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Design Improvement of Passenger Car Seat for Child Safety- FEA Approach

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***Abstract*—The main objective of this study is to evaluate existing seat model for child safety by using FEA software. As the motor vehicle crashes are the leading cause of death or saviour injury for passenger, lot of safety devices has been introduced in vehicle like seat belt, air bags etc. But these safety devices are not suitable for children because of their weight, height and size. It is not safe for children to travel by car by using these safety devices. Hence it is necessary to use other safety devices for children which are suitable to them. Child safety restraint system is used for children, which is installed on car seat by LATCH or seat belt. For this study purpose second row two way captain seat is used. Seat model is meshed by using Hypermesh version-11. Specific quality criteria are followed during meshing like minimum edge length, warpage, aspect ratio etc. Simulation is done by using LS-DYNA. Seat is tested as per FMVSS225. In this study as per FMVSS225 three pull tests are carried out: Forward pull without top tether, lateral pull to right, and lateral pull to left. Seat is checked for structural integrity and displacement criteria. Various design modifications are suggested such as increasing area of RH cushion riser, using high strength material or combination of both and providing additional reinforcement plate. These changes avoid the failure of riser and isofix wires. This seat model is effective for installing child safety restraint system.**

Keywords— FMVSS 225, LATCH, ISOFIX

I. INTRODUCTION

As the technological advancement and infrastructural growth has been done motor vehicle crashes are leading cause of death among children. To avoid these fatalities or injuries, safety has become most crucial thing in vehicle. Nowadays, new car buyers are not only looking for power, better performance and attractive design but also more concerned about safety. During the last decade lot of safety devices such as air bags, advanced seat belts, have been introduced. But these safety devices are not suitable for children because of their height, weight and size. It is not safe to hold child on passenger lap while travelling in car. In a crash because of force of collision the child would be pulled from passenger arms and crushed between passenger bode and interior part of the car. For that reason the safest way for children to travel by car is in a child seat that is suitable for their weight, size and is fitted correctly [2].

Traditionally, many people are travelling with their children without the use of CRS, which is more dangerous [1]. Generally, child restraint system is seat specially designed for children as per their age, weight and height. It is installed in car seat with the help of LATCH and seat belt [6].

A child is not ready to use a regular seat belt until:

- He/she is tall enough so that his/her legs bend at the knees against the edge of the seat.
- He/she is mature enough to remain seated with his/her back flat on the seat, not slouching.
- The lap belt sits high on the thighs or low on the hips, not on the stomach [5].
- The shoulder belt crosses the shoulder and chest, avoiding the arms and the neck [4].

A child ready to use an adult seat belt without the aid of a booster seat will be around 1.5 meters tall and roughly eight years old [3].

The above points focus on the limitations in using the regular car seat for child passenger. The child seat has the advantage that it is suitable for child occupant as per their size, weight and height. Hence there is necessity to work on child safety restraint system for passenger vehicle.

II. ROLE OF CHILD SAFETY RESTRAINT SYSTEM

Child safety restraint systems (sometimes called as a restraining car seat, infant safety seat, child safety seat) are the seats designed to protect children from fatal or savior injury during motor vehicle crashes. Commonly these seats are purchased separately and installed in vehicle as and when required. There are different types of seats as per the age, weight and height. These seats are attached to vehicle seat by LATCH and seat belt.

When motor vehicle crash takes place, due to sudden deceleration of the vehicle large amount of force is generated. The force generation time is too small. The generated force is absorbed by different parts of vehicle. Such a short duration and high amplitude force is transmitted to occupant which may cause fatal injury to occupant. If the occupant is restrained in the specific seat which is suitable for their weight, height and size then the chances of injury potential reduces drastically [7].

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III. SAFETY STANDARDS

There are four regulations applicable to child safety restraint system. These regulations ensure their proper location for effective occupant restraint and it also minimizes the possibility of anchorage failure due to the forces resulting from a vehicle crash. Following are the four regulations:

- FMVSS225
- CMVSS225
- ECER14
- ADR34

Federal Motor Vehicle Safety Standard 225 applies to child safety restraint system to ensure their proper location and strength for effective securing of child restraint to reduce the chances of anchorage system failure. This will improve the chance of effective securing of child restraint and fully achieve their potential effectiveness in vehicle [8, 9].

