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Retractor-Based Stroking Seat System and Energy-Absorbing Floor to Mitigate High Shock and Vertical Acceleration

Presented at the NATO/STO AVT-221 Specialists Meeting on "Design and Protection Technologies for Land and Amphibious NATO Vehicles", Copenhagen, Denmark, Apr 07-10, 2014

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Retractor-Based Stroking Seat System and Energy-Absorbing Floor to Mitigate High Shock and Vertical Acceleration

By
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This is a reprint of a paper presented at the NATO/STO AVT-221 Specialists Meeting on "Design and Protection Technologies for Land and Amphibious NATO Vehicles", Copenhagen, Denmark, Apr 07-10, 2014.

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ABSTRACT

The beneficial effects of seat stroke on lower lumbar loads, and energy absorbing floors on lower and upper tibia loads are numerically simulated by LS-DYNA3D in an accelerative vertical loading environment. The Hybrid III 50% male dummy occupant dummy is seated in a generic seat system of a ground vehicle interior and restrained with a 5-point seatbelt system. A retractor system is attached between the back of the stroking seat and the hull to provide the desired seat stroking characteristics. The occupant lower lumbar loads and lower tibia loads are analyzed and compared for eight different retractor functions.

Keywords*:* *Retractor, Energy absorbing floor, Seat stroke, Lumbar loads, Accelerative load, M&S analysis*

1.0 INTRODUCTION

Today's military scenarios have changed from force-on-force involving large troops to smaller local conflicts in asymmetric warfare [1]. Subsequently, the war fighter needs protected mobility and blast-resisting capability to combat both homeland and global security threats [2, 3]. With ever-increasing threat sizes and types, protection against injuries during under body blasts is of utmost importance in developing new armored vehicles, and retrofitting existing fleets. The configuration of the crew compartment is largely defined by the required level of protection and crew safety, vehicle weight and mobility on land and water.

Army ground combat vehicles have to withstand high vertical accelerative loads on the vehicle hull, floor and seat structures. These loads are in turn transmitted, in part or in full, to the mounted soldier, depending on seat and interior design features, causing injuries to the lumbar and lower leg regions. There are numerous ways of mitigating the high accelerative loads imparted into the structure using shaped hulls, (V-shape hull, Double-V hull), and/or material selection, and thus the resulting vertical acceleration to the seat and soldiers. These alone may not enough to reduce the injuries experienced by the soldiers on the field. Newer Army vehicles have blast-mitigating floor systems and stroking mine seats for enhanced energy management. Most of the stroking seat systems today are based on deforming steel cable or specially designed geometries capable of stroking up to 10 inches. These systems are fairly easy to design and incorporate into the seats and work quite well during vertical loading conditions. However, during off-axis loading, these seats may not perform as well in injury reduction, for several reasons such as unexpected soldier posture, binding of stroking mechanisms etc.

This paper demonstrates the on-axis and off-axis effectiveness of (1) a conceptual load-limiting retractor-based stroking seat system, as well as (2) the same seat integrated with an energy-absorbing (EA) floor design. A vertical drop tower simulation is employed to investigate the potential performance of these concepts during a typical blast. In order to accomplish this research, a generic seat system is modelled using finite element methods. The 50% percentile Hybrid III dummy from Humanetics is used to represent a soldier restrained with a standard automotive seat belt system. A retractor-based seat belt system is attached to the seat structure with varying load limiters to achieve the desired seat stroke. The seat-floor-occupant system is subjected to a time-varying generic vertical accelerative load to mimic a typical blast input load to the seat. Resulting crew injuries are monitored for various vertical accelerative loading scenarios. The retractor load limits for the stroking seats are optimized for varying input loading condition using modelling and simulation methods.

There are several advantages to retractor-based energy-management systems. These systems can be efficiently incorporated into the seat structures of today's military ground vehicles. When compared to the more traditional EA mechanisms with metal strips or cables, it is easier to control the stroking in retractor-based concepts using different seat belt materials and load-limiting retractors. In addition, integration of an energy-absorbing floor to such a retractor-based seat stroking system has the potential to be even more effective in mitigating the high shock and accelerative loads transmitted to the soldier in typical under body blasts, thereby reducing the potential occupant injuries. Retractor-based EA systems can be developed as a modular kit and implemented in vehicles that are already fielded as well as those under development. The underlying concept is independent of the size or weight of the vehicle, and can be easily tuned for specific configurations.

2.0 MODEL SETUP

A generic occupant compartment of light tactical vehicle (LTV) driver side is numerically modelled using finite element methods as shown in Figure 1.with a V-hull design. Shock-attenuating and energy-absorbing floor mechanism is also shown in the Figure 1. A generic seat structure with retractor-based stroking mechanism is shown in Figure 2. The passenger side also consists of a similar occupant compartment not shown in this report. The driver and passenger compartments are connected by a tunnel structure along the vehicle centre line.

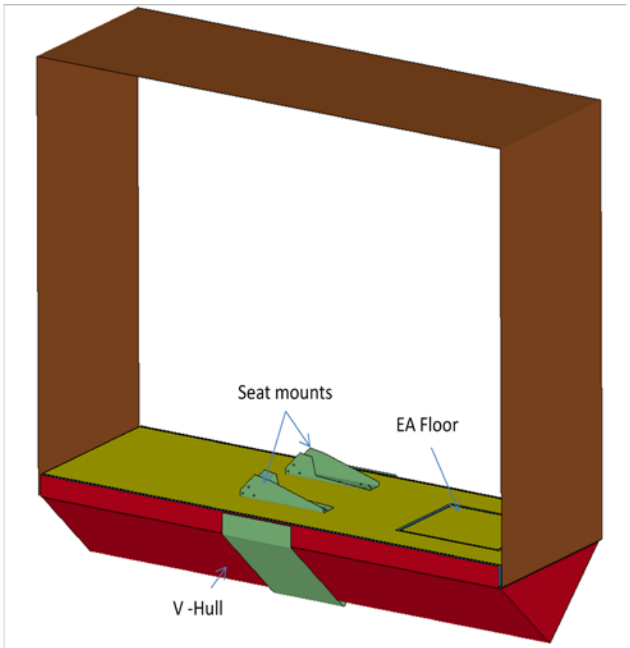

Figure 1: V-Hull occupant compartment

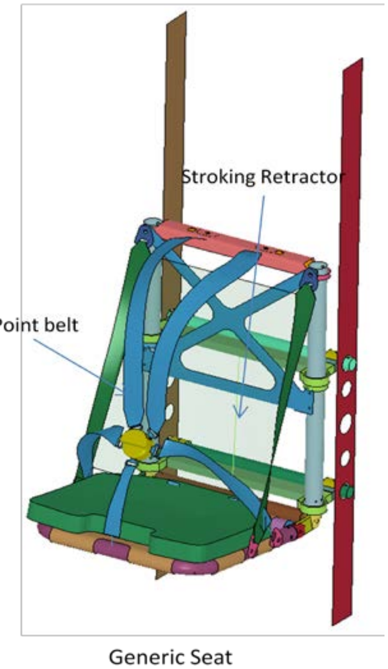

Figure 2: Generic Seat with Stroking Retractor

The Humanetics Hybrid III dummy [7] used in this study to investigate the lower lumbar loads, lower tibia loads, pelvic accelerations, etc. is shown in Figure 3. The complete subsystem is shown in Figure 4.

