DEVELOPING OF SYSTEM TO EVALUATE SAFETY OF CHILD SEAT AND RESTRAINTS SYSTEM ACCORDING TO ECE R44

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

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Great loads occur on human body in traffic accidents. Children body have less resistance to these loads. Child Restraint Systems (CRS) are the safety elements used in vehicles for children. In this study, the overturning and the dynamic test setups for CRS, have been designed and analysed according to United Nations Economic Commission for Europe Regulation No 44 (ECE R44). After manufacturing of the test setups, four different types of CRSs sold in Turkish market have been selected to evaluate their performance according to ECE R44. Each seat has been used once for the tests. The tests have been performed and evaluated according to the performances of CRSs for the dynamic test head displacement limit criterion, the acceleration limit criterion, the abdominal penetration criterion and the overturning head displacement limit criterion. 11 overturning tests and 8 dynamic tests at the sled test facility available in METU-BILTIR Center Vehicle Safety Unit have been conducted. In the tests, P-series 3 years, 6 years and 10 years old child test dummies have been used. During the dynamic tests, 3-axial accelerometer, high-g high speed camera and data acquisition system are also used to gather the test data. 8 more dynamic test with unlocked vehicle safety belt which is improper usage and commonly encountered in real life. As the result of the tests, none of the CRSs succeed in the tests for child seats which are supposed to be used by 3-6 years old children according to ECE R 44 Group II.

Keywords: Vehicle Safety, ECE R44, Child Restraint System, Overturning Test, Dynamic Test, P-series Child Test Dummy

ÖZ

AEK R44'E GÖRE ÇOCUK KOLTUĞU VE EMNİYET SİSTEMLERİ GÜVENLİĞİ DEĞERLENDİRME SİSTEMİ GELİŞTİRİLMESİ

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Kaza anında insan bedeni üzerinde yüksek yükler oluşur. Çocukların bedeninin direnci bu ivmelere karşı daha zayıftır. Çocuk Kısıtlama Sistemleri (ÇKS) çocuklar için araç içinde kullanılan güvenlik elemanlarıdır. Bu çalışmada, ÇKS devrilme ve dinamik test düzenekleri Birleşmiş Milletler Avrupa Ekonomik Komisyonu 44 numaralı (AEK 44) regülasyonuna göre tasarlanmış ve analiz çalışmaları yapılmıştır. Test düzenekleri üretildikten sonra Türkiye pazardında satılan dört farklı tipte ÇKS performanslarının değerlendirilmesi için seçilmiştir. Her koltuk testlerde bir kez kullanılmıştır. ÇKS'lerin dinamik test kafa deplasman limit kriteri, ivme limit kriteri, karın penetrasyon kriteri ve devrilme testi kafa deplasman limit kriteri performanslarını görmek için testler yapılmıştır. 11 adet devrilme ve 8 adet dinamik test ODTÜ-BİLTİR Merkezi Araç Güvenlik Birimi'nde bulunan hasarsız çarpışma test laborauarında yapılmıştır. Testlerde 3 yaş, 6 yaş ve 10 yaş çocuk test mankeni kullanılmıştır. Dinamik testler için ayrıca 3 yönlü ivme ölçer, yüksek ivmelere dayanıklı hızlı kamera ve veri toplama sistemi test verilerini toplamak için kullanılmıştır. Yanlış ve yaygın kullanım olan kilitlenmemiş araç emniyet kemeri ile 8 ek dinamik test yapılmıştır. Testlerin sonucunda 3-6 yaş için kullanılan ÇKS'lerin hiçbiri AEK R44 Grup II için başarılı olamamıştır.

Anahtar Kelimeler: Taşıt Güvenliği, AEK 44, Çocuk Kısıtlama Sistemleri, Devrilme Testi, Dinamik Test, P-serisi Çocuk Test Mankeni

To My Family

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INTRODUCTION

1.1 Effects of Traffic Accidents and Vehicle Safety

Vehicle safety is one of the most important factor of vehicle design, construction and equipment to minimize the risk of consequences of accidents. Injuries and death rates due to traffic accidents could be reduced by improving infrastructure related to highways, roads and vehicle designs. Nevertheless, auto collisions are the leading cause of injury-related deaths, an estimated total of 1.2 million people are killed every year in road crashes and as many as 50 million are injured [1].

The first vehicle accident reported was about the second steam-powered "Fardier" (artillery tractor), created by Nicolas-Joseph Cugnot in 1771. It was reported by some to have crashed into a wall during its demonstration run [2]. The first road traffic death caused by a motor vehicle is alleged to have occurred on 31 August 1869 and an Irish scientist Mary Ward died when she fell out of her cousins' steam car and was run over by it [3].

Even developments on technology, thousands of people die because of vehicle accidents every year in the World. But fatality rates have been decreased despite the number of vehicles on roads increases steadily. The raw number of accidents always increases as a function of rising population and number of vehicles on the road. Table 1.1 shows the accidents statistics of Turkey according to number of vehicles by years [4].

Table 1.1 Information of Accidents Happened in the Area of General Directorate of Security and General Commander of the Gendarmerie [4]

Accident Statistics			
Year	**Number of Accidents**	**Number of Deaths**	**Number of Injuries**
2000	500.664	5.566	136.406
2001	442.960	4.386	114.202
2002	439.958	4.169	116.045
2003	455.637	3.959	117.551
2004	537.352	4.427	136.437
2005	520.789	4.505	154.086
2006	728.755	4.633	169.080
2007	825.561	5.007	189.057
2008	950.120	4.236	184.468
2009	1.053.346	4.324	201.380
2010	1.104.388	4.045	211.496

Turkey had 5.566 deaths per 500.664 accidents in 2000, 4.045 deaths per 1.104.388 accidents in 2010. Despite the number of accidents have been doubled, the number of deaths are reduced. The number of vehicles are increased steadily from 2000 to 2010 but the rate of fatality decreases. This should be because of new technologies of vehicles which make vehicles safer and obey the regulations and directives.

The government collected traffic data of TUIK, gives the ratios and total fatalities of Turkey between the years 1990 and 2010. As seen in Table 1.2 [5].

In Table 1.3 the data related to other countries together with Turkey are given for 2004 by TUIK [5].

Table 1.2 Data for Safety Performance of Turkey [5]

Years	Total Vehicle	Population	Total Number of Traffic Accidents	Ratio of Accident to Number of Vehicles (‰)	Number of Killed Persons	Ratio of Killed Person to Population (‰)
1990	3.750.678	56.154.000	115.295	31	6.317	0.11
1991	4.101.975	57.272.000	142.145	35	6.231	0.11
1992	4.584.717	58.392.000	171.741	37	6.214	0.11
1993	5.250.622	59.513.000	208.823	40	6.457	0.11
1994	5.606.712	60.637.000	233.803	42	5.942	0.10
1995	5.922.859	61.763.000	279.663	47	6.004	0.10
1996	6.305.707	62.909.000	344.643	55	5.428	0.09
1997	6.863.462	64.064.000	387.533	56	5.125	0.08
1998	7.371.541	65.215.000	458.661	62	6.083	0.09
1999	7.758.511	66.350.000	465.915	60	5.713	0.09
2000	8.320.449	67.420.000	500.664	60	5.510	0.08
2001	8.521.956	68.365.000	442.960	52	4.386	0.06
2002	8.655.170	69.302.000	439.777	51	4.093	0.06
2003	8.903.843	70.231.000	455.637	51	3.946	0.06
2004	10.236.357	71.152.000	537.352	52	4.427	0.06
2005	11.145.826	72.065.000	620.789	56	4.505	0.06
2006	12.227.393	72.974.000	728.755	60	4.633	0.06
2007	13.022.945	70.586.000	825.561	63	5.007	0.07
2008	13.765.395	71.517.000	950.120	69	4.236	0.06
2009	14.316.700	72.561.000	1.053.346	74	4.324	0.06
2010	15.095.603	73.723.000	1.106.201	73	4.045	0.05

Table 1.3 TUIK Data Comparison of Safety Performances of Countries for 2004[5] Continued

Country	Area (km^2)	Population	Number of Traffic Accidents Involving Death and Injury	Ratio of Persons Killed in Accidents to Population (‰)	Ratio of Persons Killed in Accidents to Traffic Accidents (‰)
Malta	316	403.000	15.643	0.03	1
U.K.	242.900	59.834.000	207.410	0.05	16
Germany	357.022	82.501.000	339.310	0.07	17
Austria	83.858	8.207.000	42.657	0.11	21
Slovenia	20.273	1.998.000	12.721	0.14	22
Belgium	30.528	10.446.000	48.670	0.11	24
Italy	301.318	58.462.000	224.553	0.10	25
Sweden	449.964	9.011.000	18.029	0.05	27
Netherlands	41.526	16.255.000	27.760	0.05	29
Portugal	91.982	10.529.000	38.930	0.11	29
Norway	323.758	4.577.000	8.425	0.06	31
Spain	505.992	43.198.000	94.009	0.11	50
Czech Republic	78.866	10.221.000	26.516	0.14	52
Finland	338.145	5.237.000	6.767	0.07	55
Cyprus	9.251	749.000	2.080	0.16	56
Turkey	774.815	71.152.000	77.008	0.06	57
Denmark	43.094	5.411.000	6.209	0.07	59
France	551.500	60.340.000	85.396	0.09	61
Hungary	93.030	10.098.000	20.957	0.13	62
Ireland	70.273	4.044.000	5.781	0.09	65

Table 1.3 TUIK Data Comparison of Safety Performances of Countries for 2004[5]

Country	Area (km^2)	Population	Number of Traffic Accidents Involving Death and Injury	Ratio of Persons Killed in Accidents to Population (‰)	Ratio of Persons Killed in Accidents to Traffic Accidents (‰)
Luxembourg	2.586	455.000	692	0.11	71
Slovakia	49.036	5.385.000	8.443	0.11	71
Estonia	45.227	1.348.000	2.244	0.13	76
Latvia	64.589	2.306.000	5.081	0.22	102
Greece	131.957	11.062.000	15.547	0.15	107
Poland	312.685	38.174.000	51.069	0.15	112
Lithuania	65.300	3.425.000	6.357	0.22	118
Bulgaria	110.994	7.761.000	7.612	0.12	124
Romania	238.391	21.700.000	6.860	0.11	352

About 85% of all global road deaths, 90% of the disability-adjusted life years lost due to crashes, and 96% of all children killed worldwide as a result of road traffic injuries occur in low-income and middle-income countries. Among both children aged 5–14 years, and young people aged 15–29 years, road traffic injuries are the second-leading cause of death worldwide [1].

Human body is not capable of absorbing such energies occurred in the event of crashes and many injuries or deaths happen. With the experiences of those events, modern vehicles come with safety features to protect occupants and pedestrians in the event of a crash. There are also safety systems that prevent crashes in the first place and to protect occupants. These safety features are divided into two categories namely; active safety and passive safety. Vehicle safety system configurations are shown in Figure 1.1 [6].

Figure 1.1 Vehicle Safety System Configuration [6]

1.2 Active and Passive Safety

Active safety refers to safety systems that help avoid accidents, such as good steering and brakes. Passive safety refers to features that help reduce the effects of an accident, such as using of seat belts, airbags and strong body structures of a vehicle. Terms "active" and "passive" safety mainly are used in USA. In the UK "active" and "passive" safety are used in terms of "primary" and "secondary" safety, respectively. However, active safety is increasingly being used to describe systems that use an understanding of the state of the vehicle to both avoid and minimize the effects of a crash. These include braking systems, like brake assist, traction control systems and electronic stability control systems, that interpret signals from various sensors to help the driver control the vehicle. Additionally, sensor-based systems such as "Advanced Driver Assistance Systems" including adaptive cruise control and collision warning/avoidance/mitigation systems are also considered as active safety systems under this definition [7]. Passive safety term is used for the systems that prevent occupant to be injured or dead during event of a crash. Seat belts, airbags are examples of passive safety features. Active safety and passive safety systems evolution with respect to years are shown in Figure 1.2.

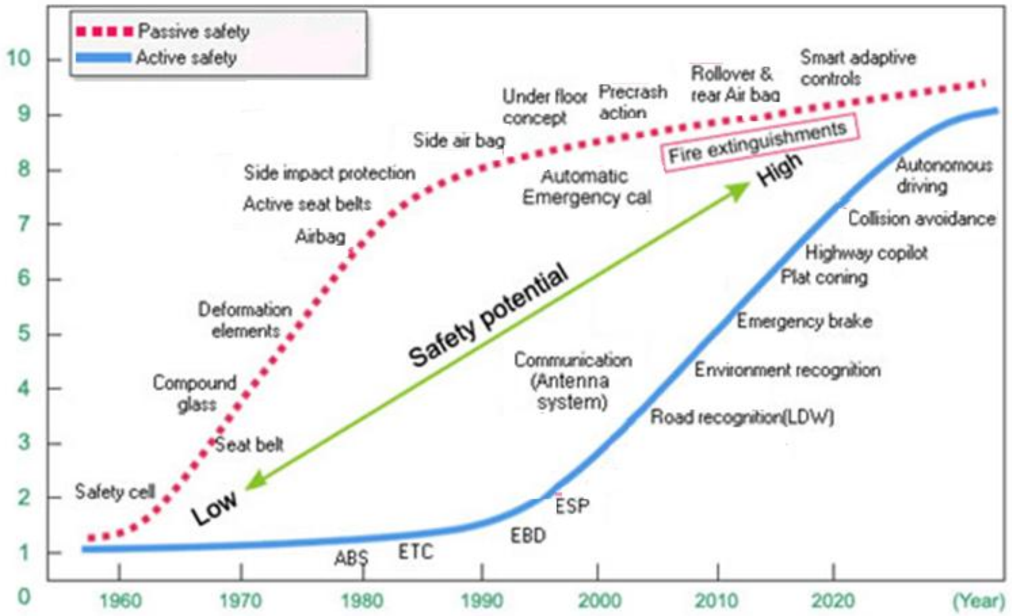


Figure 1.2 Active Safety and Passive Safety Systems [6]

1.2.1 Active Safety Systems

Active safety systems are crash avoidance systems and devices that help the driver to avoid a collision. This category includes:

- Anti-lock braking systems to prevent or reduce the severity of collision.
- Infrared night vision systems to increase seeing distance beyond headlamp range
- Adaptive high beam which automatically and continuously adapts the headlamp range to the distance of vehicles ahead or which are oncoming
- Reverse backup sensors, which alert drivers to difficult-to-see objects in their path when reversing

- Adaptive cruise control which maintains a safe distance from the vehicle in front
- Lane departure warning systems to alert the driver of an unintended departure from the intended lane of travel
- Traction control systems which restore traction if driven wheels begin to spin
- Electronic stability control, which intervenes to prevent an impending loss of control

There are many other technologies invented and being invented. Technologies above are some of these technologies.

1.2.2 Passive Safety Systems

Crashworthy systems in vehicles are designed to prevent or reduce the risk of injuries on the instant of when crash is happening. Researches on this area are performed generally by using crash test dummies. Some of the passive safety system applications are given as follows:

- Seatbelts limit the forward motion of an occupant, stretch to slow down the occupant's deceleration in a crash, and prevent occupants being ejected from the vehicle.
- Airbags inflate to cushion the impact of a vehicle occupant with various parts of the vehicle's interior.
- The laminated windshields remain in one piece when impacted, preventing penetration of unbelted occupants' heads and maintaining a minimal but adequate transparency for control of the car immediately following a collision. The tempered glass side and rear windows break into granules with minimally sharp edges, rather than splintering into granular fragments as ordinary glass does.
- Crumple zones absorb and dissipate the force of a collision, displacing and diverting it away from the passenger compartment and reducing the impact

force on the vehicle occupants. Vehicles will include a front, rear and maybe side crumple zones too.

- Side impact protection beams.
- Collapsible universally jointed steering columns, (with the steering system mounted behind the front axle - not in the front crumple zone), reduce the risk and severity of driver impalement on the column in a frontal crash.
- Pedestrian protection systems.
- Filling material of the instrument panel and other interior parts of the vehicle likely to be struck by the occupants during a crash.

To reduce the number of deaths and injuries on children, it is needed to develop new safety systems such as child seats and components [1]. But only producing new safety systems is not the end of the things which has to be done, they also have to be tested for their performances.

1.3 Crash Test Norms

In vehicle design Computer Aided Engineering (CAE) softwares are used for crash simulations widely. But it has to be supported with the real crash tests and/or sled tests for design verifications. For this purpose globally approved and detailed crash test norms have been prepared by the national and international bodies.

There are a number of crash test programs dedicated to provide consumers with a source of comparitative information in relation to the safety performance of new and used vehicles. Examples of new car crash test programs include National Highway Traffic Safety Administration's (NHTSA) NCAP (USA), the Insurance Institute for Highway Safety (IIHS, USA), ANCAP (Australia), Euro NCAP (EU) and Jap NCAP (Japan). The programs such as the Used Car Safety Ratings provide consumers information on the safety performance of vehicles based on real world crash data.

With the aim of reducing fatalities in the world, NHTSA has issued relatively few regulations since the middle of 1980s; most of the vehicle-based reduction in vehicle fatality rates in the USA during the last third of the 20th Century were gained by the initial NHTSA safety standards issued from 1968 to 1984 and subsequent voluntary changes in vehicle design and construction by vehicle manufacturers.

United Nations Economic Commission for Europe has signed the 1958 Geneva agreement Concerning the Adoption of Uniform Conditions of Approval and Reciprocal Recognition of Approval for Motor Vehicle Equipments and Parts. According to this agreement 126 regulations has published for vehicle parts and technical units. The aim of these regulations is to create standardization and specify a lower limit on vehicle parts and their quality.

Crash test systems are necessary to develop road vehicles more and more safer. Developing more safer cars by crash tests are done by the guidance of regulations, safety standards and directives. Normative documents play an effective role on improving safety of automobiles. These entire tests are applied according to the specifications of the normative documents. Some test centres obey the regulations which are developed by commissions and some other may develop their own regulations. But commonly used regulations are European Directives, United Nations Economic Commission for Europe (UNECE) Regulations, Federal Motor Vehicle Safety Standards (FMVSS) and European New Car Assessment Programme (Euro NCAP) Protocols. Under these norms most parts of vehicles are tested in appropriate ways.

Some of the examples of static and dynamic tests described in the norms are given in the following subsections.

1.3.1 Frontal-Impact Test

These tests are performed usually upon a solid concrete wall with a speed related to regulations. And also these tests could be performed by vehicle to vehicle. In Figure 1.3 the frontal impact test according to Euro NCAP Frontal Impact Testing Protocol [9] is schematically shown:

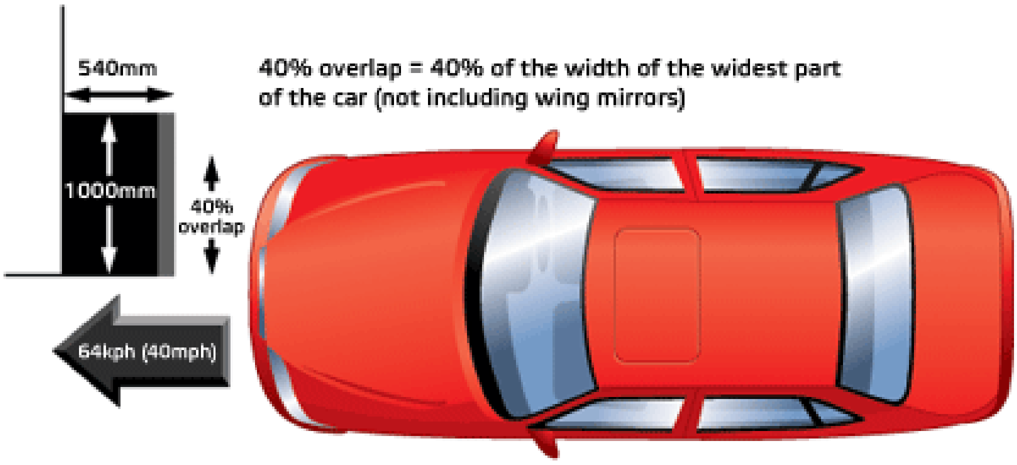


Figure 1.3 Frontal Impact Test [9]

1.3.2 Offset Test

Only part of the front of the car impacts with a barrier or vehicle. These are important, as impact forces remain the same as with a frontal impact test, but a smaller fraction of the car is required to absorb all of the force. These tests are often realized by cars turning into oncoming traffic. This type of testing is done by the IIHS and Euro NCAP [10].

1.3.3 Side Impact Test

Vehicle body is weak to absorb side impact forces and that side impacts have a very significant roles for fatality. Euro NCAP or UNECE Regulation No 95 (ECE R95) describes side impact tests for vehicles. This test according to the Euro NCAP Side Impact Testing Protocol is schematically shown in Figure 1.4 [11, 12].

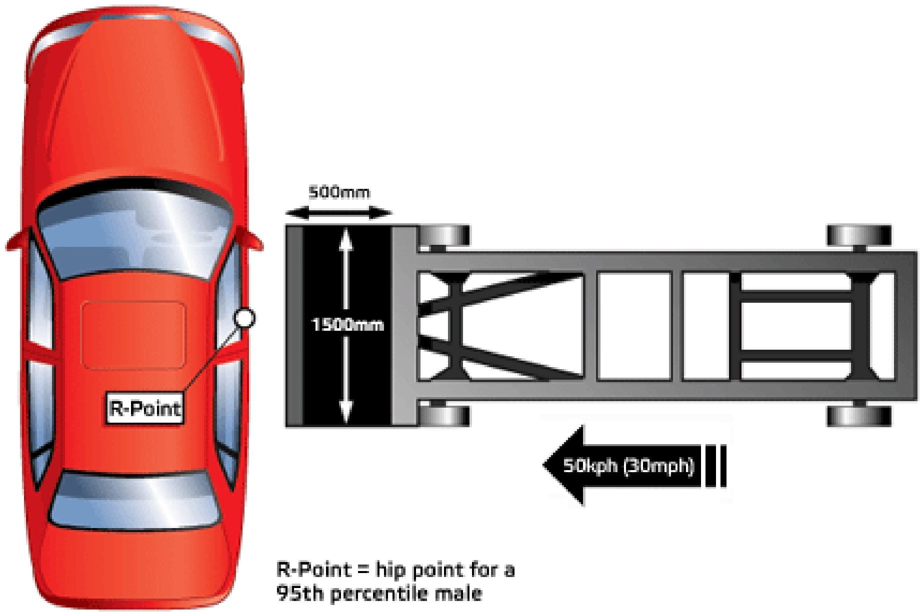


Figure 1.4 Side Impact Test [9]

1.3.4 Roll-Over Test

Roll-Over tests defines a car's ability, specifically the pillars holding the roof, to support itself in a dynamic impact. The test according to the UNECE Regulation No 66 (ECE R66) is a typical roll over vehicle test [13].

1.3.5 Dynamic Seat Belt Test

Dynamic seat belt tests are performed on sleds. Sleds are capable of reaching high g values in small time intervals. The test according to the UNECE Regulation No 16 (ECE R16) is one of the regulations for dynamic seat belt tests [14].

1.3.6 Static Seat Belt Test

The demanded test forces are fixed quasi statically using generally hydraulic cylinders at the belt and the seats to test the resistance of the seat structure as well as the belt anchorage for the forces occurring at a crash. UNECE Regulation No 14

(ECE R14) [15] is an example for the static test norms. In these tests, high forces are applied to the seatbelts over loading devices. All components of the systems, namely seats, seat and belt anchorages have to resist the defined loads without damage. The loads are applied slowly and are sustained over a long period of time, so one can assume a quasi static test [16].

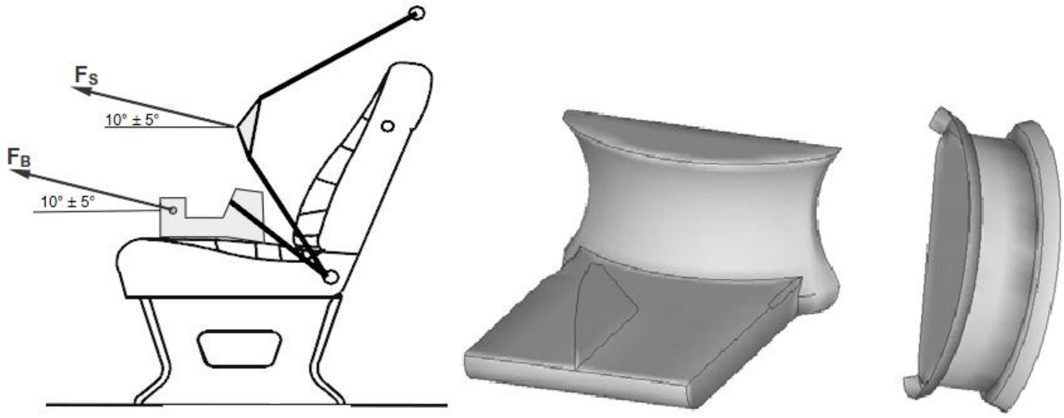


Figure 1.5 Static Seat Belt Test and Body Blocks used in Test[16]

1.3.7 Child Restraint System Test

Child's anatomy is weaker than adult's anatomy. The differences of the body surface and muscle structure changes the distrubition of the energy ocuured in event of an impact. Control of the muscles is developed less than an adult. Any kind of damage may cause more injuries on child bodies. On the other hand locations of the standart seat belts and seats in vehicles are generally designed according to adult's sizes. On this basis, child occupants has less resistant to impacts in vehicles. Child occupants' bodies should be protected with additional external safety equipment. The first safety equipment, for vehicles is a Child Restraint System (CRS). As with any part of vehicle, child restraint systems in this respect shall be subjected to the tests.

CRS tests are performed according to defined acceleration corridors in UNECE Regulation No 44 (ECE R44) [17] and FMVSS 213. Desired anchorage points, test seat structure and acceleration limits are specified in this regulations.

1.4 Crash Test Simulation on the Sled Test Facility

Real crash tests are expensive experiments. And there is no option to repeat the test again. Because of this, repeatable sled tests are performed before real crash tests. The sled tests should be performed very carefully and data collection must be done correctly. For data collection during the test, crash test dummies, high-g cameras, accelerometers and high-speed data-acquisition systems etc. are used. By the help of these systems the maximum amount of data are obtained from each test. In the following subsections important equipments used in sled test facility will be presented used in crash tests.

1.4.1 Catapult

Implementation of the simulation results in the development of the prototype, optimum interaction between all components of the restraint systems is tested with the help of vehicle crash tests. Those tests may be performed on a catapult rig or other testing systems according to the needs. The Hydropuls Crash Simulation Rig which has been established in METU-BILTIR Center Vehicle Safety Unit Sled Test Facility, Ankara takes an important role in the development of restraint systems and their components, in Turkey. Sled Test Facility in METU-BILTIR Center is shown in Figure 1.6. Properties of the catapult system are given in Table 1.4.

Figure 1.6 Sled Test Facility in METU-BILTIR Center

Table 1.4 Properties of the Catapult System in METU-BILTIR Center [18]

Acceleration force	2500 kN
Working stroke	1700 mm
Payload	2500 kg
Acceleration	90 g
Velocity	90 km/h
Tolerance on maximum speed	+/- 0,5 km/h
Repeatability (Acceleration)	± 1 g
Repeatability (Velocity)	± 0,5 km/h

1.4.2 Crash Test Dummy

Test dummies are full-scale anthropomorphic test devices (ATD) that simulate the dimensions, weight proportions and articulation of the human body, and are usually instrumented to record data about the dynamic behaviour of the ATD in simulated vehicle impacts [19]. This data can include numerous variables. Commonly used variables are velocity of impact, crushing force, bending, folding or torque of the body and acceleration/deceleration rates during a collision for use in crash tests. Crash test dummies remain indispensable in the development of all types of vehicles, from automobiles to aircraft.

Crash test dummies are divided mainly into two groups such as ballast dummies and dummies with the sensors. Ballast dummies are non-sensored dummies and they only simulates occupant's movements in the event of a crash. They are not capable of sending data but they give true physical reactions during tests. The sensored dummies are fully instrumented ATDs. Crash test dummy is a calibrated test instrument used to measure human injury potential in vehicle crashes with help of instruments used on the ATDs.

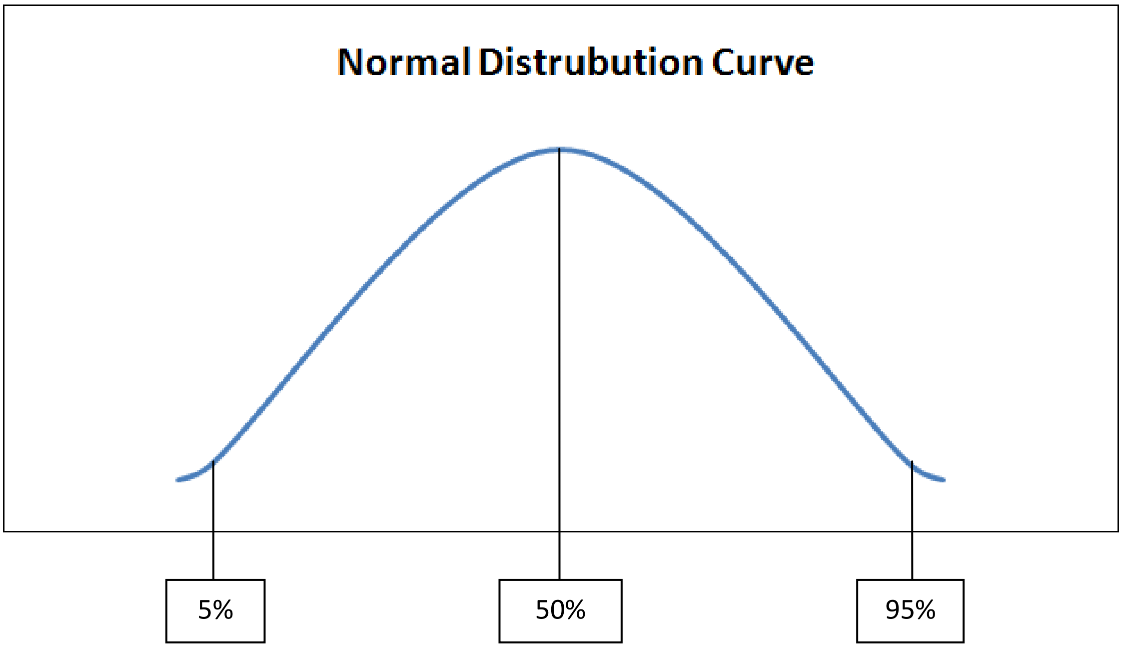


Figure 1.7 Normal Distrubution Curve of the Human Body Size

Crash test dummies do not have standard of weights and sizes. For adult ATDs they are categorized into three groups according to their weights and sizes. As shown in the Figure 1.7 they are divided into three body groups. They are %5 percentile, %50 percentile and %95 percentile dummies. These three types of dummies may be ballast or instrumented types either. For child occupants, child dummies are categorized into 5 different ages. It starts with a newborn child test dummy, 9 months old , 3 years old, 6 years old and 10 years old child test dummys alternately. In P-Dummy's manufactured by Humanetics ATD, child test dummys can be instrumented only for their chest accelerations. A three axial accelerometer can be used for the child dummies. However, new generation of child dummies (i.e. Q-dummies) are instrumented. In Figure 1.8 crash test dummies of different sizes are shown.

Figure 1.8 Crash Test Dummies

1.4.3 Sensors Used in Crash Test Dummies

In tests, several sensors such as accelerometers, loadcells etc. are required. The device which measures the proper acceleration is called accelerometer. There are kinds of models, such as single- and multi-axis. It is available to detect the direction and magnitude of acceleration.

An accelerometer measures proper acceleration, which is the acceleration that experiences relative to freefall and is the acceleration felt by people and objects. At any point in space time the equivalence principle guarantees the existence of a local inertial frame, and an accelerometer measures the acceleration relative to that frame [20]. Acceleration is quantified in the SI unit metres per second per second (m/s^2) or popularly in terms of g-force (g).

Inside the dummy, there are load sensors that measure the amount of force on different body parts during a crash. Movement sensors are used in the dummy's chest. They measure how much the chest deflects during a crash.

1.4.4 High-Speed Data-Acquisition

Data from sensors and high speed camera system can be collected by a high speed data acquisition system. High-speed data acquisition systems commonly have multiple channels for real-time signal data recorders. All systems works with software for performing all system settings, viewing digital data (either captured or generated), performing signal recordings. In Figure 1.9 Minidau high speed data acquisition system is shown.

Figure 1.9 Minidau Advanced with 32 Channels

1.4.5 High-Speed Cameras

Crash tests are rapid events and occur very quick that human eye cannot detect it properly. Even it is possible to measure most of parameters in many situations but following the case visually is often very important to get additional information. Thus high speed cameras are very important instruments for recording the case for data collection. High speed cameras and video systems are used worldwide in demanding environments where accurate high speed recordings should be taken. On the other hand if the high speed cameras are mounted on the sled, high-g acceleration is applied to the high speed cameras as well. In this case, these high speed cameras must be high-g cameras which withstand to the high-g acceleration loadings.

Figure 1.10 High-g High Speed Camera

In crash tests, high speed cameras can record the details of impacts and provide in-depth visual insights into events that happen during crashes. Crash tests take only a few hundred milliseconds. This means that it only takes milliseconds from the first contact until the structure comes to complete standstill. In order to make this short event visible and investigatable for the engineers it is necessary to use high speed cameras. In Figure 1.10 high-g high speed camera is shown. These cameras can take 1000 or more pictures per second (this is very fast compared to a standard video camera that only takes 25 pictures per second) [21].

1.4.6 Lighting

For crash testing facilities lighting system plays an important role. The frame rates in crash testing often exceed 1000 fps and it is important to have a lighting system that has an extremely constant intensity. METU-BILTIR Center Vehicle Safety Unit Sled Test Facility has 12 crane motioned lighting system. The lighting system has an average of 150.000 Lux illumination.

1.5 Scope of Thesis

By the years vehicle safety has become one of the most impotant factors of vehicle designs. The child restraint systems improve the child's resistant in the event of a crash. Because of this, the child restraint systems must satisfy the minimum requirements defined by UNECE Regulation No 44 (ECE R44) [17]. To observe the performances of CRSs, the tests must be performed according to ECE R44. For performing ECE R44 tests, specially designed dynamic test setup and overturning test setup are required.

In this thesis, to test CRSs the dynamic test setup and the overturning test setup will be designed and manufactured and tests according to ECE R44 will be performed. The tests will be performed for a some of the CRSs sold in the market. For understanding the performance of the child restraint systems available in the market, benchmarking study according to overturning and dynamic tests will be carried out for these different brand child seats which are used in vehicles.

In Chapter 2, United Nations Economic Comissions for Europe Regulation 44 will be explained. The requirements of ECE R44 will be specified. These requirements will affect the design parameters for the test setups.

In Chapter 3, design of the dynamic test setup and the overturning test setup will be presented with design parameters according to ECE R44. The dynamic test setup will be compatible for the frontal and the rear impact dynamic tests. For the overturning test, a setup which allows rotation of the CRS in a range of 0^0-360^0 will be designed.

Finite element analysis provides good estimations about the real applications. In Chapter 4, analysis of those test setups will be examined.

In Chapter 5, overturning and dynamic tests will be presented. The test data obtained from overturning tests and dynamic tests and their assesments according to ECE R44 wil be presented in this chapter. The behavior of the CRSs in dynamic and overturning tests according to ECE R44 will be discussed.

Finally, in Chapter 6, conclusion and suggestions for the future work will be given.

CHAPTER 2

CHILD RESTRAINT SYSTEM TESTING ACCORDING TO UNECE VEHICLE REGULATION 44

A vehicle’s seating system is perhaps the most important component because of its constant use by the occupants and its role in the overall crash protection provided to the occupants. There are numerous tests required to demonstrate the performance of the vehicle parts such as seat, seat belt anchorages etc.

2.1 Definitions of Seat Components

In the following sections firstly components of standard seats which are designed for adults, secondly the components of Child Restraint Systems (CRS) will be discussed.

Most vehicle seats are made of inexpensive but durable material in order to withstand as much use as possible. The most important component of the seat is its frame. Frame is the structural element which determines its physical properties such as weight, strength, and dimensions.

