, new regulations of governments particularly focus on vehicle safety and there are some global regulations including FMVSS (Federal Motor Vehicle Safety Standards) and ECE. The industry has to develop vehicles to meet the ECE or FMVSS regulations and customer/industry demands as well. All these rules continuously become harder due to increasing awareness on human and vehicle safety (Farahani et al., 2002).

The appropriateness of seat belt anchorages for vehicles is inspected with ECE-R14 regulation. Physical tests are carried out and confirmation is provided for each seat within the conditions written in the regulation, without considering whether the safety belt attachments are positioned on BIW or seat. The following forces (See Table 1, 2 & 3) are exerted to the seat depending on vehicle category using specific pulling equipments (UNECE, 2012).

There are different configurations of seat belt systems which are used in order to minimise deaths and injuries caused by traffic accidents. The most common used of these structures are three-point seat belts (Pişgin & Solmaz, 2018). Anchorages of this type can be only on the chassis or there are different variations which they exist on the seat. In the systems with all support points on the seat, it is aimed to increase the safety level with more effective seizing of passengers by the seat belt.

Arslan and Kaptanoglu (2010) investigated to design the seat attachment brackets of different seat types for a commercial vehicle. They aimed to meet ECE-R14 standard by conducting FEA and physical tests for verification. Hessenberger (2003) researched on comparison of the two FEA software in terms of the explicit and implicit analysis of seat belt anchorages. Then, he revealed the advantages and disadvantages of them for evaluating. Shi and Xu (2018) discussed a seat safety method which helps to meet the safety standards, besides reduces the development costs and development period as increasing the physical test passing ratio. The exact pretreatment of the front seat was conducted in HyperWorks software. Then, the model formula was solved in LS-DYNA which showed the strength results of seat.

Table 1. Pulling forces applied to the two lower belt anchorages

M1 Category	22,250 N + 20 x the seat mass(kg) x 9.81 m/s^2
M2 Category	11,100 N + 10 x the seat mass(kg) x 9.81 m/s^2
M3 Category	7,400 N + 6.6 x the seat mass(kg) x 9.81 m/s^2

Table 2. Pulling forces applied to the three-point belt anchorages (Lap / Pelvis block)

M1 Category	13,500 N + 20 x the seat mass(kg) x 9.81 m/s^2
M2 Category	6,750 N + 10 x the seat mass(kg) x 9.81 m/s^2
M3 Category	4,500 N + 6.6 x the seat mass(kg) x 9.81 m/s^2

Table 3. Pulling forces applied to the three-point belt anchorages (Shoulder / Torso block)

M1 Category	13,500 N
M2 Category	6,750 N
M3 Category	4,500 N

The additional force calculations supplemented to the forces above represents the inertial force of the seat. For example; in Table 2, M1 category (United Nations, 2017) pull force is represented as 13,500 N + COG (Center of gravity) effect. In other words, it is a physical effect of the seat mass to the relevant anchorages. This force can be applied onto the related parts of the seat during test. Moreover; the extra load addition and load distribution should be decided by the manufacturer. The technical team, which performs the test, should agree with it.

2. MATERIAL AND METHOD

First of all; in ECE-R14, the specified pulling forces have to be applied on test parts in the fastest way. Although there is a maximum load application time of 60 seconds, the manufacturer may request to complete the load application in 4 seconds. Then, the safety belt anchorages must withstand the required load for not less than 0.2 second (UNECE, 2012).

After pulling the test specimen, permanent deformations and local ruptures or cracks on the seat structure do not cause failing of the test. However; it is expected that the structure of safety belt mechanism has to protect its rigidity and remain attached to the main body. In this study, the customer did not accept any deformations or ruptures on the seat frame and this required stronger metal frame rigidity.

In our physical tests, the both loads were arranged as 14850 N (Legal value + 10%). Afterwards, they were increased to 16200 N (Legal value + 20%) to observe the seat structure behavior in harder situations. Moreover, the seat should resist the loads more than 10 seconds which is longer than legal duration.