Figure 3: Hybrid III dummy

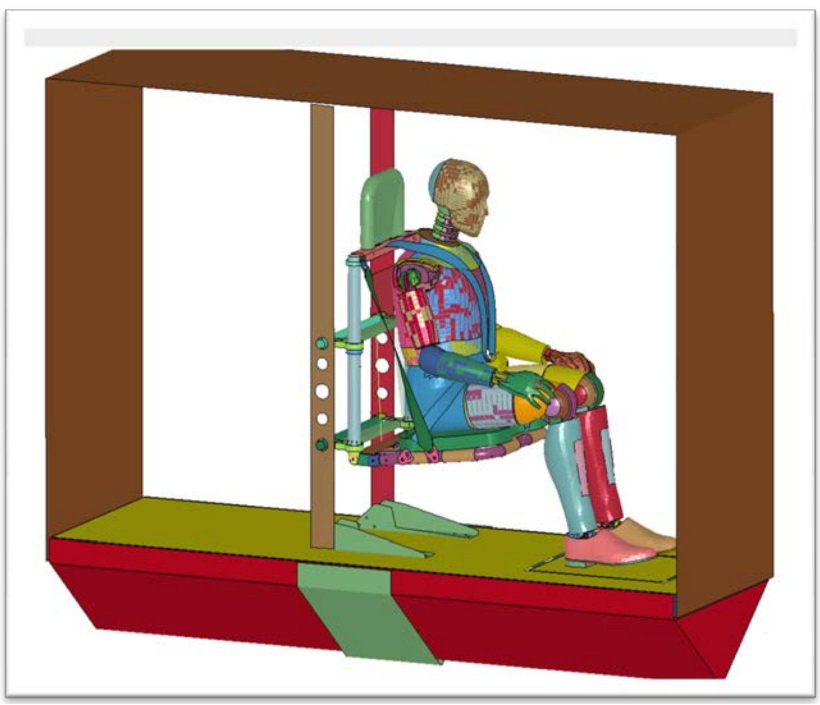

Figure 4: Complete subsystem

2.1 Structure model

The structure is modeled with ½" RHA material and is a generic representation of the typical occupant compartment in a light tactical vehicle (LTV). Because the loading used here is an enforced blast pulse, this hull structural thickness does not have any effect on the results.

2.2 Seatbelt model

Automotive seat belts with five point restraints and 10% elongation webbing is modeled using ELEMENT_SEATBELT, SECTION_SEATBELT and MAT_SEATBELT input cards. LS-DYNA provides features to model the loading and unloading characteristics from a uni-axial test. Parameter LLCID in MAT_SEATBELT provides the ability to model the loading curve which allows the defenition of force as a function of engineering strain. Parameter ULCID , provides the unloading characteristics as a function of force versus engineering strain. LLCID and ULCID curves are shown in Figure 5 as a Percentage elongation on x-axis and Newtons on y-axis.

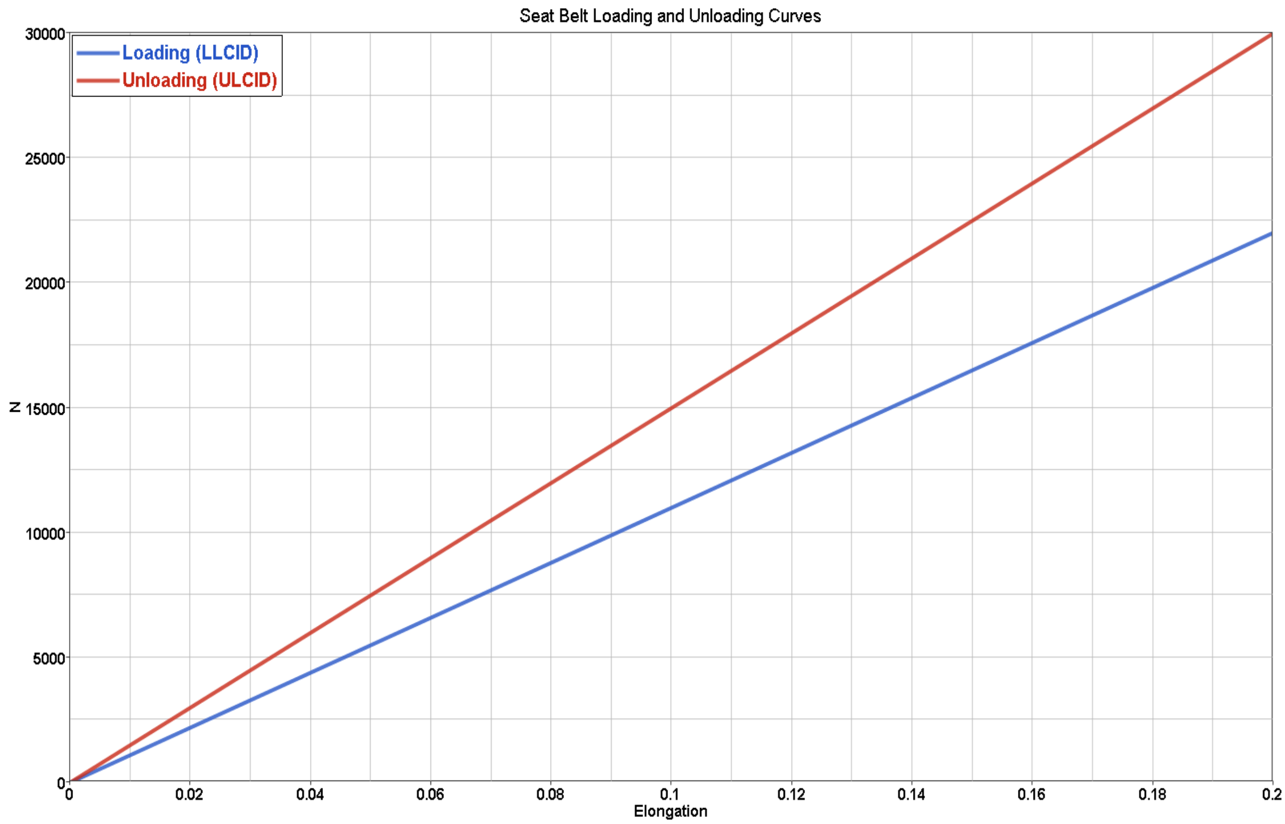

Figure 5: Seat belt loading and unloading curves

2.3 Retractor model

Retractor[8] is modeled using ELEMENT_SEATBELT_RETRACTOR card in LS-DYNA. This card requires two curves one for loading and one unloading.