Seat belt is a passive safety element which is a harness designed to protect the occupants in the vehicle against high decelerations and its resultant effects such as collisions or sudden stops. Automobile passive safety systems are designed to reduce the risk of injuries during the instant of crash. Seat belt's duty is to prevent occupants from hitting to interior fittings of the vehicle and to hold occupants in the right position for the airbag deploy. In addition to these, seat belts absorb energy during sudden decelerations and provide less speed differences between vehicle and occupants.

There are different types of seat belts:

• Lap Belt: This is also known as 2-point belt. Lap belt is an adjustable strap which goes over the waist and has two points to connect the vehicle as seen in Figure 2.1.

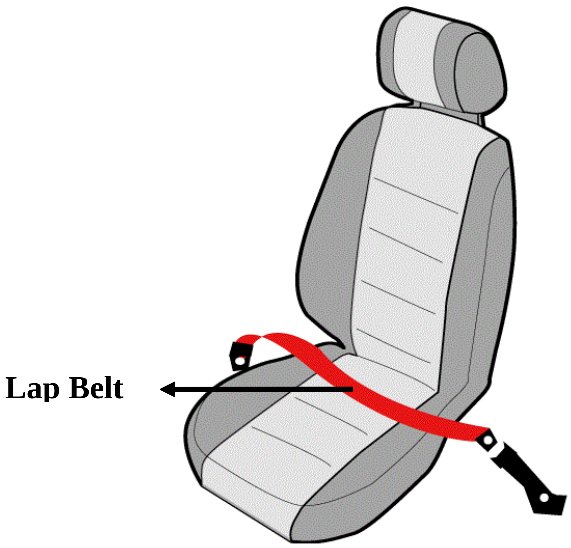


Figure 2.1 Lap Belt [22]

• 3-Point Belt: It has one single continuous belt shown in Figure 2.2 which is composed of sash and lap belt. Sash belt is the part of seat belt which goes over the shoulder.

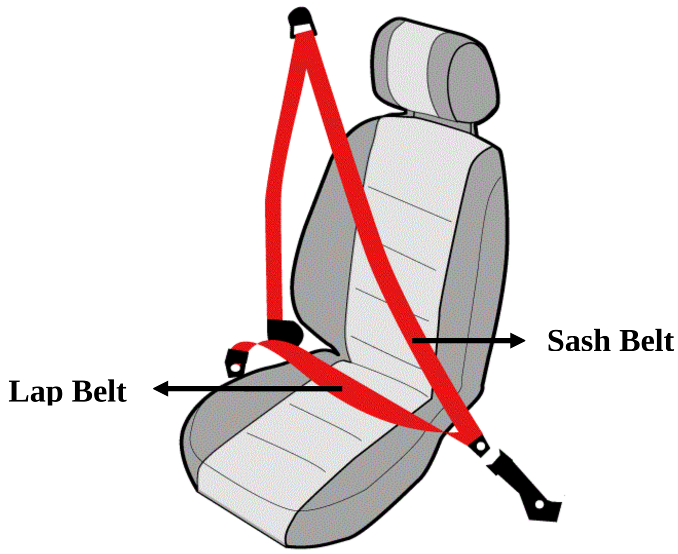


Figure 2.2 3-Point Belt [22]

There are also multiple point seat belts such as five point, six point, seven point harnesses.

Webbing is the fabric belt and generally black and woven from thousands of strands of polyester. It is designed to elongate by 10% to 15% in an accident to absorb energy. Webbing must be in good condition, damaged or broken strands weaken webbing, just like any piece of cloth. Webbing is generally about 50mm wide, wider webbing is used on some special applications and race/rally harnesses.

Retractor is designed to stow webbing when it is not in use and to lock it in sudden change of acceleration.

Adjuster means seat belt can be adjusted appropriately to human morphology and addition to this ability used to remove the slack of the belt. Adjusters generally exist at the top part of tongue connectors.

Tongue is male connector which joins with the buckle when connecting the seat belt to the anchorages. Tongue gets into the female connector which is generally located near the hip of the seat. Tongue with adjuster is shown in Figure 2.3.

Figure 2.3 Tongue with Adjuster

Stalk or cable is used between the buckle and the anchorage points to connect buckle with seat anchorages. Another duty of stalk is to position the buckle. Buckle with stalk is shown in Figure 2.4.

Figure 2.4 Buckle with Stalk

Anchorage points of seat belts are attached to the vehicle. Anchorage points are fabricated by manufacturer to absorb the loads during the accident.

These parts explained above are used to secure the passengers in a vehicle. And they also used for securing the CRSs. In the following subsections CRS types and safety tests will be explained.

2.2 Child Restraint System

CRSs are seats designed specifically to protect children from injury or death during collisions. CRS is an arrangement of components which may include the combination of straps or flexible components with a securing buckle, adjusting devices, attachments and in some cases a supplementary device as a carry-cot, infant carrier and/or an impact shield, capable of being anchored to a power-driven vehicle. It is so designed as to reduce the risk of injury to the wearer, in the event of a collision or of an unexpected deceleration of the vehicle, by limiting the mobility of the wearer's body.

The carry cot is designed to distribute the restraining forces over the child's head and body excluding its limbs in the event of a collision Infant carrier is a restraint system intended to accommodate the child in a rearward-facing semi-recumbent position. The impact Shield is a device used for securing the child and designed to distribute the restraining forces over the greater part of the height of the child's body in the event of a frontal impact. Figure 2.5 shows carry cot and impact shield.

Figure 2.5 Carry Cot and Impact Shield

CRS’s are divided into 5 groups according to the mass of infant. The main reason is to protect children in an appropriate way according to their body sizes. Group 0 is an appropriate CRS type for children of a mass less than 10 kg, for children who is less than 13 kg shall use Group 0+ type CRS, between 9 kg and 18 kg children shall use Group I type CRS, Group II is suitable for 15 kg to 25 kg and between 22 kg and 36 kg the appropriate CRS type is Croup III.

Attaching the CRS is the most important factor of children safety. Because the CRSs are external components for vehicles. They should be secured to the vehicle with the most safety way. For this purpose generally vehicle’s adult safety belts are used. But on some CRSs specially designed securing elements, named ISOFIX systems, are being used.

ISOFIX is the international standard for attachment points for child safety seats in passenger cars. The system has various other regional names including "Lower Anchors and Tethers for Children (LATCH)" in the United States and "Lower Universal Anchorage System (LUAS)" or "CANFIX" in Canada [23]. It has also been called the "Universal Child Safety Seat System (UCSSS)". ISOFIX is a system for the connection of child restraint systems to vehicles which has two rigid vehicle anchorages, two corresponding rigid attachments on the child restraint system and a mean to limit the pitch rotation of the child restraint system. ISOFIX mechanism can be seen in Figure 2.6. Part 1 is the locking mechanism of the child seat. Part 2 is the clearance of the vehicle seat for ISOFIX fixation. Part 3 is the rigid vehicle anchorages for ISOFIX.

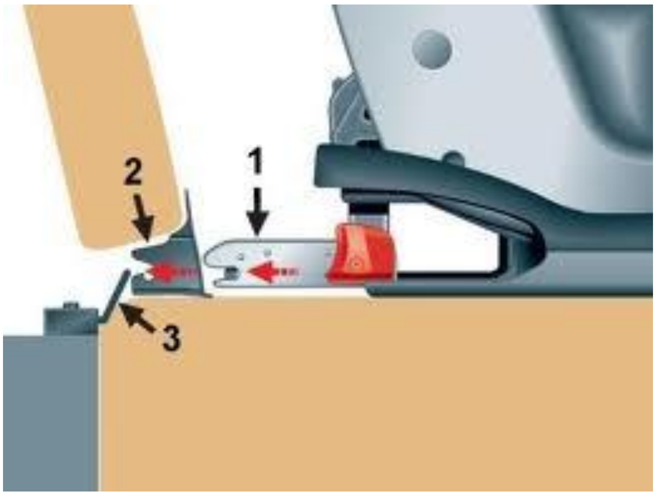


Figure 2.6 ISOFIX Attachment

2.3 Child Dummies

In the following subsection CRS overturning and dynamics tests will be explained. As explained in previous subsection 2.2, CRSs have different groups for appropriate child body sizes. To test the CRSs properly five different specially designed test dummies are generated. They are new born dummy, ¾ years old dummy, 3 years old dummy, 6 years old dummy and 10 years old dummy. For overturning and crash tests, dummy weights are one of the most important factors. Because of this the dummies' weights are specified according to that age's average. New born dummy is 3.4 kg, ¾ years old dummy is 9 kg, 3 years old dummy is 15 kg, 6 years old dummy is 22 kg and 10 years old dummy is 32 kg.

In the overturning and dynamic tests suitable test dummies should be used according to CRS type. Child restraint systems should be tested with appropriate dummies given in Table 2.1.

Table 2.1 Appropriate Crash Test Dummies According to the CRS Type

CRS Type	Crash Test Dummies			
Group 0	Newborn	¾ years old		
Group 0^+	Newborn	¾ years old		
Group I	¾ years old	3 years old		
Group II	3 years old	6 years old		
Group III	6 years old	10 years old		
Group I, II	¾ years old	3 years old	6 years old	
Group II, III	3 years old	6 years old	10 years old	
Group I, II, III	¾ years old	3 years old	6 years old	10 years old

2.4 United Nations Economic Commission for Europe Regulation R 44

United Nations Economic Commission for Europe Regulation R 44 (UNECE R44) [17] regulation is applied to the child restraint systems which are suitable for installation in power-driven vehicles having three or more wheels, and which are not intended for use with folding (tip-up) or with side-facing seats. The main test procedures related to this thesis study are the overturning and dynamic child restraint system tests of ECE R44 [17].

2.4.1 Overturning Test Procedure

In ECE R44 [17] the aim of the overturning tests for child restraint systems is as "the child test dummy shall not fall out of the device and, when the test seat is in the upside down, position of the child test dummy's head shall not move more than 300 mm from its original position in a vertical direction relative to the test seat."

In the overturning test, the restraint shall be fastened to the specially designed "test seat" or vehicle seat. The whole seat shall be rotated around a horizontal axis of the seat through an angle of 360° at a speed of 2-5 degrees/second. Test seat should rotate over X-axis and Y-axis according to vehicle coordinate system and rotation axes are shown in Figure 2.7 and Figure 2.8, respectively.

Figure 2.7 Rotation over X-Axis

Figure 2.8 Rotation over Y-Axis

This test shall be performed again rotating in the reverse direction after having replaced, if necessary, the child test dummy in its initial position. With the rotational axis in the horizontal plane and at 90° to that of the two earlier tests, the procedure shall be repeated in the two directions of rotation. These tests shall be carried out using both the smallest and the largest appropriate child test dummy of the group or groups for which the restraining device is intended.

2.4.2 Dynamic Test Procedure

In ECE R44 [17], the dynamic test can be performed on the sled test facility. The acceleration test device dynamic test procedure is explained below for dynamic tests. For frontal impact, the sled shall be so propelled that, during the test, its total velocity change ΔV is 50 - 52 km/h and its acceleration curve is given between the high-g and low-g acceleration area of the graph given below, and stay above the segment defined by the coordinates (5g, 10ms) and (9g, 20ms). The graphical representation of the frontal impact g-corridor is given in Figure 2.9.

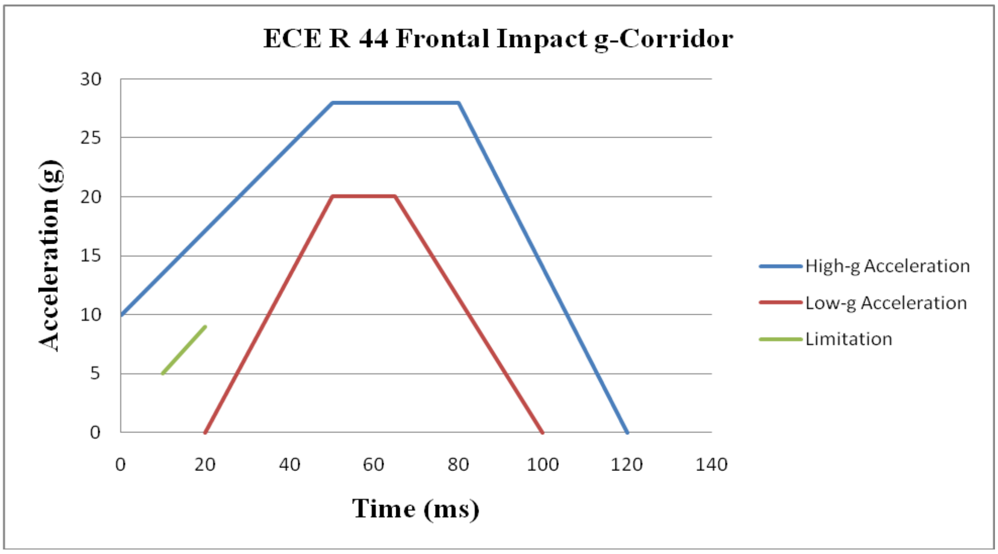


Figure 2.9 Acceleration Corridor of Frontal Impact

For rear impact, the sled shall be so propelled that, during the test, its total velocity change ΔV is 30 - 32 km/h and its acceleration curve is within the hatched area of the graph given below and stay above the segment defined by the coordinates (5g, 5ms) and (10g, 10ms). The graphical representation of the rear impact g-corridor is given in Figure 2.10.

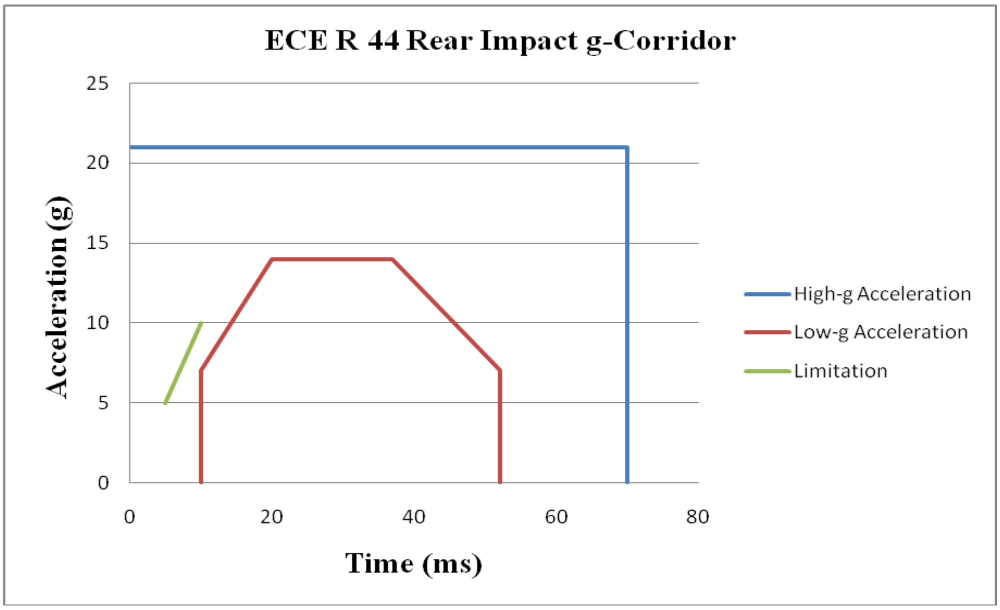


Figure 2.10 Acceleration Corridor of Rear Impact

According to the ECE R44 [17], if the dynamic tests are performed at a higher speed and/or the acceleration curve has exceeded the upper level of the given area and the child restraint meets the requirements, then the test shall be considered as satisfactory.

CHAPTER 3

DESIGN OF TEST STRUCTURES FOR OVERTURNING TESTS AND DYNAMIC TESTS OF CHILD RESTRAINT SYSTEMS

3.1 Introduction

Normative tests are not performed always on vehicles. Components like seats can be tested individually on specially designed structures. The child seats are mounted on special test seats for this purpose. The special test seat which is specified in the ECE R44 [17] regulation, has to be designed and manufactured.

The overturning and dynamic test seats are basically same but test seat for dynamic tests should be more stronger than overturning test seat. Because of this issue it has been decided that manufacturing two separate test seats will meet the requirements better.

3.2 Test Seat Specifications

Some of the requirements of the test seat are given in ECE R 44 [17]. First of all the test seat should have sufficiently rigid structure because it must remain undeformed after the tests. For overturning tests it is not an important problem, as much as dynamic tests, because the structure has to withstand its own weight, the child seat and the child dummy weight. But for the dynamic test seat, the structure has to withstand an acceleration of at least 20 g during dynamic tests which will be the most important factor for designing the dynamic test seat. Some specifications are defined in ECE R44 [17]. The test seats must have sufficiently rigid seat back and seating section structure. Because of this, the seat back and seating section shall be manufactured with sufficiently rigid sheet metal. For connections with anchorage points the seating section must have clearances for access to the anchor brackets. The seating section plate described in ECE R44 [17] is shown in Figure 3.1.

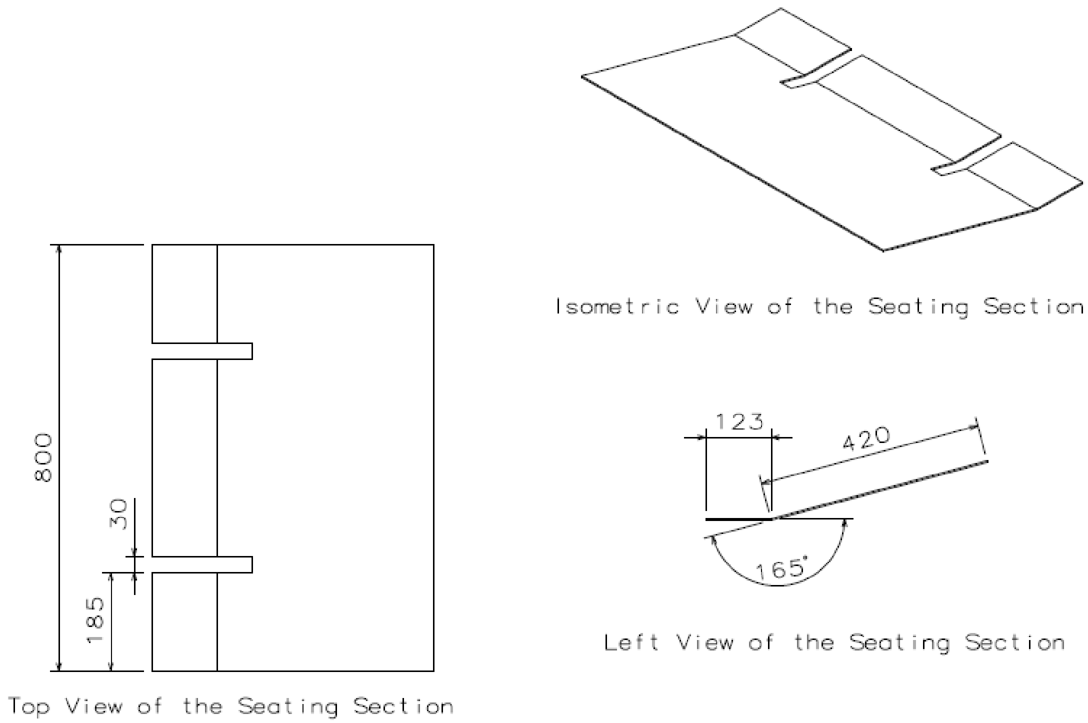


Figure 3.1 ECE R44 Test Seat Seating Section Structure [17]

The width of the test seat must be fixed and it is specified in Regulation ECE R44 [17], it shall be 800 mm. To simulate a true seat structure, the seating section shall be bended after 123 mm of the seating section. The value of the bending is 15^0, defined in ECE R44 [17].

3.3 Anchorage Points

One of the most important articles in the regulation is positions of the anchorage points. The anchorage points are the points where the safety belts or other safety instruments will be attached. The positions of anchorage points are defined in ECE R44 [17] as shown in Figure 3.2 and 3.3.

Child Restraint System (CRS) categorized as "universal" and "restricted" shall use following points:

- For child restraint using lap belts, points A and B.
- For child restraint using lap and diagonal belts, points A, BO and C.
- For child restraints using ISOFIX attachment, H1 and H2.

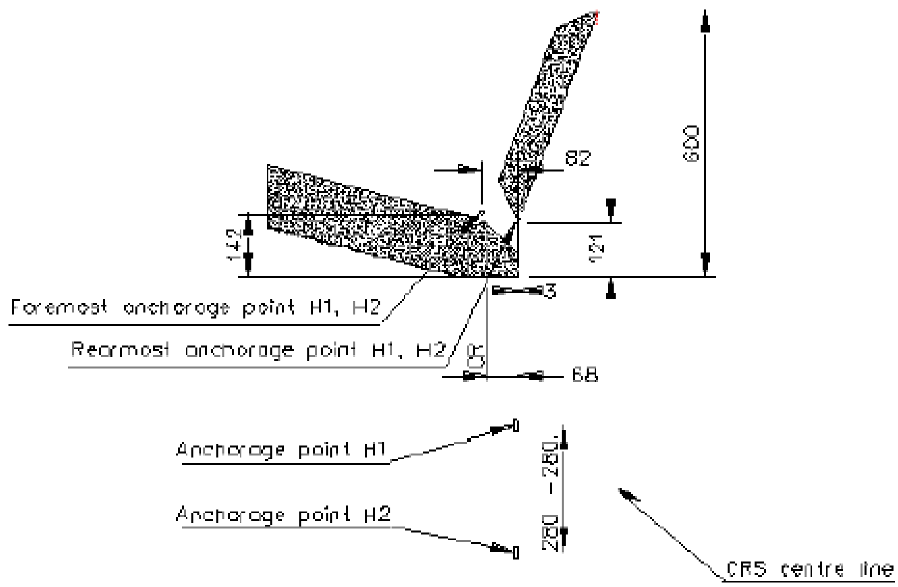


Figure 3.2 Position of ISOFIX Points [17]

CRS categorized as "semi-universal" shall use following points:

- Anchorages A, B and/or H1 H2 and D shall be used for child restraints in the "semi-universal" category having only one additional upper anchorage.

- Anchorages A, B and/or H1 H2, E and F shall be used for child restraints in the "semi-universal" category having only one additional upper anchorages.
- Anchorage points R1, R2, R3, R4 and R5 are the additional anchorage points for rearward-facing child restraint systems in the "semi-universal" category having one or more additional anchorages.

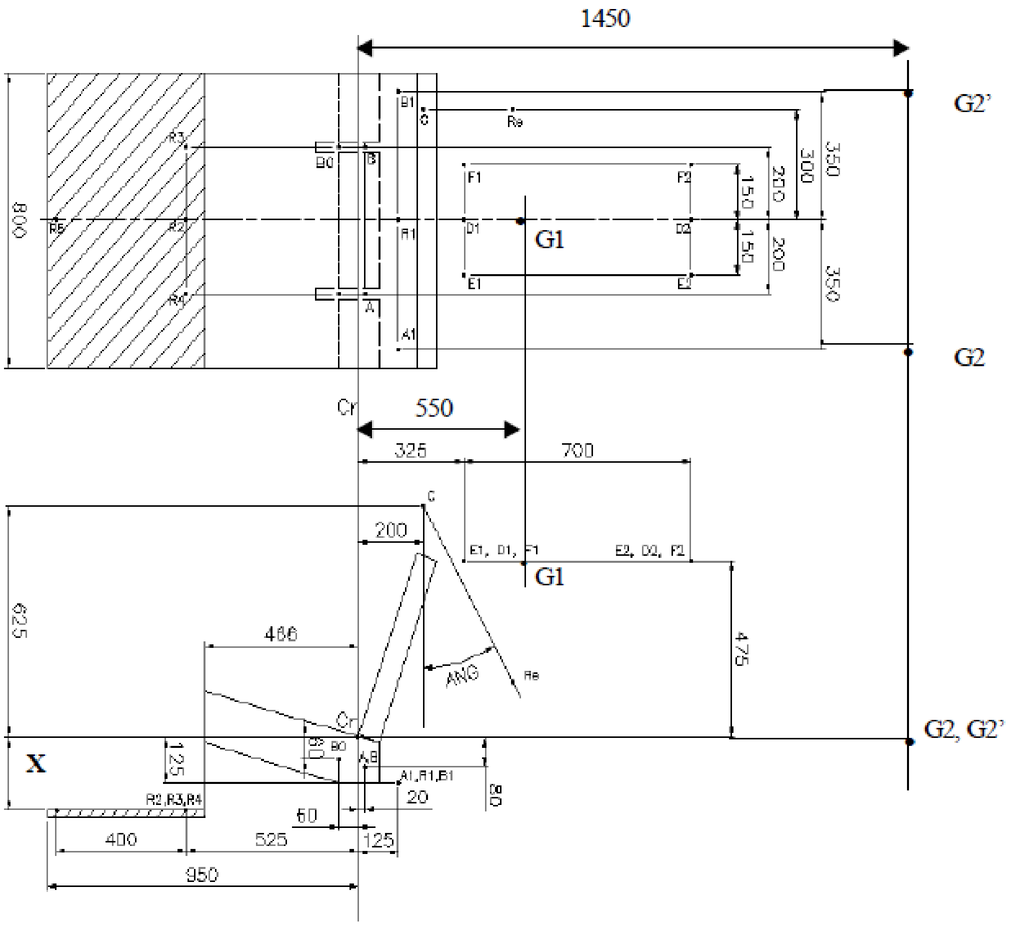


Figure 3.3 Technical Drawings Showing Anchorage Points [17]

For carry-cots in group 0 shall use the following points:

- Points A1 and/or B1 can be used alternatively, as specified by the manufacturer of the restraint systems. A1 and B1 are located on a transverse line through R1 at a distance of 350 mm from R1.

For testing of the child restraints with top tether shall use the following points shown in Figure 3.4:

- The anchorage G1 or G2 shall be used.

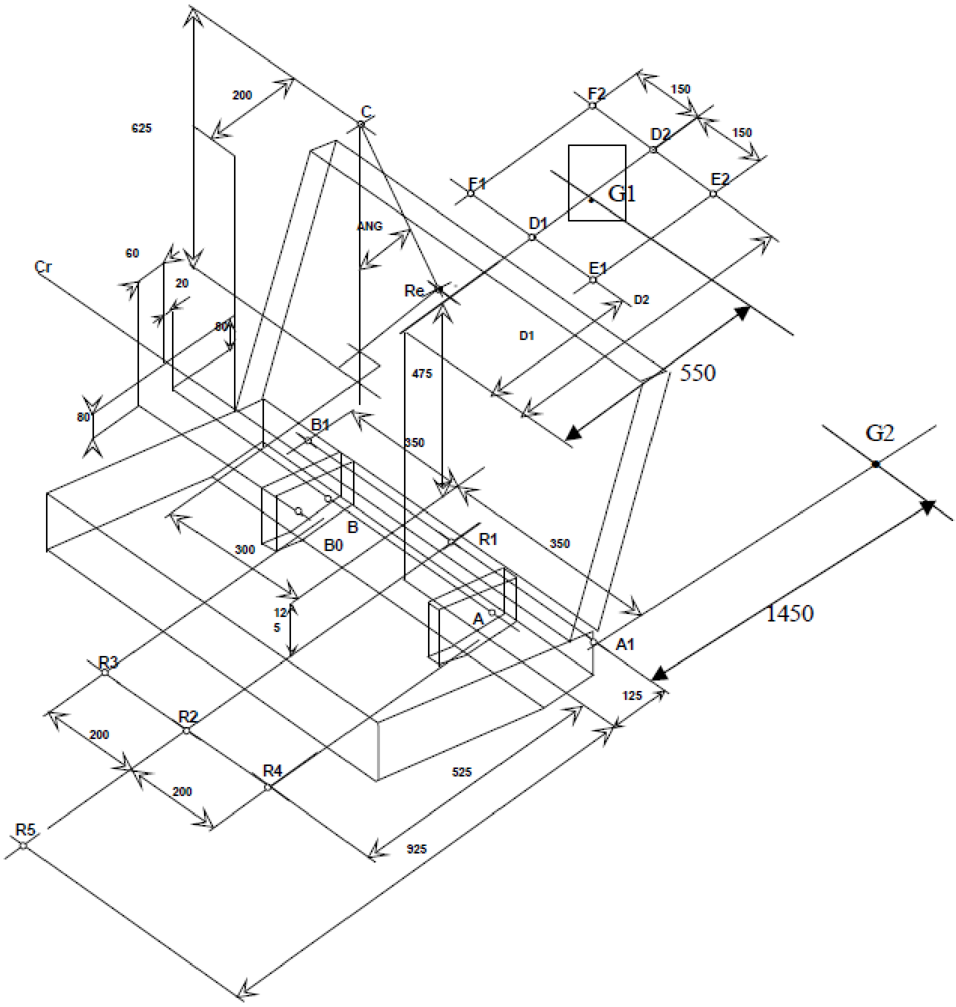


Figure 3.4 Position of Anchorage Points [17]

3.4 Design of Overturning Test Setup

The overturning test simulates overturning of a vehicle. For this purpose, the overturning tests shall be performed to simulate the incident of overturning of the vehicle. ECE R44 [17] specified the important properties for the overturning test. As specified in ECE R44 [17], for the overturning tests the test seat shall be rotated about 360 degrees at a speed of 2^{o}-5^{o}/second. The test seat should rotate both clockwise and anti-clockwise directions about x and y axes according to the test seat coordinate system. The coordinate system of the test seat is shown in Figure 3.5. The aim of the overturning test is to measure the test dummy's head displacement with respect to its initial position. This displacement shall not exceed 300 mm. This specification creates another design parameter that there must be more than 300mm space when the overturning test seat became upside-down during the test. And the test seat must have the appropriate anchorage points to allow fastening the seat belt and other CRS parts.

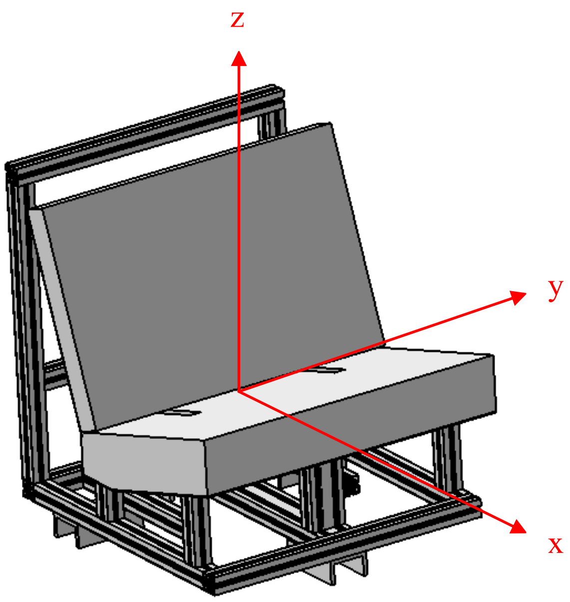


Figure 3.5 Coordinate of System of the Test Seat

According to the definitions, the test seat structure system is composed with the same components for both overturning configurations. Two turning configurations needed according to ECE R 44 [17]. One of the turn will be about the X-axis and the other one will be about the Y-axis of the test seat. Configuration 1 for turning about X-axis and Configuration 2 for turning about Y-axis are shown in Figure 3.6 and Figure 3.7, respectively.

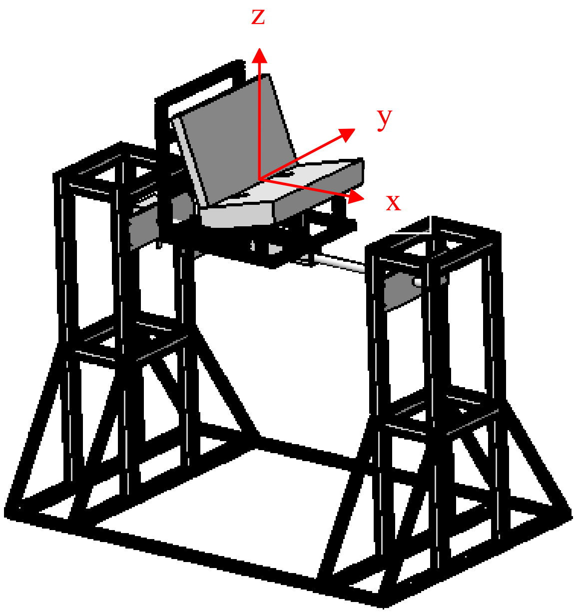


Figure 3.6 Configuration 1 Turning About X-Axis

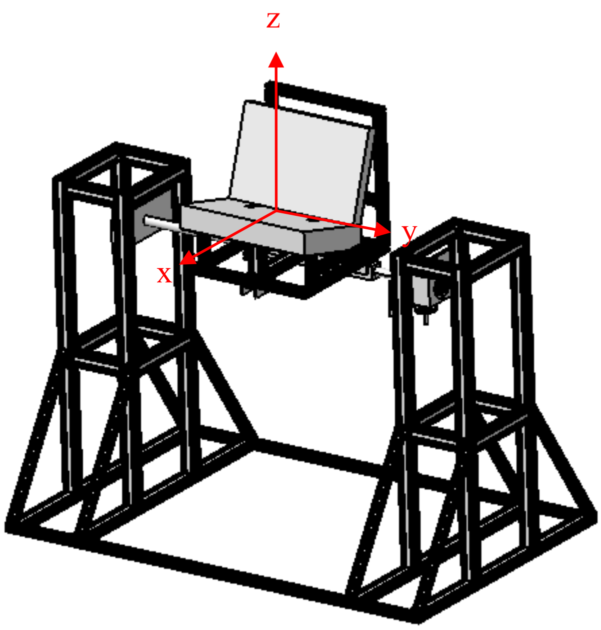


Figure 3.7 Configuration 2 Turning About Y-Axis

3.4.1 Overturning Test Setup Structural Frame

The overturning test setup structural frame is the main part of the system on which the test seat, electric motor and electric board are mounted. The overturning test setup structural frame is shown in Figure 3.8.

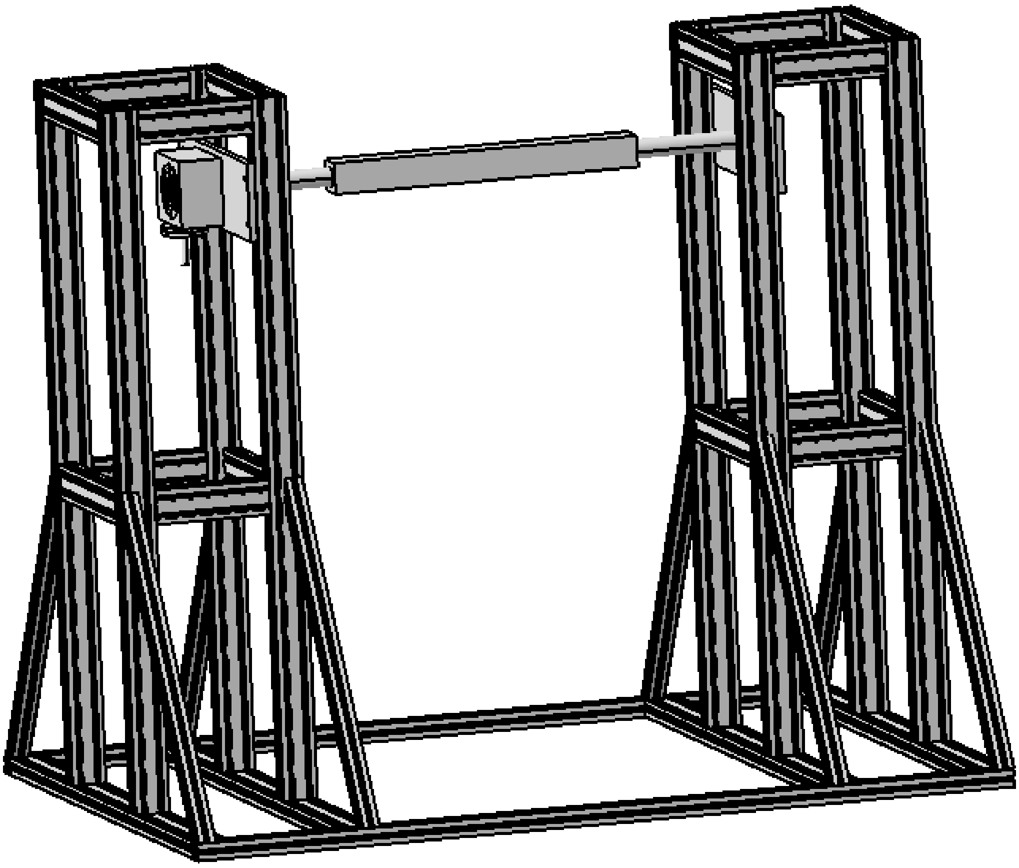


Figure 3.8 Overturning Test Setup Structural Frame

3.4.2 Support Element

The support element’s main duty is to make connection between the front and back securing points of the overturning test setup structural frame. The test seat will be mounted on the support element that is the second duty of the support element. Additionally support element has a connection between the electric motor. This will provide rotation of the element about its axis which passes through its centreline. By the connection between test seat and support element, test seat will turn with support element. The support element is designed with two different sections as shown in Figure 3.9. Square-sectioned one is designed for to hold the test seat and the circular-sectioned one is designed for to transmit the rotational motion of the electric engine. Support elements are shrink fitted and bolts are used to each other to create a solid connection. For support element stainless steel is selected as material. Material properties of the support element parts are given in Table 3.1.