2.1. Definition Of The Seat

The seat mentioned in the study is a second row passenger seat of an M1 category vehicle. It was tested and simulated within the scope of product development activities. It is basically a 60/40 split-folding rear seat which offers 3 different folding options for users (60% part, %40 part and both parts foldable), so that users are able to arrange the luggage and passenger positions in several scenarios.

There are three seat belt anchorages for the seat. Two of them are body-connected type and the other one is positioned on seat. Therefore, applied pull forces are directly transferred to the seat and the BIW of vehicle through anchorages. There are five body attachment brackets used for fixing the seat to the vehicle (See Figure 1).

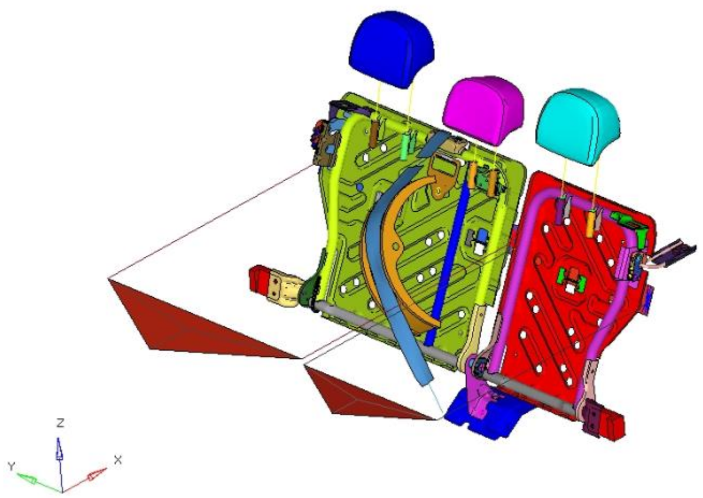


Figure 1:
The image of second row seats created in 3D modeling software

Material is a very important factor affecting the test performance. The material of frame tubes was selected as DP800 steel to obtain appropriate formability without neglecting safety (See Table 4). Samples of DP800 material were subjected to tensile tests. As a result of tests; its yield strength, tensile strength and elongation values as well as stress-strain curve were obtained. These results were used for modelling material in FEA. The material thickness of frame tube was 1.5 mm.

Table 4. 800DP Steel Mechanical Properties

Material Name	Minimum Yield Strength (MPa)	Minimum Tensile Strength (MPa)	Elongation
DP800	575	875	%8

After determining the material properties, it was found out that frame tube elements cannot have elongation value more than 8%.

3. DESIGN VERIFICATION PERIOD: FEA & PHYSICAL TESTS

Hypermesh and Hypercrash softwares were used to model finite elements and create mathematical models as pre-processing. The pulling forces were calculated depending on the seat weight. The safety belt coming from the belt anchorage on vehicle to the belt buckle isn't modeled due to having no impact on the seat structure in FEA. Because, these anchorages are on the BIW of vehicle. All the forces related to seat (e.g. Torso Block, COG) were implemented to the FEA models (See Figure 2), making 10 degree angle to X-axis in the median vehicle plane with ±5° tolerance value. The mesh element sizes were arranged approximately as 5mm to obtain sufficient results which are close to the physical tests.