2.4 Floor model

The floor structure is modeled with ¼" RHA. Blast mitigating energy absorbing material is inserted below the floor and above the V hull. During loading, this material will absorb the shock and deform sufficiently enough to mitigate the lower tibia loads.

2.5 Hybrid III dummy model

The Humanetics Hybrid III model is positioned as shown in Figure 4. Both the feet are placed on the floor seperated 132 mm apart.

3.0 NUMERICAL ANALYSIS METHOD

The vertical loading from the blast is modeled in this report by imposing a short-duration acceleration (pulse) into the vehicle hull [4]. The numerical analysis method presented in this report involves the following four steps:

(1) The first step is to establish the baseline occupant injury responses for a non-stroking seat, without energy-absorbing floors, when the structure is exposed to a half-sine vertical acceleration pulse (peak of 200 g), lasting 5 ms, as shown in Figure 6; the corresponding velocity, or ΔV, is 6.3 m/s. For the 350 g and 500 g pulses, the velocities are 8.7 m/s and 9.3 m/s, respectively, as shown in the right side of Figure 6.

(2) The second step is to compare the baseline occupant injury responses from step 1 with a conventional stroking seat as shown in Figure 7.

(3) The third step is to establish occupant injury responses of retractor-based stroking seat system for a variety of retractor designs.

(4) The fourth step is to evaluate the best performing retractor seat system against the 350 g and 500 g vertical pulses to show the robustness of the new retractor-based EA system as compared to the conventional stroking seat.

(5) The last step is to evaluate the effect of off-axis loading on the hull and determine how the seat and the dummy respond when the 200g, 350g and 500g peak accelerations are applied along an oblique vector (non-vertical). Again, the best performing retractor system is compared against the conventional stroking system.

The retractor force-displacement curves used in this study are shown in Figure 9. All simulations have been perfomed using LS-DYNA [5,6]

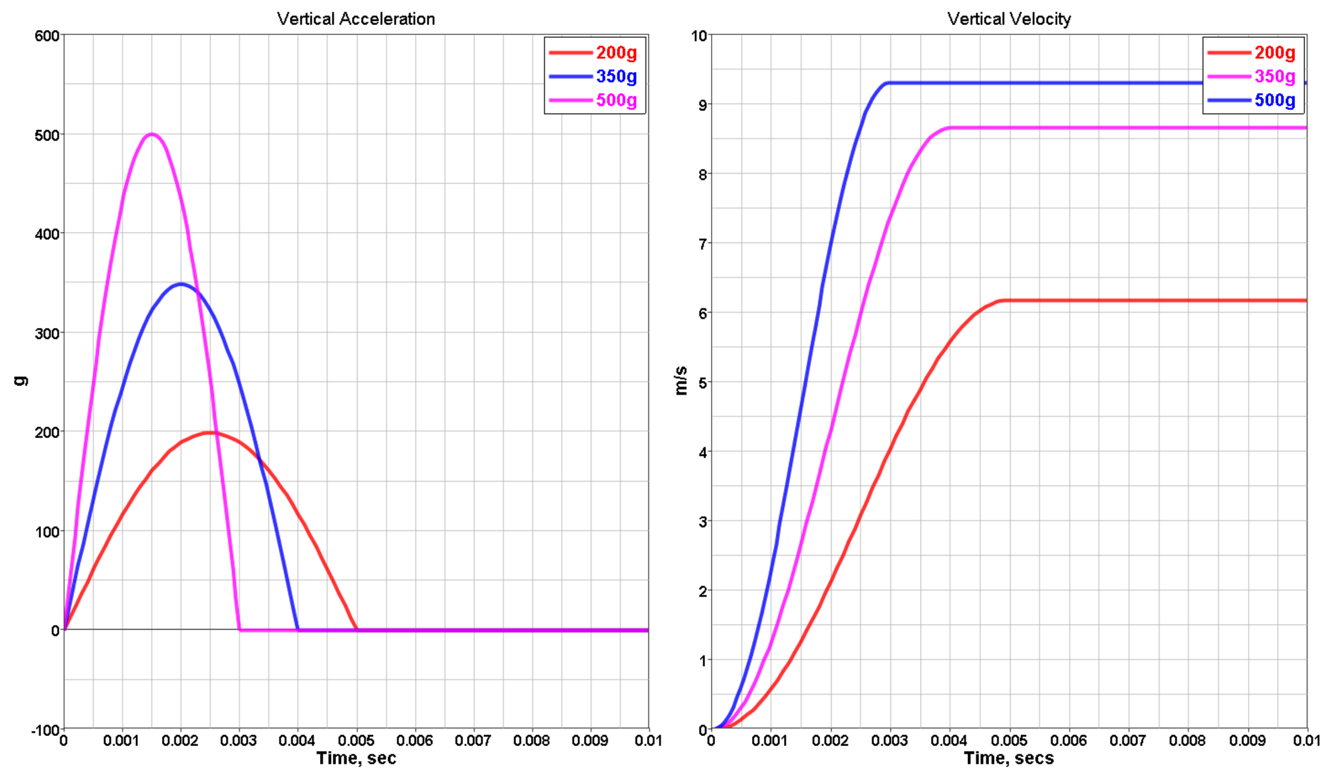

Figure 6: Input vertical acceleration & velocity

3.1 Baseline

Initial baseline analysis is performed with a generic vertical accelerative load of 200 g for 5 milliseconds shown in Figure 6 is input to the V hull. Baseline M&S analysis seat is not allowed to stroke and dummy floors does not have any energy absorbing or shock attenuating mechanisms.

