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A Study on Influence of Seatbelt with and without Force Limiter to Outcome of Human Body Chest Model in Frontal Impact Test

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Abstract:

Background: Regular and force limiting seatbelts are the two dominate seatbelt restraint systems during the road crash. They have the different behave due to the theory of the design which may cause the different consequences of the chest protection results.

Objective: The purpose of this paper was to study on protection of occupant chest in frontal impact, by using different seatbelts with and without force limiter. The fracture and non-fracture human body models were also used with these two seatbelts to check the protection difference caused by the different rib fracture settings.

Method and Material: A Human Body Model (HBM) was positioned according to the sled test environment. Then two kinds of seatbelts were created in the same configurations. Four simulations were carried out in two groups. The rib fractures were produced in one group of the simulations and the other group of the simulations was implemented without rib fractures. All the chest deflection locations were analyzed at the same points as measuring on the Test Device for Human Occupant Restraint (THOR) dummy.

Results: Results demonstrated that the force limiting seatbelt could better protect the chest in the frontal impact. And the difference caused by non-fracture human model with force limiting seatbelt was significant in the simulation.

Conclusions: The influence of the force limiting seatbelt on minimizing chest deflection is more significant than that of regular seatbelt. Force limiting seatbelt is not appropriate to study the chest deflection when used with the non-fracture human body model.

Keywords: Comparison, Thorax, Seatbelt, Chest Deflection, Biomechanics

1 Introduction

Chest injury, according to the statistics, is the first cause of occupants' death in road crash [1], [2]. The principal cause of this injury is the rib fractures caused by contact between seatbelt and ribcage. So the seatbelt should be mostly thought over in the biomechanical study of the chest injury [3]. Due to different restraint conditions, thorax deforms and injury risks varies, and should be focused on in biomechanics study [4], [5]. During the impact, the seatbelts, no matter what types, play a key role in fixing the position of the passenger when he/she moves forward. And the force caused by the constriction will result in the deflection of the chest. As a consequence of the compression, the rib may fracture and all the organs of the chest or upper abdomen will be in risk of rupture.

Deflection of the chest can invade the thorax space for the organs, which will cause compression of the organs. Furthermore, it can reflect the rib bending. And a fracture will happen if the rib reaches the failure criteria during the bending, which is regarded as a judgement of the injury. The human body is not coupled as the mechanical dummy, which means the deflection in one part may not have much influence on another area. Therefore, four-point deflections of the chest are tested when it comes to calculating the deflection.

As the primary restraint system for the occupant protection during the impact, regular seatbelt and force limiting seatbelt are two of the most common types of seatbelts. Due to deferent behaviors during the impact, they may cause various injury responses like deflection. And, the deflection outcome of the four points in the chest can show the difference more comprehensively than the maximum chest deflection measured only in one point. And it is known that the force limiting seatbelt can better reduce the maximum chest deflection in most studies.

Because of the variety of the human body, the fracture numbers during even the same test are totally different, and fractures may affect the chest deflection. For the human body model, there are two dominant methods mentioned when predicting the injury: The element elimination method and the probabilistic method based on the post processing. The element elimination method can display fractures. Rib fractures are usually identified in most of the frontal tests, and the fractured ribs can represent the stiffness loss in the impact. In the probabilistic method, all ribs are set with element elimination functionality disabled in the Finite Element (FE) model. When choosing this method, the fracture number should be very small, and this small number may not affect the total stiffness [6]. Due to this assumption, there must be some difference between the two prediction methods.

To set all the human body models in the same test condition, the Gold Standard (GS) sled test was selected. Shaw reported [7] a series of whole body sled test results in this test condition, which contains eight tests with regular seatbelt. All the simulation models and seatbelts are built in the same position according to the cadaver test.

Though compared with the regular seatbelt, the force limiting seatbelt is more difficult to control due to the complexity and noise. Both of two seatbelts are constructed with the same method and go across similar paths.

The purpose of this study was to contrast the chest protection with two seatbelts. Two methods based on two distinct fracture theories were conducted to test the difference between the deflections of two models with the rib fracture functionality enabled and disabled.