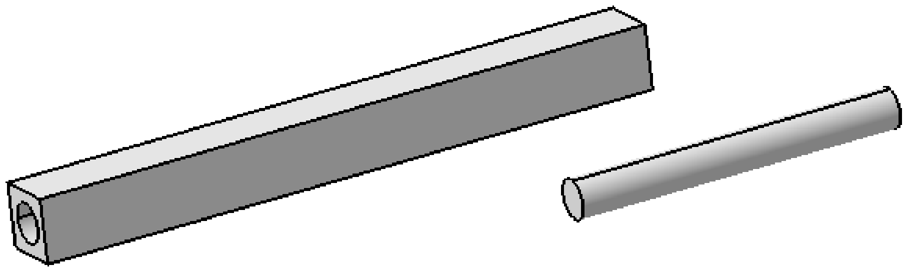


Figure 3.9 Support Element Parts

Table 3.1 Material Properties of ASTM 201

Material Properties of ASTM 201	
Property	**Value**
Elastic Modulus (N/mm^2)	193000
Poisson's Ratio	0.31
Shear Modulus (N/mm^2)	73664
Mass Density (g/mm^3)	7.75
Tensile Strength (N/mm^2)	750
Yield Strength (N/mm^2)	330

3.4.3 Electric Motor and Electric Board

Overturning operation of the test seat is provided by the electric motor shown in Figure 3.10. The electric motor properties are selected according to the restrictions of the ECE R 44 which is 2^0-5^0/second as turning speed. The electric motor is fixed to the overturning test setup structural frame with bolts.

Figure 3.10 Electric Motor

The speed of the electric motor can be adjusted by electric board. The electric board is shown in Figure 3.11.

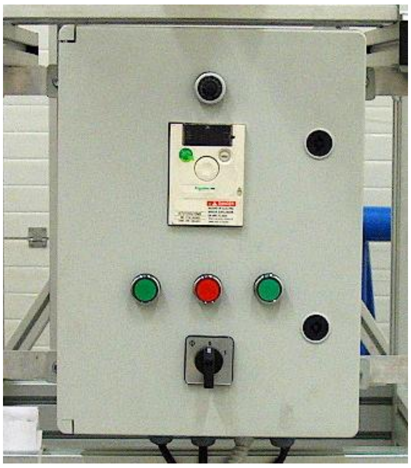


Figure 3.11 Electric Board

3.4.4 Overturning Test Setup Structural Frame and Test Seat Profile

At the design stage, two different aluminium profiles are used for the overturning test setup structural frame. One is 90x45 aluminium sigma profile. That is used on the towers of the overturning test setup structural frame. Rest of the parts and supports of the overturning test setup structural frame, are manufactured with 45x45 aluminium sigma profile.

The test seat is manufactured only with 45x45 aluminium sigma profile. The connections of aluminium profiles are done with bolt connections. This allows us to make flexible connections sliding on the channels of the sigma profile. According to regulation, if any design changes needed in the future, it can be done with this flexibility. 2-D cross sections of the 90x45 and 45x45 aluminium sigma profiles are shown in Figure 3.12 and Figure 3.13, respectively.

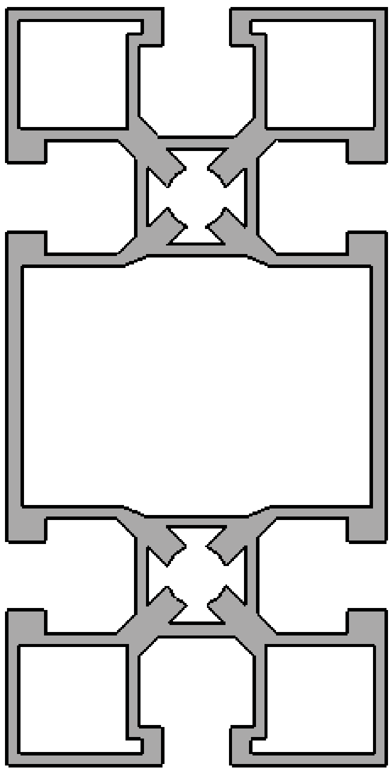


Figure 3.12 90 x 45 Aluminium Sigma Profile

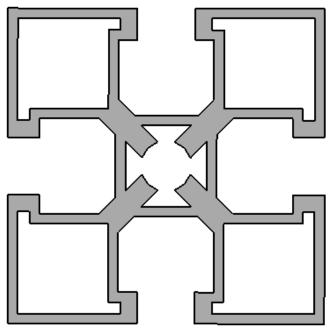


Figure 3.13 45 x 45 Aluminium Sigma Profile

Material properties of the aluminium sigma profile are given in Table 3.2.

Table 3.2 Material Properties of Aluminium 6063 – T6

Material Properties of Aluminium 6063 – T6	
Property	**Value**
Elastic Modulus (N/mm^2)	69000
Poisson's Ratio	0.33
Shear Modulus (N/mm^2)	25800
Mass Density (g/mm^3)	2.7
Tensile Strength (N/mm^2)	240
Yield Strength (N/mm^2)	215

3.5 Design of Dynamic Test Setup

The dynamic tests are performed to simulate the crash of a vehicle. ECE R 44 specifies the important properties for the dynamic tests. As specified in ECE R 44, for the dynamic tests sled shall have an accelerate motion. That acceleration motion differs for the frontal crash and the rear crash. The test seat shall withstand to that acceleration motion. The most important design parameter is acceleration that the test seat shall withstand.

Dynamic test according to the definition of ECE R 44, the test seat structure is composed with the same components for both the frontal and the rear crash configurations. Whole test seat is manufactured with steel profiles. For the rear crash configuration an extra support structure shall be used. Configuration 1 for the frontal crash and Configuration 2 for the rear crash are shown in Figure 3.14 and Figure 3.15, respectively.

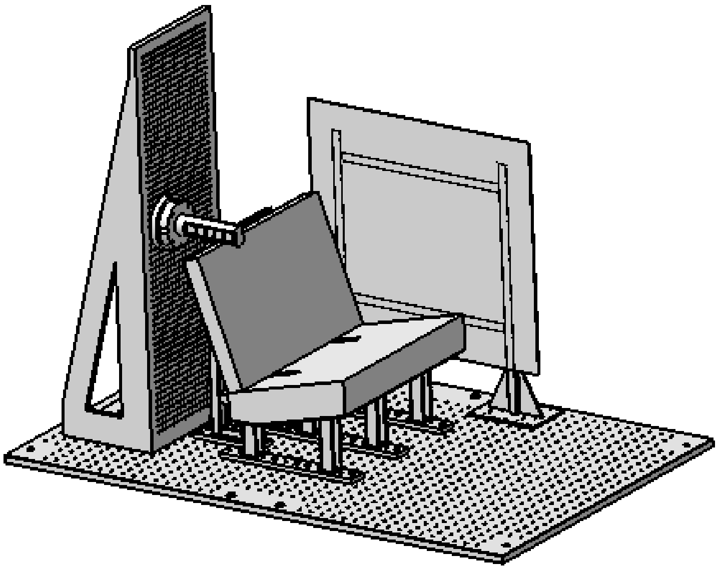


Figure 3.14 Configuration 1 Dynamic Frontal Test

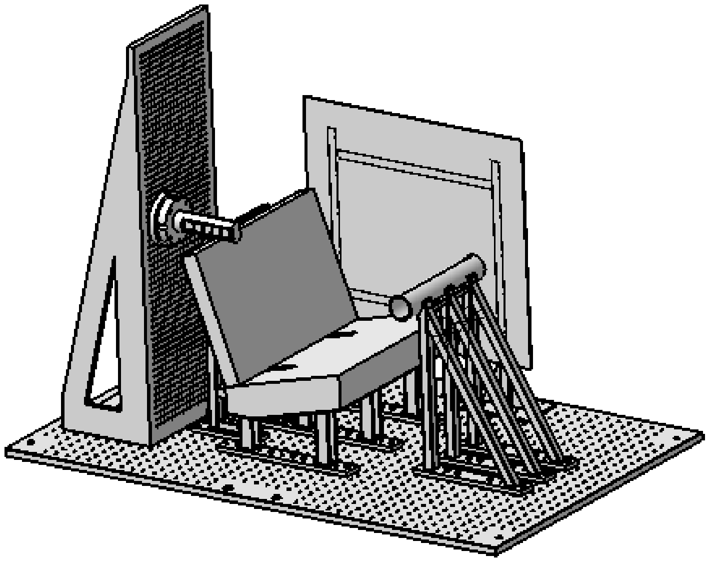


Figure 3.15 Configuration 2 Dynamic Rear Test

3.5.1 Test Seat

At the design stage, three different steel profiles and 20 mm thick sheet bars are used for the test seat. The designed test seat is shown in Figure 5.16. First, U-profile is used for the main support of the seat back and seating part. U-profiles are rolled 10 mm thick sheet metals. Sheet bars are drilled to make connection with aluminium plate and U-profiles are welded with sheet bars. Additional supports are used to for security of test seat. Those additional supports are made of 40x40x4 steel profiles. For the frame of the test seat, because of its weight, 40x40x2 steel profiles are used. All connections are welded to each other. Cross sections of profiles are shown in Figure 3.17 for U-profile, 40 x 40 x 4 steel profile in Figure 3.18 and 40 x 40 x 2 steel profile in Figure 3.19, respectively.

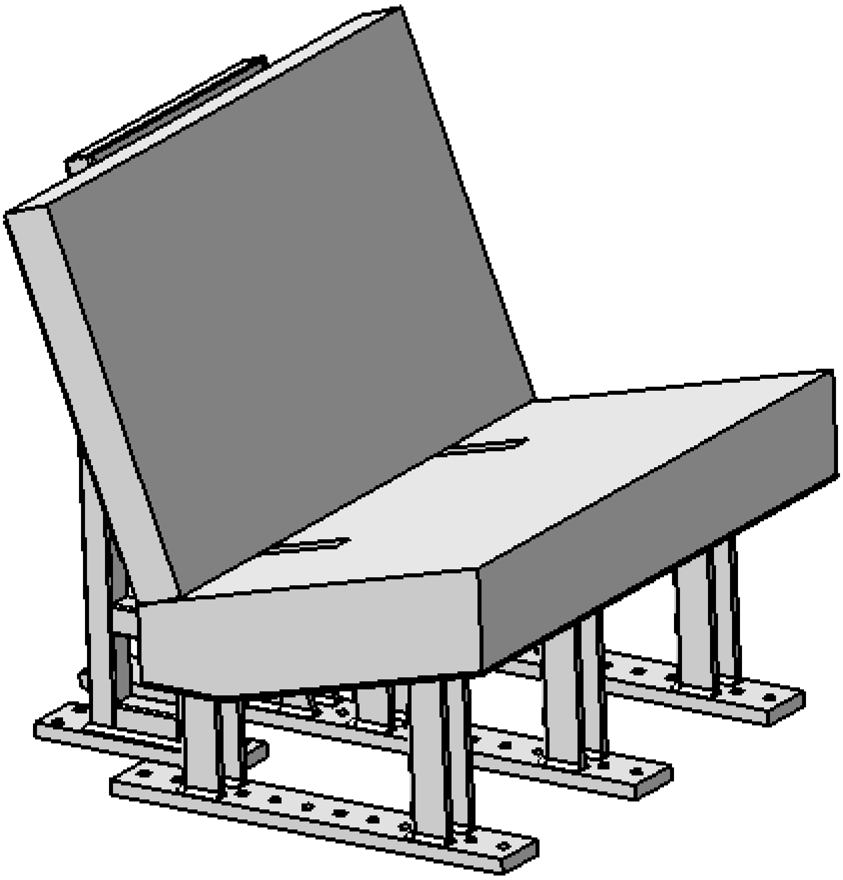


Figure 3.16 Test Seat Designed According to ECE R44

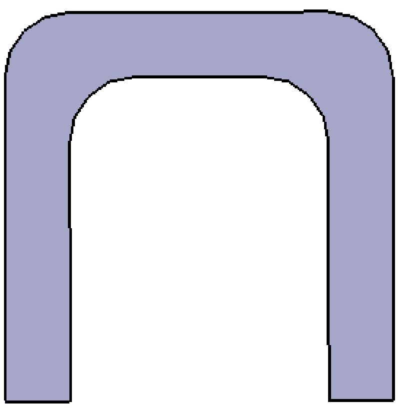


Figure 3. 17 Cross Section of U-Profile

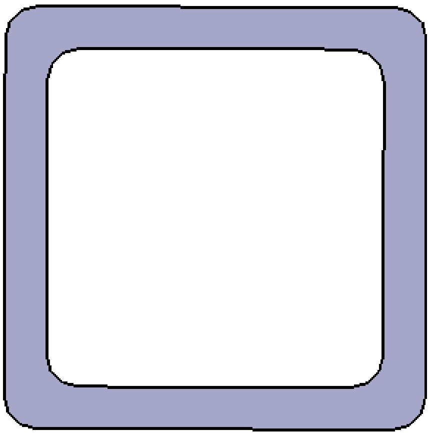


Figure 3. 18 Cross Section of 40 x 40 x 4 Steel Profile

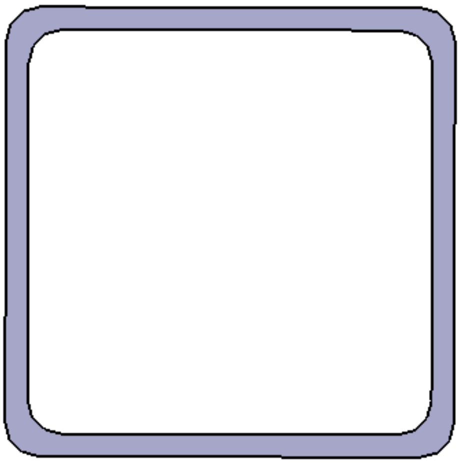


Figure 3. 19 Cross Section of 40 x 40 x 2 Steel Profile

Material properties of S 235 are given in table 3.3.

Table 3.3 Material Properties S 235

Material Properties of S 235	
Property	**Value**
Elastic Modulus (N/mm^2)	200000
Poisson's Ratio	0.3
Shear Modulus (N/mm^2)	76923
Mass Density (g/mm^3)	7.85
Tensile Strength (N/mm^2)	360
Yield Strength (N/mm^2)	235

3.5.2 Sled

Sled is the main part of the system on which the aluminium plate, seat belt anchorage point fixture, ECE R 44 test seat and rearward testing support structure are fixed and the sled is shown in Figure 3.20.

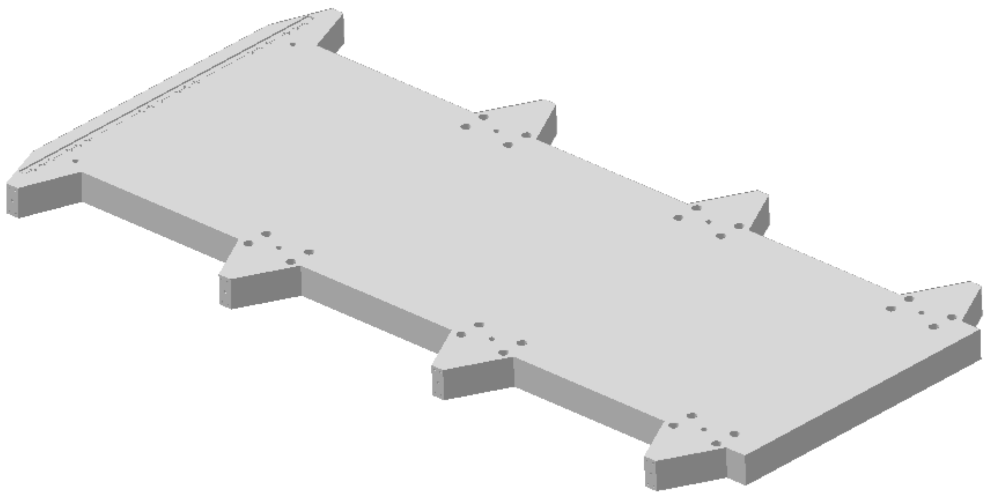


Figure 3.20 Sled

3.5.3 Rearward Testing Support Structure

For rearward-facing devices, a special frame shall be fitted on the sled in order to support the child restraint. A steel tube has to be attached on that support. This support structure will be attached firmly to the sled in such a way that a load of 5000 ± 50 N applied horizontally to the centre of the tube does not cause a movement greater than 2 mm. The dimensions of the tube shall be: 500 x 100 x 90 mm. The rearward testing support structure is shown in Figure 3.21. Same materials given in Table 3.3 is used for the support structure.

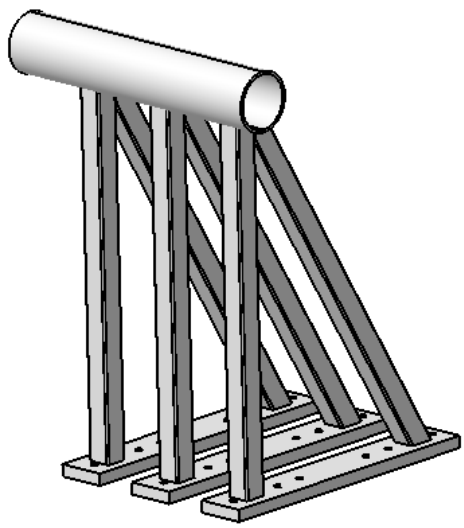


Figure 3.21 Designed Rearward Testing Support Structure

3.5.4 Displacement Frame

For head displacement limits, a displacement measuring frame shall be designed. A special frame shall be fitted on the sled in order to observe if the child test dummy's head inside limits or not. A steel frame has to be attached on that support. This displacement frame attached firmly to the sled in such a way that the acceleration load shall not cause a movement. The dimensions of the frame shall cover the displacement limits given in Figure 5.12. The designed displacement frame rearward is shown in Figure 3.22. Same materials given in Table 3.3 is used for the displacement frame.

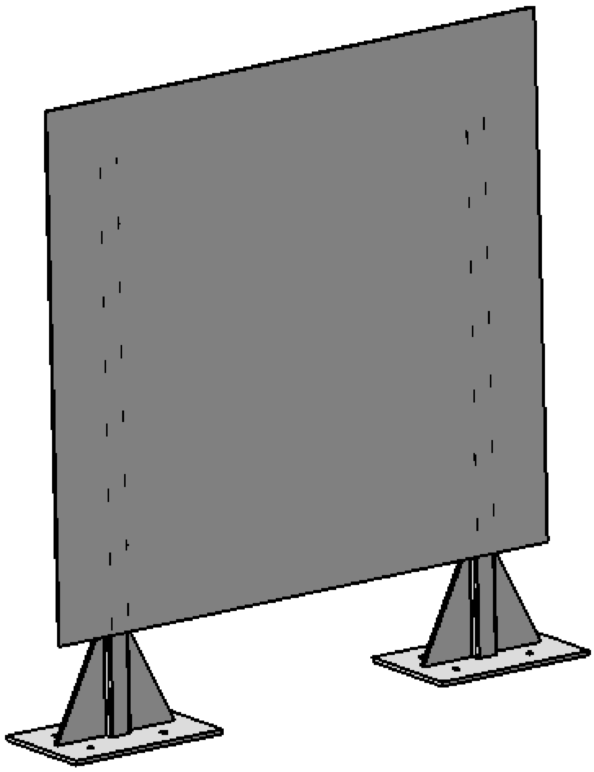


Figure 3.22 Designed Displacement Frame

CHAPTER 4

FINITE ELEMENT ANALYSIS OF DYNAMIC AND OVERTURNING TEST SETUP FOR CHILD RESTRAINT SYSTEMS

4.1 Finite Element Modelling and Analysis

Computer Aided Engineering (CAE) provides good estimations instead of using trial and error method for the applications. CAE enables reduction in design time, effort, product cost, tool cost and production time while improving quality and safety in engineering. Finite Element Analysis (FEA) is one of the most important areas of CAE. It is a numerical technique to analyze the structures with solving partial differential equations. The method has become widespread in all fields of the engineering but first developed for the aerospace structures. Currently heat transfer, fluid flow, electric and magnetic problems also find solutions by using FEA [24, 25].

In this study, commercially available FEA software, ANSYS 12.1[26] and Ls-Dyna Version 971[27] have been used. ANSYS is one of the static problem solver and the dynamic problem pre-processor. By using ANSYS, the static problem in the overturning test setup will be solved. ANSYS has also been used as the pre-processor to prepare the models for LS-Dyna to solve the dynamic crash problem. Ls-Dyna is an explicit solver commonly used for the simulation crash analysis. Crash and occupant safety analysis software must be able to handle large deformations, sophisticated material models, complex contact conditions among multiple components, and short-duration impact dynamics. Ls-Dyna software is capable of simulating different types of car crash events such as frontal impact, side impact, rear impact and rollover.

Crashworthiness simulation is less expensive and yields more information than the experimental techniques. Because of its extensive capabilities for handling crashworthiness and occupant safety simulations, Ls-Dyna is used worldwide.

4.2 Finite Element Modelling for Dynamic Analysis

IST Catapult System is used as the sled system for dynamic tests in METU-BILTIR Center Vehicle Safety Unit. The dynamic tests of the child restraint systems will be performed on the test seat with using the support structure and the displacement measurement frame. The test seat, the support structure and the displacement measurement frame are firstly mounted on the plate and the plate is mounted on the sled. To join the sled, the plate and the test seat, bolts are used as fasteners. Assembly of all these is shown in Figure 3.15.

4.2.1 Finite Element Modelling of Test Seat

The model of the designed test seat, which has been described in Chapter 3, is shown in Figure 4.1. In the FE model, the connections between parts of the test seat are generated with "tied contacts" for describing the welded joints.

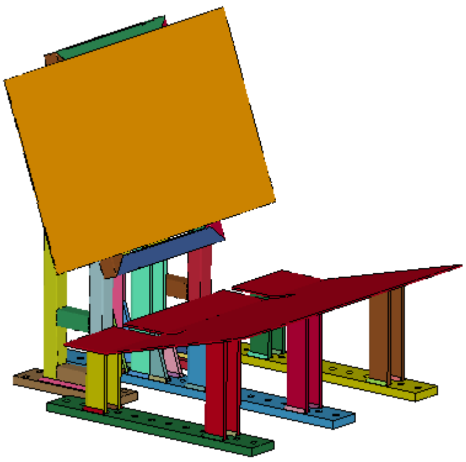


Figure 4.1 Designed Test Seat

In the FEA, the bolt connections are not defined since modelling the bolts would cause increasing the number of elements and therefore computational time. It has been also experimentally observed that bolt joints behave as rigid during the dynamic tests.

The properties of S 235 steel which is used for all parts of the test seat are defined for the material model. The material properties have been given in Table 3.3.

4.2.2 Finite Element Modelling of Support Structure

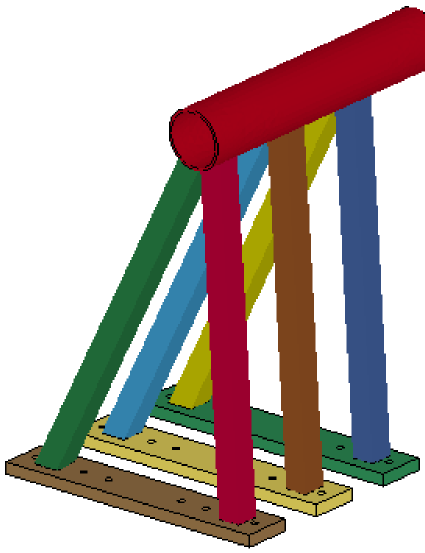


Figure 4.2 Designed Support Structure

The support structure is used for rearward-facing child seats. The model of the designed support bar, which has been described in Chapter 3, is shown in Figure 4.2. In the FE model, the welded joints are generated with “tied contacts”.

Modelling bolt connections increase the number of elements, therefore bolt connections are neglected to reduce the computational time.

The density, shear modulus, yield stress, plastic hardening modulus and bulk modulus are defined for the material according to the S 235 properties which have been given in Table 3.3.

4.2.3 Finite Element Modelling of Displacement Measurement Frame

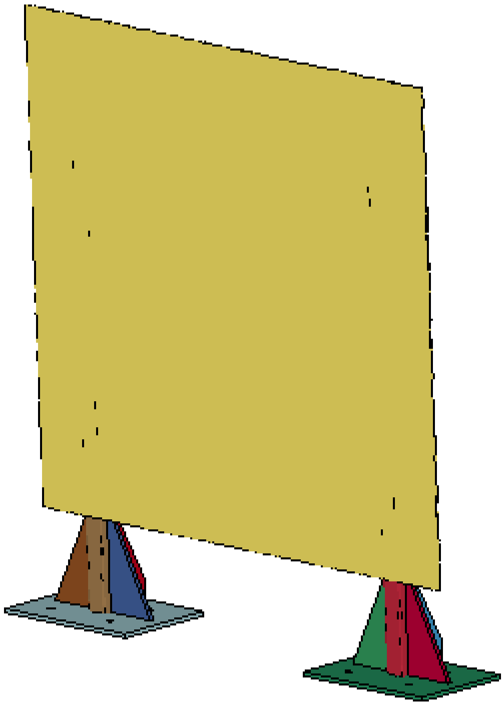


Figure 4.3 Designed Displacement Frame

The displacement measurement frame is used for to determine if the head of the test dummy stays in the limits during the test. The displacement measurement frame model has been described in Chapter 3 and shown in Figure 4.3. The parts of the displacement measurement frame are welded together and in the FE model, the welded joints are generated with "tied contacts". To reduce the computational time, bolt connections are neglected. The material properties of S 235 given in Table 3.3 are used for material model.

4.2.4 Modelling of Acceleration Applied to the Dynamic Test Setup

For dynamic crash simulation analysis, Ls-Dyna explicit solver is used for a defined acceleration curve in a very short time interval. First, the model is pre-processed by using the Ls-Dyna module of ANSYS 12.1 for meshing. In this model, the user can define parameters in the desired form and units.

According to ECE R44, the designed test setup will be used at a maximum acceleration value of 28g. For the FE analysis, the maximum acceleration value of 50g is considered in 110 milliseconds. The acceleration-time curve is shown in Figure 4.4.

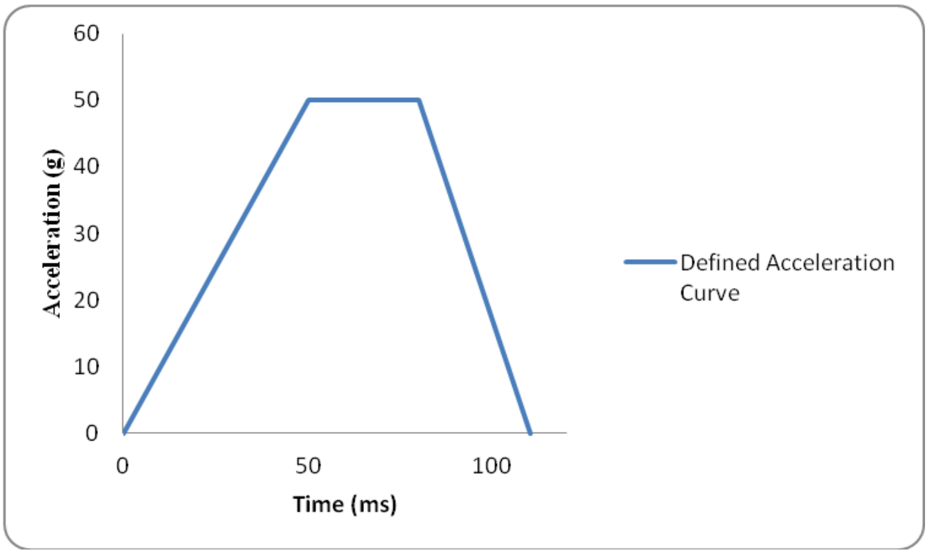


Figure 4.4 Defined Acceleration Value

If the system withstands this maximum loading condition, it means that the system can be used without any problems up to this maximum acceleration value (i.e. 50g), which is greater than the regulative needs (i.e. 28g). The time period is limited with 110 milliseconds because the greater acceleration values are applied in this time period. After 110 milliseconds the sled gets into the deceleration period.

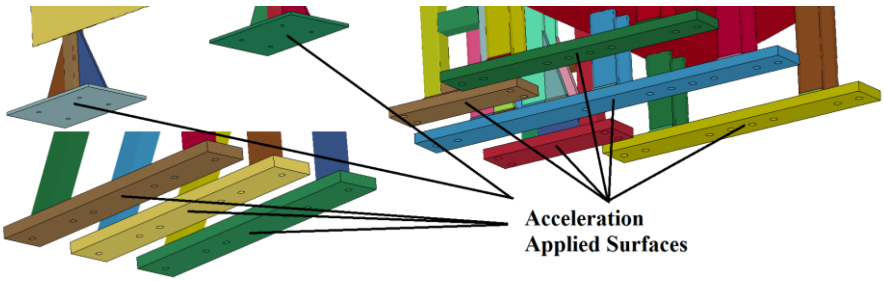


Figure 4.5 Bottom Parts of the Test Seat

During the analysis, the acceleration created by the hydraulic piston in the system is applied to the sled and the plate. This acceleration will be transmitted to the test seat, the support structure and the displacement measurement frame through the surfaces shown in Figure 4.5.

4.3 Simulations for Dynamic Analysis

4.3.1 Simulation of Test Seat Behaviour Under Crash Loading

During the simulations, von Mises stresses are calculated for all parts of the dynamic test seat. In the von Mises stress distribution, the occurred stresses are given for every 10 millisecond time changes. In Figure 4.6 the first 10 millisecond results are shown.

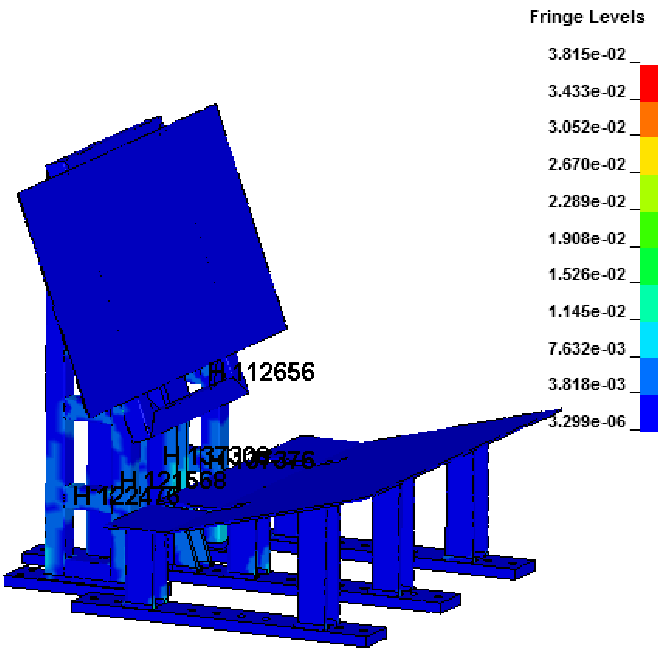


Figure 4.6 Test Seat Simulation after 10 Milliseconds

In Figure 4.7 the results after 20 milliseconds are shown. The von-Mises stresses are increasing as expected. The simulation after 30 milliseconds is shown in Figure 4.8.

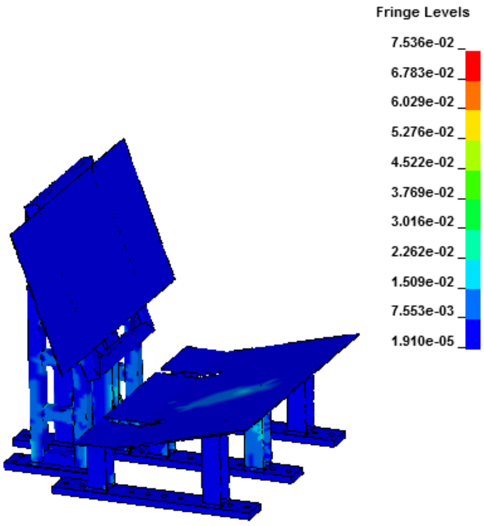


Figure 4.7 Test Seat Simulation after 20 Milliseconds

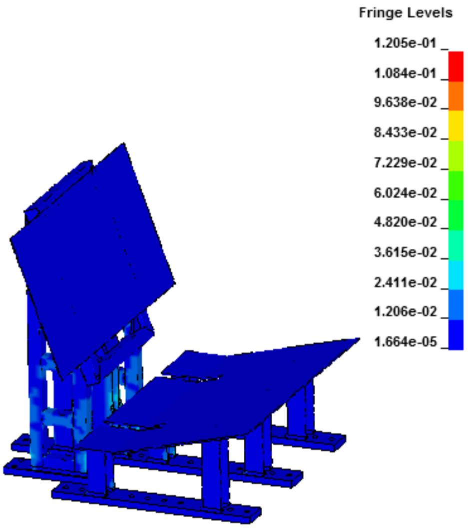


Figure 4.8 Test Seat Simulation after 30 Milliseconds

Von-Mises stress distribution is in an increasing form and it is proportional with the acceleration curve. In Figure 4.9, the results after 40 milliseconds are shown.

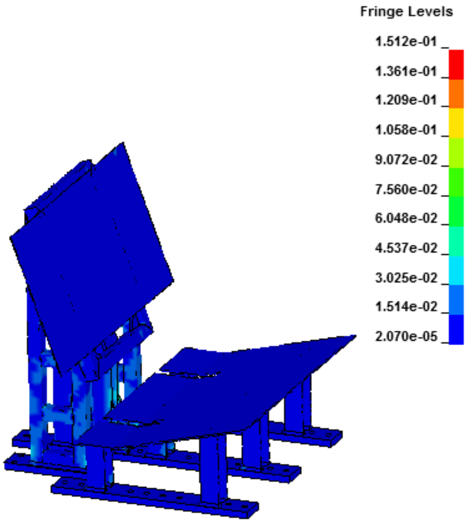


Figure 4.9 Test Seat Simulation after 40 Milliseconds

The acceleration curve defines 50g at 50 milliseconds. The maximum von-Mises stress values are observed after 50 milliseconds. In Figure 4.10, the highest stress values are obtained. As seen in the figure, the maximum stress values are not completely on the whole test seat. The maximum values are observed on a few elements of the test seat.

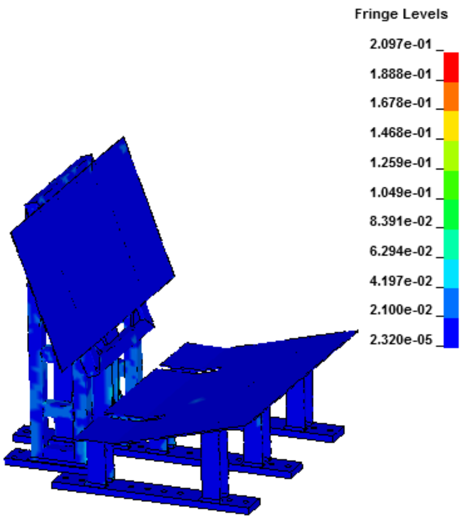


Figure 4.10 Test Seat Simulation after 50 Milliseconds

After 50 milliseconds, the acceleration curve does not increase and keeps at same level for 30 milliseconds. In Figures 4.11, 4.12 and 4.13 it can be seen that the stress values does not increase but stays in a stable trend.