3.2 Conventional stroking seat

In order to assess the validity of the retractor based stroking seat model, it is necessary to understand how the conventional stroking seat will perform in a vertical accelerative loading. The stroking mechansm is represented as a non-linear spring with force vs displacement (FD) as shown in figure 7 as model input. Figure 7 is a typical FD characteristics of a conventional stroking seat. The conventional seat stroking mechanism can be a simple metal wire pulling, a coiled spring compression, tube on tube or can be any other mechanical devices moving relative to each other casuing the seat to stroke

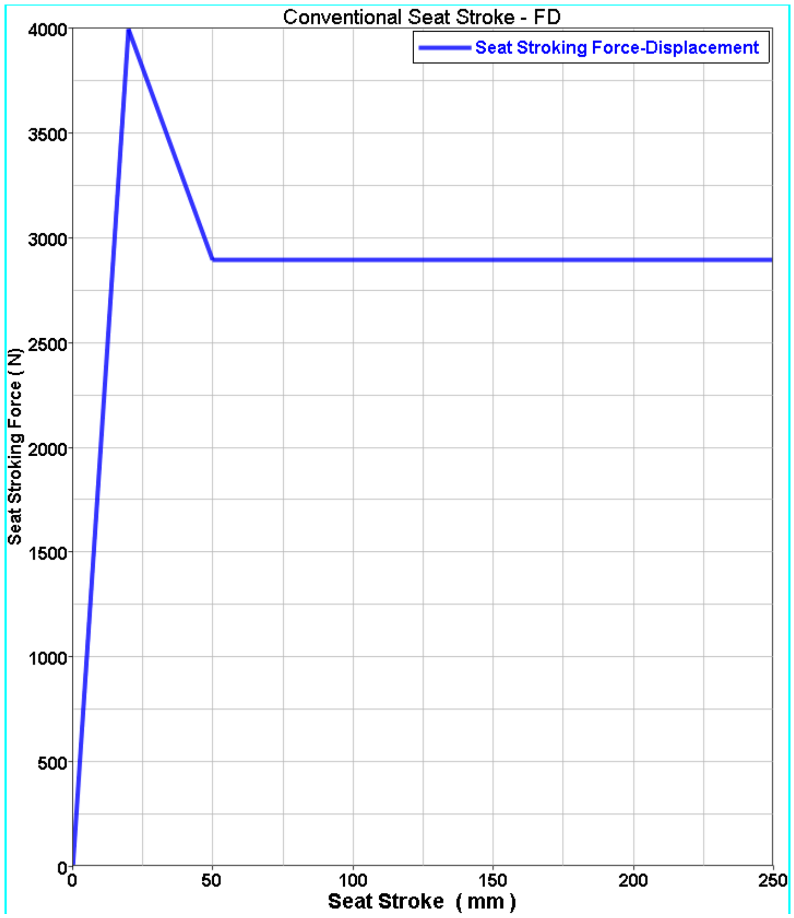

Figure 7: Conventional seat force-displacement (FD) curve

3.3 Retractor-based stroking seat

The conventional stroking seat mechanism is replaced by a seatbelt retractor. There are several advantages to retractor-based energy-management systems. These systems can be efficiently incorporated into the seat structures of today's military ground vehicles. When compared to the more traditional EA mechanisms, it is easier to control the stroking in retractor-based concepts using different seat belt webbing and load-limiters. Retractor-based EA systems can be developed as a modular kit and implemented in vehicles that are already fielded as well as those under development. The underlying concept is independent of the size or weight of the vehicle, and can be easily tuned for specific configurations.

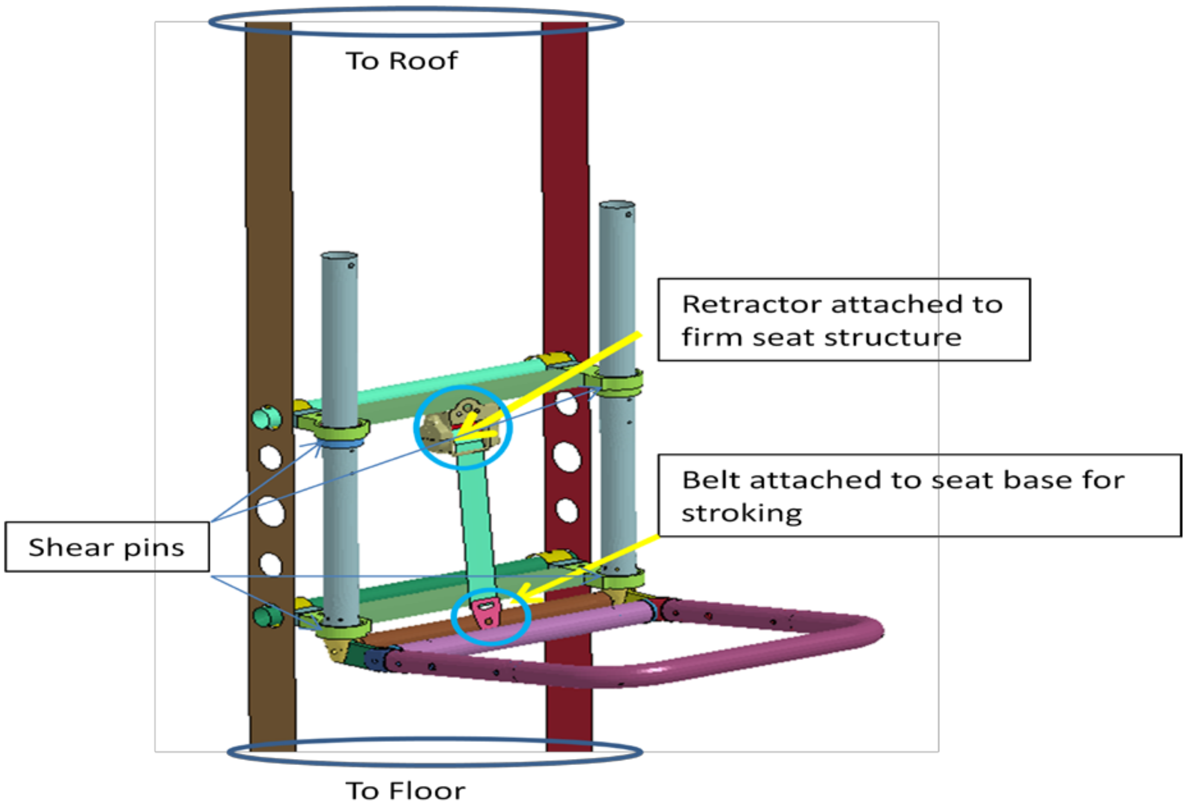

Figure 8: Stroking retractor attachment scheme

Figure 8 shows the detailed attachment scheme for the stroking retractor used in the report. The retractor with torsion bar is attached to the non-stroking stiff part of seat structure as shown on Figure 6. Other end of the retractor is attached to the seat base via the anchor. There are four shear pins that control the initial breaking load. Once the shear pins are released, the seat cushion attached to the retractor is free to move downwards depending upon the occupant load against the vertical accelerative load from the hull (input). The downward motion of the seat cushion and the occupant is controlled by the retractor system which is attached to the stroking seat as shown.