Table I. Comparison of Regulation

Regulation	Test Description	Load	Load Direction	Requirement
FMVSS225	Forward with top tether	15 kN	10±5˚ upward from horizontal plane	Structural integrity
	Forward pull without top tether	11 kN with 20% overload	10±5˚ upward from horizontal plane	i. X point longitudinal displacement < 175 mm ii. Structural integrity
	Lateral pull left	5 kN with 20% overload	75±5˚ in horizontal plane to vertical longitudinal plane	i. X point resultant displacement <150 mm ii. Structural integrity
	Lateral pull to right	5 kN with 20% overload	75±5˚ in horizontal plane to vertical longitudinal plane	i. X point resultant displacement < 150 mm ii. Structural integrity
ECER14	Forward with top tether	8 kN	0±5˚ upward from horizontal plane	i. X point longitudinal displacement < 125 mm ii. Structural integrity
	Forward pull without top tether	8 kN	0±5˚ upward from horizontal plane	i. X point longitudinal displacement < 125 mm i. Structural integrity
	Lateral pull left	5 kN	75±5˚ in horizontal plane to vertical longitudinal plane	i. X point resultant displacement < 125 mm ii. Structural integrity
	Lateral pull to right	5 kN	75±5˚ in horizontal plane to vertical longitudinal plane	i. X point resultant displacement < 125 mm i. Structural integrity
ADR 34	Forward with top tether	3.4 kN	0˚ to horizontal plane	Structural integrity only

These regulations apply to passenger cars, trucks, multipurpose passenger vehicles and buses.

IV. MODELLING OF SEAT STRUCTURE

Second row two way captain seat available on engineering site is taken for study. There are total 73 components. Seat is meshed by using Hypermesh version 11. For meshing of the seat specific quality criteria is followed. Seat is meshed with following quality criteria.

Minimum element length= 1 mm

Maximum element length= 10mm

Warpage= 20˚

Jacobian= 0.6

Aspect Ratio= 3

Skew= 60

Minimum quad angle= 45˚

Maximum quad angle= 135˚

Minimum tria angle= 20˚

Maximum tria angle= 120˚

Fig.1 Meshed Seat Model

Seat is meshed by using shell meshing, solid meshing and 1-D meshing. Minimum element length governs the run time during simulation.

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V. MATERIAL SELECTION

For giving materials LS-DYNA material manual is used. Different materials are used as per the crucial component. In total 12 types of materials are used. For base plate and fixture rigid material is used, for flex wire elastic material is used. For lower and upper track, side member, back frame side member, locking mechanism elastic plastic material is used.

Table II. Material Properties

Sr. No.	**Material Name**	**Card Image**	**ρ tonns/mm^3**	**E MPa**	**σ MPa**
1	MAT1- Steel	MATL1	7.85e-9	210000	
2	Null Material	MATL9	6.620e-11	210000	
3	Rigid	MATL20	7.85e-9	210000	
4	Rigid Fix	MATL20	7.85e-9	210000	
5	Rigid Fixture 2	MATL20	1.0e-9	210000	
6	340 XF CRS	MATL24	7.85e-9	210000	340.680
7	340 XF HRS	MATL24	7.85e-9	210000	340.680
8	420 XF CRS	MATL24	7.85e-9	210000	420.840
9	420 XF HRS	MATL24	7.85e-9	210000	420.840
10	QSTE 550	MATL24	7.85e-9	210000	512.00
11	Steel_1018	MATL24	7.85e-9	210000	370
12	Foam_Mat	MATL57	6.620e-11	4.5	

VI. TEST SETUP

The test set-up (fig.2) consists of SFAD 2 (Static Force Application Device 2) assembled on seat which represents a child seat on isofix wires such that it rests on cushion foam.

A. Forward Pull

A static pull of 11 kN with overload of 20% is applied at 10° to horizontal along X- axis (Graph1).