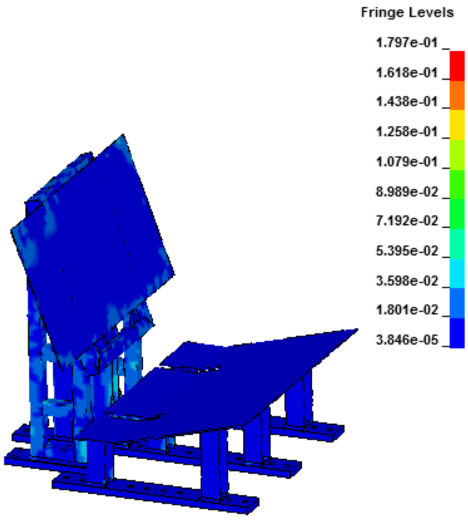


Figure 4.11 Test Seat Simulation after 60 Milliseconds

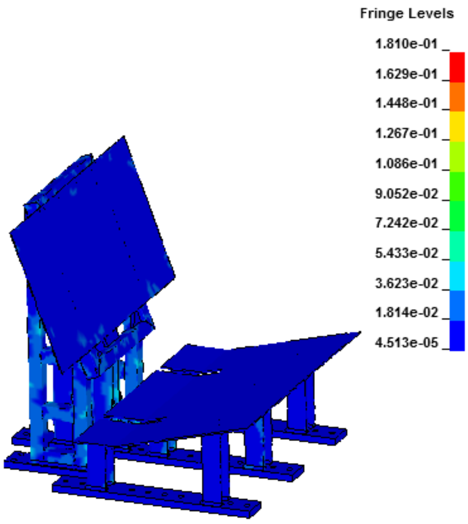


Figure 4.12 Test Seat Simulation after 70 Milliseconds

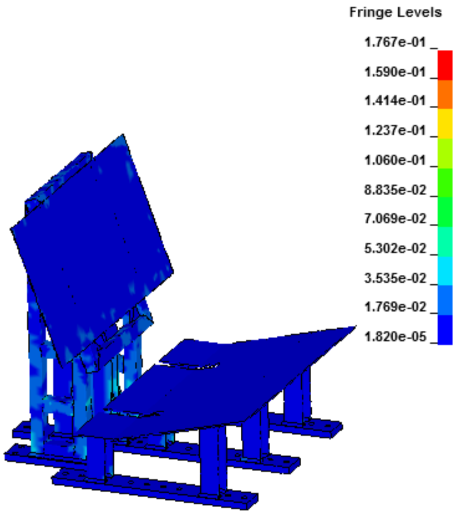


Figure 4. 13 Test Seat Simulation after 80 Milliseconds

After 80 milliseconds, the acceleration curve enters in a decreasing acceleration trend. So one can assume that the stress values decrease. After 80 milliseconds, the stress values starts to decrease. In Figure 4.14, it is seen that the von-Mises stress values decrease.

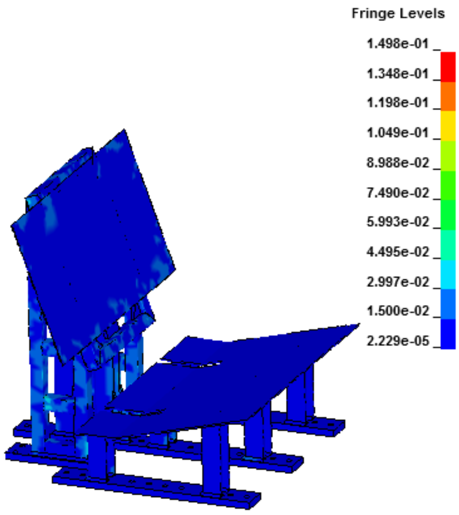


Figure 4.14 Test Seat Simulation after 90 Milliseconds

In Figures 4.15 and 4.16, the stress values continue to decrease. But the stress values do not totally become zero because the real motion does not end. It enters in deceleration trend. Because of this the analysis has not been continued for deceleration for the solution time.

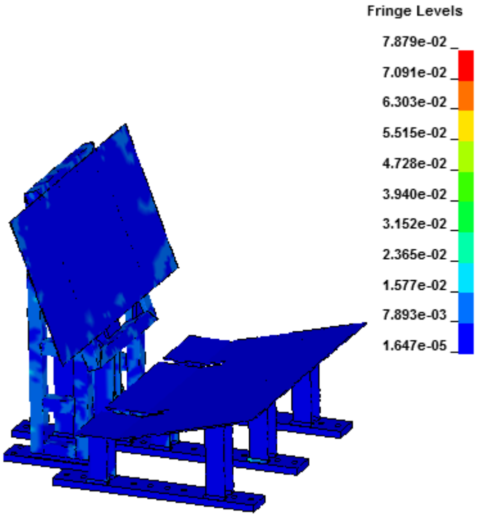


Figure 4.15 Test Seat Simulation after 100 Milliseconds

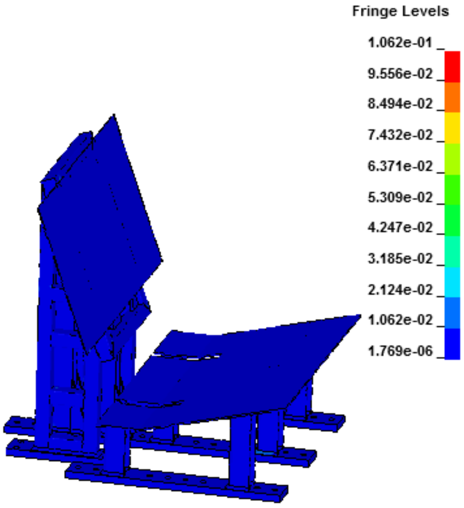


Figure 4.16 Test Seat Simulation after 110 Milliseconds

The maximum stress values observed according to the defined acceleration curve in the analysis are shown in Figure 4.17.

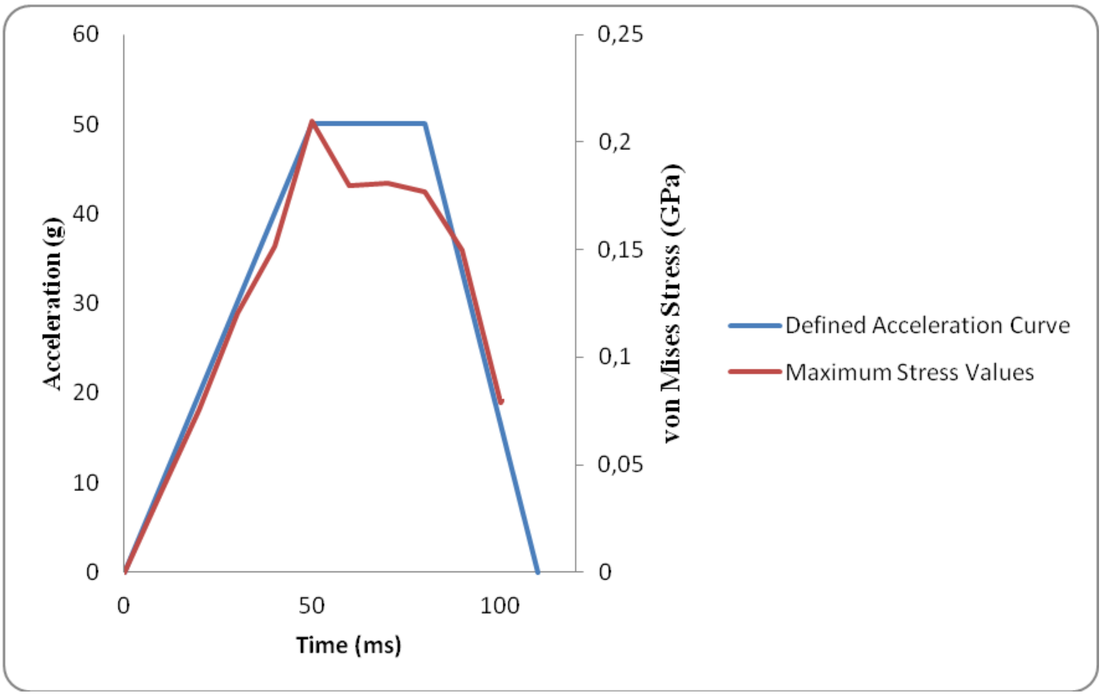


Figure 4.17 Maximum Stress Values

As seen in Figure 4.17, change in the stress values follow a similar change with the acceleration. The maximum stress values are under the defined material physical properties for all analysis period.

4.3.2 Simulation of Support Structure Behaviour Under Crash Loading

During the simulations, von Mises stresses are calculated for all parts of the support structure. In the von Mises stress distribution, the occurred stresses are given for every 10 millisecond time changes. Up to 50 milliseconds, the acceleration is increasing. As given in the Figure 4.18-4.22, the maximum von-Mises stress value occurs at 50 milliseconds and it is 5.348 E-2 GPa.

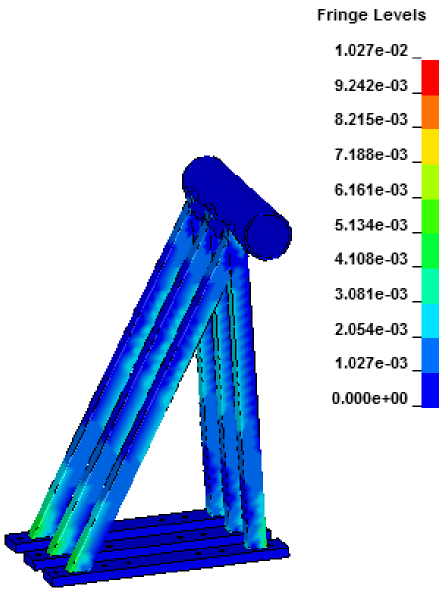


Figure 4.18 Support Bar Simulation after 10 Milliseconds

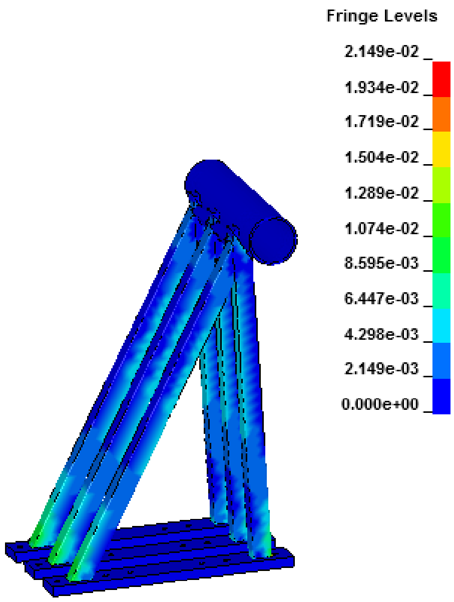


Figure 4.19 Support Bar Simulation after 20 Milliseconds

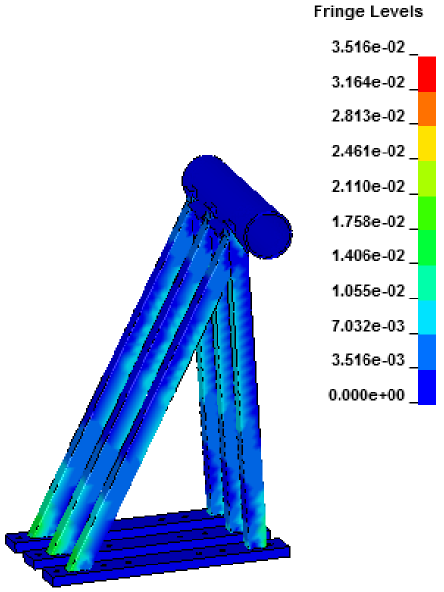


Figure 4.20 Support Bar Simulation after 30 Milliseconds

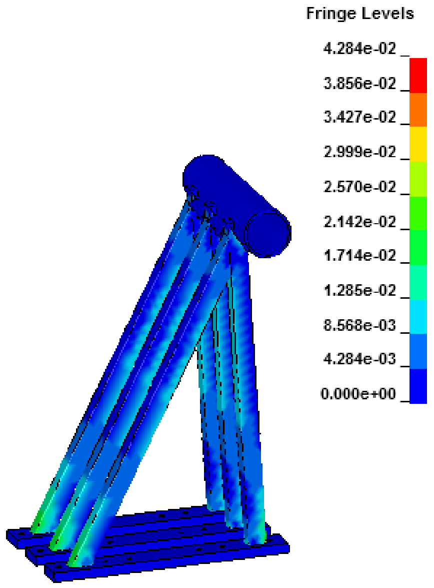


Figure 4.21 Support Bar Simulation after 40 Milliseconds

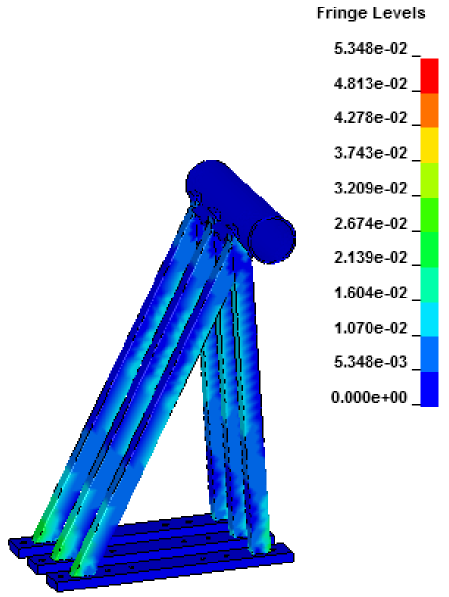


Figure 4.22 Support Bar Simulation after 50 Milliseconds

After 50 milliseconds the acceleration value is 50g during 30 milliseconds. By examining Figure 4.23-4.25, it can be seen that the von-Mises stresses distribution on the support bar are similar.

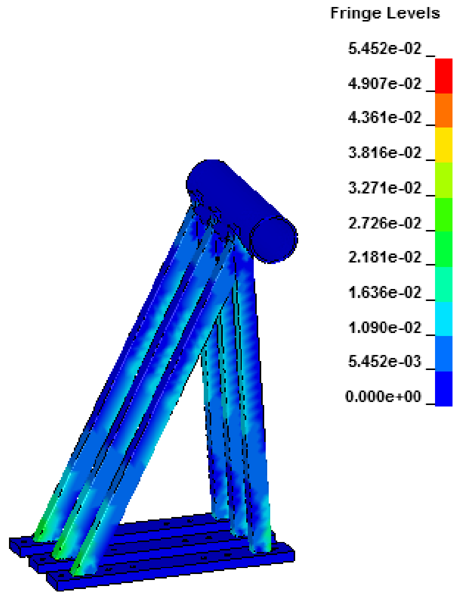


Figure 4.23 Support Bar Simulation after 60 Milliseconds

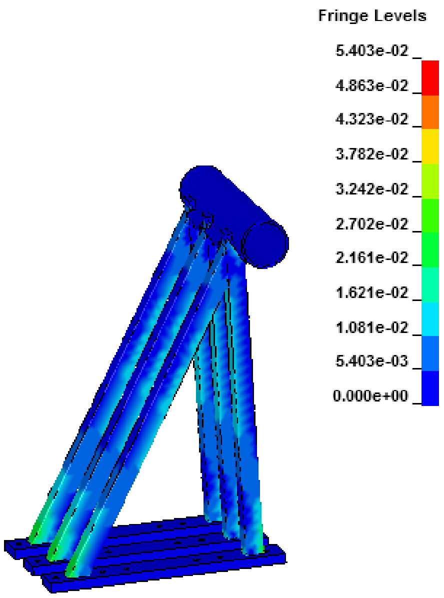


Figure 4.24 Support Bar Simulation after 70 Milliseconds

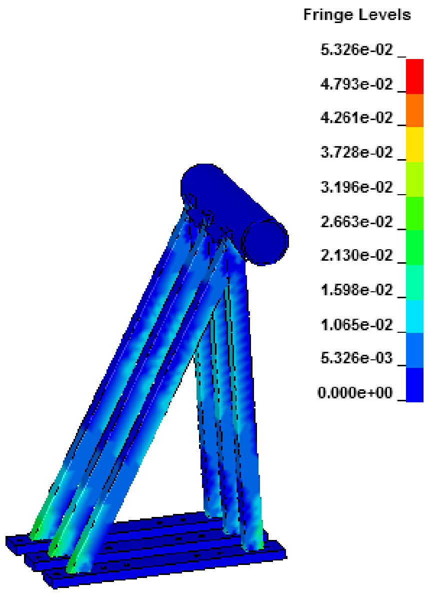


Figure 4.25 Support Bar Simulation after 80 Milliseconds

After 80 milliseconds, the acceleration value decreases to 0g and the stresses observed on the support bar starts to decrease too. The results between 90 ms and 110 ms are shown in Figures 4.26-4.28.

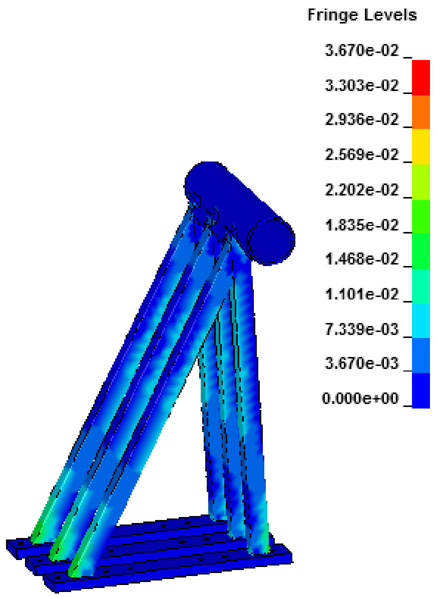


Figure 4.26 Support Bar Simulation after 90 Milliseconds

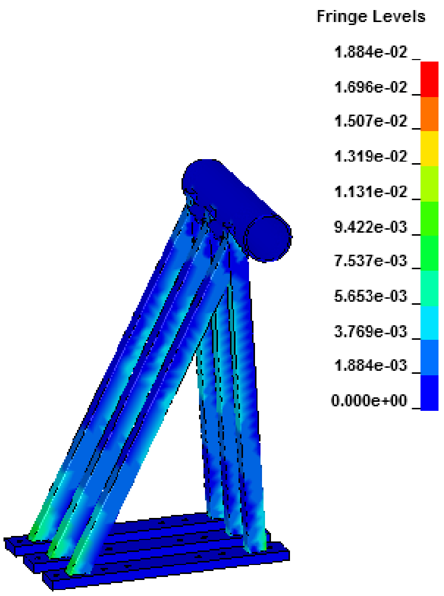


Figure 4. 27 Support Bar Simulation after 100 Milliseconds

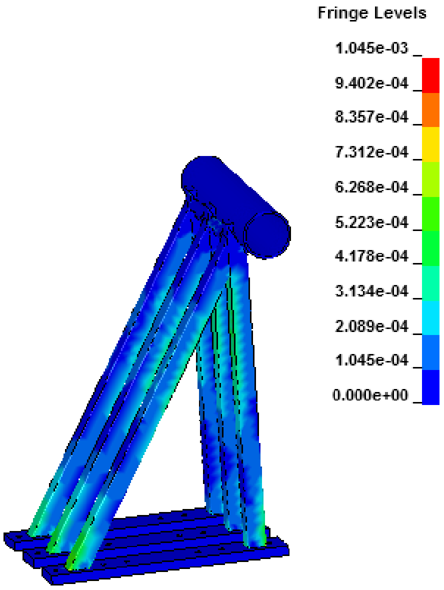


Figure 4. 28 Support Bar Simulation after 110 Milliseconds

4.3.3 Simulation of the Displacement Measurement Frame Under Crash Loading

Same as the test seat and the support structure, the same acceleration curve is applied to the displacement measurement frame. The results from the start to 50 ms can be seen in Figures 4.29-4.33.

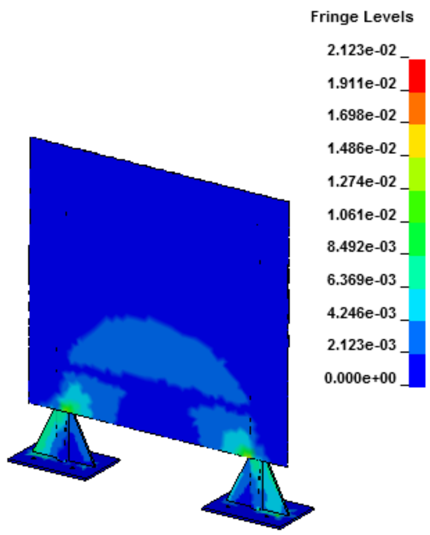


Figure 4.29 Displacement Measurement Frame Simulation after 10 Milliseconds

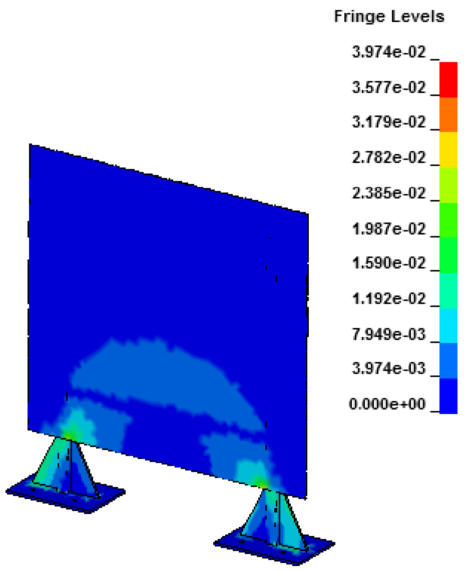


Figure 4.30 Displacement Measurement Frame Simulation after 20 Milliseconds

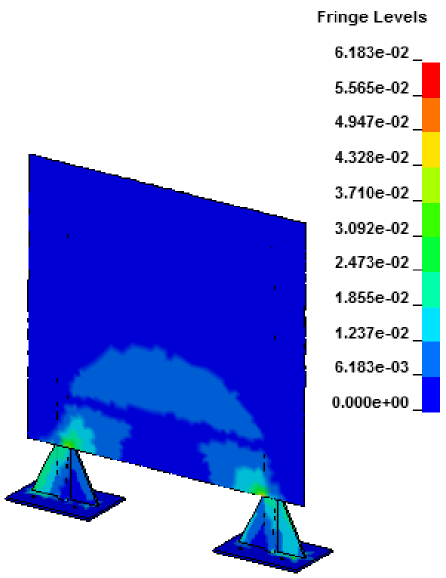


Figure 4.31 Displacement Measurement Frame Simulation after 30 Milliseconds

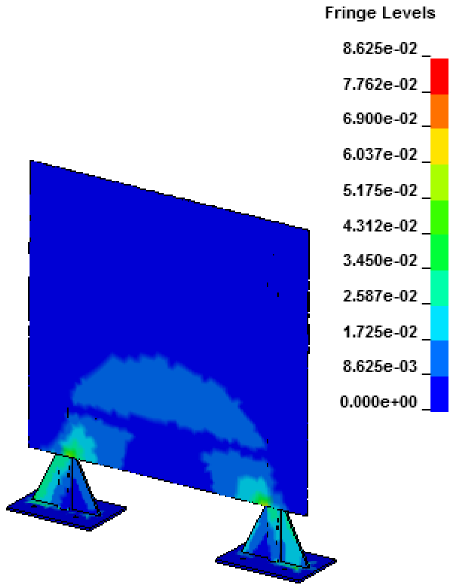


Figure 4.32 Displacement Measurement Frame Simulation after 40 Milliseconds

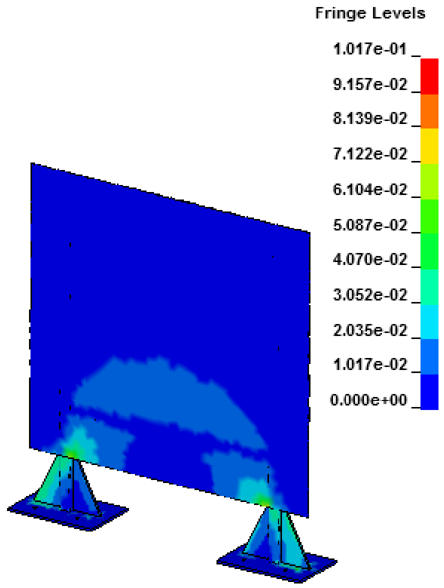


Figure 4.33 Displacement Measurement Frame Simulation after 50 Milliseconds

Results between 50 milliseconds and 80 milliseconds are shown in Figures 4.34-4.36.

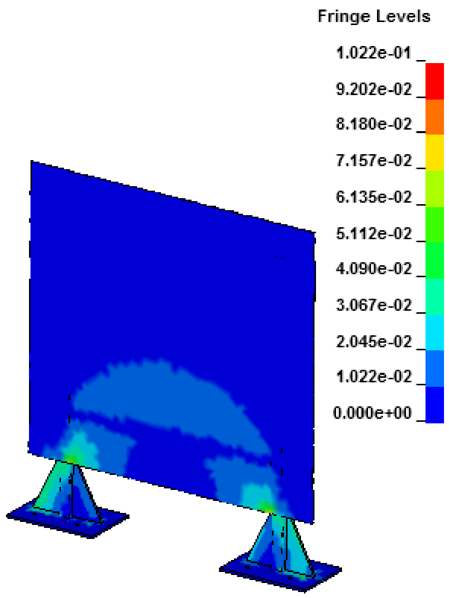


Figure 4.34 Displacement Measurement Frame Simulation after 60 Milliseconds

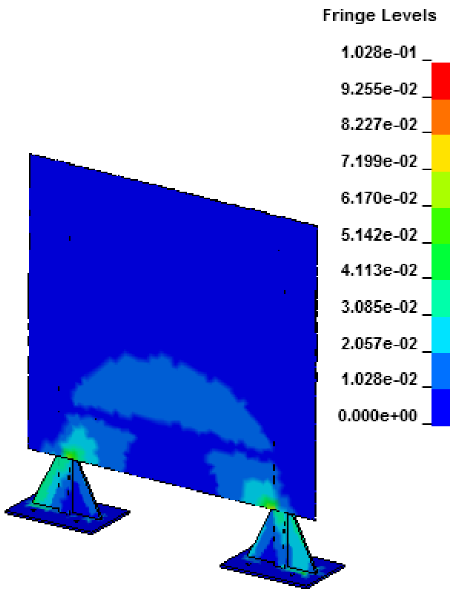


Figure 4.35 Displacement Measurement Frame Simulation after 70 Milliseconds

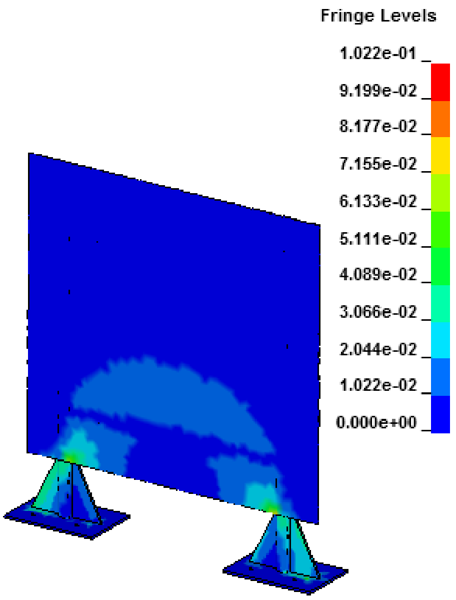


Figure 4.36 Displacement Measurement Frame Simulation after 80 Milliseconds

The results between 90 ms and 110 ms are shown in Figures 4.37-4.39.

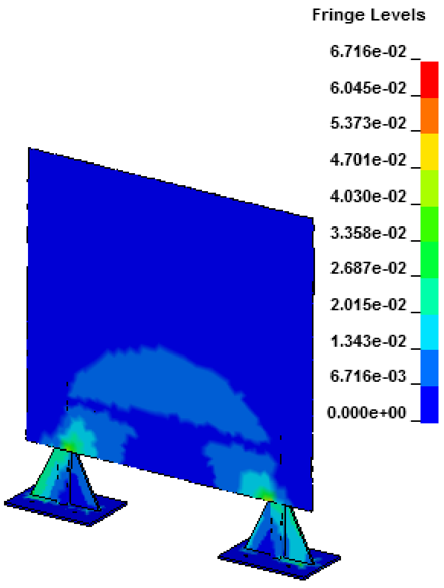


Figure 4.37 Displacement Measurement Frame Simulation after 90 Milliseconds

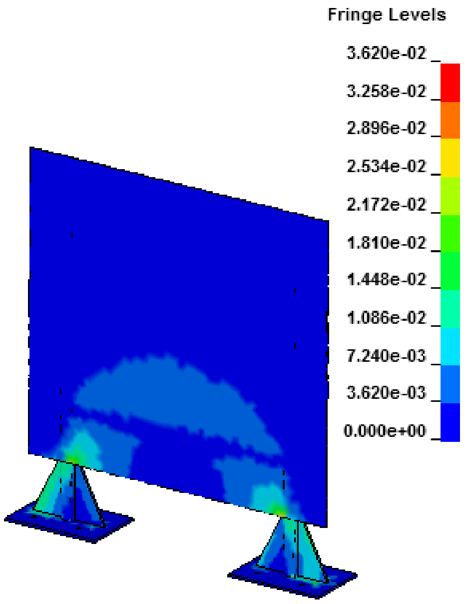


Figure 4.38 Displacement Measurement Frame Simulation after 100 Milliseconds

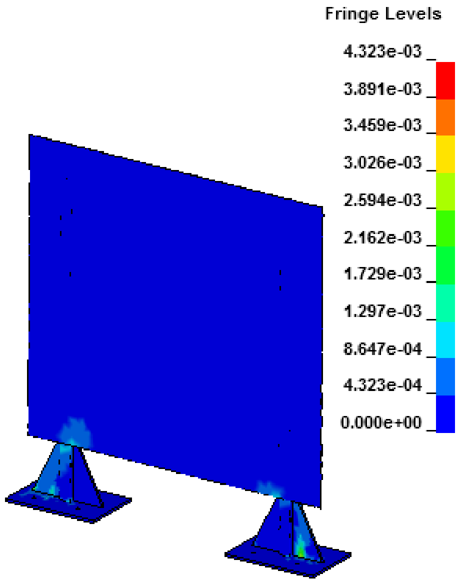


Figure 4.39 Displacement Measurement Frame Simulation after 110 Milliseconds

4.3.4 Angular Variations in Dynamic Test Setup Components

Dynamic test setup components must be sufficiently rigid. Angluar changes observed under the acceleration loads are given in the following Figure 4.40-4.43. As seen in figures, the angular variations are less than 0.04^0 and these are negligible.

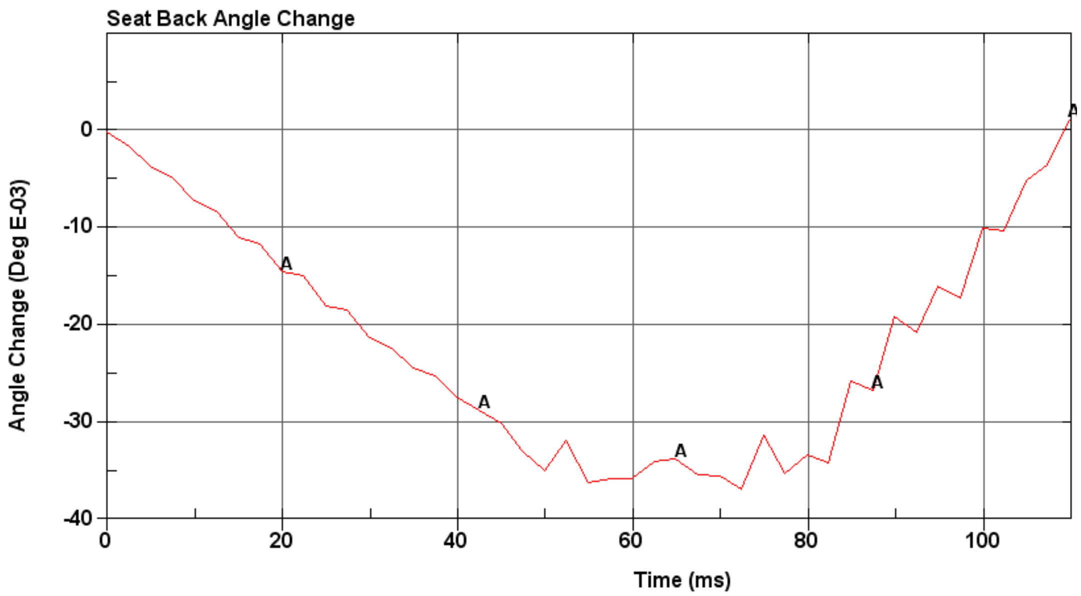


Figure 4.40 Seat Back Angle Change Under Acceleration Load

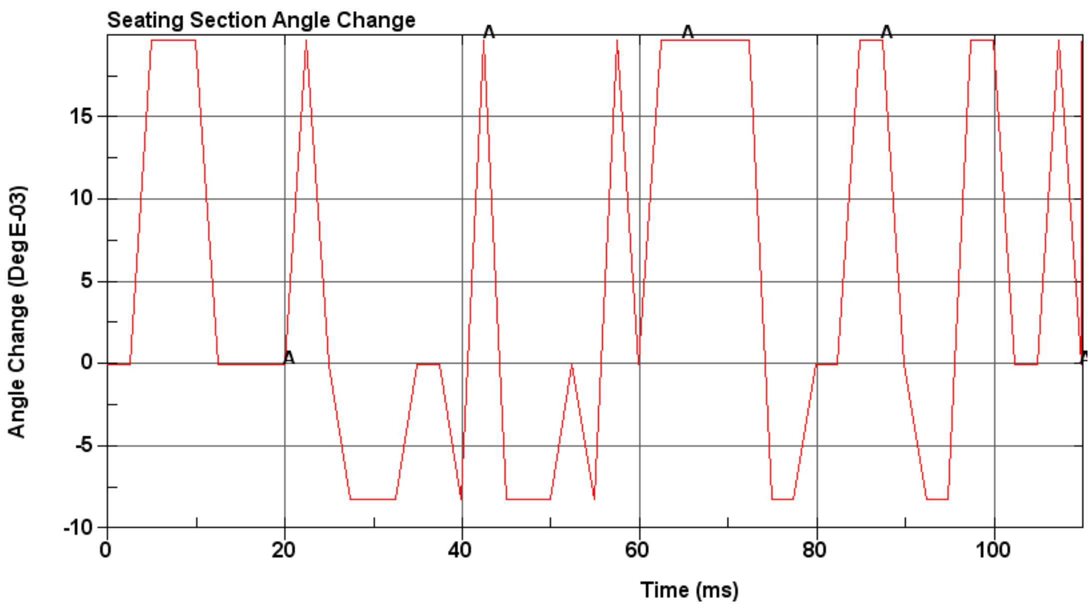


Figure 4.41 Seating Section Angle Change Under Acceleration Load

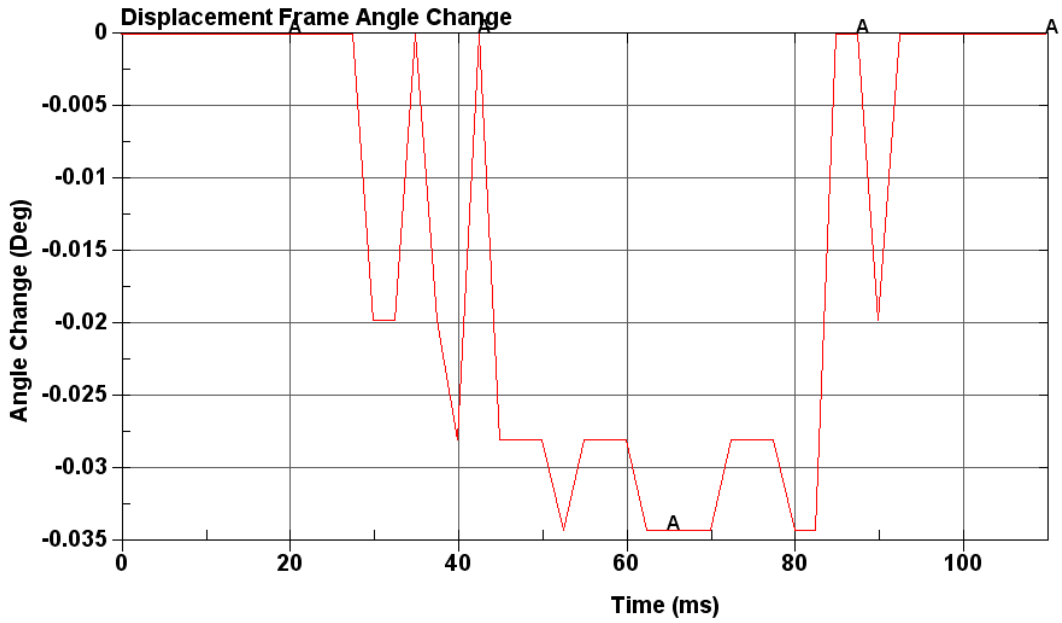


Figure 4.42 Displacement Frame Angle Change Under Acceleration Load

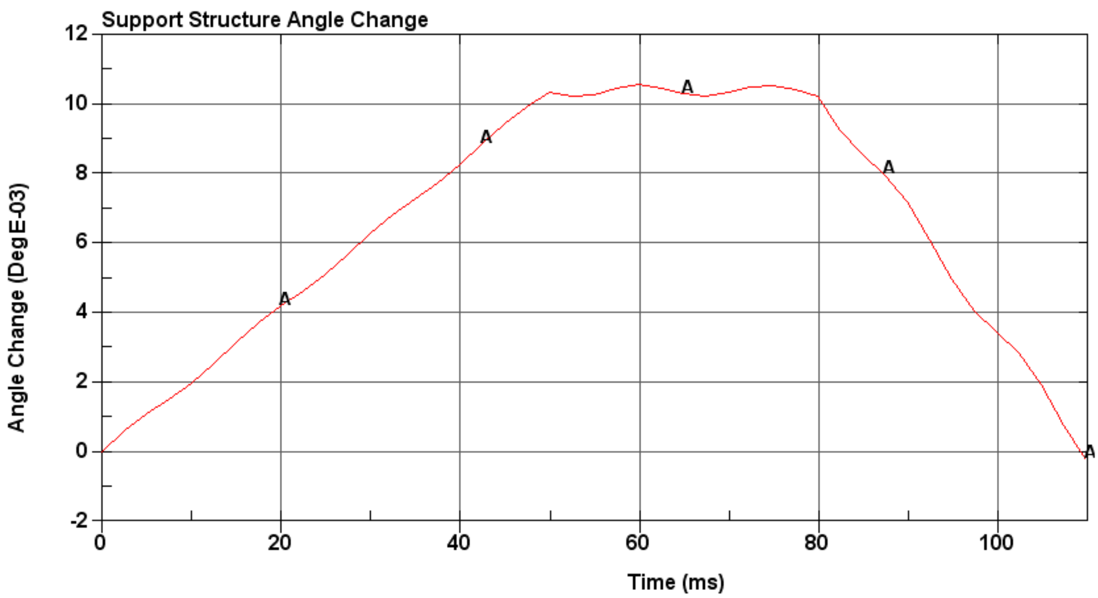


Figure 4.43 Support Structure Angle Change Under Acceleration Load

4.4 Finite Element Modelling for Static Analysis

Static analyses have been performed for the overturning test setup and the support structure. In the following subsections, these will be presented.