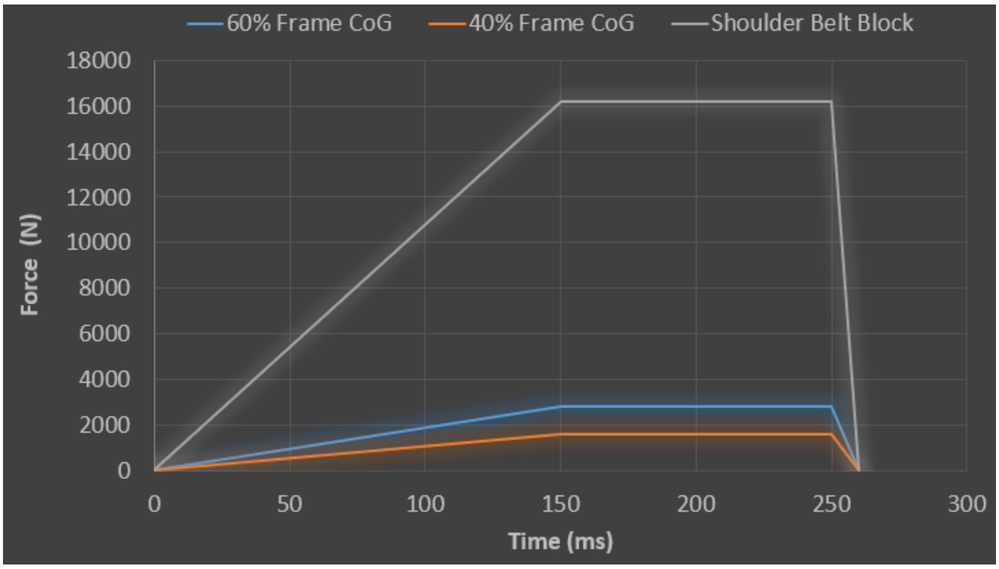


***Figure 2*:**
The Force-Time Graph of FEA Simulations

There are different types of elements used in the finite element modeling such as one-dimensional (Rigid, Beam, Truss, Spring) elements, two-dimensional (Shell) elements and three-dimensional elements (Tetra, Hexa) and their quantity is 114548 in total (See Table 5). Also, the quantity of total nodes is 105551.

Seat frame as well as welds were modelled with shell elements, fasteners were modelled with both beam and hexa elements. Lastly, safety belt was modelled with shell and truss elements.

Table 5. Mesh Elements Type & Quantities

Element Type	Quantity
One-dimensional elements	564
Tria (2-D)	3420
Quad (2-D)	71094
Tetra (3-D)	21241
Hexa (3-D)	18229

The Figure 3 illustrates all the element types used for modeling. The mesh quality was improved limiting tria elements amount up to 10% of quad elements.

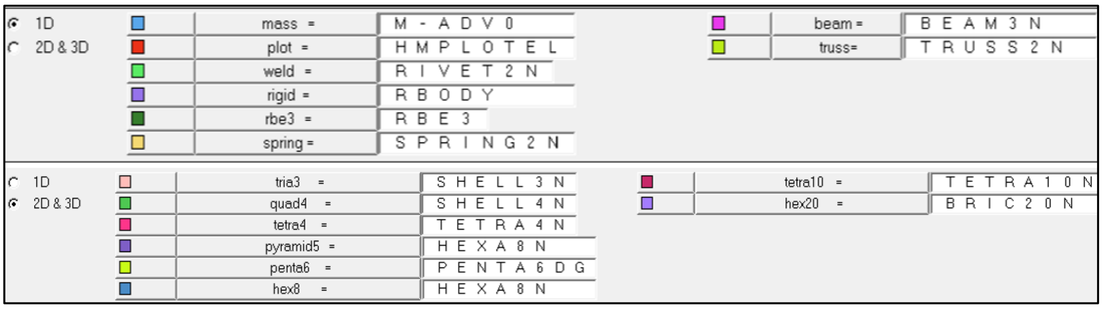


Figure 3:
Element types used in FEA modeling software

The metal frame, which is the main model of FEA work, has a mesh structure quality created according to the below standard (See Figure 4),