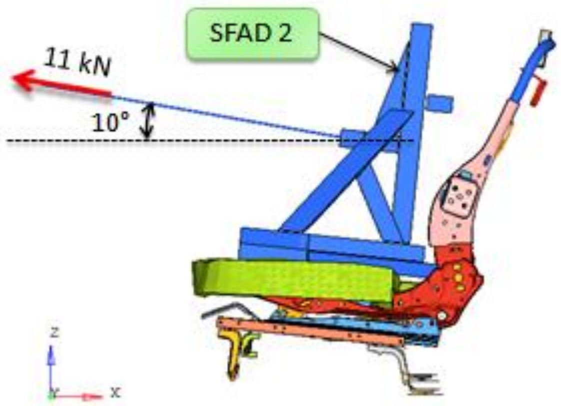
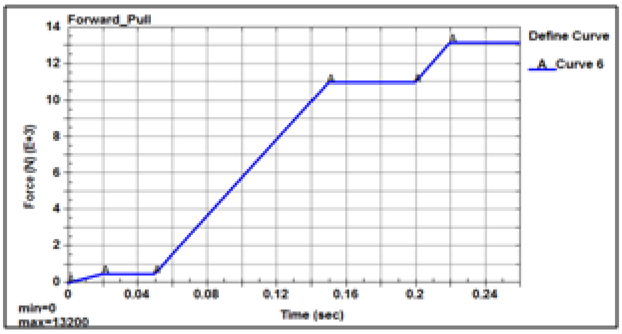


Fig.2 Forward Pull Test Set-up

Test Requirements

- The seat must meet structural integrity criteria.
- The X displacement of load application point must be < 175 mm.



Graph 1. Load Curve for Forward Pull Test

B. Lateral Pull to Left

A static pull of 5 kN with overload of 20% is applied at 75° Left of vertical and in horizontal plane (Graph 2).

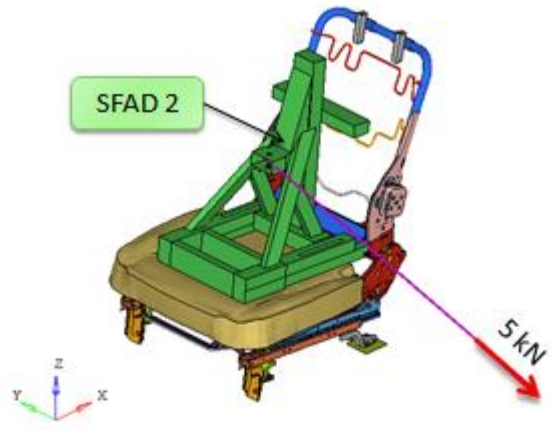
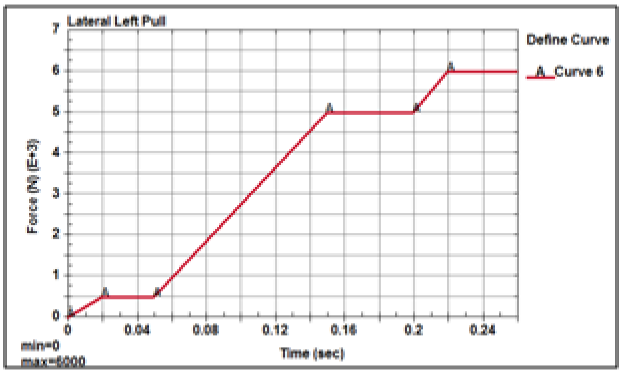


Fig.3 Lateral Left Pull Test Set-up

Test Requirement

- The seat must meet structural integrity criteria.
- The resultant displacement of load application point < 150mm.



Graph 2. Load Curve for Lateral Left Pull

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C. Lateral Pull to Right

A static pull of 5 kN with overload of 20% is applied at 75° Left of vertical and in horizontal plane (Graph 3).