4.4.1 Finite Element Modelling of Overturning Test Setup

The overturning test setup is designed to perform the overturn tests with child test dummies. The child restraint system (CRS) is firstly placed on the overturning test setup and then the child test dummy is placed.

For the static load analysis, ANSYS 12.1 is used for a defined load. First, the model is pre-processed with ANSYS 12.1 for meshing and definitions such as material properties, connections etc.

According to ECE R44, the designed test setup will be used at a maximum load value of 36 kg for the 10 year old child test dummy with a mass of 36 kg and a child restraint system with a mass of 10 kg. For the analysis approximately 50 kg load is considered as the maximum value.

The load is assumed to be applied from the centre of gravity of the test seat and the test setup. That will overcome to the moments that will occur. At the overturning action, moments occur because of the dummy movements but this effect of the moment is negligible. In the analysis software, mass cannot be defined directly. The load can be defined as pressure to the overturning test setup. First, the mass is multiplied with gravitational acceleration. Then it is divided by the surface area of the seat. And approximately the pressure is calculated 1.25E-3 MPA. This load is defined to the analysis software as pressure as shown in Figure 4.41.

4.4.2 Finite Element Modelling of Support Structure

The support structure is used for the rearward facing CRSs. The test seat, the support structure and the displacement measurement frame are firstly mounted on the plate and the plate is mounted on the sled.

The support bar is used for rearward-facing child seats. In Chapter 3, Figure 3.15, the use of the support bar can be seen. Although, there is no need static analysis for the test seat, displacement measurement frame, the support structure should be verified with static analysis. According to ECE R44, a steel tube shall be attached to the sled in such a way that a load of 5000 ± 50 N applied horizontally to the tube does not cause a displacement greater than 2 mm [17]. Static and dynamic analyse results of the support bar are given Figures 4.18-4.28.

For static analysis, the support bar is fixed from the bottom parts of the plate as shown in Figure 4.40.

The material properties are defined for the material model according to the S 235, which are given in Chapter 3, Table 3.3.

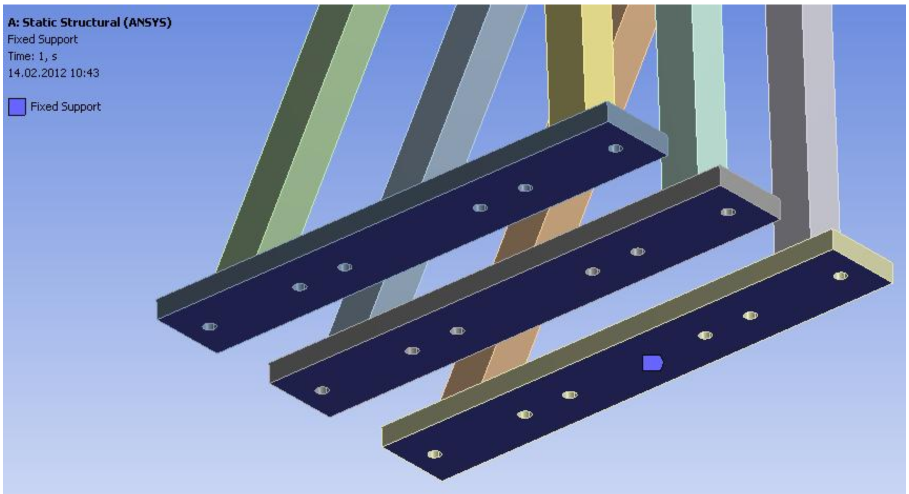


Figure 4.44 Support Bar Fixed Bottom Parts

4.5 Simulations for Static Analysis

4.5.1 Static Finite Element Analysis of the Overturning Test Setup

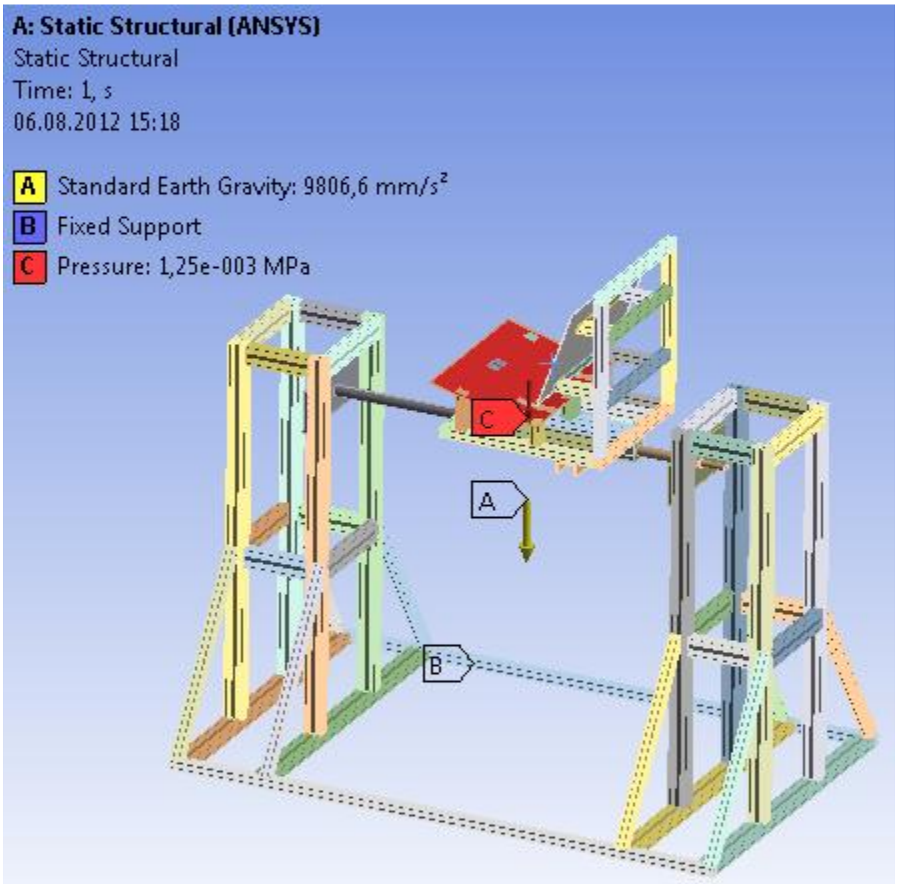


Figure 4.45 Overview of the Static Analysis of Overturning Test Device

The analysis results are given in Figure 4.42. As seen, the maximum stress value is nearly 30 MPa which is under the yield stress of the material. The material property is given in Chapter 3, Table 3.1 and Table 3.2. The observed result, 30 MPa, is very low for the system.

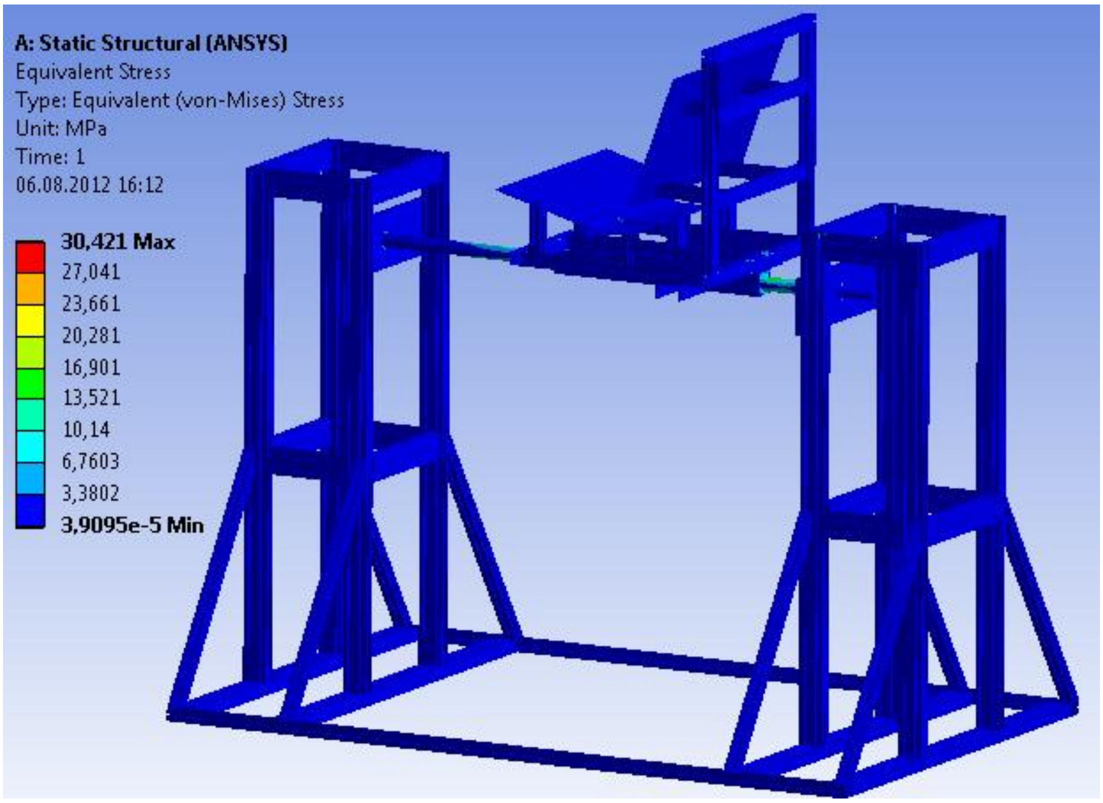


Figure 4.46 Result of The Static Analysis of the Overturning Test Device

4.5.2 Static Finite Element Analysis of the Support Structure

The load is applied to the bar from its outer surface as shown in Figure 4.43. The value of the force is 5000N which is the defined load in ECE R44.

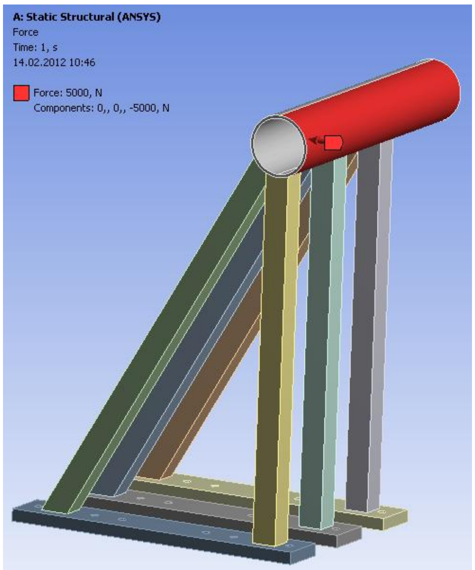


Figure 4.47 Applied Force on Support Bar

The effects of applied force are shown in Figures 4.44, 4.45 and 4.46. Directional deformation of the support bar is 0.14 mm as the maximum which is far smaller than the maximum value of 2 mm which is described in ECE R44. Maximum von-Mises stress is measured as 44.58 N and the safety factor is 5.6.

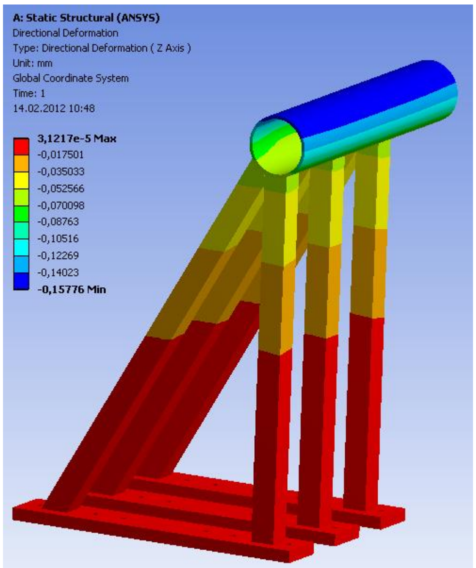


Figure 4.48 Directional Deformation on Support Bar

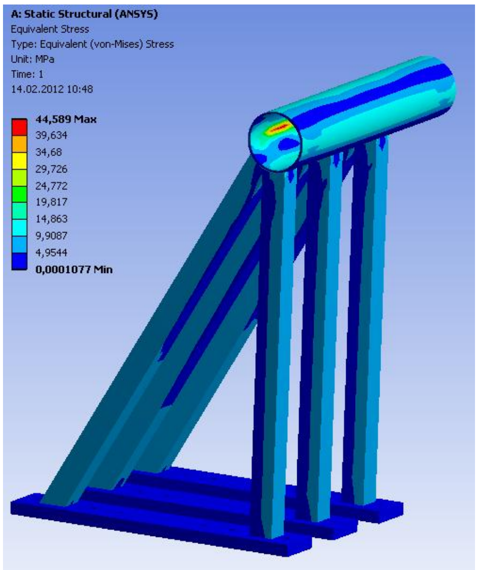


Figure 4.49 von-Mises Stress Distribution on Support Bar

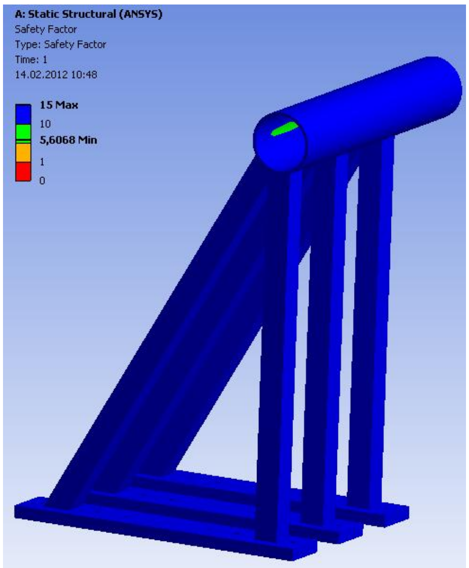


Figure 4.50 Safety Factor of the Support Bar

CHAPTER 5

PERFORMING OVERTURNING AND DYNAMIC TESTS AND ANALYSIS OF TEST RESULTS

5.1 Test Planning for ECE R44

Eleven pairs of overturning tests have been performed for different Child Restraint Systems (CRSs) with the child test dummies of 3 years old, 6 years old and 10 years old. Eight pairs of dynamic tests have been performed for different CRSs with the child test dummies of 3 years old, 6 years old.

Four different company's CRSs are used for these tests. Although the names and brands of CRSs will not be published in this thesis, the code names will be given to discuss the results. Structurally dissimilar CRSs with different prices are selected to observe their test performances. In Table 5.1, the related groups for each CRS according to ECE R44 [17] and relative prices are given. The groups of CRS according to the regulation have already been reviewed in Chapter 2. In Figure 5.1, photographs of the particular CRSs and their code names are shown.

Table 5.1 CRS's Prices, Groups and Related Child Test Dummy Information

CRS	Price	Group	Related Child Test Dummy
CRS A	300 Unit Price	I, II	3 years old, 6 years old
CRS B	150 Unit Price	II, III	3 years old, 6 years old, 10 years old
CRS C	75 Unit Price	II, III	3 years old, 6 years old, 10 years old
CRS D	250 Unit Price	I, II, III	3 years old, 6 years old, 10 years old

CRS A for Group I, II

CRS B for Group II, III

CRS C for Group II, III

CRS D for Group I, II, III

Figure 5.1 CRS Codes and Groups

CRS A is the most expensive one in the CRSs selected and can be used for Group I and Group II. The seat back angle is adjustable. CRS A has its own seat belt to be used to secure the children for 4 years old. In this case, the CRS A will be fastened to the seat of the vehicle by using the adult seat belt available on the vehicle as shown in Figure 5.2.

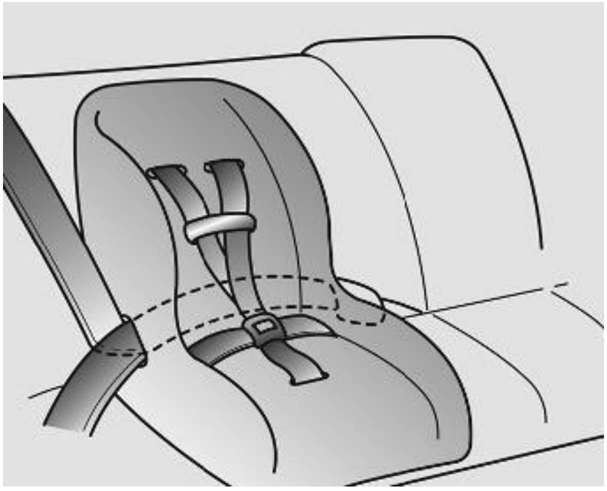


Figure 5.2 CRS Secured with Vehicle Seat Belt

On the other hand, the adult seat belt of the vehicle is required to secure children in older than 3 years old. CRS B is suitable for Groups II and III. It has a relatively simple design and it has not any adjustable components as shown in Figure 5.1. Its price is relatively half of price of the CRS A. It does not have any own seat belt. Therefore, the adult seat belt of the vehicle is required to secure the children. CRS C is very simple alternative and the cheapest one in the selected CRSs. It only helps to rise the children body to fit the adult seat belt of the vehicle. It is manufactured for both Group II and III. It does not have seat back and any adjustable component. CRS D is the second most expensive in the selected CRSs and can be used for Group I, II and III. It has own seat belts for 3 years old and adult seat belt is used for older ages. CRS A and CRS D has a head supporting component for 3 years old children.

5.2 Overturning Tests

5.2.1 Overturning Test Plan

Overturning tests are performed with the overturning test setup which is described in Chapter 3. The rotational speed must be in range of 2-5 ^{o}/sec [17] as mentioned in Chapter 2. For this thesis study, the rotational speed of 2.75 ^{o}/sec is applied for all the type of CRSs tested. Test sample groups, appropriate child test dummies and test list for overturning tests are given in Table 5.2.

Table 5.2 Overturning Test List

Test Number	CRS Type	Child Test Dummy
Test 1	CRS A	3 Years Old Child Test Dummy
Test 2	CRS B	3 Years Old Child Test Dummy
Test 3	CRS C	3 Years Old Child Test Dummy
Test 4	CRS D	3 Years Old Child Test Dummy
Test 5	CRS A	6 Years Old Child Test Dummy
Test 6	CRS B	6 Years Old Child Test Dummy
Test 7	CRS C	6 Years Old Child Test Dummy
Test 8	CRS D	6 Years Old Child Test Dummy
Test 9	CRS B	10 Years Old Child Test Dummy
Test 10	CRS C	10 Years Old Child Test Dummy
Test 11	CRS D	10 Years Old Child Test Dummy

5.2.2 Evaluation Criteria for Overturning Test

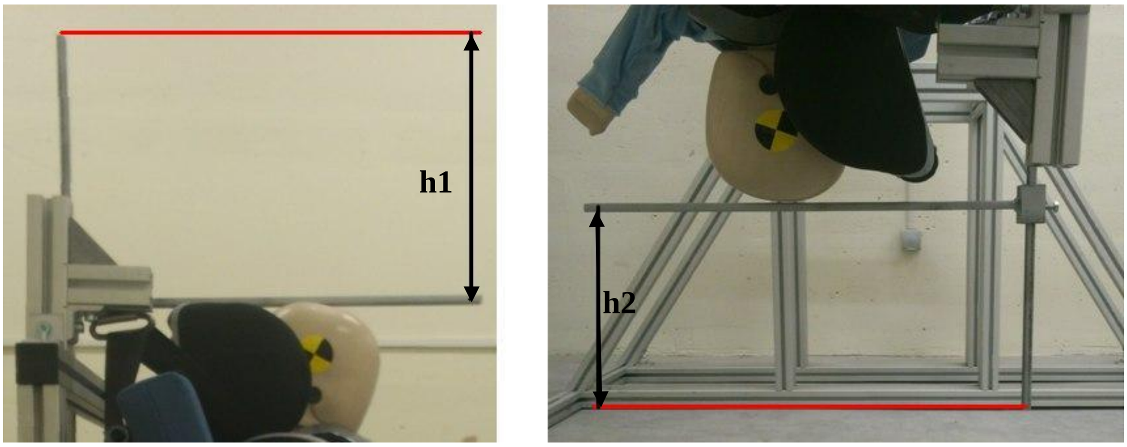
The test dummies without sensors (i.e. ballast) are used as described in ECE R44 [17]. During the overturning tests, the maximum head displacement value shall not be greater than 300 mm for a successful result.

Figure 5.3 Instants of Overturning Test

Different instants during the overturning test are given in Figure 5.3. It has been observed that the maximum head displacement occurs when the test seat becomes upside down. To measure the head displacement, two positions are recorded. The initial position, h_1, is measured before starting the test with the measuring scale as shown in Figure 5.4.a. The second position, h_2, is recorded when the test seat is rotated 180 degrees as shown in Figure 5.4.b. The difference between these two measurements gives the head displacement for the overturning test and this must be lower than 300 mm in both CW and CCW direction tests. For results;

If h_1-$h_2 \leq 300$ mm, then successful,

If h_1-$h_2 > 300$ mm, then failed.



a. Initial Position **b.** Upside Down Position

Figure 5.4 First and Second Positions of the Overturning Test

5.2.3 Results of Overturning Tests

In Tables 5.3-5.5, initial positions and upside down positions of the child test dummies are given. For 3 years old test dummy, CRS A and CRS D is used with their own seat belt system. But the CRS B and CRS C are not integrated with their own seat belts, they are tested with the standard adult seat belts.

Table 5.3 Head Displacement during Overturning Test with 3 Years Old Test Dummy

Test Samples	CRS A	CRS B	CRS C	CRS D
Initial Position	276 mm	362 mm	370 mm	325 mm
Upside Down Position for CW Rotation about X-Axis	257 mm	275 mm	270 mm	265 mm
Displacement in Z-Direction, Δz	19 mm	87 mm	100 mm	60 mm
Upside Down Position for CCW Rotation about X-Axis	267 mm	289 mm	282 mm	275 mm
Displacement in Z-Direction, Δz	9 mm	73 mm	88 mm	50 mm
Upside Down Position for CW Rotation about Y-Axis	257 mm	282 mm	286 mm	280 mm
Displacement in Z-Direction, Δz	19 mm	80 mm	84 mm	45 mm
Upside Down Position for CCW Rotation about Y-Axis	261 mm	284 mm	289 mm	288 mm
Displacement in Z-Direction, Δz	15 mm	78 mm	81 mm	37 mm

According to ECE R44, the maximum displacement in z-direction must be lower than 300 mm. For the 3 years old child test dummy, the measurements are given in Table 5.3. The results show that all values are below 300 mm. However, each CRS has different performance in these tests. CRS A achieved the best performance. The maximum displacement in z-direction is 19 mm for CRS A. CRS D is the second best in these CRSs. CRS B and CRS C are the third and fourth CRSs in the set as seen in Table 5.3.

Table 5.4 Head Displacement During Overturning Test with 6 Years Old Test Dummy

Test Samples	**CRS A**	**CRS B**	**CRS C**	**CRS D**
First Position	195 mm	280 mm	275 mm	275 mm
Upside Down Position for CW Rotation about X-Axis	150 mm	205 mm	220 mm	224 mm
Displacement in Z-Direction, Δz	45 mm	75 mm	55 mm	51 mm
Upside Down Position for CCW Rotation about X-Axis	155 mm	215 mm	245 mm	237 mm
Displacement in Z-Direction, Δz	40 mm	65 mm	30 mm	38 mm
Upside Down Position for CW Rotation about Y-Axis	145 mm	207 mm	218 mm	215 mm
Displacement in Z-Direction, Δz	50 mm	73 mm	57 mm	60 mm
Upside Down Position for CCW Rotation about Y-Axis	165 mm	210 mm	230 mm	229 mm
Displacement in Z-Direction, Δz	30 mm	70 mm	45 mm	46 mm

The results of 6 years old test dummy are given in Tables 5.4. For the 6 years old child test dummy, the results are similar with the tests performed with the 3 years old child test dummy. All the results are below the limit of ECE R44. CRS A is the best in the set. CRS C is the second, CRS D is the third and CRS B is the fourth best in these CRSs.

Table 5.5 Head Displacement During Overturning Test 10 with Years Old Test Dummy Continued

Test Samples	**CRS B**	**CRS C**	**CRS D**
First Position	175 mm	225 mm	161 mm
Upside Down Position for CW Rotation about X-Axis	130 mm	175 mm	148 mm
Displacement in Z-Direction, Δz	45 mm	50 mm	13 mm
Upside Down Position for CCW Rotation about X-Axis	150 mm	161 mm	156 mm
Displacement in Z-Direction, Δz	25 mm	64 mm	5 mm
Upside Down Position for CW Rotation about Y-Axis	155 mm	176 mm	143 mm
Displacement in Z-Direction, Δz	20 mm	49 mm	18 mm
Upside Down Position for CCW Rotation about Y-Axis	165 mm	183 mm	144 mm

Table 5.5 Head Displacement During Overturning Test 10 with Years Old Test Dummy

Test Samples	**CRS B**	**CRS C**	**CRS D**
Displacement in Z-Direction, Δz	10 mm	42 mm	17 mm

The results of the overturning tests performed with the 10 years old test dummy are under the limit of ECE R44. CRS D is the best in the set. CRS B is the second and CRS C is the third in these CRSs. The test results of 10 years old test dummy is given in Table 5.5. In Figures 5.5, 5.6, 5.7, 5.8 the results are grouped according to direction of rotations and child test dummy ages. Displacement trends can be seen in these tables.

When the Tables 5.3-5.5 are examined, it can be seen that the displacement measurements between first position and second position for the CW rotations are greater than the measurements for the CCW rotation for all tests. This is observed because of the position of the seat belt D-ring which is the upper anchorage part of seat belt. For the CW rotations, the shoulder belt lets the test dummy move. This is due to the orientation of the shoulder seat belt and child test dummy. As seen in Figure 2.9 the shoulder belt part of the seat belt is over the right shoulder of child test dummy. In CCW rotation, the child test dummy rotates to its right while in CW rotation it rotates to its left. The dummy is not held from its left shoulder and the dummy is free to move more for CW rotations.

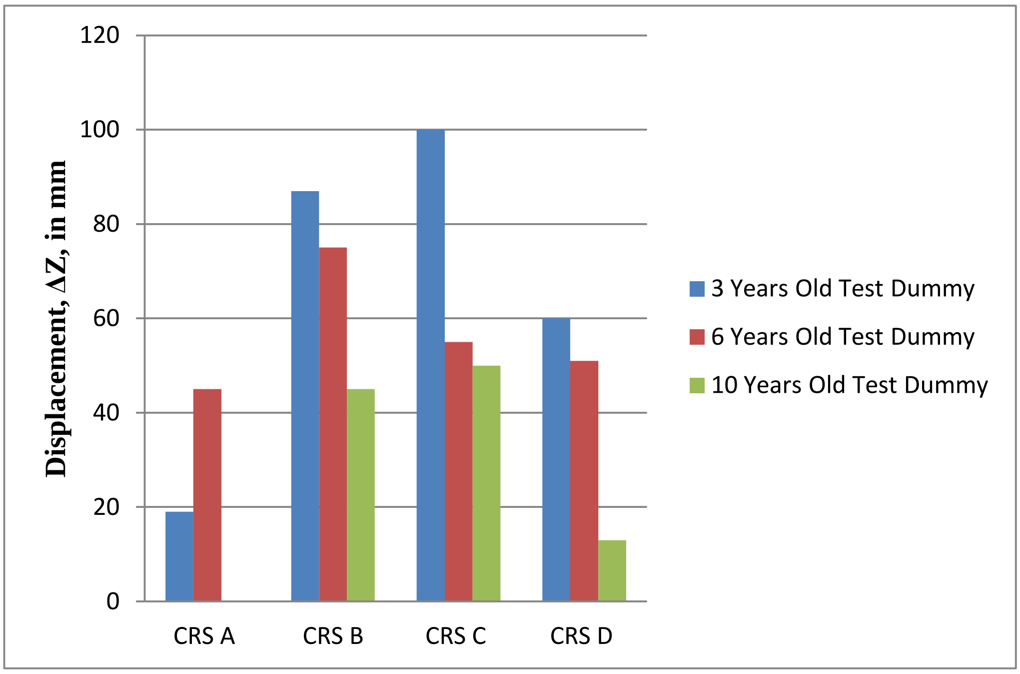


Figure 5.5 Displacements in Z-Direction for CW Rotation About X-Axis

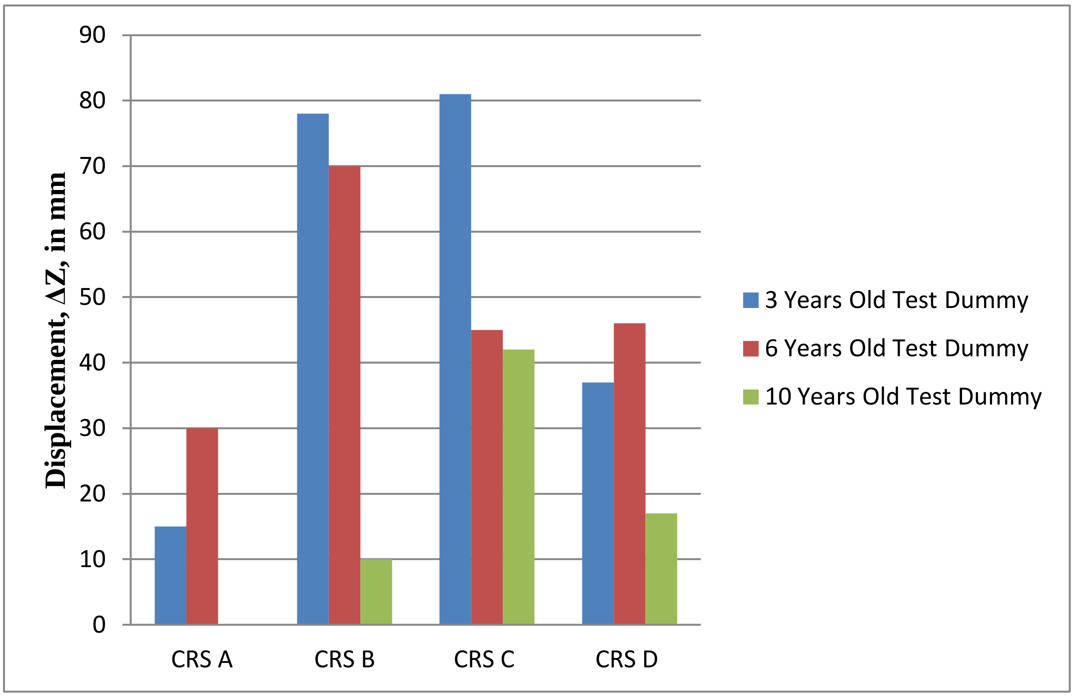


Figure 5.6 Displacements in Z-Direction for CCW Rotation About X-Axis

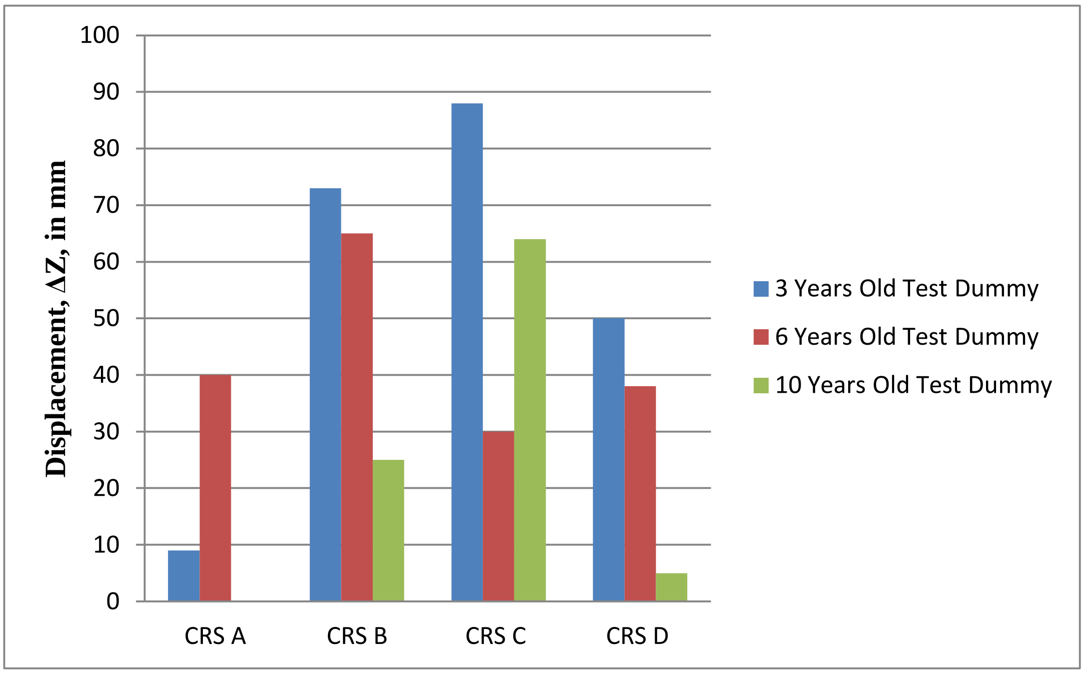


Figure 5.7 Displacements in Z-Direction for CW Rotation About Y-Axis

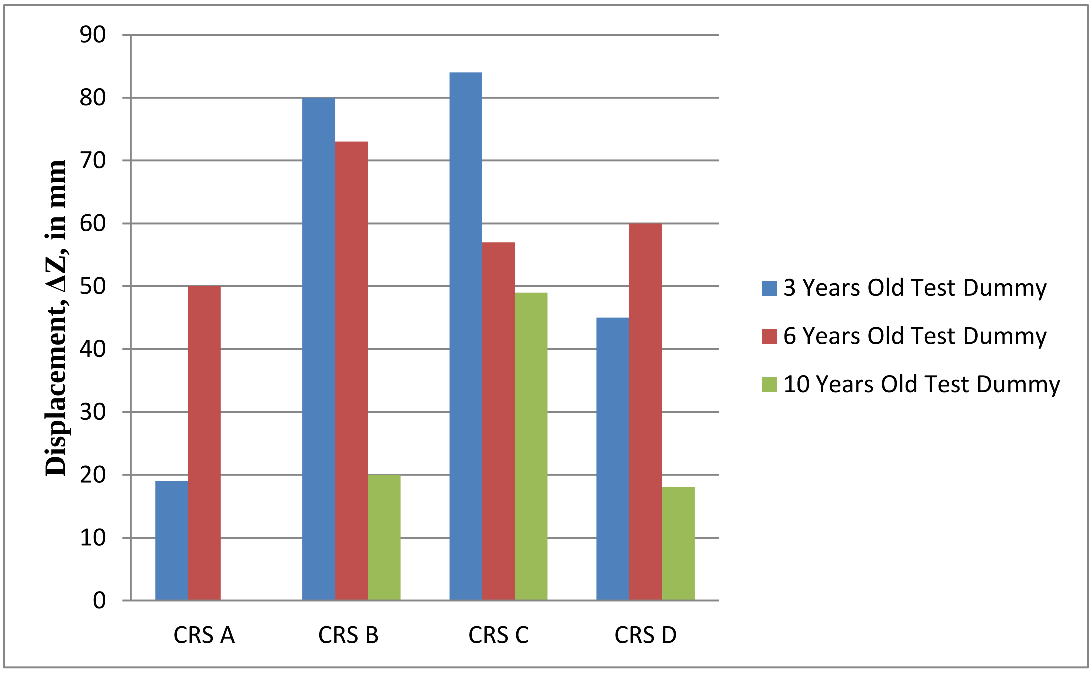


Figure 5.8 Displacements in Z-Direction for CCW Rotation About Y-Axis

5.3 Dynamic Tests

5.3.1 Dynamic Test Planning

Dynamic tests are performed with the IST Crash Test Simulation System. The frontal impact acceleration corridor is given in Figure 2.8. For this study, the iterated test signal is produced with IST Crash Test Simulation System in METU-BILTIR Center Sled Test Facility and given in Figure 5.9.