Eight different retractors are analyzed in this study. Figure 9 shows the normalized retractor force-displacement curves. The retractor forces are normalized to the conventional seat-stroking force and displacements or stroke is normalized to peak value of 250 mm. Retractor 8 is a two-stage [9, 10] digresive load limiting retractor (DLLR), all others are constant-force retractors with different load limiters. Maximum seat stroke allowable in this study is 250 mm.

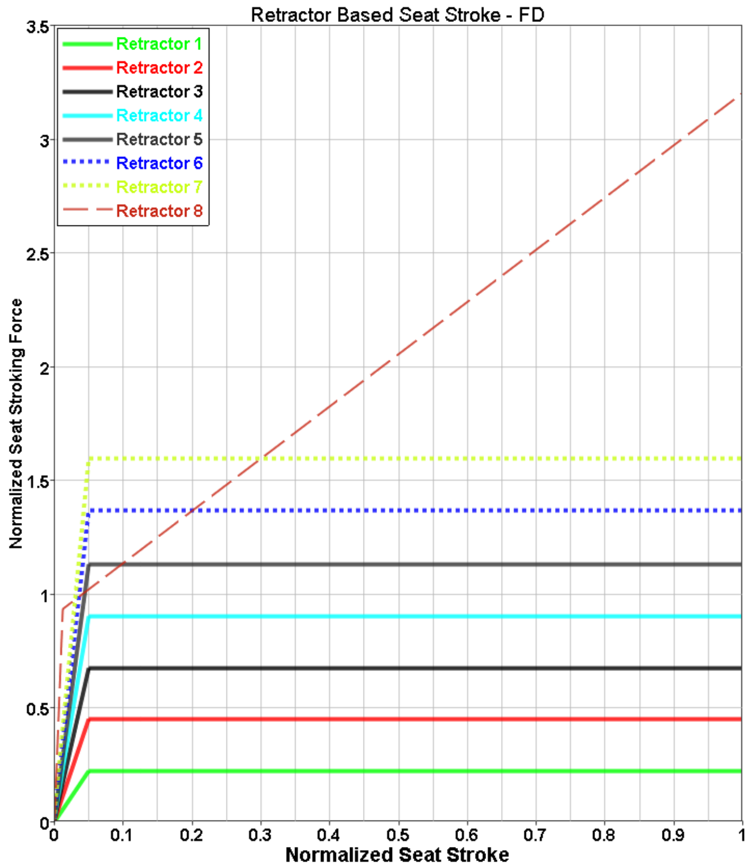

Figure 9: Retractor based seat FD

4.0 NUMERICAL ANALYSIS RESULTS

4.1 Baseline – Non-stroking seat

The injury responses of the occupant seated in the non-stroking seat are shown in Figure 10. The lower lumbar vertical load peaks at 650 lbf (2,891 N) and the duration is between 15 ms to 35 ms. The left lower tibia loads peaks around 3500 lbf (15,568N) and the right lower tibia loads shows peak value of 4500 lbf (20,016 N) with duration from 7 ms to 15 ms for a non-stroking seat. The pelvic vertical acceleration shows a peak value of 45 g's between 12 ms to 45 ms. From the curves below, it is clear that the lower tibia experiences the shock between 7 ms to 15 ms. During this time, the lower lumbar spine experiences minimal load and it will be in tension. When the tibia loads peak, the lower lumbar load starts to pick up a compressive load. The lower lumbar compressive load is active between 15 ms to 35 ms. Peak pelvic vertical accelerations also occur during this time frame.