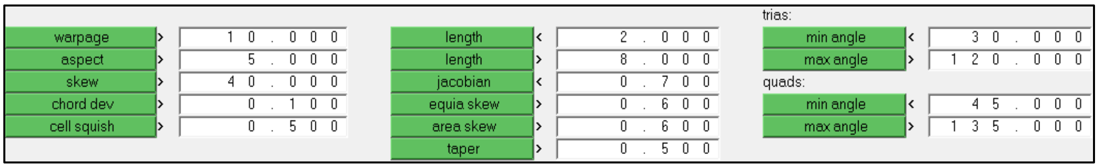
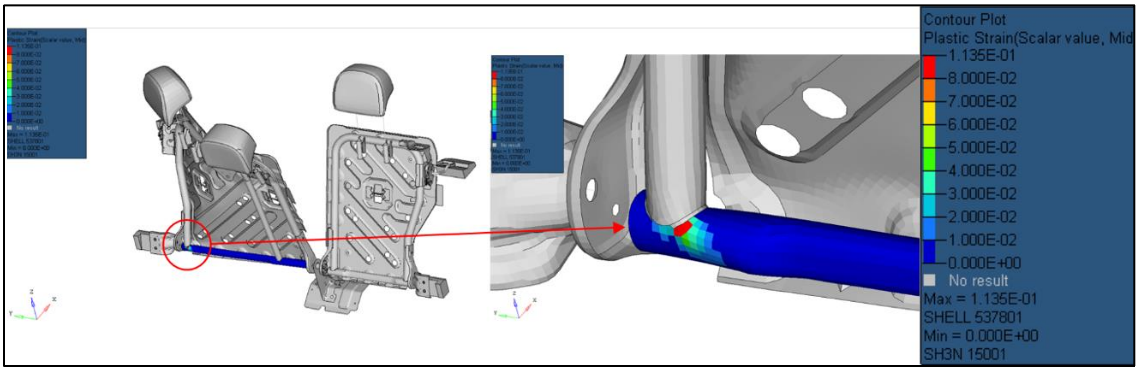


Figure 4:
The Quality Standards of Mesh Modeling

After all the necessary parameters were completed, models were solved using explicit method in Radioss solver using a hardware which has 4-core, 2.9 GHz processor. First, the total energy was compared with hourglass energy – 0 Joule in the study – to check the simulation accuracy in terms of energy. The Figure 5 below shows the strain values obtained from the initial simulation. Red elements having more than 8% plastic strain illustrate the undesirable behavior of the seat frame. This situation was especially seen at the tube to tube connection point of the 60% frame structure (The right-hand part).



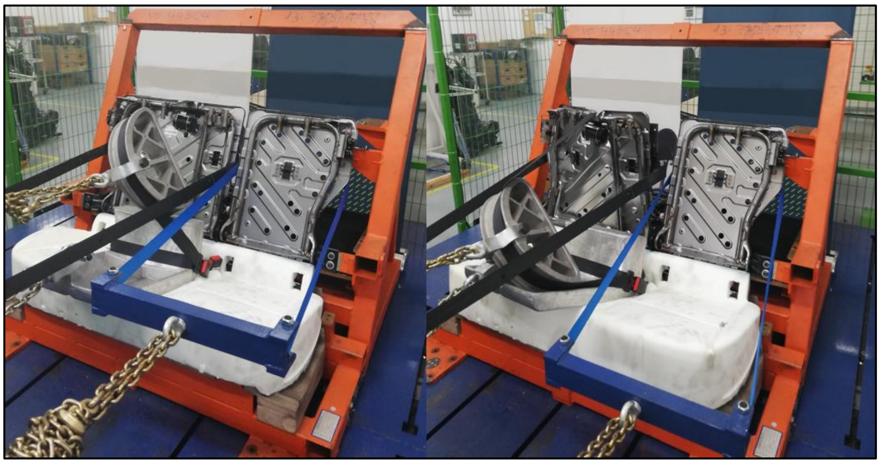
a. *b.*

Figure 5:
FEA Images of Triple Seat;
***a.** Simulated Elements on Tube to Tube Connection **b.** Plastic Strain Contour Plot*

The first simulation result showed an unwanted behavior for the frame. But, the same sample was modified changing the production parameters (e.g. weld settings) and subjected to simulation again. Then, the test result was successful; however, it was very important to pass the test with a stronger sample consistently without depending on production parameters. It was decided to implement design improvements to the metal frame for obtaining more robust structure.