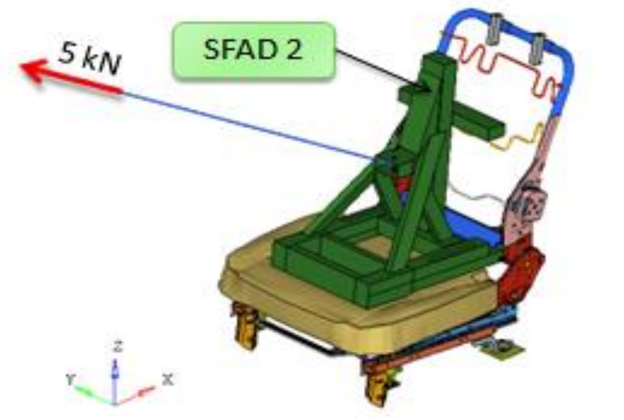
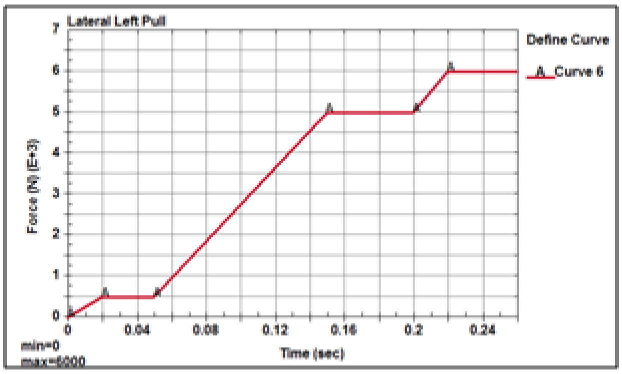


Fig.4 Lateral Right Pull Test Set-up

Test Requirement

- The seat must meet structural integrity criteria.
- The resultant displacement of load application point < 150mm.

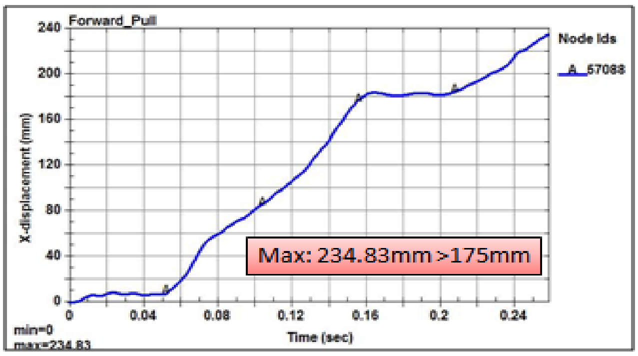


Graph 3. Load Curve for Lateral Right Pull

VII. Baseline Results and Design Modification

i) Forward Pull Test Result

X displacement of load application point vs time is plotted. From the graph 4 it is clear that X displacement of load application point is 234.83 mm > 175 mm.



Graph4. X-displacement of Load Application Point

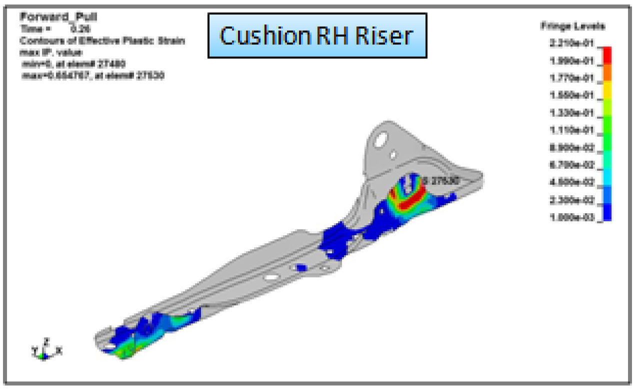


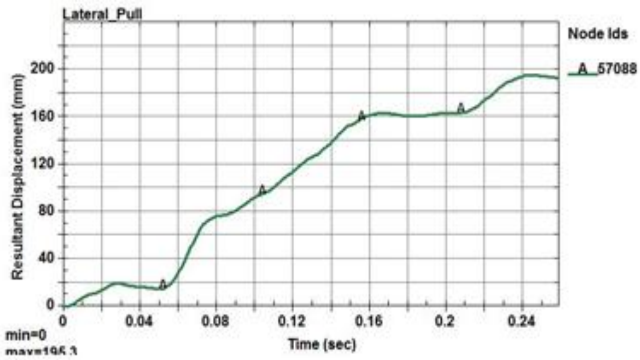
Fig.5 Strain in RH Cushion Riser

Seat does not meet structural integrity criteria as RH Cushion Riser shows strain above allowable limit and can tear off. The X-displacement of seat is 234.83mm hence does not meet displacement criteria of 175mm.

From the above results it is concluded that cushion RH riser need to be strengthen.

ii)Lateral Left Pull Test Result

Resultant displacement of load application point vs time is plotted. From the graph 5, it is clear that resultant displacement of load application point is 195.3 mm.