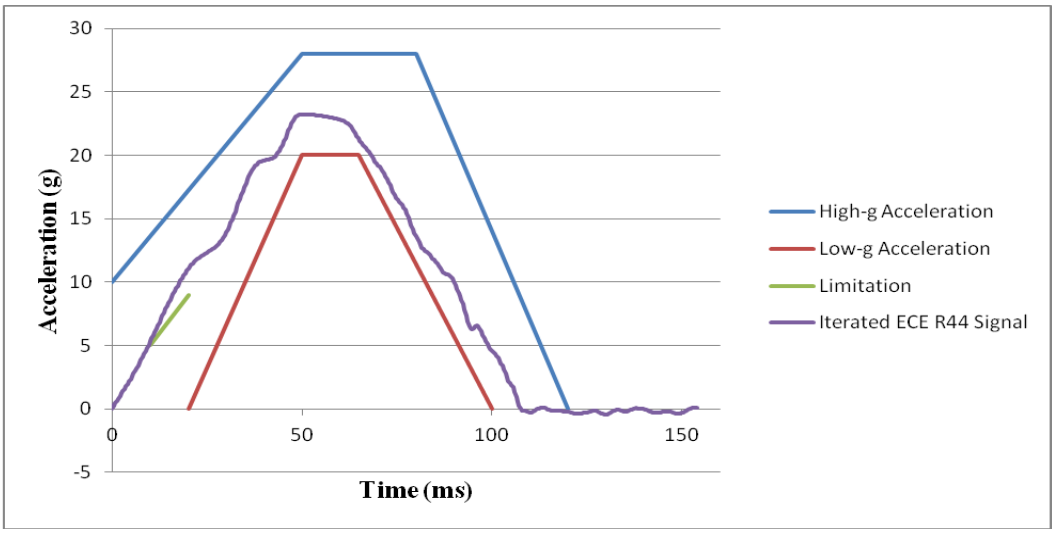


Figure 5.9 Iterated Test Signal According to ECE R44

Apart from this system, other important elements of the tests are 3 years old and 6 years old P series instrumented child test dummies. For dynamic tests video records are the most important data along with the sensor data. Weinberger Vision Visario G2 high speed camera is used to record whole crash simulation. The camera is set to 1000 frame/second (fps) to record the crash simulation and a video sample is shown in Figure 5.9. For the dynamic tests, the dummies are instrumented for the chest acceleration values. Because of this, Kayser Threde Minidau Advanced data acquisition system is used to record the data occurred on the child test dummy during the crash simulation.

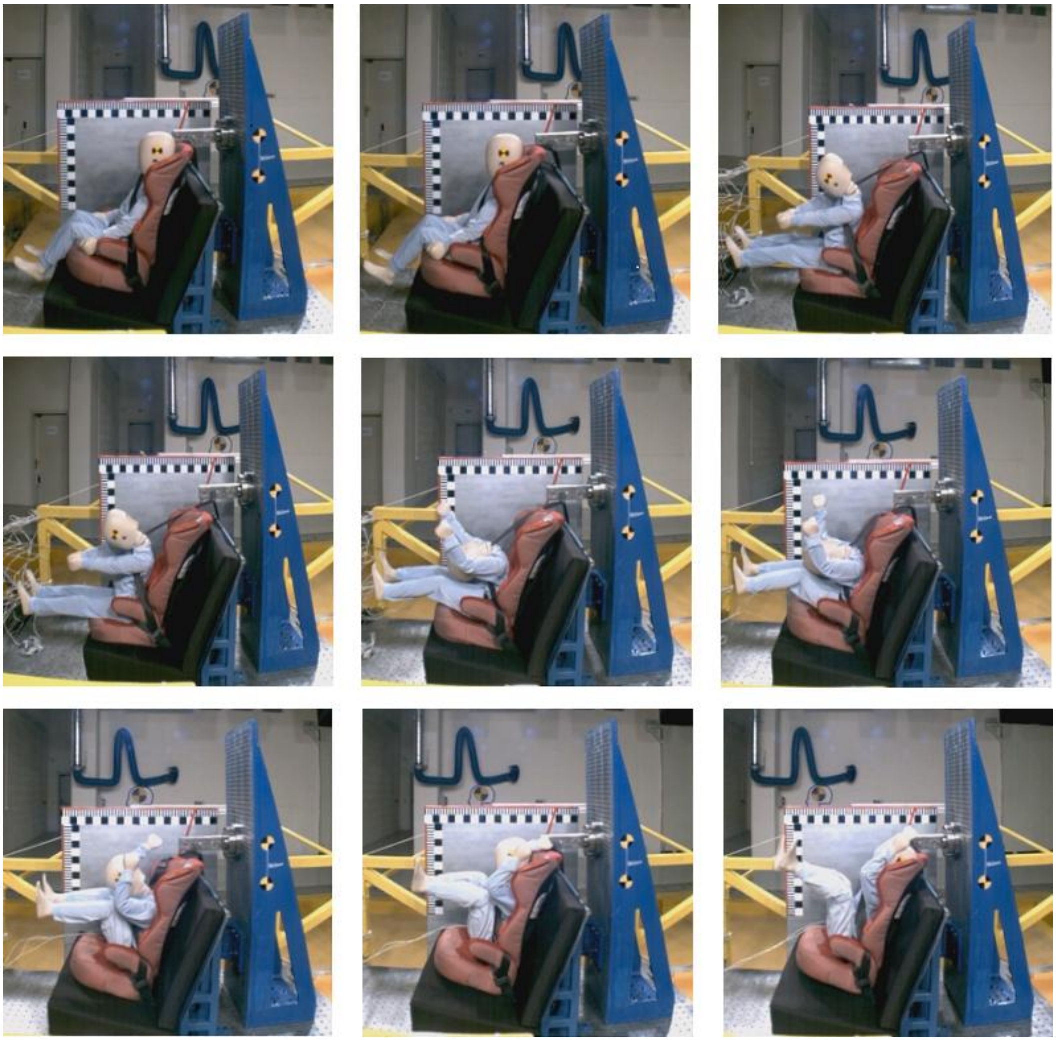


Figure 5.10 Dynamic Test Video Sample

The dynamic tests are performed with the locked and the unlocked seat belt retractors to compare the normative conditions and misusage conditions. The gathered data will be evaluated according to ECE R44. Dynamic test video samples are given in Figure 5.10 and the test list is given in Table 5.6.

Table 5.6 Dynamic Test List

Test Number	CRS Type	Child Test Dummy	Seat Belt Condition
Test 1	CRS A	3 Years Old Child Test Dummy	Locked
Test 2	CRS B	3 Years Old Child Test Dummy	Locked
Test 3	CRS C	3 Years Old Child Test Dummy	Locked
Test 4	CRS D	3 Years Old Child Test Dummy	Locked
Test 5	CRS A	6 Years Old Child Test Dummy	Locked
Test 6	CRS B	6 Years Old Child Test Dummy	Locked
Test 7	CRS C	6 Years Old Child Test Dummy	Locked
Test 8	CRS D	6 Years Old Child Test Dummy	Locked
Test 9	CRS A	3 Years Old Child Test Dummy	Unlocked
Test 10	CRS B	3 Years Old Child Test Dummy	Unlocked
Test 11	CRS C	3 Years Old Child Test Dummy	Unlocked
Test 12	CRS D	3 Years Old Child Test Dummy	Unlocked
Test 13	CRS A	6 Years Old Child Test Dummy	Unlocked
Test 14	CRS B	6 Years Old Child Test Dummy	Unlocked
Test 15	CRS C	6 Years Old Child Test Dummy	Unlocked
Test 16	CRS D	6 Years Old Child Test Dummy	Unlocked

5.3.2 Evaluation Criteria for Dynamic Tests

The child test dummies are fitted with three accelerometers. These accelerometers are used for X-direction, Y-direction and Z-direction. The data gathered with sensors are filtered. In the vehicle safety tests, commonly used filters are Channel Frequency Class (CFC) filters. As defined by SAE J211, the accelerometer used in child dummies is filtered with CFC 60 [28]. The CFC filter types are given in Table 5.7. The limits for Z-direction acceleration and resultant acceleration are given as 30g and 55g, respectively. If the over-limit accelerations last less than 3ms than the tests are evaluated as conforming according to ECE R44. The directions of chest accelerometer are shown in Figure 5.11.

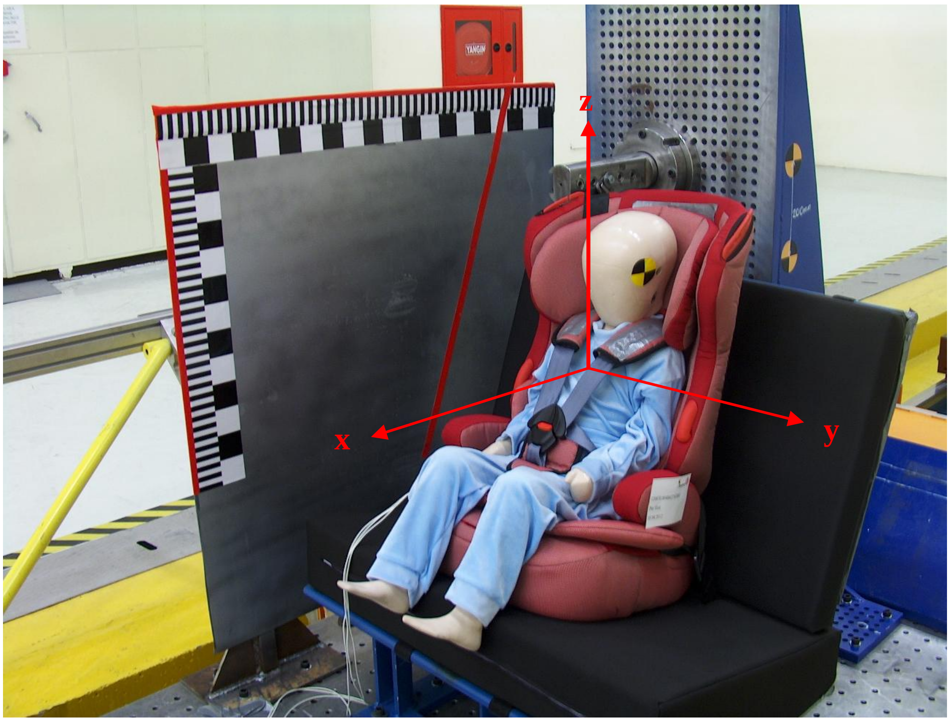


Figure 5. 11 Directions of Chest Accelerometer

Table 5.7 CFC Filter Types [28]

Filter	Filter Parameters	
CFC 60	3 dB Limit Frequency	100 Hz
	Stop Damping	-30 dB
	Sampling Frequency	At least 600 Hz
CFC 180	3 dB Limit Frequency	300 Hz
	Stop Damping	-30 dB
	Sampling Frequency	At least 1800 Hz
CFC 600	3 dB Limit Frequency	1000 Hz
	Stop Damping	-40 dB
	Sampling Frequency	At least 6 kHz
CFC 100	3 dB Limit Frequency	1650 Hz
	Stop Damping	-40 dB
	Sampling Frequency	At least 10 kHz

A sample of modelling clay shall be vertically placed to the front of the lumbar vertebrae by means of thin adhesive tape. A deflection of the modelling clay does not necessarily mean that penetration has taken place. Only penetration caused by seat belt or CRS belt is an important sign of penetration. The modelling clay samples shall be of the same length and width as the lumbar spinal column; the thickness of the samples shall be 25 ± 2 mm [17]. Only the modelling clay supplied with the child test dummies, which is shown in Figure 5.11, is used.

Figure 5.12 Modelling Clay supplied with the Child Test Dummies

The child restraints for forward facing child restraints, the head of the child test dummy should not pass beyond the limits BA and DA as shown in Figure 5.12 for a successful result. This is judged by observing up to 300 ms or the moment that the child test dummy has come to a definitive standstill, whatever occurs first, according to the video records.

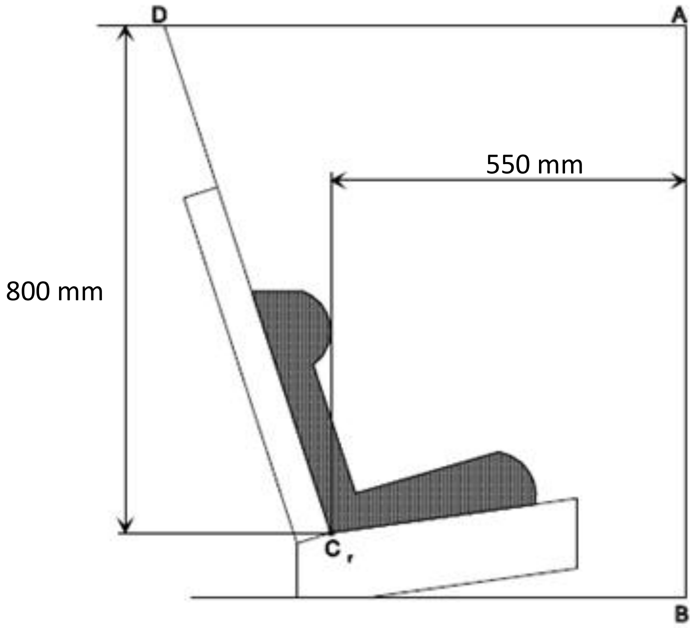


Figure 5.13 Head Displacement Limits

5.3.3 Results of Dynamic Tests

Despite the physical differences of the test dummies, the displacement limits, the chest acceleration limit and the abdominal penetration criteria are the same for all tests in ECE R44. CRS A and CRS D have been tested with their own seat belts for 3 years old child test dummy. The tests are performed with the adult seat belts for CRS B and CRS C tests with 3 years old child test dummy and for all the seats with 6 old child test dummy.

The child test dummy's head must remain in the limits which are defined in Figure 5.12 during the tests. Any movement further than the limits is counted as failure according to ECE R44. Tests have been performed according to the definition of ECE R44 by using the locked seat belt and to make a comparison between locked and unlocked seat belt usage 8 more tests with unlocked seat belt have been performed. The displacement limits are examined after the tests with the video record taken during the tests. During the test video inspection the farthest position from the initial position is taken into account. Table 5.8 shows the position of the head at its farthest position for each test case.

In Table 5.8 (a-h) shows the photographs for the test with the locked seat belts according to ECE R44. According to the displacement criterion, CRS A is failed for both of 3 and 6 years old test dummies as shown in Table 5.8 (a-e). CRS B was successful for 3 years old child test dummy but it failed for 6 years old child test dummy. CRS C was successful for both 3 and 6 years old child test dummies. CRS D is failed for both 3 and 6 years old child test dummies.

Table 5.8 (i-p) shows the photographs for the tests performed with the unlocked seat belts. When the displacements of the head are examined for the test with locked seat belt and test with unlocked seat belts, generally the displacements increased in the tests with the unlocked seat belts as expected. For the photographs of Table 5.8 (d) and Table 5.8 (l) is compared, there was a contradiction to this. After the test of CRS D with locked seat belt and 3 years old child test dummy, it was observed that the metal part shown in Figure 5.13 had been deformed. It can be said that unexpected result was due to this deformation occurred.

Although CRS C was found successful for the test performed with 6 years old child test dummy with locked seat belt (i.e proper way usage), the head position passed the limits for the unlocked seat belt usage (i.e misusage of the seat belt).

Table 5.8 Test Video Inspection for Displacement Limit Continued

Test Video Inspection for Displacement Limit	
Locked Seat Belt	Unlocked Seat Belt
(a) 3 Years Old Test Dummy Tested With CRS A Displacement Limits	(i) 3 Years Old Test Dummy Tested With CRS A Displacement Limits
	
(b) 3 Years Old Test Dummy Tested With CRS B Displacement Limits	(j) 3 Years Old Test Dummy Tested With CRS B Displacement Limits
	

Table 5.8 Test Video Inspection for Displacement Limit Continued

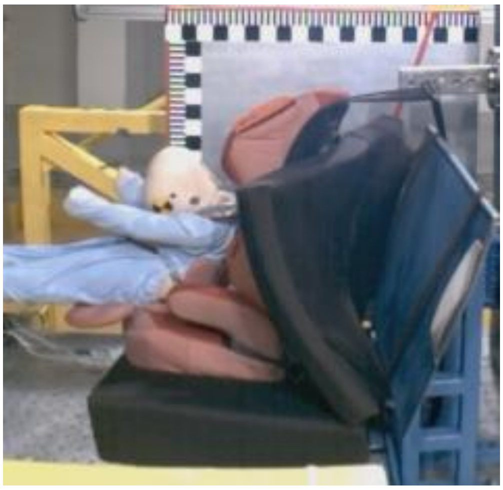
Test Video Inspection for Displacement Limit	
Locked Seat Belt	Unlocked Seat Belt
(c) 3 Years Old Test Dummy Tested With CRS C Abdominal Penetration	(k) 3 Years Old Test Dummy Tested With CRS C Abdominal Penetration
	
(d) 3 Years Old Test Dummy Tested With CRS D Displacement Limits	(l) 3 Years Old Test Dummy Tested With CRS D Displacement Limits
	

Table 5.8 Test Video Inspection for Displacement Limit Continued

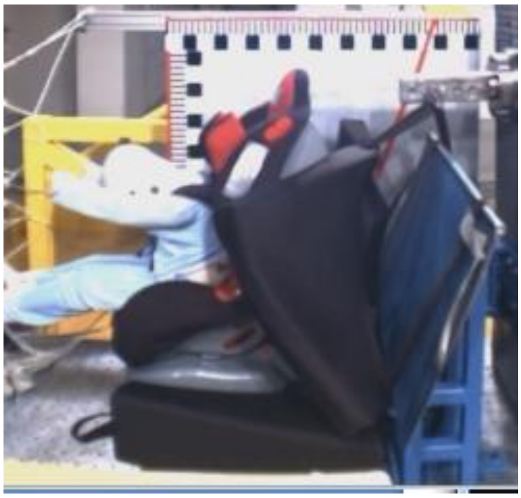
<table>
<tr><th colspan="2">Test Video Inspection for Displacement Limit</th></tr>
<tr><th>Locked Seat Belt</th><th>Unlocked Seat Belt</th></tr>
<tr><td>(e) 6 Years Old Test Dummy Tested With CRS A Displacement Limits</td><td>(m) 6 Years Old Test Dummy Tested With CRS A Displacement Limits</td></tr>
<tr><td></td><td></td></tr>
<tr><td>(f) 6 Years Old Test Dummy Tested With CRS B Displacement Limits</td><td>(n) 6 Years Old Test Dummy Tested With CRS B Displacement Limits</td></tr>
<tr><td></td><td></td></tr>
</table>

Table 5.8 Test Video Inspection for Displacement Limit

Test Video Inspection for Displacement Limit	
Locked Seat Belt	Unlocked Seat Belt
(g) 6 Years Old Test Dummy Tested With CRS C Displacement Limits	(o) 6 Years Old Test Dummy Tested With CRS C Displacement Limits
	
(h) 6 Years Old Test Dummy Tested With CRS D Displacement Limits	(p) 6 Years Old Test Dummy Tested With CRS D Displacement Limits
	

It is observed that the head displacement limit for X-direction is exceeded for some of the tests performed with locked and unlocked seat belts. CRS B and CRS C for 3 years old child test dummy and CRS C for 6 years old child test dummy achieved a successful test according to ECE R44. With unlocked seat belt CRS B and CRS C for 3 years old child test dummy remain in the limits. CRS C does not have a seat back and CRS B has a thin seat back relatively. Because of these factors, the dummy remain in the limits.

The test performed with 3 years old child test dummy and CRS D, unlocked seat belt performance looks better than locked one. But the test performed with locked seat belt, a failure occurred at CRS's own seat belt. And that may have effect the results. The failure can be seen in Figure 5.43. The bottom part of the CRS seat belt is dislocated from its position and the seat belt part is bended.

Figure 5.14 CRS D Seat Belt Failure

The acceleration values are gathered by the data acquisition system. The test dummies are instrumented with a 3 axial accelerometer. As indicated in the ECE R44, acceleration value for Z-Direction and the resultant acceleration value will be evaluated. The test results are given alternately from the Z-Direction acceleration to the resultant acceleration in Figure 5.14 – Figure 5.45.

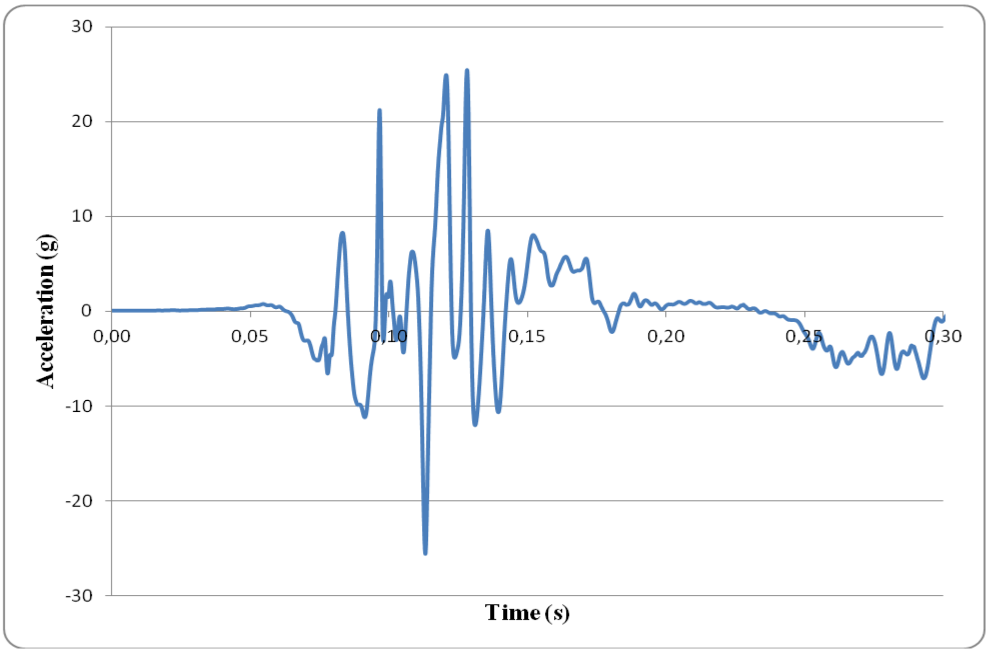


Figure 5.15 Z-Direction Acceleration Value on 3 Years Old Child Dummy during the Test of CRS A with Locked Seat Belt

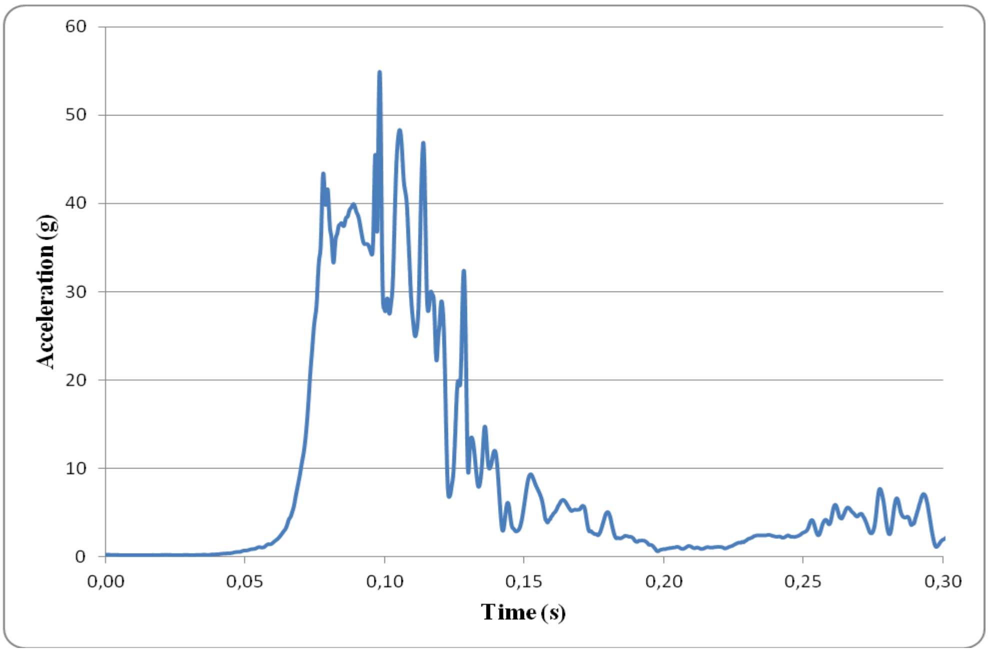


Figure 5.16 Resultant Acceleration Value on 3 Years Old Child Dummy during the Test of CRS A with Locked Seat Belt

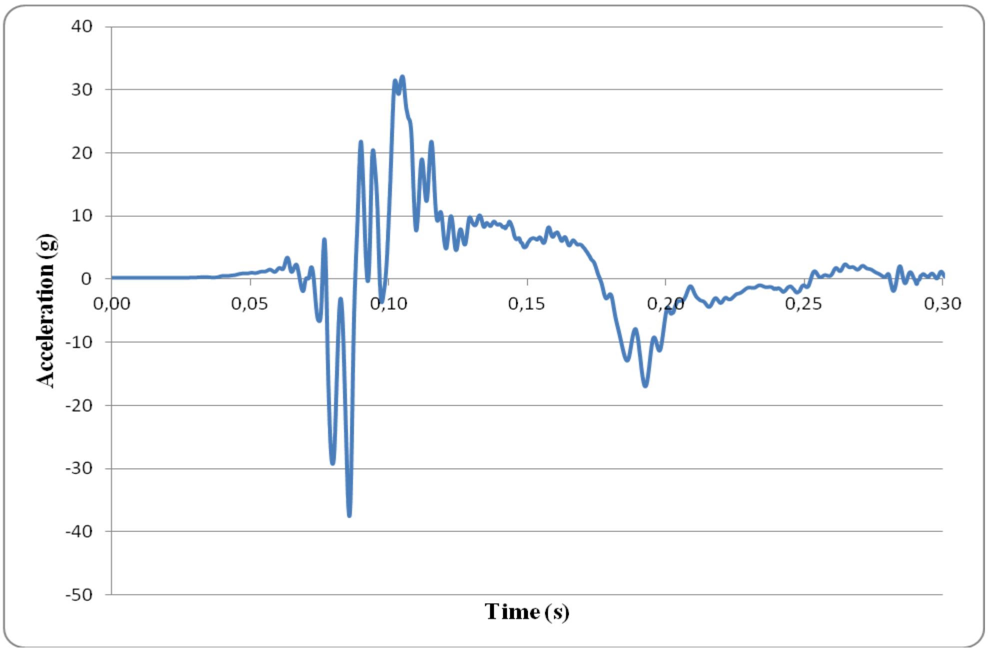


Figure 5.17 Z-Direction Acceleration Value on 3 Years Old Child Dummy during the Test of CRS B with Locked Seat Belt

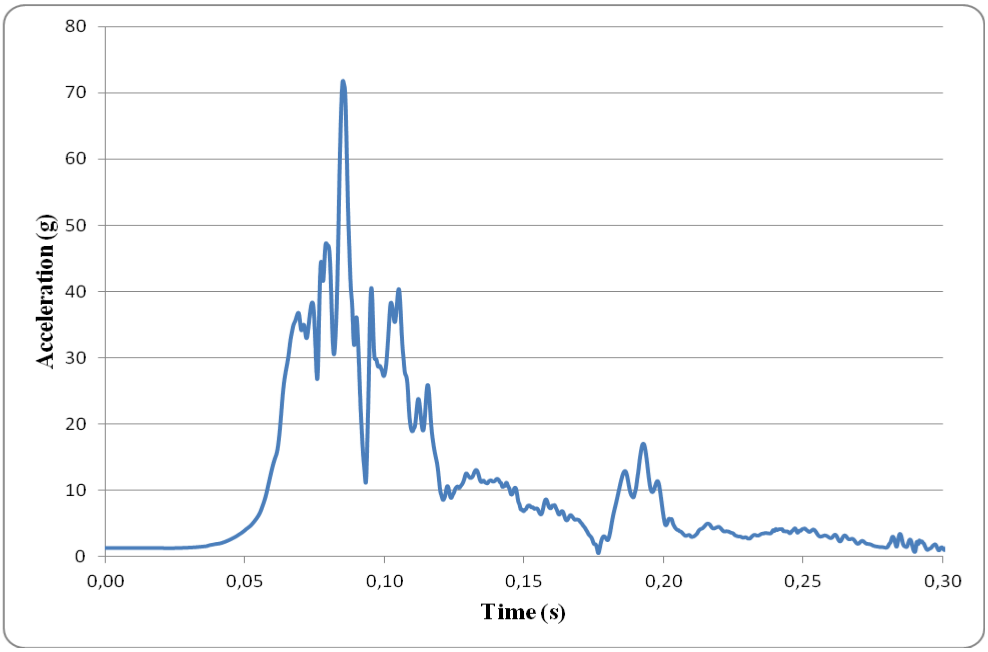


Figure 5.18 Resultant Acceleration Value on 3 Years Old Child Dummy during the Test of CRS B with Locked Seat Belt

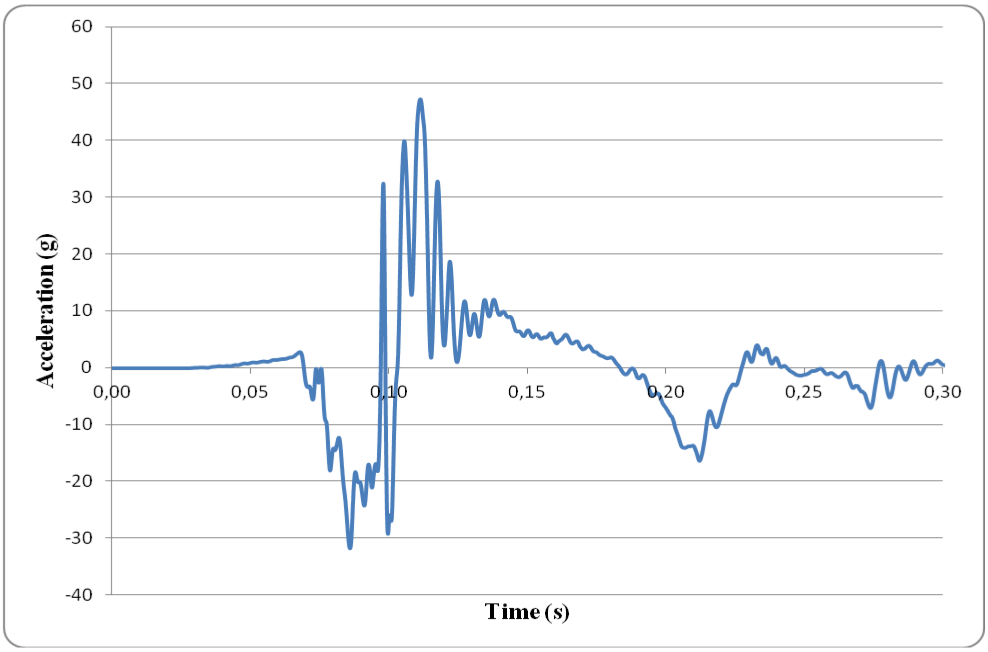


Figure 5.19 Z-Direction Acceleration Value on 3 Years Old Child Dummy during the Test of CRS C with Locked Seat Belt

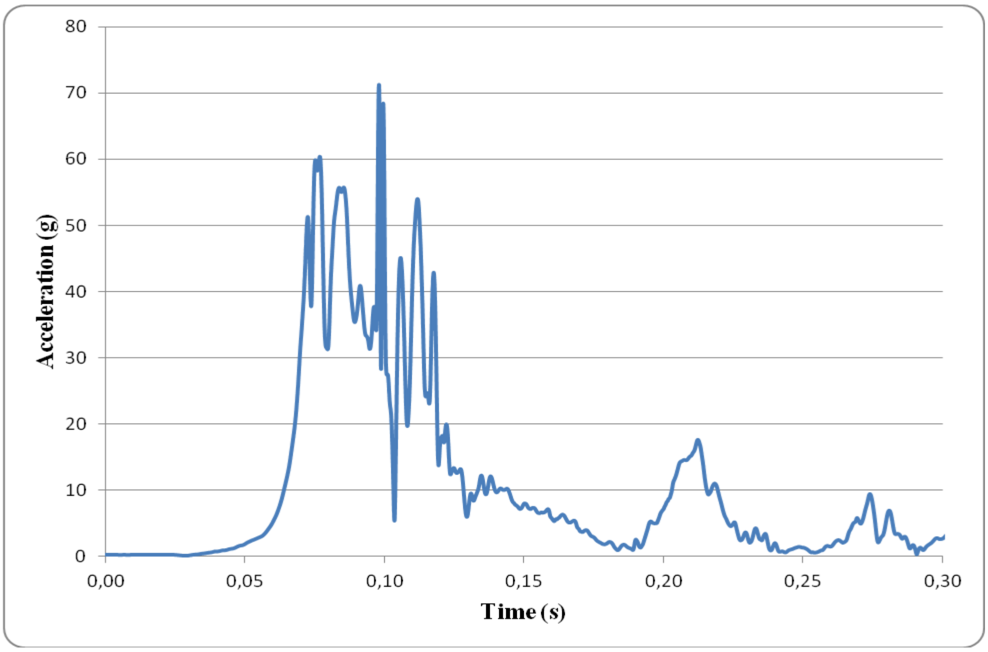


Figure 5.20 Resultant Acceleration Value on 3 Years Old Child Dummy during the Test of CRS C with Locked Seat Belt