All the parts in FEA model comprise of isotropic elasto-plastic material. They use user-defined functions for the work-hardening portion of the stress-strain curve at different strain rates (Altair Engineering Inc., 2014).

In parallel, finite element works are generally supported with physical tests to check their reliability. Therefore, the specific pulling test setup was prepared using the initial frame. As it is seen in the Figure 6, the backrest of specimen does not include foam, but seat integrity still provided.



a. *b.*

Figure 6:
Physical Test Setup of Initial Design;
***a.** Pre-Test Image **b.** Post-Test Image*

There is a 1350 N pre-loading rule in the physical test before full loading. One of the biggest difference in comparison to ECE-R14 is the standing time to force. The sample has to resist the full loading period for ten seconds (See Table 6), whereas it is 0.2 second for ECE-R14. There are two special apparatus to perform the test. They represent torso and pelvis of human body.

Table 6. The Initial Test Setup Document

Physical Safety Belt Anchorage Test Specifications							
	Actions	**Parameter**					
Loading		Time (Second)	Force (Newton)				Percentage (%)
			Shoulder Block	Lap Block	COG (40% Seat)	COG (60% Seat)	
Step	Preload		1350 in total				
1	Load increase	1	**14850**	**14850**	1597	2719	**110 (legal +10%)**
	Holding	1					
2	Load increase	1	**16200**	**16200**	1742	2967	**120 (legal + 20%)**
	Holding	10					
3	Load releasing	1					Down to 0%

The initial physical test was performed according to specifications above. The load distribution applied to the seat was given in the Figure 7 depending on time.