Graph 5. Resultant Displacement of Load Application Point

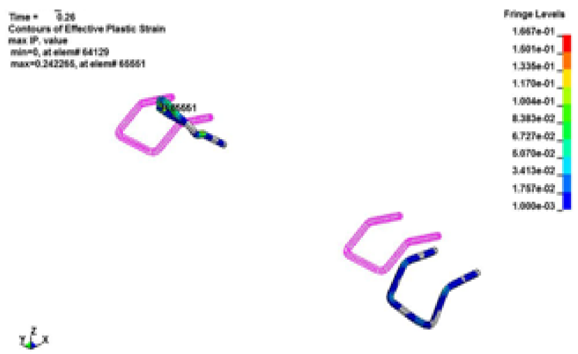


Fig.6 Strain in Isofix Wires

Resultant displacement of load application point is 195.3 mm which is greater than 150 mm. Hence seat does not meet displacement criteria. Isofix wires are failing.

From the above results it is necessary to change the material of isofix wires.

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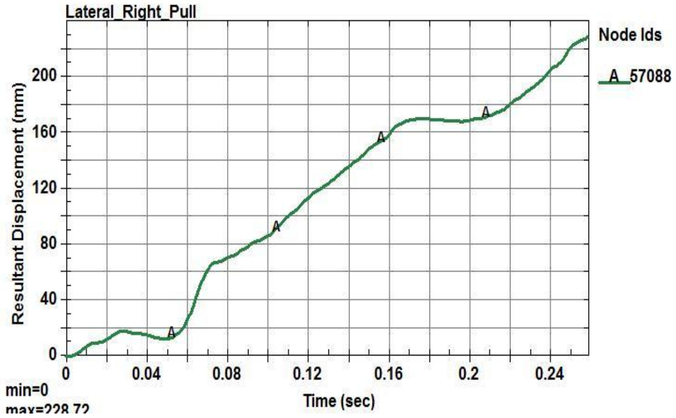
iii)Lateral Right Pull Test Result

Resultant displacement of load application point vs time is plotted. From the graph 6 it is clear that resultant displacement of load application point is 228.72 mm.



Graph 6. Resultant Displacement of Load Application Point

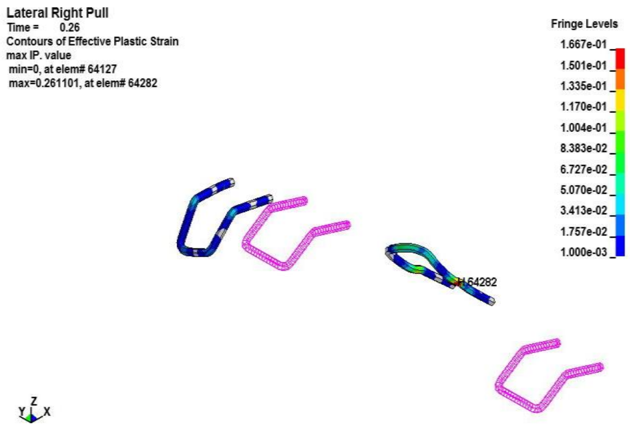


Fig. 7 Strain in Isofix Wires

Seat does not meet structural integrity criteria as isofix wires shows strains above allowable limit and can tear off. The X-displacement of seat is 228.72mm hence does not meet displacement criteria of 150mm. Isofix wires need to be strengthened.

iv)Design Modifications

Baseline seat model is submitted for simulation in LS-DYNA. The result of simulation are shown above which clearly indicates that seat is failing for both requirements. Hence the baseline seat model is not effective for installing child safety restraint system on it. It is required to make suitable design changes and material changes in order to avoid the failure. In first iteration the cross cection of cross member is changed(Fig.8). By doing this modification the X-displacement of load application point is reduced drastically but RH cushion riser is showing failure. In second iteration material of RH cushion riser is changed. In third iteration area at failure lacation is increased (Fig.9). This results in reduction in strain but it is not safe. Hence in fourth iteration reinforcement plate of 2 mm thickness is added at failure location (Fig.10). By adding plate seat is passing for structural integrity criteria but resultant displacement of load application point in lateral right pull is 156.57 mm > 150mm. By viewing the behaviour of seat, strength of backside floor mounting bracket is increased..The thickness is increased from 2.6 to 3.2 mm and material is changed to 420 XF CRS. Now the seat is passing for displacement and structural integrity criteria.