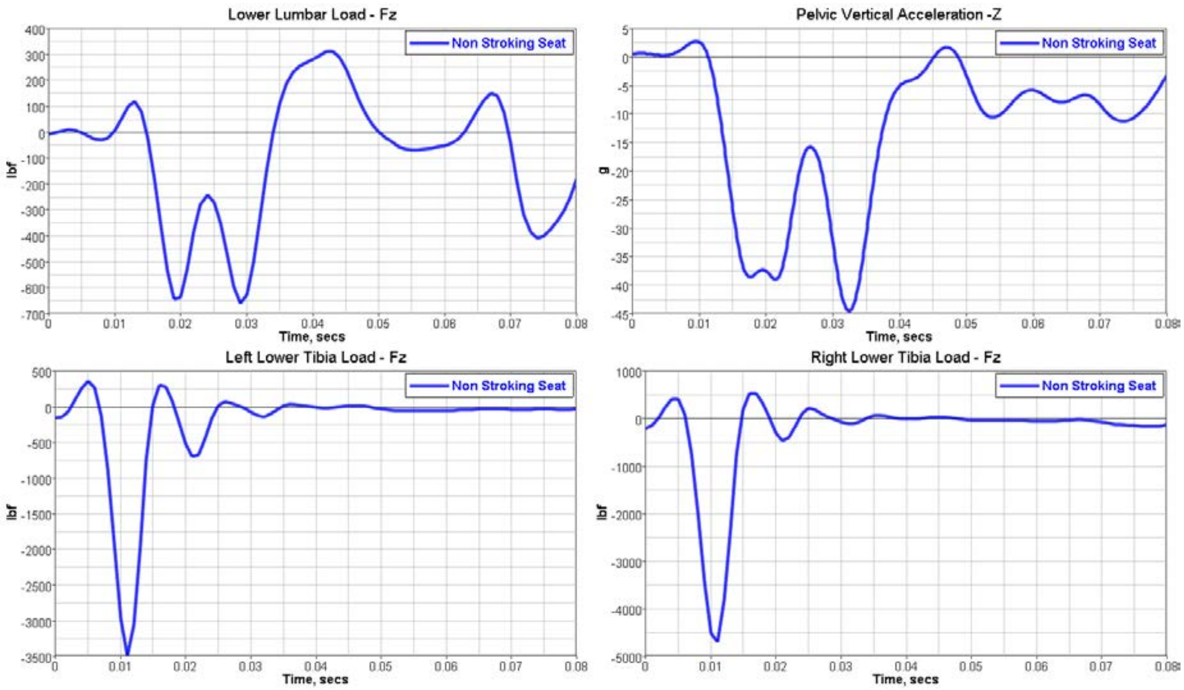

Figure 10: Dummy responses of a non stroking seat

4.2 Conventional Stroking Seat Performance

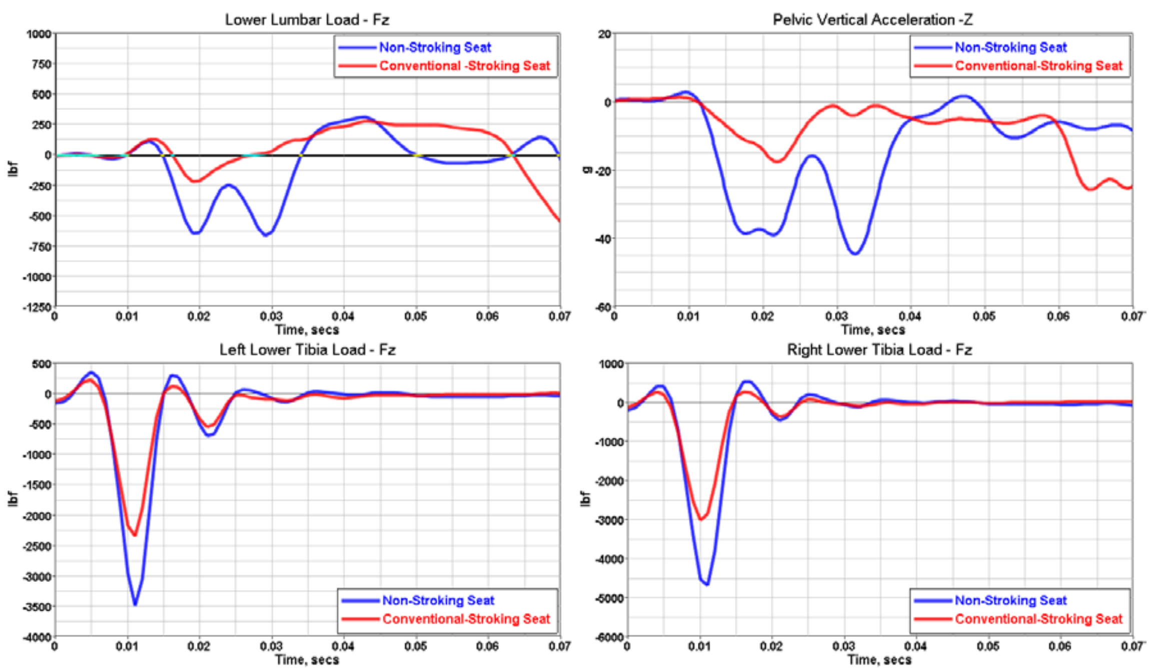

Figure 11: Crew responses for non-stroking & conventional stroking seat

Figure 11 shows the dummy responses for a conventional stroking seat comparing to the non-stroking seat. It is clear from the lower lumbar loads and pelvic acceleration curves that the stroking seat does reduce the lumbar loads and pelvic vertical accelerations, as expected. For stroking seats, the peak lumbar loads and pelvic accelerations are slightly lower than that of the non-stroking seat and occur between 12 ms to 35 ms. Since there is no EA mechanism for floor, tibia loads remain nearly unchanged between non-stroking and stroking seats.

4.3 Retractor-based stroking seat performance

Dummy responses for eight different retractors are analyzed and compared to the non-stroking and stroking seats. Table 1 summarizes the dummy responses of non-stroking, conventional stroking and retractor-based stroking seat.

Table 1: Dummy responses for different seat EA concepts

Seat system		**Pelvic vertical acceleration (g)**	**Lower lumbar load (lbf)**	**Left lower tibia load (lbf)**	**Right lower tibia load (lbf)**
Non Stroking	NS	45	657 [2922 N]	3472 [15443 N]	4675 [20794 N]
Conv Stroking (CS)	CS	18	310 [1378 N]	3000 [13344 N]	4664 [20745 N]
Retractor Stroking (RS)	1	44	795 [3536 N]	1988 [8843 N]	2485 [11053 N]
	2	43	613 [2727 N]	1986 [8834 N]	2479 [11027 N]
	3	30	580 [2580 N]	1986 [8834 N]	2480 [11031 N]
	4	22	453 [2015 N]	1988 [8843 N]	2483 [11044 N]
	5	**17**	**212 [943 N]**	**1990 [8852 N]**	**2483 [5445 N]**
	6	19	300 [1334 N]	2320 [10319 N]	2486 [11058 N]
	7	21	440 [1957 N]	2350 [10453 N]	2832 [12597 N]
	8	35	490 [2180 N]	3500 [15568 N]	4300 [19126 N]

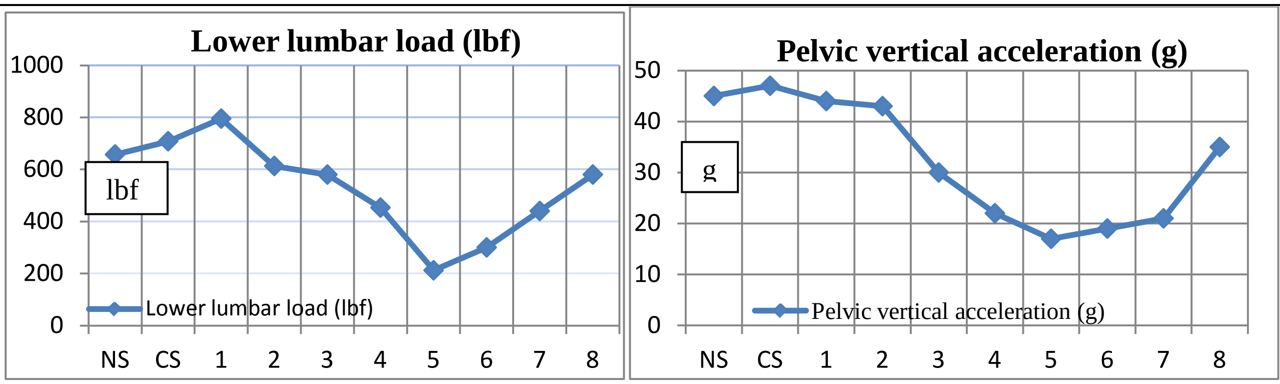

Figure 12: Pelvic vertical acceleration and Lower lumbar load for different seat EA systems

Figure 12 shows the lower lumbar loads and pelvic vertical accelerations from Table 1. The curves in the Figure 12 and Table 1 show that Retractor 5 results in lowest dummy responses for 200 g vertical acceleration input. The lower lumbar loads for non-stroking, conventional stroking and retractor based stroking seats are shown in Figure 13. It is clear from the curves that retractor-based stroking shows significant reductions in lower lumbar loads for 200 g vertical input. Retractor 5 is chosen for further studies in the next step to optimize the lumbar loads, tibia loads and pelvic vertical acceleration for higher input accelerations. Figure 14 shows the occupant positions at different instants of time.