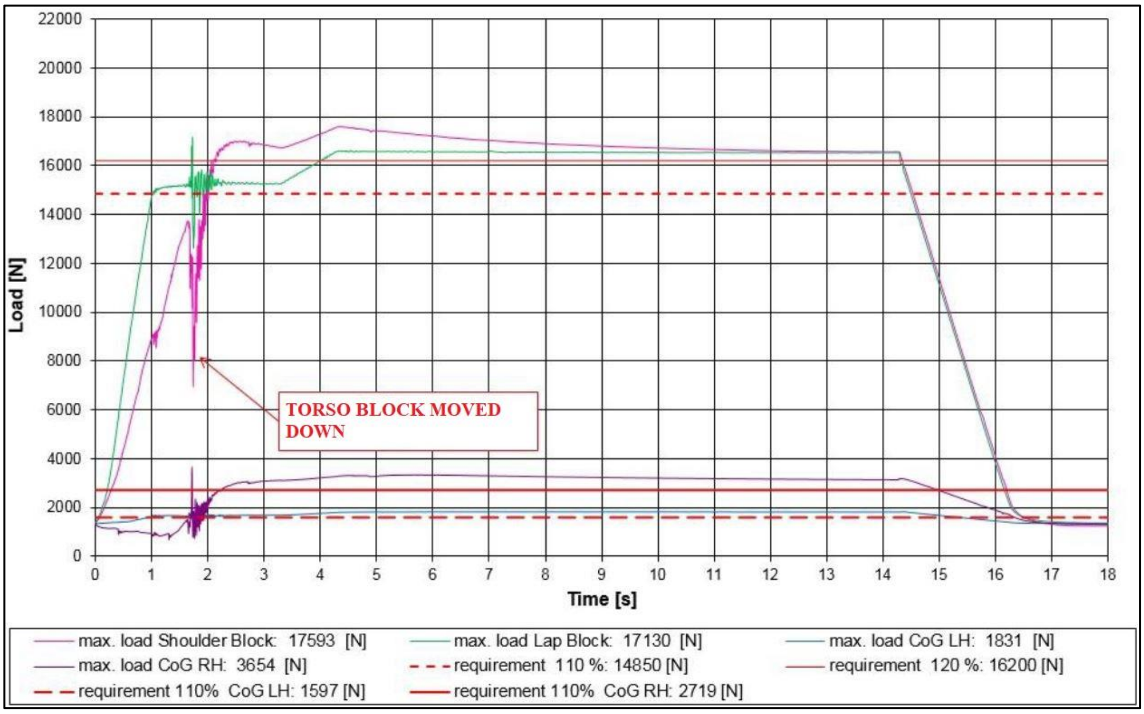


Figure 7:
Load-Time Graph of Physical Pulling Test

Results were parallel to the FEA outputs. As it was mentioned before, there was an unwanted situation in terms of seat integrity in case of not having optimum welding parameters.

Additionally, one of the important factors was X-axis displacement value of center upper anchorage. Although the X-displacement value of physical test was acceptable in terms of legal ECE-R14, it was not suitable according to the harder specifications of customer. The displacement behavior graph was given in the Figure 8. This graph was a result of frame vulnerability which caused the decreasing of endurance against pulling forces, so that the upper seat area approached towards pulling pistons more than expected.

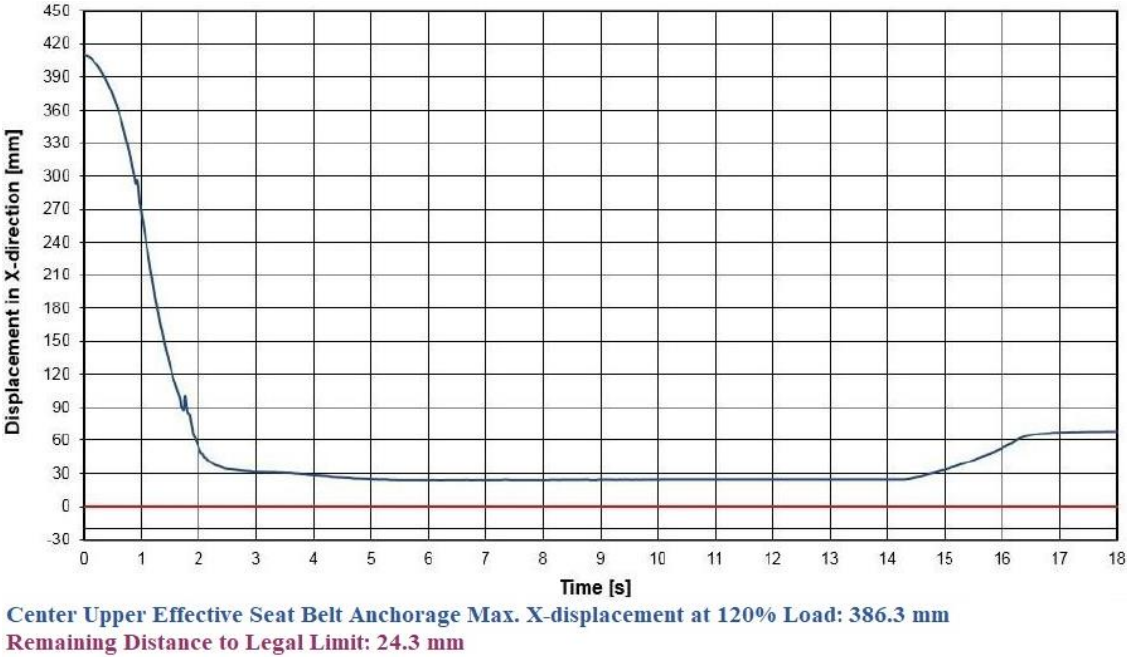


Figure 8:
Effective Upper Anchorage X- Displacement Graph

These results were eliminated modifying the production parameters having the better quality. However, both the simulation and the physical anchorage test demonstrated that there had to be a more robust structure to pass the tests efficiently independent from other factors. Then, design change studies were begun to improve the safety factor.