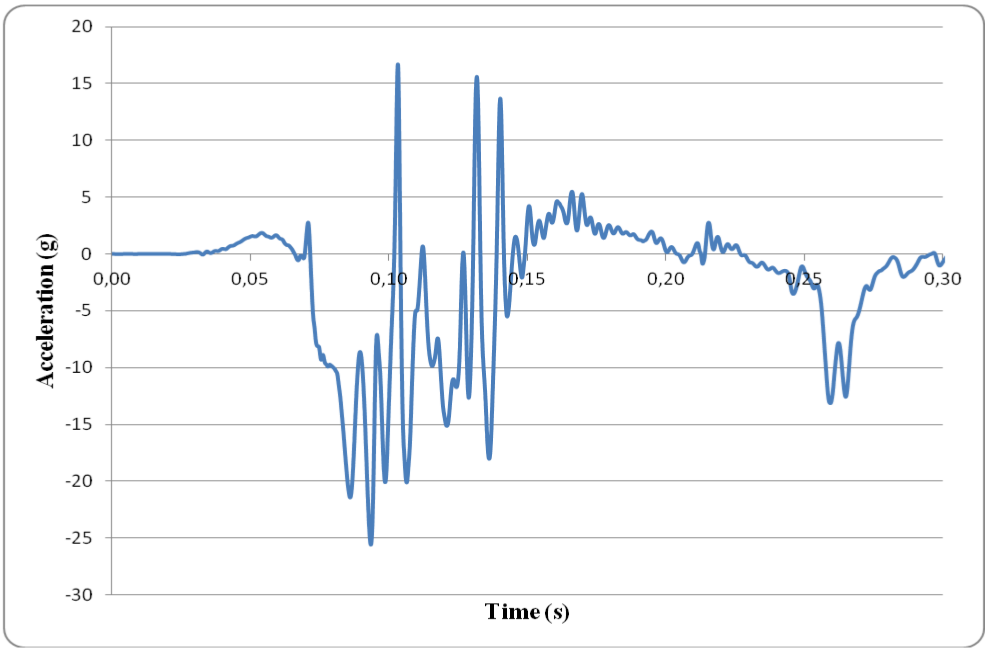


Figure 5.21 Z-Direction Acceleration Value on 3 Years Old Child Dummy during the Test of CRS D with Locked Seat Belt

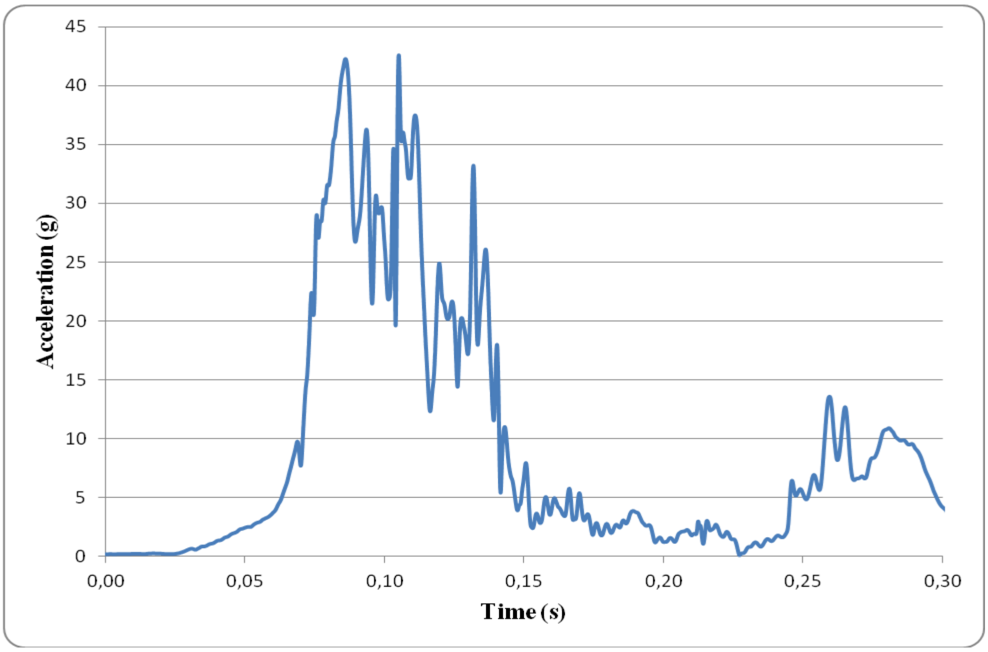


Figure 5.22 3 Resultant Acceleration Value on 3 Years Old Child Dummy during the Test of CRS D with Locked Seat Belt

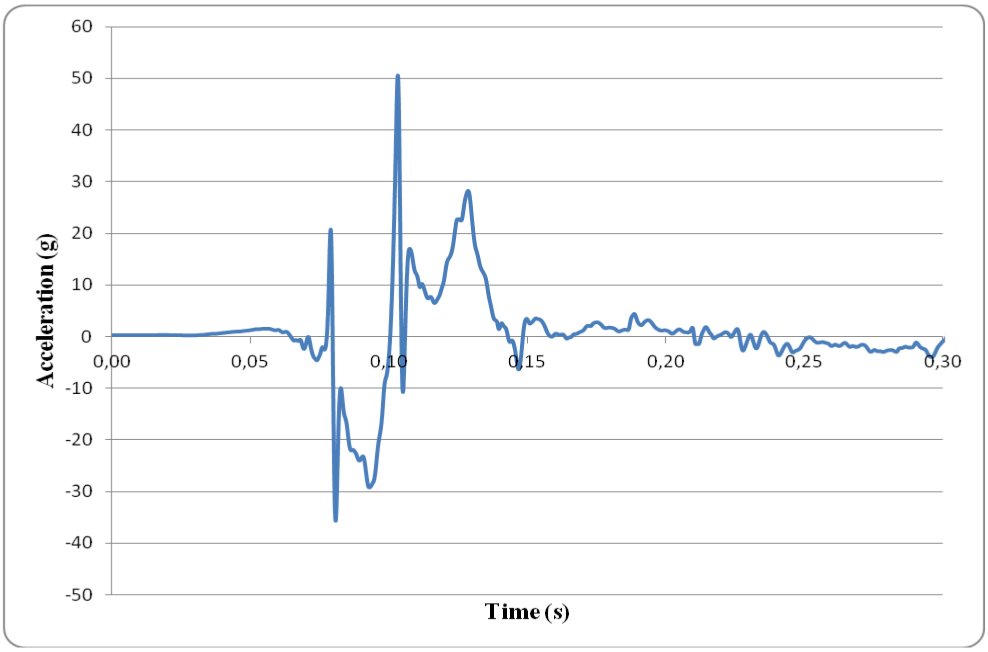


Figure 5.23 Z-Direction Acceleration Value on 6 Years Old Child Dummy during the Test of CRS A with Locked Seat Belt

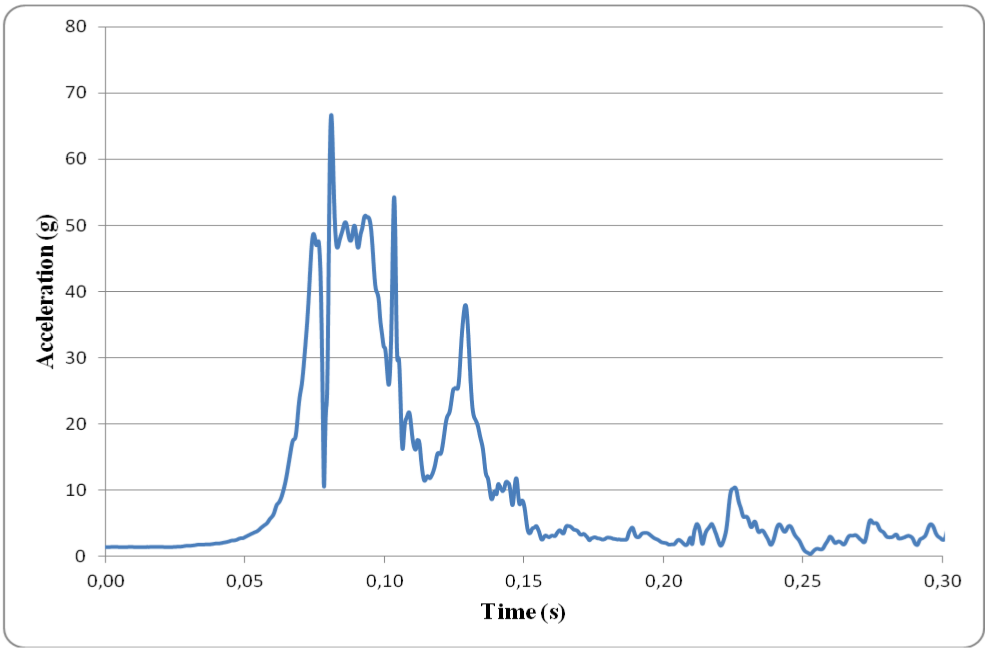


Figure 5.24 Resultant Acceleration Value on 6 Years Old Child Dummy during the Test of CRS A with Locked Seat Belt

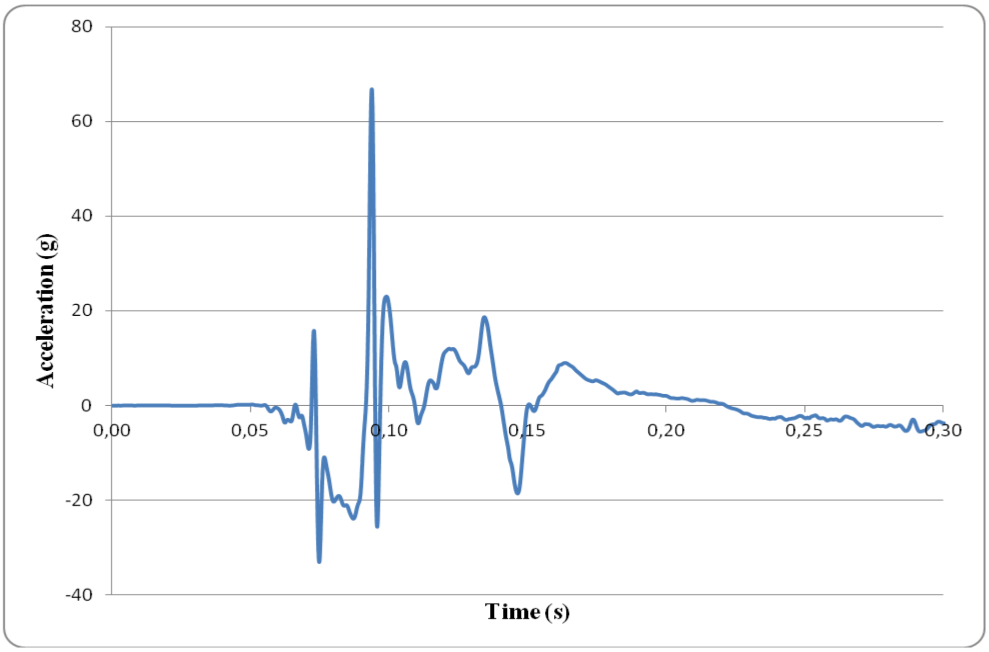


Figure 5.25 Z-Direction Acceleration Value on 6 Years Old Child Dummy during the Test of CRS B with Locked Seat Belt

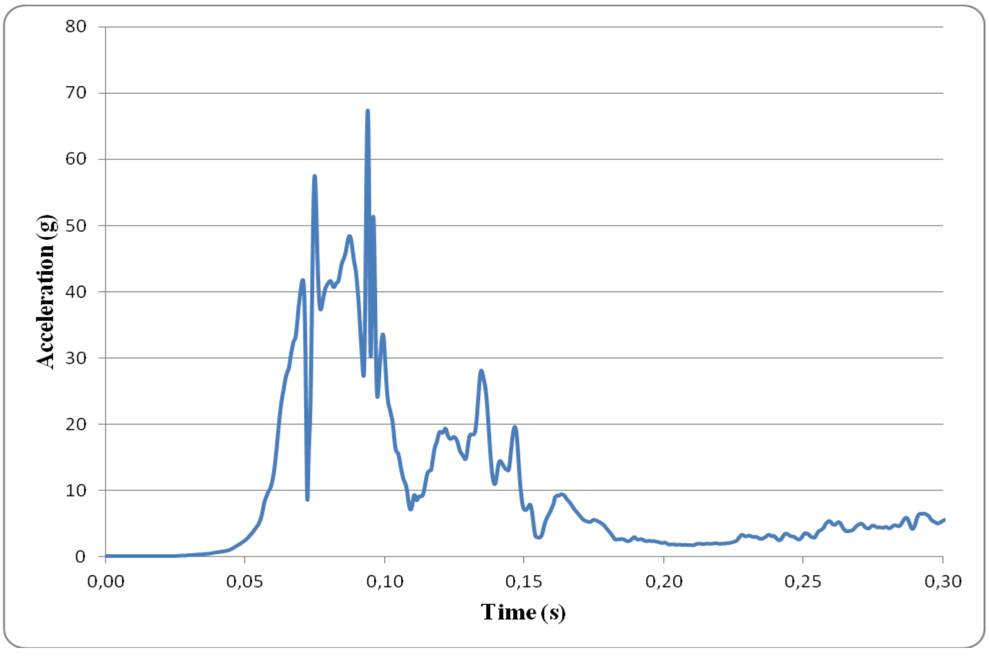


Figure 5.26 Resultant Acceleration Value on 6 Years Old Child Dummy during the Test of CRS B with Locked Seat Belt

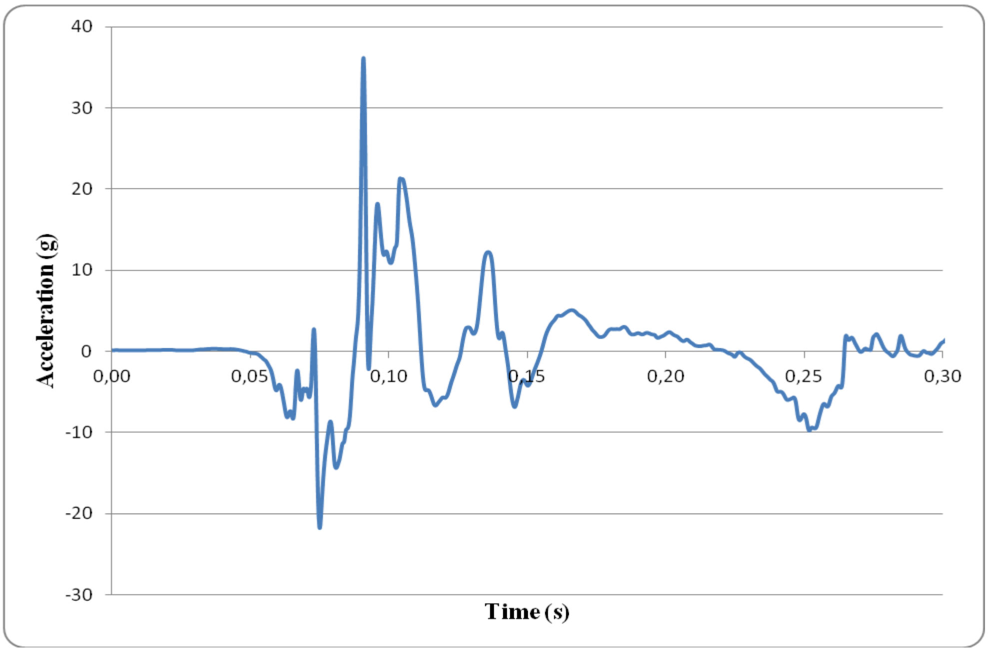


Figure 5.27 Z-Direction Acceleration Value on 6 Years Old Child Dummy during the Test of CRS C with Locked Seat Belt

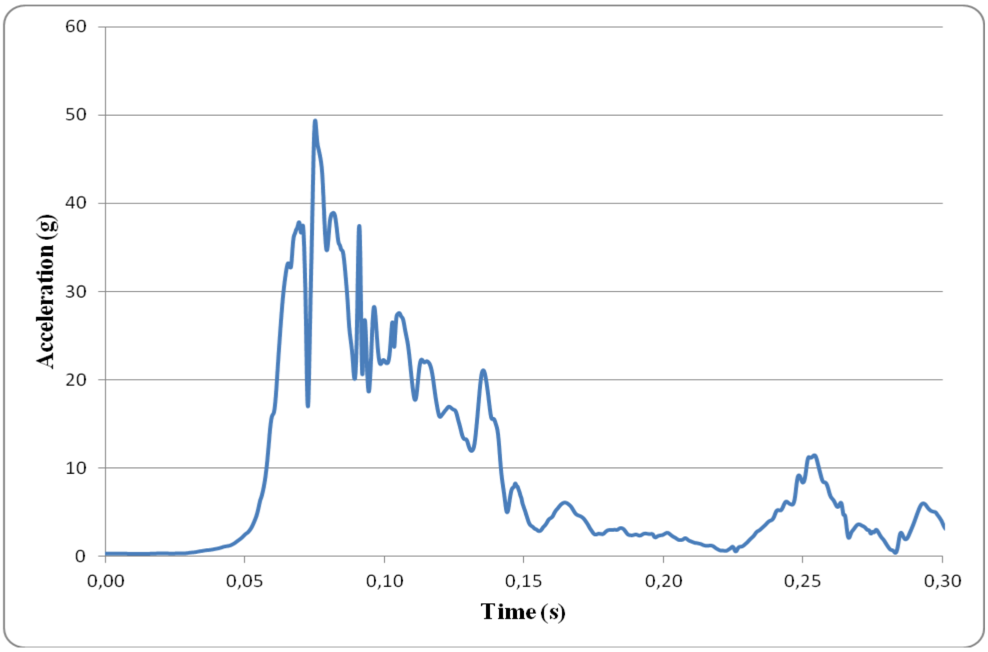


Figure 5.28 Resultant Acceleration Value on 6 Years Old Child Dummy during the Test of CRS C with Locked Seat Belt

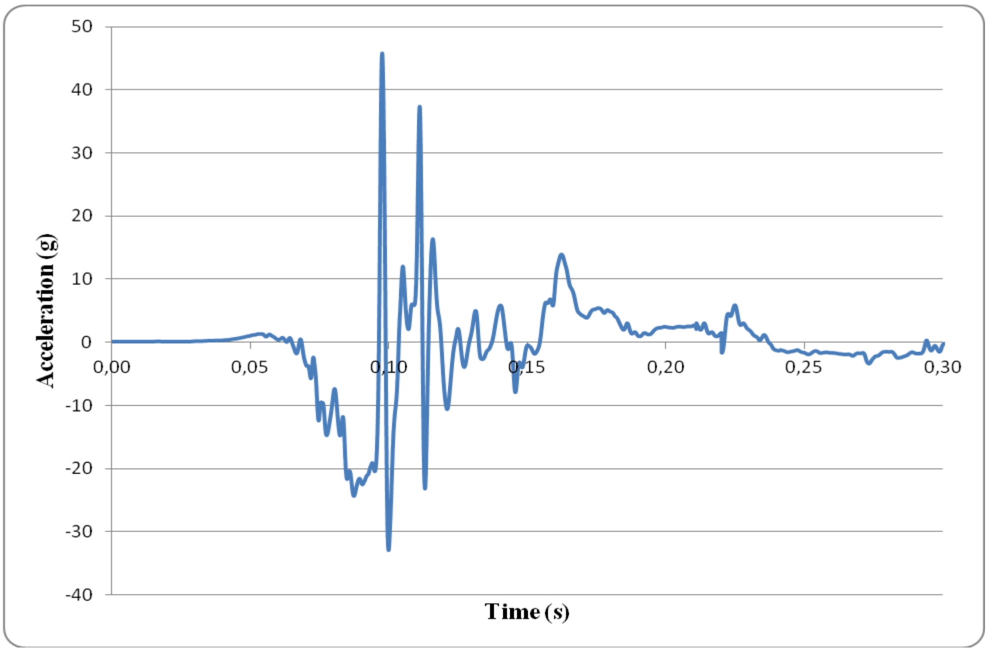


Figure 5.29 Figure 5.14 Z-Direction Acceleration Value on 6 Years Old Child Dummy during the Test of CRS D with Locked Seat Belt

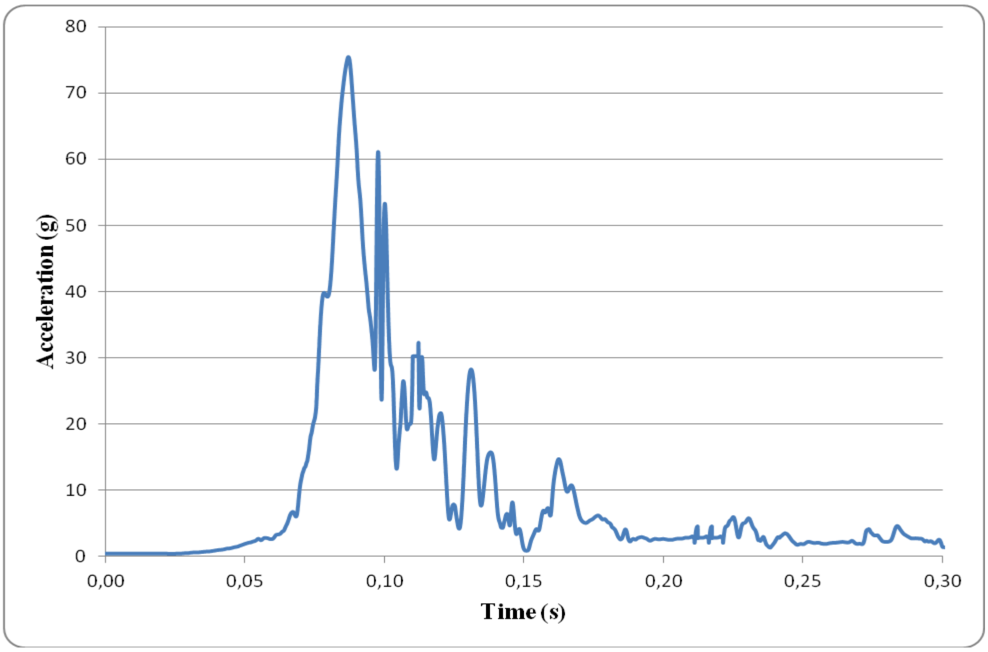


Figure 5.30 Resultant Acceleration Value on 6 Years Old Child Dummy during the Test of CRS D with Locked Seat Belt

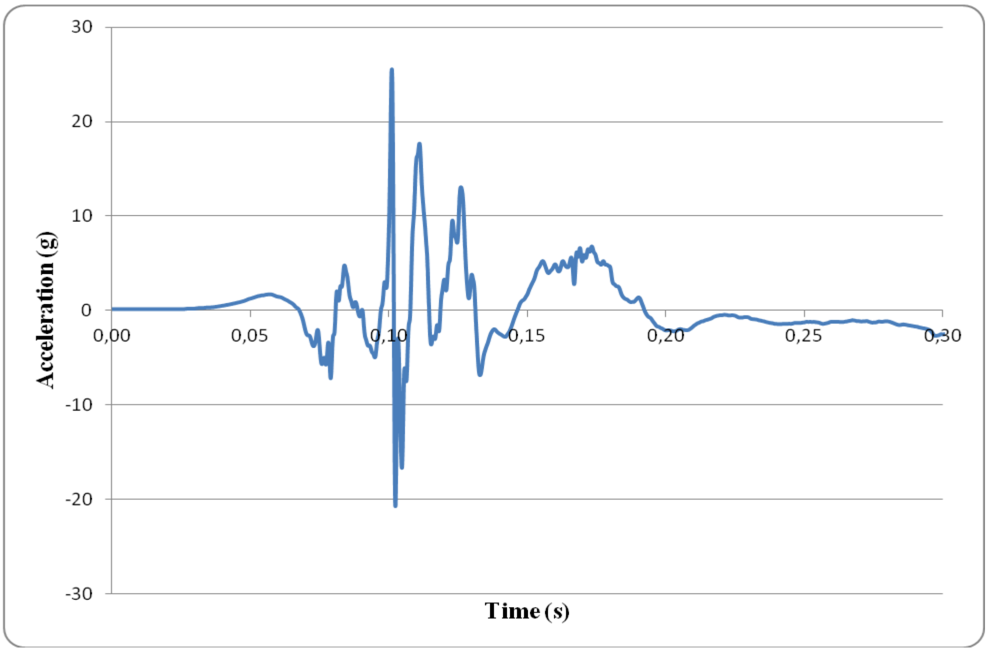


Figure 5.31 Z-Direction Acceleration Value on 3 Years Old Child Dummy during the Test of CRS A with Unlocked Seat Belt

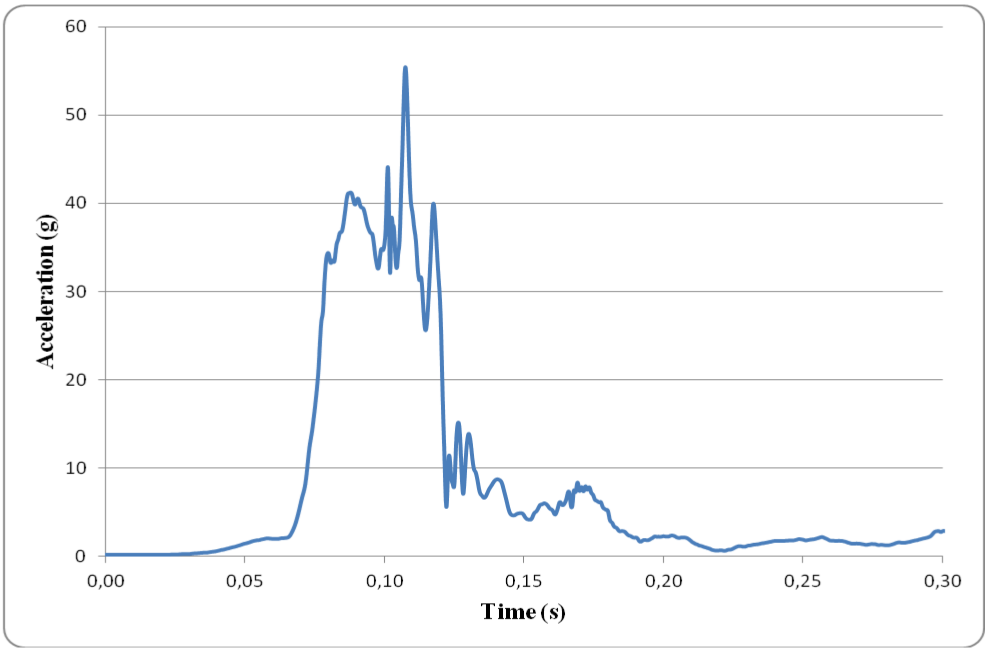


Figure 5.32 Resultant Acceleration Value on 3 Years Old Child Dummy during the Test of CRS A with Unlocked Seat Belt

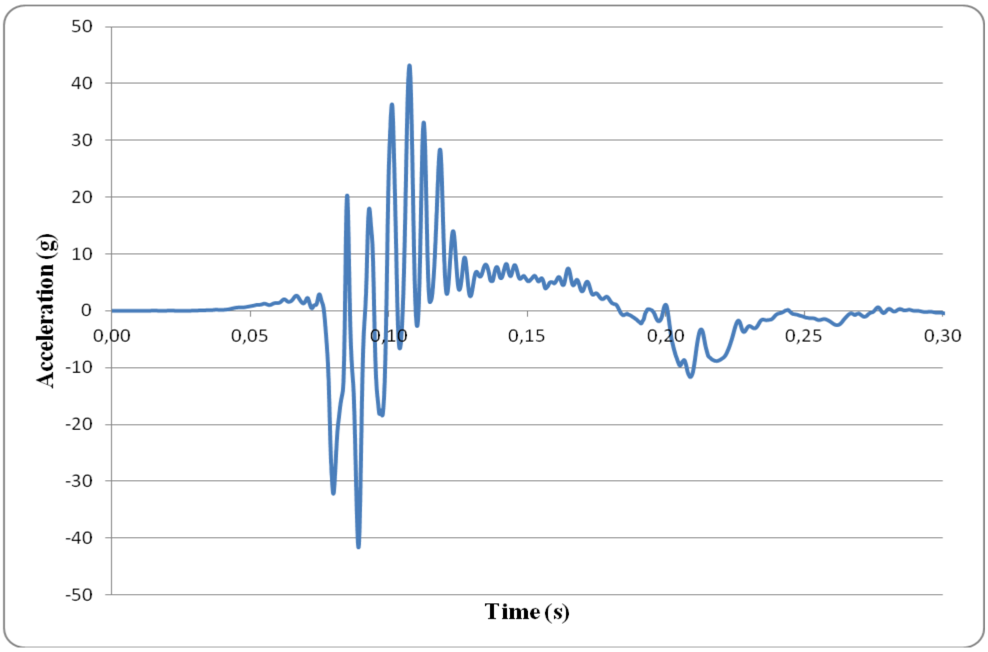


Figure 5.33 Z-Direction Acceleration Value on 3 Years Old Child Dummy during the Test of CRS B with Unlocked Seat Belt

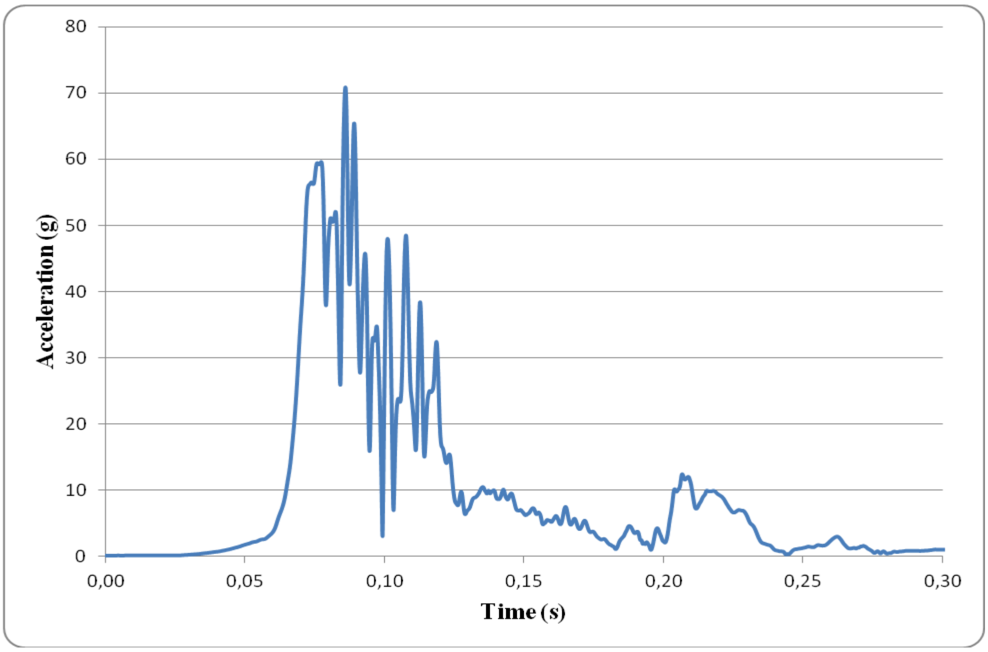


Figure 5.34 Resultant Acceleration Value on 3 Years Old Child Dummy during the Test of CRS B with Unlocked Seat Belt

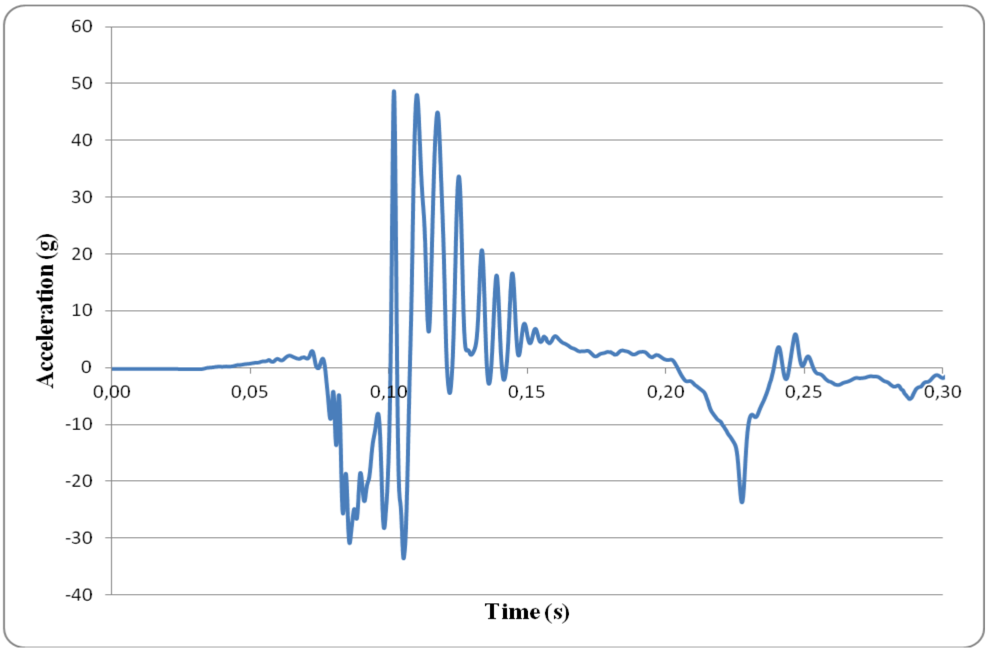


Figure 5.35 Z-Direction Acceleration Value on 3 Years Old Child Dummy during the Test of CRS C with Unlocked Seat Belt

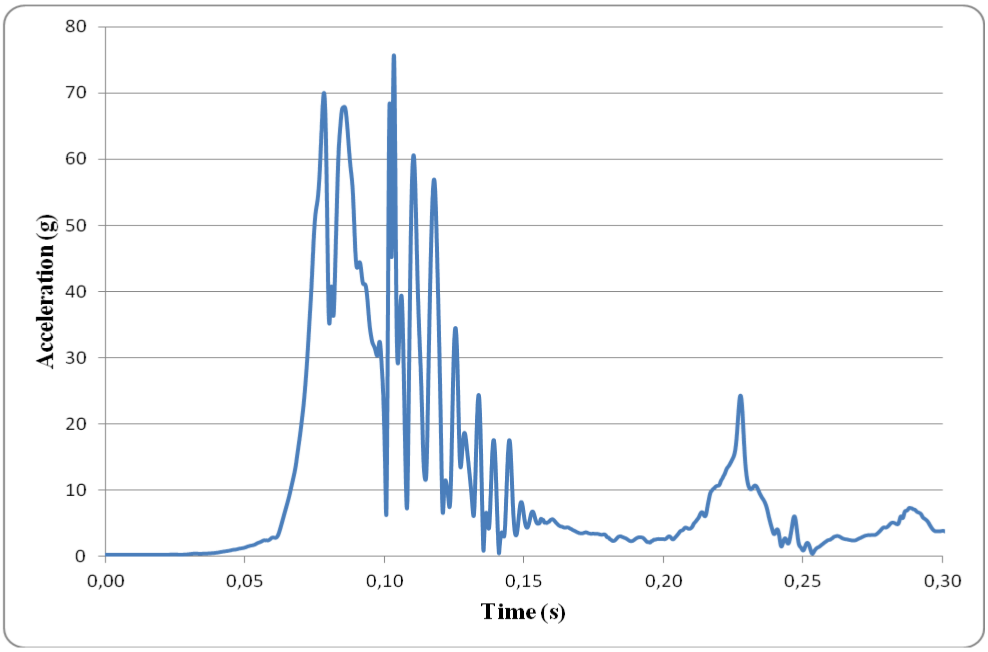


Figure 5.36 Resultant Acceleration Value on 3 Years Old Child Dummy during the Test of CRS C with Unlocked Seat Belt