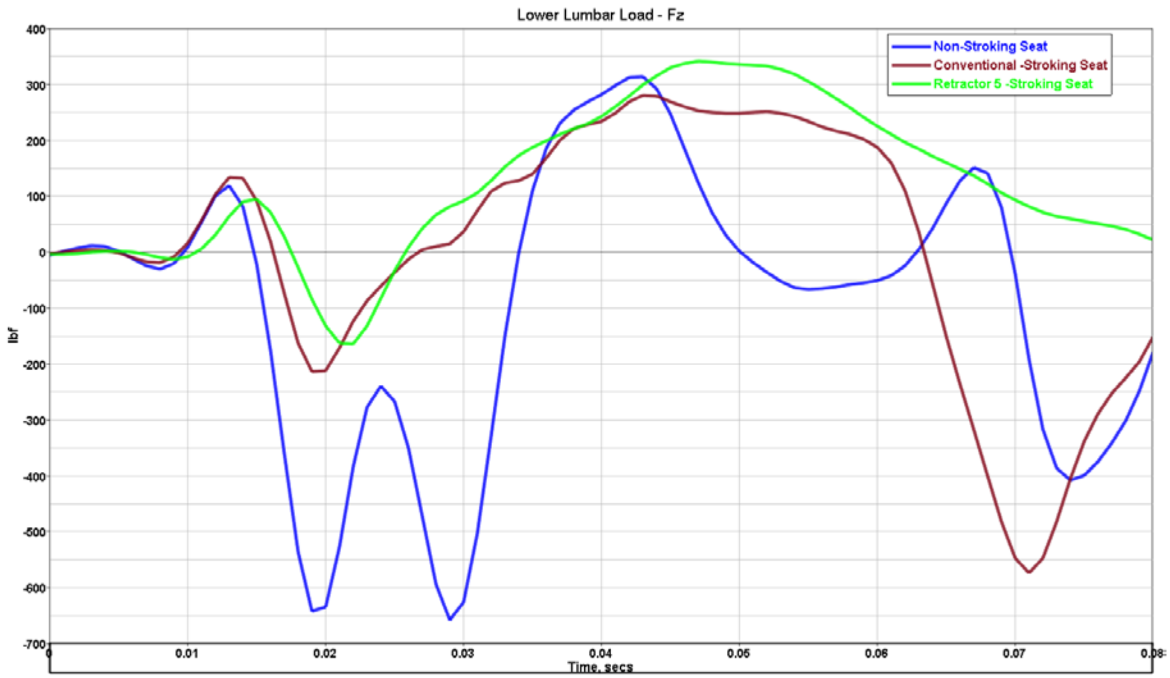

Figure 13: Dummy responses for retractor-based stroking seat vs. conventional stroking seat & non-stroking seat

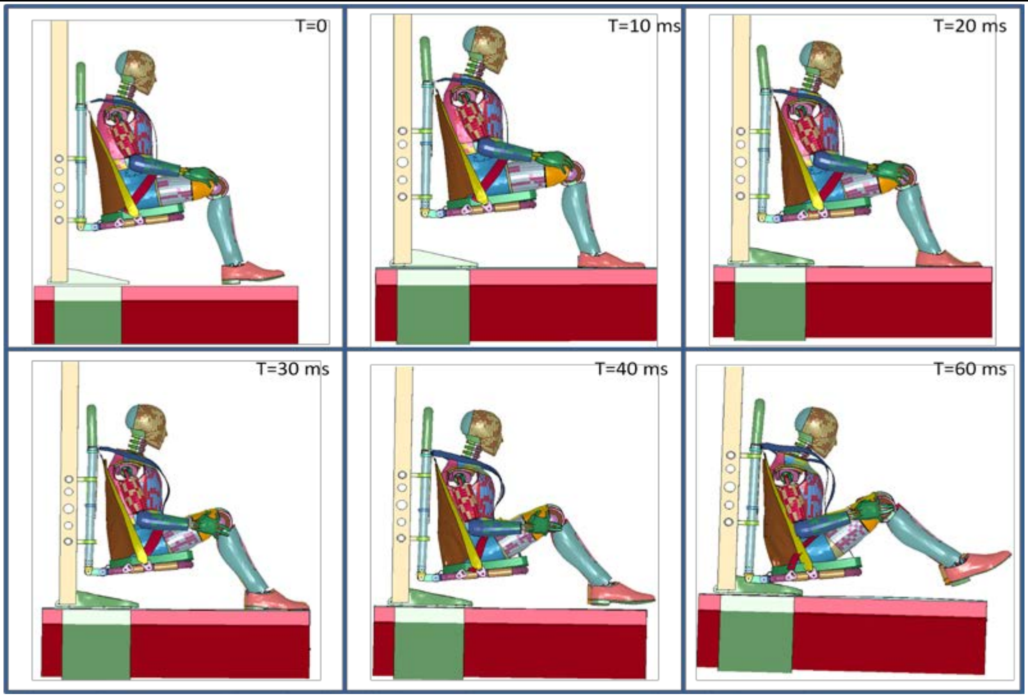

Figure 14: Dummy kinematics at different instants of time

5.0 EFFECT OF ENERGY-ABSORBING (EA) FLOOR

Having identified the best retractor system (Design #5), the next step is to find out how will the energy-absorbing (EA) floor will influence the dummy responses when exposed to same input vertical acceleration. In this set of simulations, the effect of EA floor is analyzed for a non stroking seat, conventional stroking seat and the best retractor stroking seat at 200g, 350g and 500g vertical acceleration input. Results are summarized in table 2.

Table 2: Dummy responses with floating floor & stroking seats

	Pelvic vertical acceleration (g)			Lower lumbar loads (lbf)			Average tibia loads (lbf)		
Input	**NS Seat**	**CS Seat**	**RS Seat**	**NS Seat**	**CS Seat**	**RS Seat**	**NS Seat**	**CS Seat**	**RS Seat**
200 g	42	18	16	600 [2669 N]	300 [1334 N]	196 [872 N]	900 [4003 N]	950 [4226 N]	956 [4252 N]
350 g	44	35	17	1250 [5560 N]	605 [2691 N]	212 [943 N]	1500 [6672 N]	1600 [7117 N]	1053 [4684 N]
500 g	46	42	24	1260 [5604 N]	650 [2891 N]	244 [1085 N]	1700 [7562 N]	1700 [7562 N]	1586 [7055 N]

5.1 Off-Axis loading

The last step in the analysis is to evaluate the effect of off-axis loading on the hull and determine how the seat and the dummy respond when 200g, 350g and 500g peak accelerations are applied along the vector defined in Figure 15.