4. DESIGN VARIATIONS

Design changes were implemented to the dovetail region (Tube to Tube Connection) of the 60% frame. Because, the most vulnerability was clearly observed at this area after FEA and physical tests. Four different types of wires were implemented to the initial version to obtain more robust product using welding process. Some of them were showed in Figure 9.

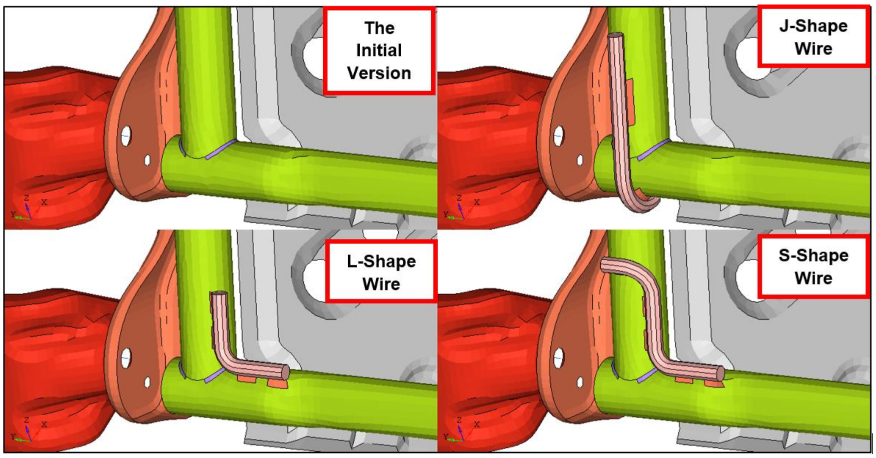


Figure 9:
Different Formed Wire Implementation on Tube to Tube Connection

One of the wires was not feasible due to production difficulty and it was not mentioned in the article. All the new designs were simulated in FEA with the same parameters conducted on the initial design. One of the new approaches showed positive results (See Figure 10). It is a J-shape wire consists of C18D steel. It has 8 mm diameter with 110 mm in length. The strain value did not exceed 8% with this combination in FEA and this simulation presented a non-deformation case.