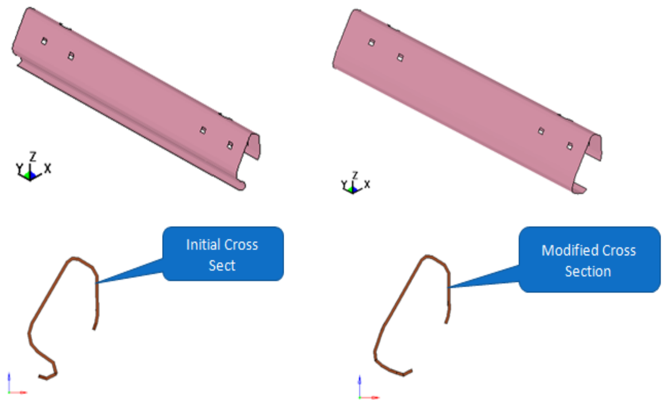


Fig.8 Design Modification in Cross Member

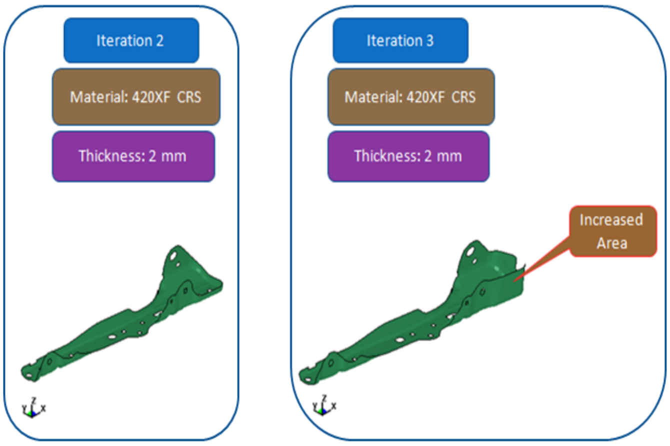


Fig.9 Design Modification in RH Cushion Riser

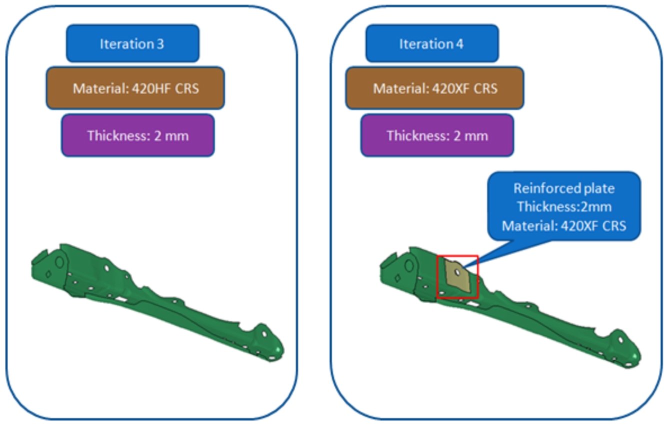


Fig.10 Reinforcement at Failure Location

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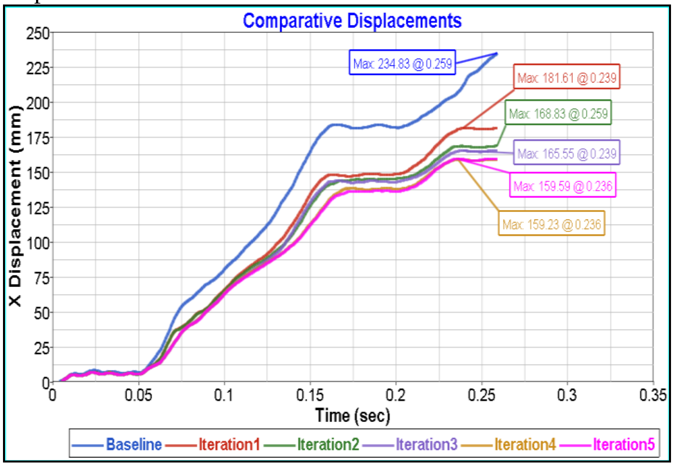
These are the some major design modifications in existing seat model to meet regulation requirements.