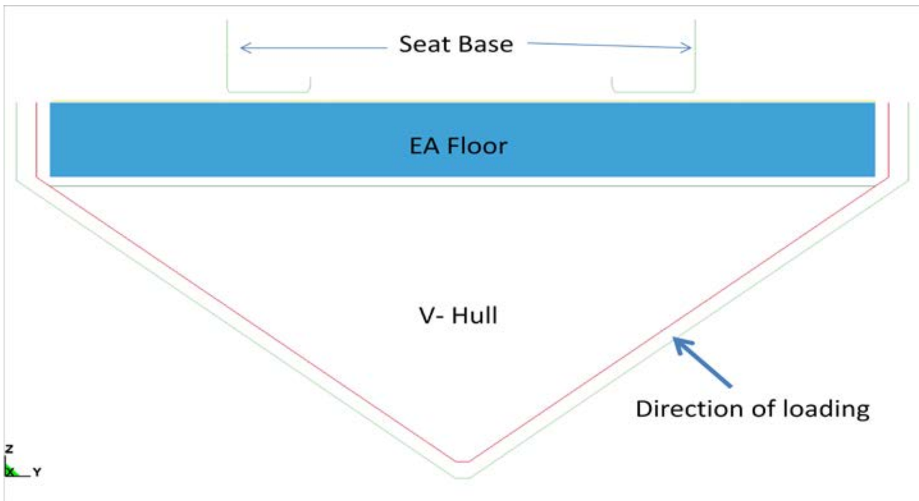

Figure 15: Off-axis loading on the V hull

Table 3: Dummy responses and responses for conventional (CS) and retractor (RS) seats

	Pelvic vertical acceleration (g)		Lower lumbar loads (lbf)		Average tibia loads (lbf)		Seat Stroke (mm)	
Input	CS Seat	RS Seat	CS Seat	RS Seat	CS Seat	RS Seat	CS Seat	RS Seat
200 g	11	8	322 [1432 N]	105 [467 N]	200 [890 N]	300 [1334 N]	35	90
350 g	18	10	350 [1557 N]	150 [667 N]	370 [1646 N]	360 [1601N]	64	110
500 g	19	16	470 [2091 N]	330 [1468 N]	420 [1868 N]	390 [1735 N]	78	170

Table 3 summarizes the dummy responses and seat stroke results from off –axis loading. The retractor stroking seat shows lower dummy responses compared to conventional stroking seat when exposed to off-axis loading. The seat strokes more in retractor-based system compared to conventional seat stroking system, on an average, by an increase of 50%. The initial and final positions of the seat and dummy are in captured in Figure 16.

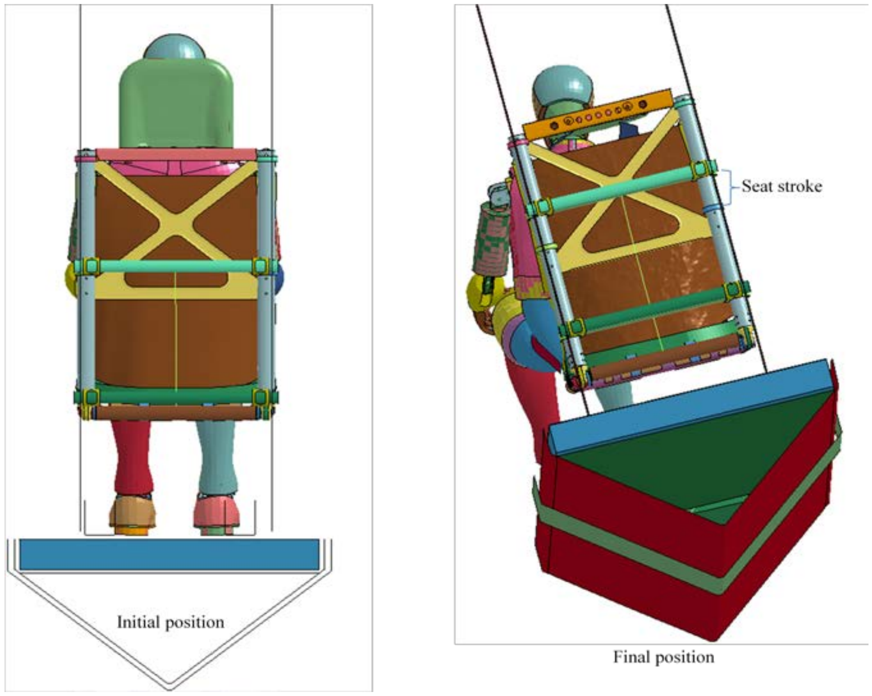

Figure 16: Initial and final positions of the Seat and dummy for off-axis loading

6.0 CONCLUSIONS

- Dummy responses have been analyzed numerically in a generic occupant compartment consisting of a various stroking and non-stroking seat and floor mechanisms.
- A retractor-based stroking seat has been proposed to mitigate the high vertical accelerative loads arising from under body blasts, and shows promising results. The retractor-based stroking seat helps reduce the pelvic vertical acceleration and lower lumbar spine loads significantly, when compared to other two designs described in this report.
- Retractor-based systems are relatively easier to develop and tune the seat stroke for varying inputs compared to traditional methods of pulling a wire, bending metal components, etc. In addition, these systems are relatively easier to integrate to any seat due to their modular design nature.
- The next step is to develop the physical retractor system analyzed in this report and evaluate in a vertical drop tower test to validate the numerical findings.
- Numerical setup in this report is an ideal boundary condition for both conventional and retractor stroking seats to stroke, which may not be completely realistic.

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LIST OF SYMBOLS, ABBREVIATIONS, ACRONYMS

M&S	Modelling and Simulation
RHA	Rolled Homogeneous Armor (steel)
LS-DYNA	COTS structural dynamics software from Lawrence Livermore
DoA	Department of the Army
DoD/DOD	Department of Defense
EA	Energy Absorbing
LTV	Light Tactical Vehicle
FD	Force-Displacement
LLCID	Load curve for loading (Pull-out, Force)
ULCID	Load curve for unloading (Pull-out, Force)
DLLR	Digressive load limiting retractor
NS	Non Stroking
CS	Conventional Stroking
RS	Retractor Stroking
RDECOM	Research, Development and Engineering Command
TARDEC	Tank Automotive Research, Development and Engineering Centre