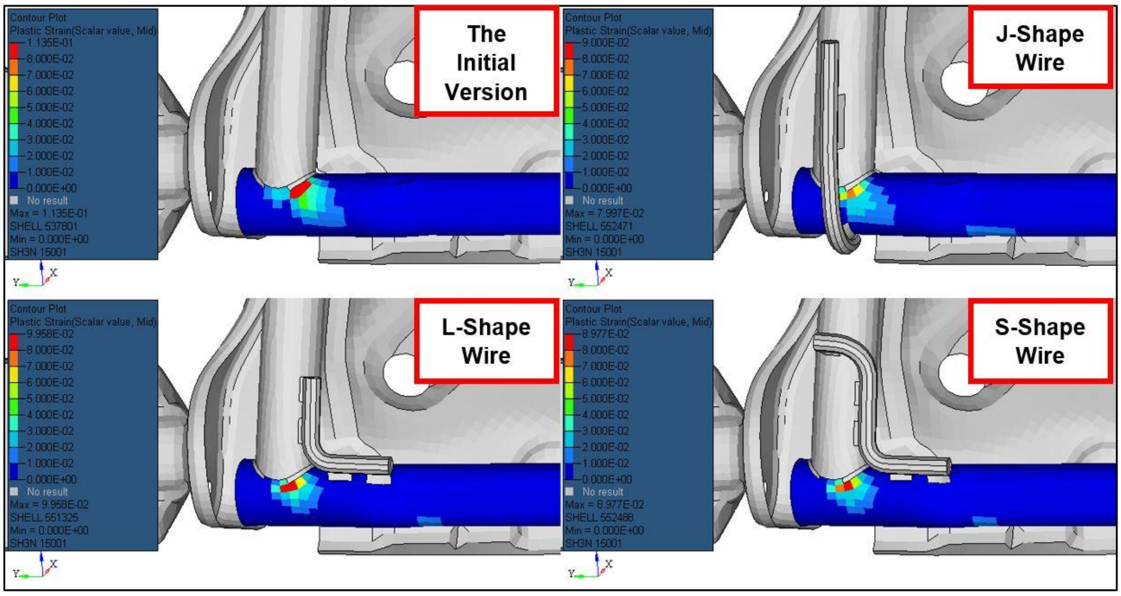
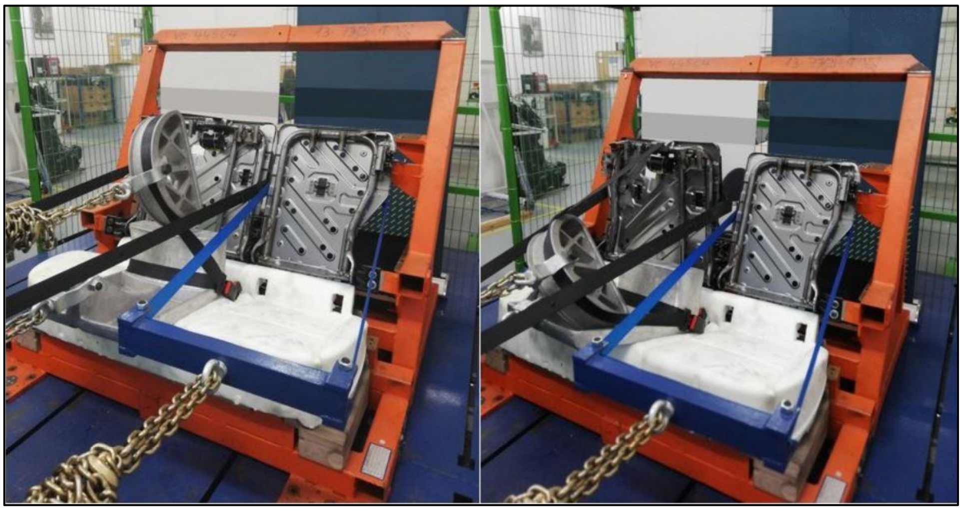


Figure 10:
Strain Values of Modified Frames According to Wire Types

The frame supported with J-shape wire, was also physically tested to examine the similarity with FEA simulation results. The same test setup was implemented according to the steps given above (see Table 6).

The Figure 11 below illustrates the pre-test and post-test visuals of seat frame supported with J-shape wire.



a. *b.*

Figure 11:
Physical Test Setup of New Design;
a. *Pre-Test Image* ***b.*** *Post-Test Image*

Applied pulling forces were endured more successful compared to the initial seat. No rupture or deformation were observed at the dovetail area (tube to tube connection) after loading (see Figure 12). Moreover, the maximum X-displacement value was 300 mm which was lower than initial value. Eventually, design verification study was successfully assured as required.

Figure 12:
Post-Test Image of Seat Frame

Nonetheless, it was obvious that the seat was exposed to permanent shape deformation under significant pulling forces (Figure 13).

a. *b.*

Figure 13:
Post-Test Deformations;
***a.** Seat Lock Mechanism **b.** Upper Center Seat Belt Anchorage*

5. CONCLUSIONS

In conclusion, the previous existing design was able to withstand required forces with optimum welding parameters, there was still a need of technical strengthening to improve the safety factor.

As an output of this, pulling safety test activities were analysed within the company R&D department and valuable know how was gained after lots of practice with FEA simulations. The information was obtained about what amount of force severity could affect the seat and what kind of improvement needed for that case with analyses.

Also, physical tests were practised. It was seen that there were very reliable results among FEA and real tests in terms of expected deformation and displacement.

Finally; a second row triple passenger seat, which has better endurance to potential force, was developed within the study. A three-point belt anchorage mechanism was implemented and two of the anchorages were positioned on BIW, whereas the other one was located on the seat.

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