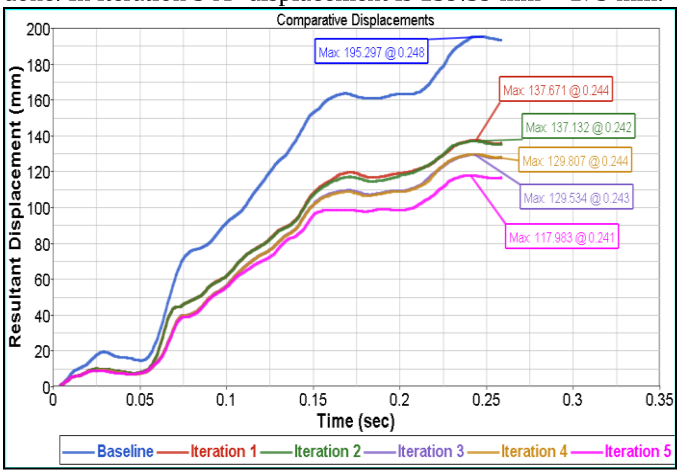
VIII. RESULT SUMMARY

In the following graphs results of all iteration are combined. As the strength of seat model goes on increasing the displacement of seat is reduced.



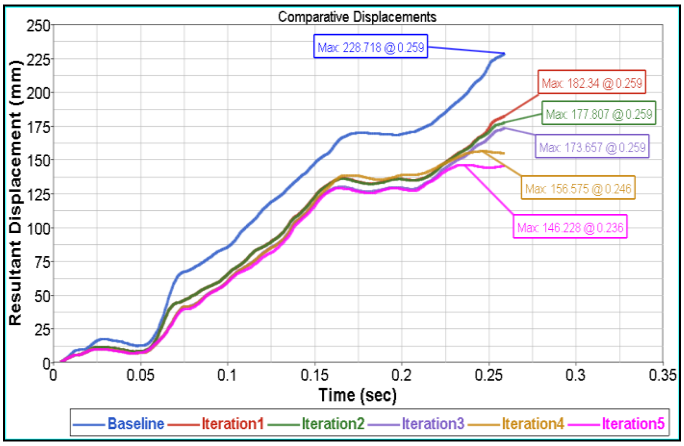
Graph 7. Combined X-displacement in Forward Pull

Graph 7 shows the combined X displacement of load application point vs time plot. From the graph 7 it is clear that X displacement is reduced as the successive iterations are done. In iteration 5 X -displacement is 159.59 mm < 175 mm.



Graph 8. Combined Resultant Displacement in Lateral Left Pull

Graph 8 shows the combined resultant displacement of load application point vs time plot. From the graph 8 it is clear that resultant displacement is reduced as the successive iterations are done. In iteration 5 resultant displacement is 117.98 mm < 150 mm.



Graph 9. Combined Resultant Displacement in Lateral Right Pull

Graph 9 shows the combined resultant displacement of load application point vs time plot. From the graph 9 it is clear that resultant displacement is reduced as the successive iterations are done. In iteration 5 resultant displacement is 146.23 mm < 150 mm.

From the above three graphs it is clear that seat is passing for displacement criteria.

IX. CONCLUSION

Existing seat model (Second row two way captain seat) is evaluated for child safety. Initially seat is failing for displacement as well as structural integrity criteria. Initial displacement of load application point is 234.83 mm and RH cushion riser is badly failing at washer.Various design modifications were suggested such as increasing the area of riser, using high strength material for riser, backside floor mounting bracket or combination of both and providing additional reinforcement plate. X displacement for forward pull is less than 175 mm and resultant displacement for lateral left, lateral right pull is less than 150 mm. Hence seat is passing for displacement criteria. Plastic strain of RH cushion riser and isofix wire is within allowable limit; seat is passing for structural integrity criteria. The seat model is effective for installing child safety restraint system.Final design (Iteration 5) meets FMVSS225 test requirements and is accepted as one of the best solutions meeting customer's needs and expectations.

ACKNOWLEDGMENTS

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