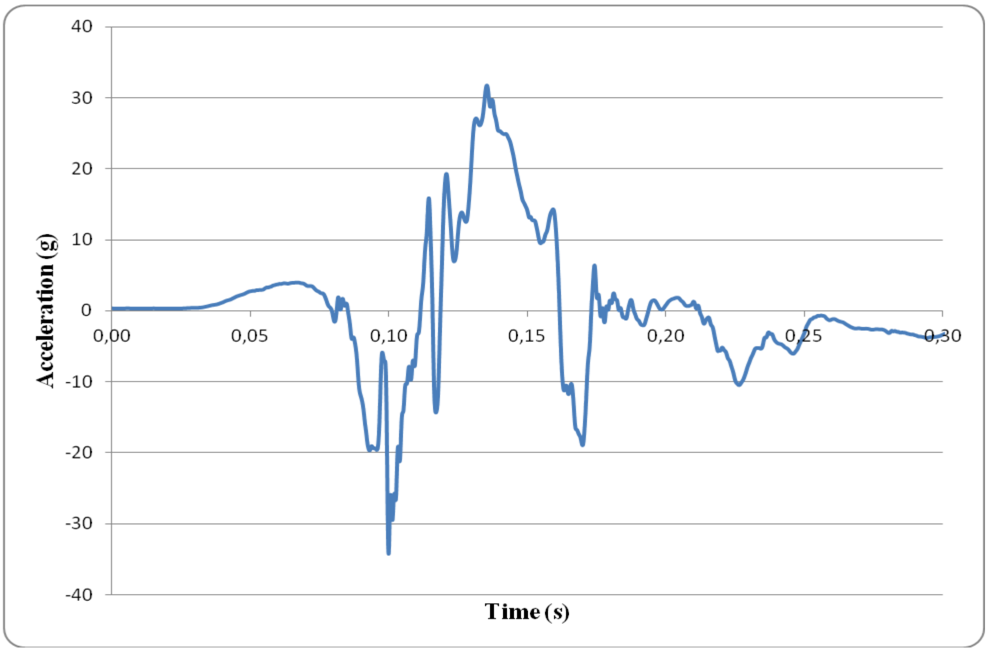


Figure 5.37 Z-Direction Acceleration Value on 3 Years Old Child Dummy during the Test of CRS D with Unlocked Seat Belt

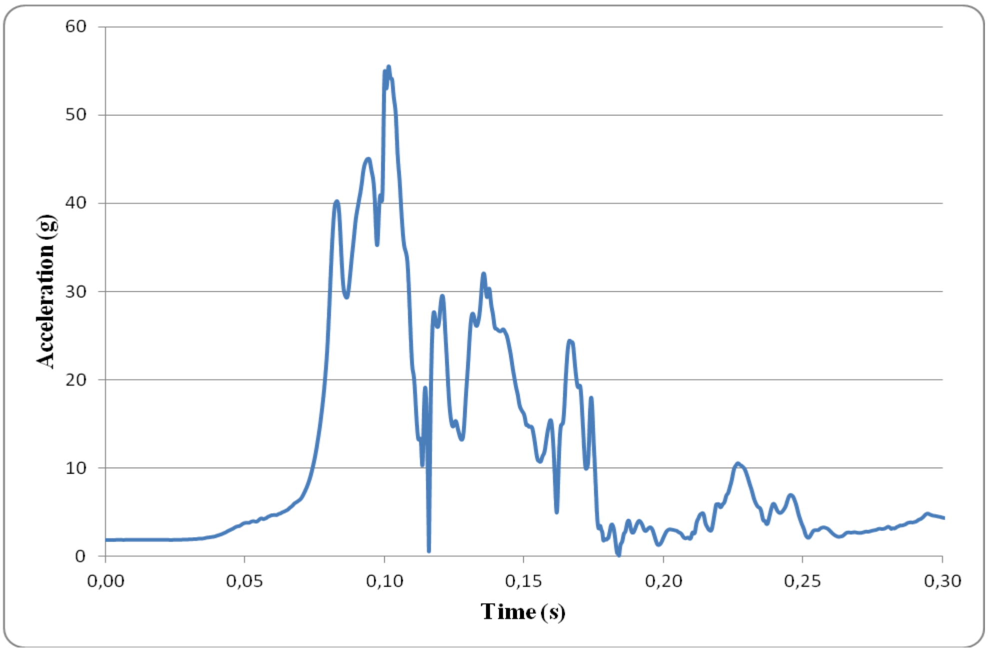


Figure 5.38 Resultant Acceleration Value on 3 Years Old Child Dummy during the Test of CRS D with Unlocked Seat Belt

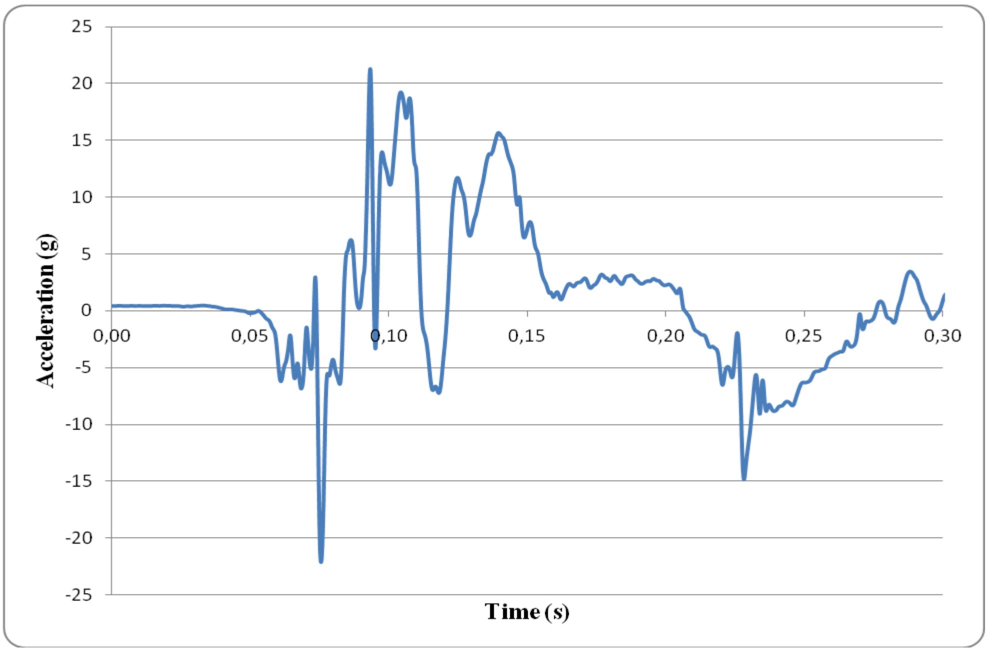


Figure 5.39 Z-Direction Acceleration Value on 6 Years Old Child Dummy during the Test of CRS A with Unlocked Seat Belt

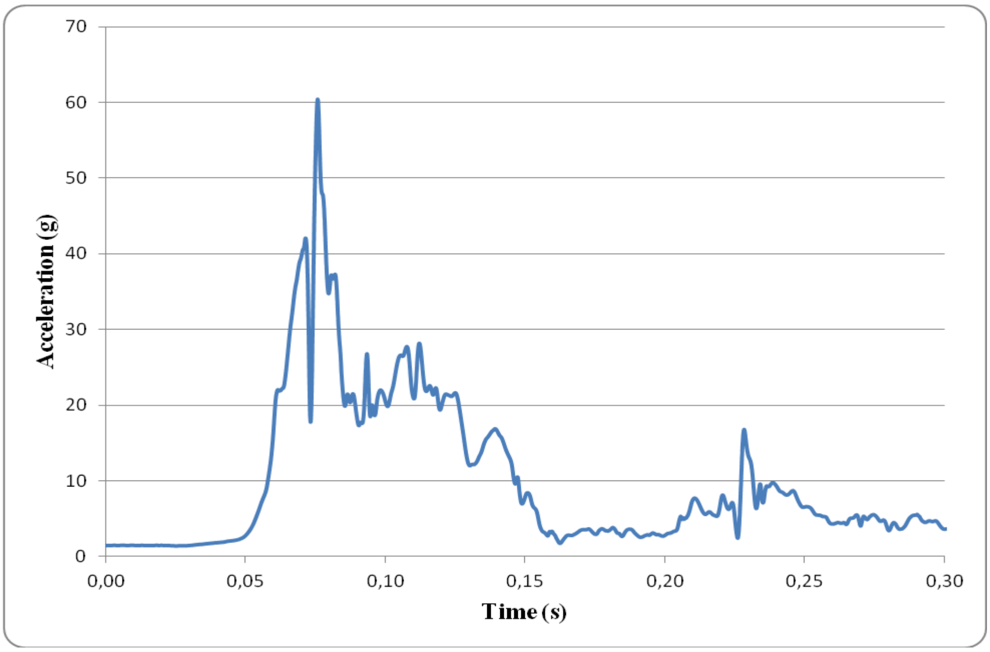


Figure 5.40 Resultant Acceleration Value on 6 Years Old Child Dummy during the Test of CRS A with Unlocked Seat Belt

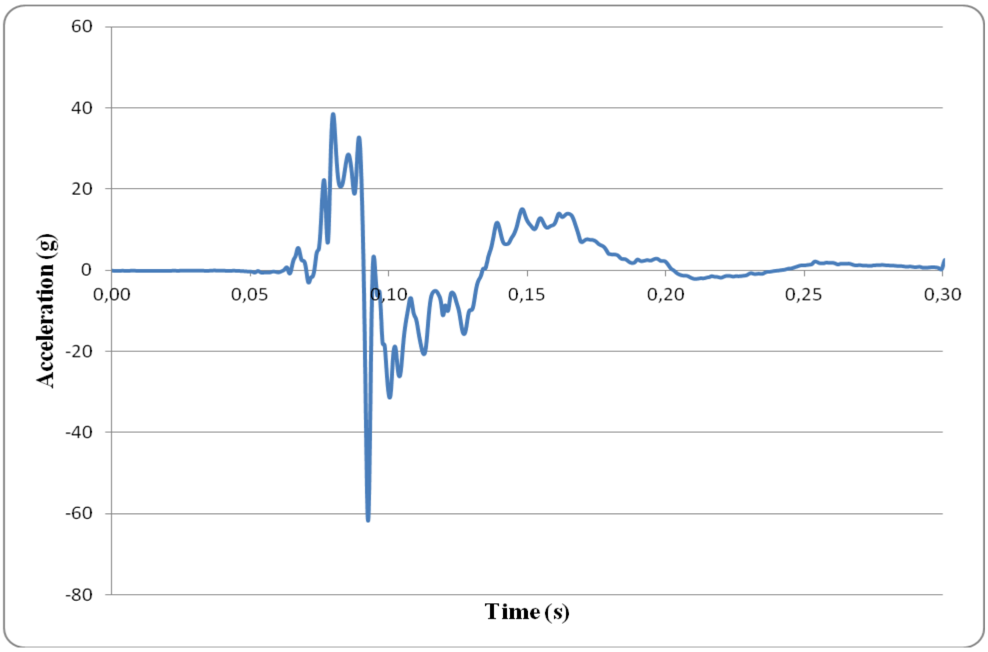


Figure 5.41 Z-Direction Acceleration Value on 6 Years Old Child Dummy during the Test of CRS B with Unlocked Seat Belt

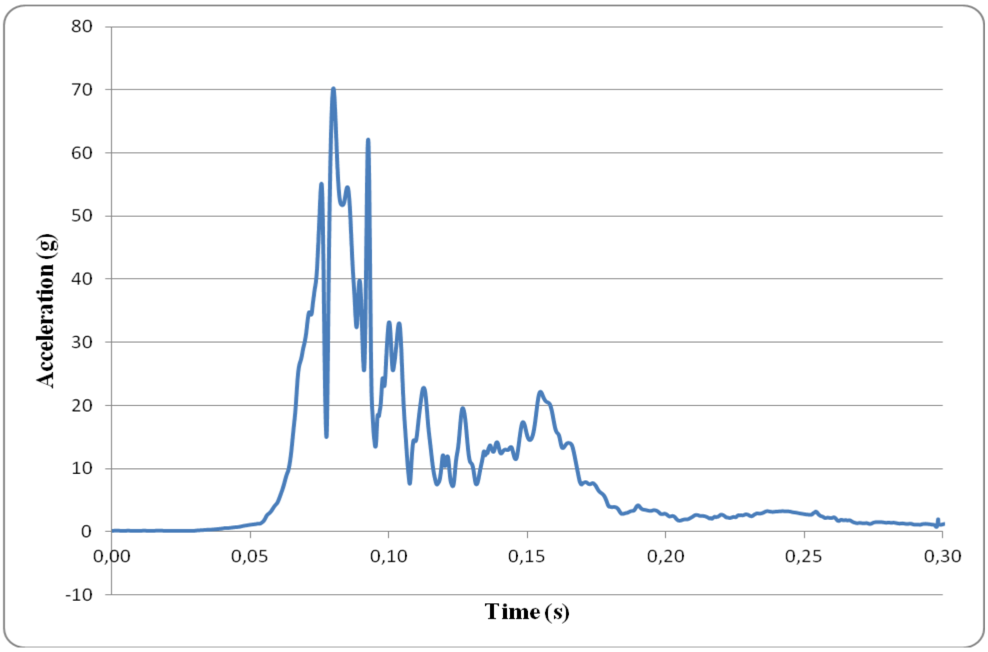


Figure 5.42 Resultant Acceleration Value on 6 Years Old Child Dummy during the Test of CRS B with Unlocked Seat Belt

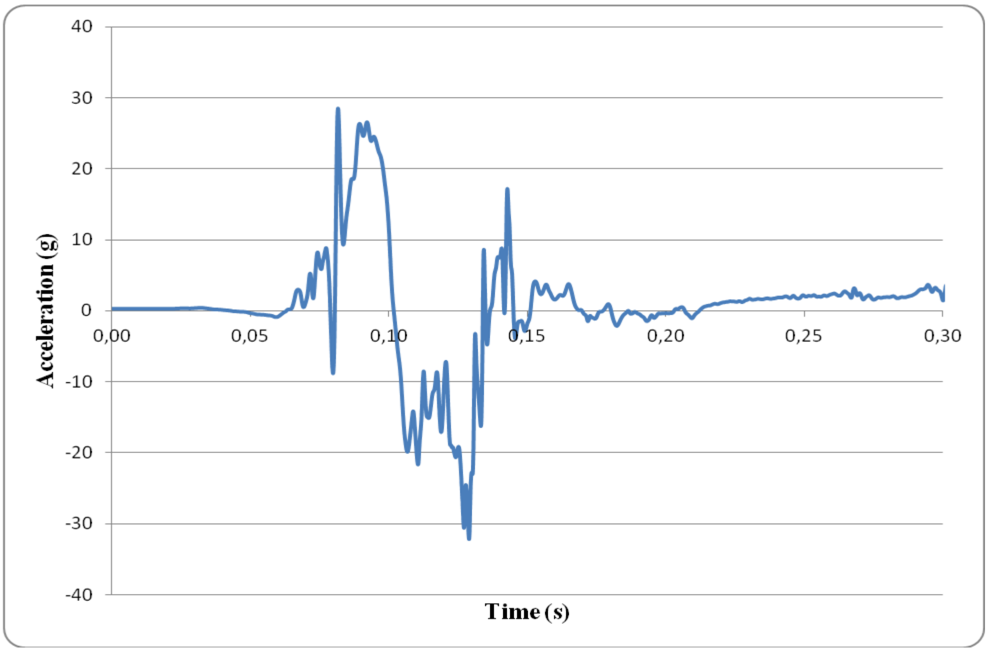


Figure 5.43 Z-Direction Acceleration Value on 6 Years Old Child Dummy during the Test of CRS C with Unlocked Seat Belt

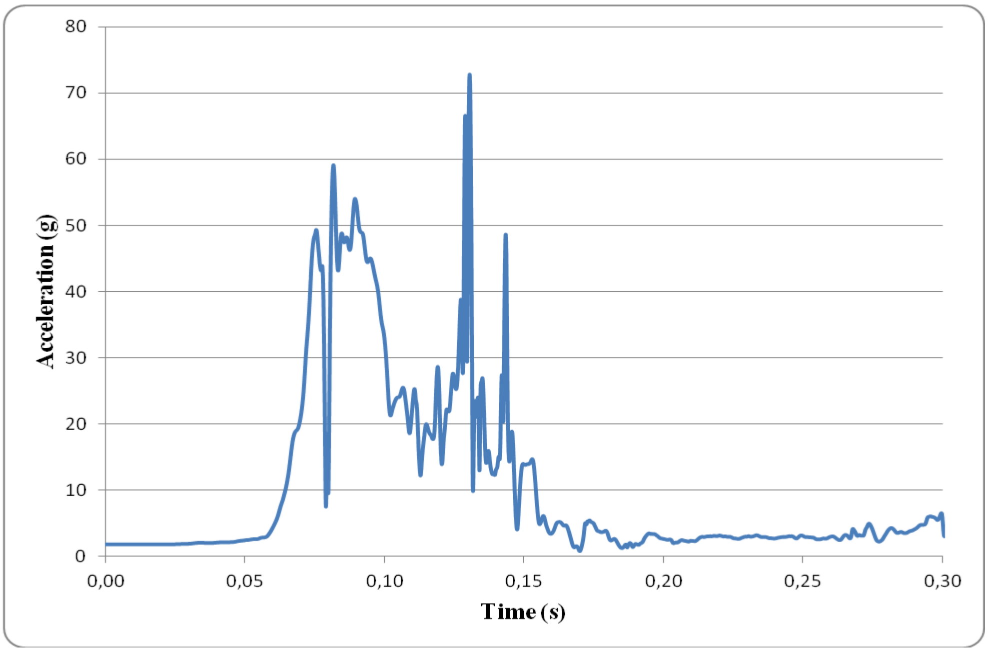


Figure 5.44 Resultant Acceleration Value on 6 Years Old Child Dummy during the Test of CRS C with Unlocked Seat Belt

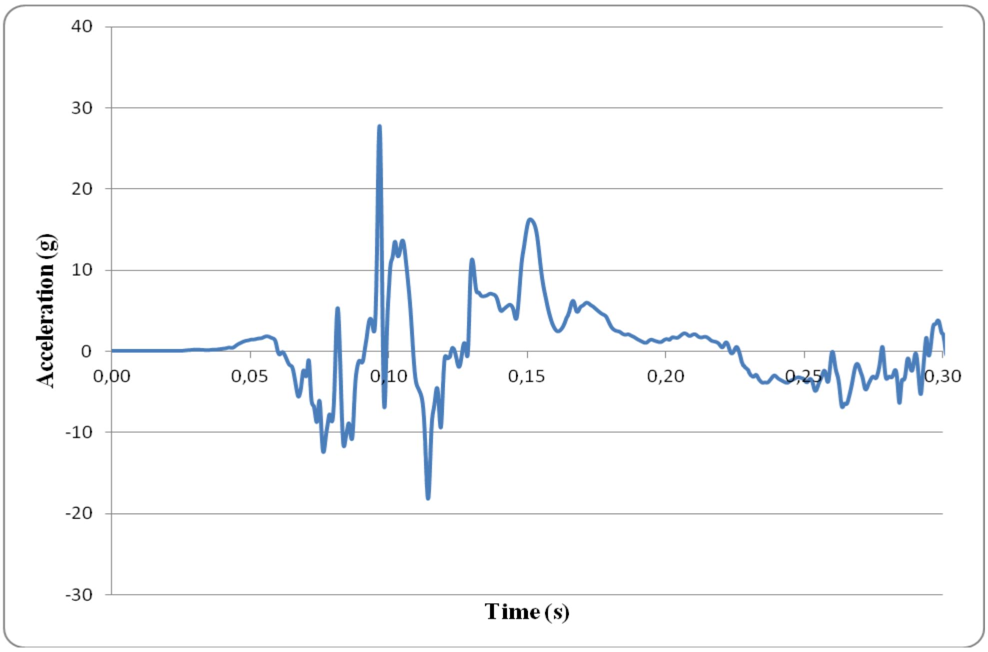


Figure 5.45 Z-Direction Acceleration Value on 6 Years Old Child Dummy during the Test of CRS D with Unlocked Seat Belt

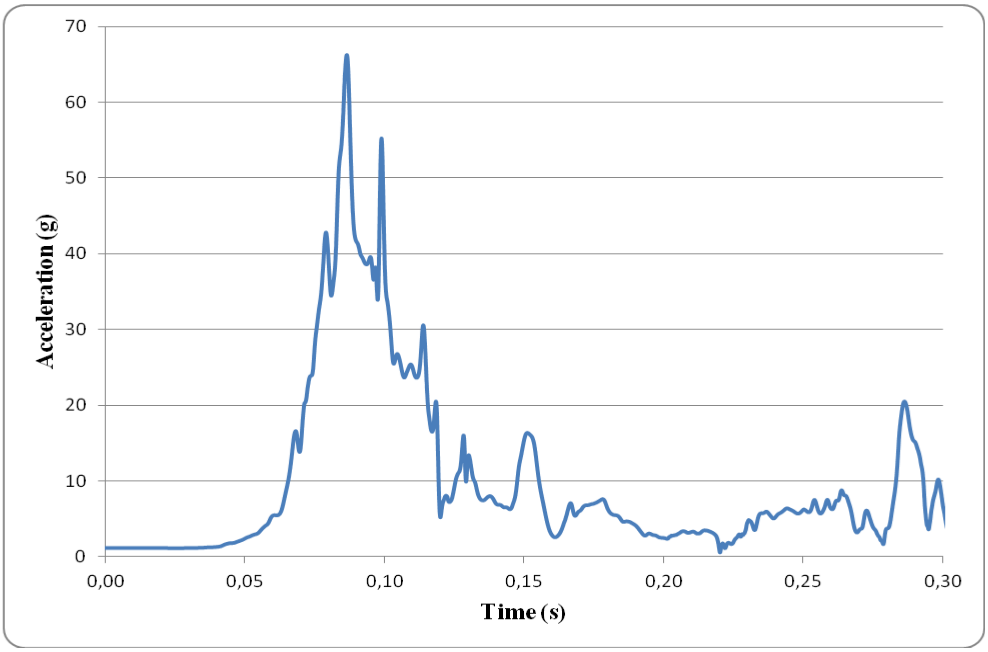


Figure 5.46 Resultant Acceleration Value on 6 Years Old Child Dummy during the Test of CRS D with Unlocked Seat Belt

According to ECE R 44, the limit of the acceleration in Z-direction is 30 g and the limit of the resultant acceleration is 55 g. However, some cases can be considered as acceptable although these limits are exceeded. In these cases, the duration of the application of higher acceleration, Δt, shown in Figure 5.46 must not be greater than 3 ms to accept the result. This duration, Δt, is defined as "Critical Time". If these excess acceleration applications occur in more than one region in the curve as shown in Figure 5.46, the critical time is determined by summing up all of these regions. And the result is checked for the time limit of 3 ms.

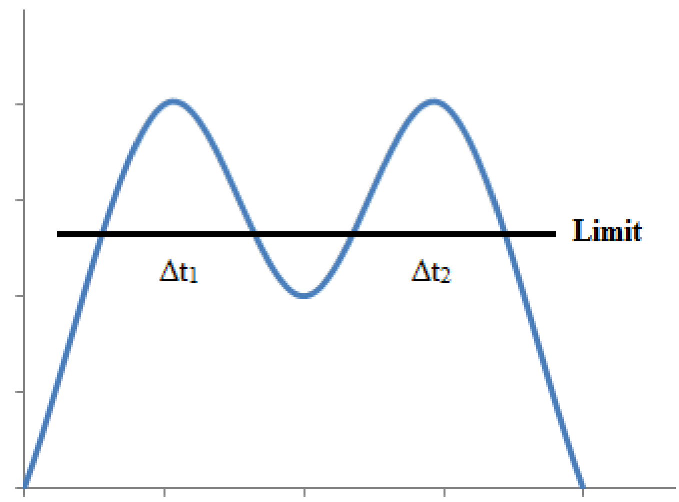


Figure 5.47 Critical Time Limit Calculation

According to acceleration-time curves given in Figures 5.14-5.45, critical time, Δt, are determined for each case. The critical times are given in Table 5.9 for locked seat belt condition and in Table 5.10 for comparison between locked and unlocked seat belt cases. In the evaluation of locked seat belt case, if Δt is less than or equal to 3 ms, "Successful" is written in the evaluation box of the table. If Δt is greater than 3 ms, "Failed" is written in the evaluation box of the table.

Table 5.9 Critical Time for Locked Seat Belt Case According to CRS Types and Test Dummies

CRS Type and Test Dummy	Critical Time for Z-Direction Acceleration, Δt_z	Critical Time for Resultant Acceleration, Δt_r	Critical Time Criterion	Evaluation
CRS A with 3 Years Old Test Dummy	0 ms	0 ms	≤ 3.00 ms	Successful
CRS B with 3 Years Old Test Dummy	1.45 ms	3.00 ms	≤ 3.00 ms	Successful
CRS C with 3 Years Old Test Dummy	8.55 ms	6.90 ms	≤ 3.00 ms	Failed
CRS D with 3 Years Old Test Dummy	0 ms	0 ms	≤ 3.00 ms	Successful
CRS A with 6 Years Old Test Dummy	2.50 ms	1.55 ms	≤ 3.00 ms	Successful
CRS B with 6 Years Old Test Dummy	9.35 ms	1.60 ms	≤ 3.00 ms	Failed
CRS C with 6 Years Old Test Dummy	0.90 ms	0 ms	≤ 3.00 ms	Successful
CRS D with 6 Years Old Test Dummy	2.00 ms	9.15 ms	≤ 3.00 ms	Failed

By examining the results for locked seat belt cases given in Table 5.9, it can be said that CRS C is failed for 3 years old child dummy test and CRS B and CRS D are failed for 6 years old child dummy.

Table 5.10 Critical Time Comparison Between Locked and Unlocked Seat Belt Case According to CRS Types and Test Dummies

CRS Type and Test Dummy	Locked Seat Belt		Unlocked Seat Belt	
	Critical Time for Z-Direction Acceleration, Δt_z	Critical Time for Resultant Acceleration, Δt_r	Critical Time for Z-Direction Acceleration, Δt_z	Critical Time for Resultant Acceleration, Δt_r
CRS A with 3 Years Old Test Dummy	0 ms	0 ms	2 ms	0.45 ms
CRS B with 3 Years Old Test Dummy	1.45 ms	3 ms	6.35 ms	5.96 ms
CRS C with 3 Years Old Test Dummy	8.55 ms	6.90 ms	10.10 ms	10.20 ms
CRS D with 3 Years Old Test Dummy	0 ms	0 ms	0 ms	0.30 ms
CRS A with 6 Years Old Test Dummy	2.50 ms	1.55 ms	0 ms	1.25 ms
CRS B with 6 Years Old Test Dummy	9.35 ms	1.60 ms	5.15 ms	3.85 ms
CRS C with 6 Years Old Test Dummy	0.90 ms	0 ms	0.80 ms	2.65 ms
CRS D with 6 Years Old Test Dummy	2 ms	9.15 ms	0 ms	3.15 ms

Due to the misusage of the seat belt, unlocked seat belt, the acceleration values shown in Figures 5.14-5.45 and critical time shown in Tables 5.9 and 5.10 are affected. It is observed that generally resultant acceleration increase. Although CRS B is successful for the locked seat belt test but for the unlocked seat belt test the critical time is more than the time limit.

The abdominal penetration is only evaluated only by checking the modelling clay mounted on the abdomen of the test dummy by visual inspection. After the tests modelling clays are controlled and no deformation should occur on the modelling clay. The after test photographs are shown in Table 5.11 for locked and unlocked seat belt cases to make a comparison between them.

In Table 5.11 (a-h) shows the photographs for the test with the locked seat belts according to ECE R44. According to the abdominal penetration criterion, CRS A, CRS B, CRS C and CRS D was successful for 3 and 6 years old test dummies as shown in Table 5.11 (a-h).

Table 5.11 (i-p) shows the photographs for the tests performed with the unlocked seat belts. When the abdominal penetration of the seat belt are examined for the tests with locked seat belt and tests with unlocked seat belts, generally abdominal penetrations occurred for the tests with the unlocked seat belts as expected.

Table 5.11 Abdominal Penetration Inspection After Test Continued

Abdominal Penetration Inspection After Test	
Locked Seat Belt	Unlocked Seat Belt
(a) 3 Years Old Test Dummy Tested With CRS A Abdominal Penetration	(i) 3 Years Old Test Dummy Tested With CRS A Abdominal Penetration
	

Table 5.11 Abdominal Penetration Inspection After Test Continued

<table>
<tr><th colspan="2">Abdominal Penetration Inspection After Test</th></tr>
<tr><th>Locked Seat Belt</th><th>Unlocked Seat Belt</th></tr>
<tr><td>(b) 3 Years Old Test Dummy Tested With CRS B Abdominal Penetration</td><td>(j) 3 Years Old Test Dummy Tested With CRS B Abdominal Penetration</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>(c) 3 Years Old Test Dummy Tested With CRS C Abdominal Penetration</td><td>(k) 3 Years Old Test Dummy Tested With CRS C Abdominal Penetration</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>(d) 3 Years Old Test Dummy Tested With CRS D Abdominal Penetration</td><td>(l) 3 Years Old Test Dummy Tested With CRS D Abdominal Penetration</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>(e) 6 Years Old Test Dummy Tested With CRS A Abdominal Penetration</td><td>(m)6 Years Old Test Dummy Tested With CRS A Abdominal Penetration</td></tr>
<tr><td>
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</table>

Table 5.11 Abdominal Penetration Inspection After Test

Abdominal Penetration Inspection After Test	
Locked Seat Belt	Unlocked Seat Belt
(f) 6 Years Old Test Dummy Tested With CRS B Abdominal Penetration	(n) 6 Years Old Test Dummy Tested With CRS B Abdominal Penetration
	
(g) 6 Years Old Test Dummy Tested With CRS C Abdominal Penetration	(o) 6 Years Old Test Dummy Tested With CRS C Abdominal Penetration
	
(h) 6 Years Old Test Dummy Tested With CRS D Abdominal Penetration	(p) 6 Years Old Test Dummy Tested With CRS D Abdominal Penetration
	

As seen in the Table 5.11, the test performed with locked seat belt never caused to abdominal penetration. But for the cases with unlocked seat belt tests, modelling clays are deformed with seat belt except CRS A and CRS D for 3 years old child dummy tests. These CRSs use their own seat belt for 3 years old child test dummy.

CRSs' own seat belt does not make a loop on the abdominal, so the results are better than the other unlocked tests.

5.4 Evaluation of the Test Results for CRSs According to ECE R44 Criterions

ECE R44 states one criterion for the overturning tests and four criteria for the dynamic tests. For the overturning tests, the head of the child test dummy head must not move more than 300 mm as described in Section 5.2.2. In dynamic tests, the first criterion is the displacement limit in Z-direction. Second one is the limit for the resultant. Third one is acceleration and the fourth one is abdominal penetration. According to ECE R44 a particular CRS is considered as "successful" if it passes all these five criteria. The tests are performed for the youngest and the oldest child test dummies in the related Group defined in ECE R44. The particular CRS must be "successful" for both of the child test dummies to be counted as "successful" for the related group.

Group II is the common group for selected CRSs. Group II is used for 3 and 6 years old child test dummies. An evaluation table for these CRSs have been prepared according to ECE R44. The results are shown in Table 5.12.

Table 5.12 Evaluation of CRSs for Group II According to ECE R44

Child Restraint Systems	Child Test Dummy used in Tests	Overturning	Displacement Limit	Critical Time for Z-Direction Acceleration	Critical Time for Resultant Acceleration	Abdominal Penetration	Result for Each Dummy	Overall
CRS A	3 years old child test dummy	Successful	Failed	Successful	Successful	Successful	Failed	Failed
	6 years old child test dummy	Successful	Failed	Successful	Successful	Successful	Failed	
CRS B	3 years old child test dummy	Successful	Successful	Successful	Successful	Successful	Successful	Failed
	6 years old child test dummy	Successful	Failed	Failed	Successful	Successful	Failed	
CRS C	3 years old child test dummy	Successful	Successful	Failed	Failed	Successful	Failed	Failed
	6 years old child test dummy	Successful	Successful	Successful	Successful	Successful	Successful	
CRS D	3 years old child test dummy	Successful	Failed	Successful	Successful	Successful	Failed	Failed
	6 years old child test dummy	Successful	Failed	Successful	Failed	Successful	Failed	

CHAPTER 6

CONCLUSIONS AND FUTURE WORK

6.1 Conclusions

In this study, United Nations Economic Commission of Europe Regulation 44 which is very detailed, difficult to interpret, is examined. The test procedure and checklists according to ECE R44 have been prepared and these are approved by Turkish Accreditation Agency.

ECE R44 requires overturning and dynamic tests to be performed. To be able to perform these tests, the overturning and dynamic test setups have designed. The designed test setups have been analysed and approved using Finite Element Analysis Software. After analyses, manufacturing of the overturning and dynamic test setups, according to ECE R44 [17], has been supervised.

The effects occurred on the different child test dummies have been examined by performing the overturning and dynamic tests for different Child Restraint Systems (CRSs) which are available in the market. The overturning and dynamic tests are performed with four different test samples and the different child test dummies. These tests have been performed at the METU-BILTIR Center Vehicle Safety Unit Sled Test Facility.

The overturning test setup and dynamic test setup are designed according to ECE R44 [17] and analysis results are given as follows:

• The probable future test addition, side impact, for dynamic test setup according to ECE R44 has taken into account and modular design has been made.

• According to finite element analysis, the overturning test setup and dynamic test setup found to be satisfactory for the tests. Eleven overturning test and sixteen dynamic test have been performed and no negative effect has been observed on test setups.

• The computer analyses and the tests performed at the METU-BILTIR Center Vehicle Safety Unit showed that the overturning test setup and dynamic test setup can be safely used for the tests.

• The adult seat belts used for the dynamic tests sustain under loads. Experimentally it is observed that changing adult seat belts after five tests will improve the safety of the tests.

Results of the tests are evaluated according to the ECE R44 [17] and conclusions about the tests and their results are given as follows:

• The performances of different CRSs in terms of the effects on child test dummies for displacements, accelerations and abdominal penetrations are analyzed and discussed by using P-Series crash test dummy which are available in METU-BILTIR Center Vehicle Safety Unit Sled Test Facility

• The test samples which are used for both overturning and dynamic tests have been prepared according to the United Nations Economic Commission for Europe regulation during the study.

• Important experience has been gained about the ECE R44 regulation and usage of equipments related to overturning and dynamic sled testing.

The followings have also been concluded according to the results of the performed tests:

• It has been shown that the approved CRSs do not succeed in the dynamic tests. That is a major fault for The Ministry of Science, Industry and Technology and shows that the Conformity of Production checks do not performed regularly by The Ministry of Science, Industry and Technology during sales.

• It has also been shown that the effects occurred on different child test dummies shows differences, especially on dynamic tests. Increasing the age of the child dummy brought out life-threatening effects. However, a regular trend cannot be observed because each test has exactly different from others.

• It is shown that integrated seat belt using CRSs decreases the harmful effects occurred on child test dummies.

• It is shown that locked seat belt usage performance is better than unlocked seat belt usage by limiting the displacement in x-direction, abdominal penetration and acceleration occurred on test dummy.

6.2 Future Work

Future work can be suggested for this particular study as follows:

• After performing tests with 9 months old and 10 years old child dummies, evaluations for Group I and Group III may be done.

• Different types of child test dummies such as Q-Series child test dummies can be used in the dynamic tests and a comparison between these studies may be done.

• Since Q-Series child test dummies have more sensors the more detailed data can be read from the data acquisition system. And with these data, more detailed new study may be done.

• The dynamic test setup is suitable for the side impact tests. With the Q-Series child dummies additional tests can be performed for side impacts so the effect side impacts can be seen.

• Different types of CRSs, the rear faced or carry cot type, can be used in the tests and comparison between current study and new study may be done.

• A finite element analysis for the thesis study can be performed and a comparison between the test results and finite element analysis results may be done.

• Different seat belt positions impact pulses can be used in the tests and a comparison between the current thesis study and the new study may be done.

• A new child restraint system, integrated seat belt or securing mechanism against impacts may be developed or some improvements may be proposed in the guidance of test results.

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