2 Method

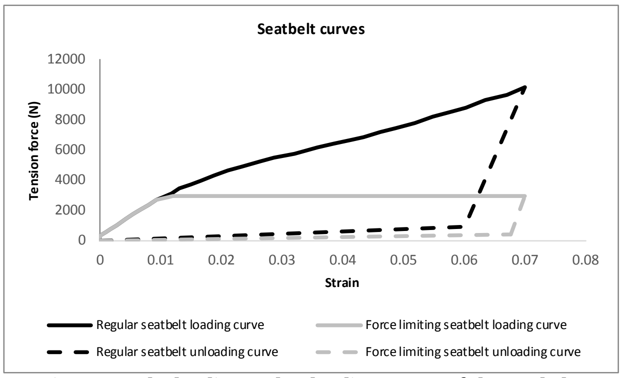

Figure 1 : The loading and unloading curves of the seatbelts

To study the different chest deflection outcomes with varied seatbelts, the Human Body Models (HBMs) were settled in the identical position, and all the boundary conditions were set the same. The only difference was the seatbelt setting. The regular seatbelt FE model was created according to the material provided by the manufactory. However, the force limiting seatbelt was modified in order to gain the same response as the measurement from the tests (**Figure 1**). The HBMs utilized in study were the Global Human Body Models Consortium version 4.2 (GHBMC V4.2).

Table 1 : Simulation matrix

Simulation ID	Number of fracture ribs enabled	Seatbelt types
Simulation 1	*all*	*Regular*
Simulation 2	*none*	*Regular*
Simulation 3	*all*	*Force limiting*
Simulation 4	*none*	*Force limiting*

In order to verify the influence of the fracture on the chest deflection, the fracture option defined as models with or without rib fracture was used. For one series of the simulations, the fracture was enabled to stimulate the response of the ribcage during the impact. The packaged method in the HBM was the element elimination method based on the strain-fracture criteria. Another series of simulations were based on the strain-based injury criteria of the probabilistic method. This method assumes that a small number of fractures will not affect the ribcage stiffness, and the effect of this is very small which requires the element elimination option is disabled. The regular and force limiting seatbelt were both used to get a further view of better suitable seatbelt for the probabilistic method.

According to the discussion above a simulation matrix was built to guide the study of this paper (**Table 1**). Element elimination method means the fracture will happen and shown with the deletion of the element. In non-fracture HBM, the element elimination functionality is disabled in the simulation, and only the peak strain was selected. And ribs will not crack or break (no fracture) though the strain might be critical.

3 Results

After the simulations, all the chest deflections in four measurement points were recorded (**Table 2**). Chest deflection measurement locations are upper right (UR), upper left (UL), lower right (LR) and lower left (LL).

All the deflection outcomes from simulations have the same trends though the figures change a lot in the last two simulations.

Table 2: Deflection results of all the measure points(-: compression +: expansion)

Simulation	*Deflection (mm)*

ID	*UR*	*UL*	*LR*	*LL*
Simulation 1	*-35.502*	*-49.298*	*+32.256*	*-43.999*
Simulation 2	*-35.001*	*-43.781*	*+31.284*	*-31.996*
Simulation 3	*-28.267*	*-34.413*	*+32.53*	*-21.194*
Simulation 4	*-25.878*	*-29.865*	*+36.913*	*-9.530*

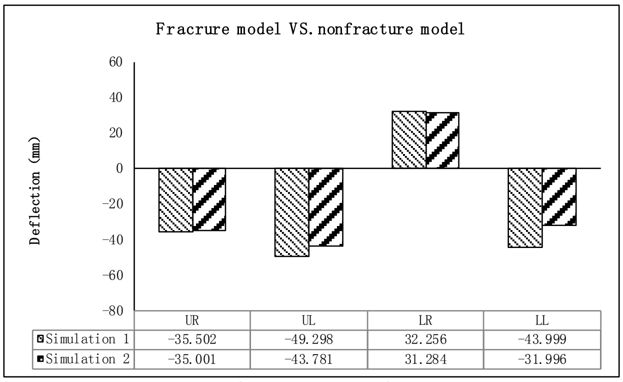

Figure 2: Deflection comparison between fracture and no fracture simulations with regular seatbelt.

The deflection changes in the right side are very tiny (less than 1mm), which means there is no difference between the fracture and no fracture models if the chest deflection was applied to judge the injury (**Figure 2**). This is different from the study of the seatbelt position on rib fracture study, in which the right side of the body is more responsive to the seatbelt position. In the chest deflections, the left side is more responsive when the model is changed from "non-fracture" to "fracture" model due to the loss of the local stiffness because of the fracture ribs. The LL is more sensitive, because in most cases of the tests from Shaw (2009), the lower left ribs will have more fracture injuries, which means the ribcage here will lose more stiffness during the impact compared with other measurement areas.

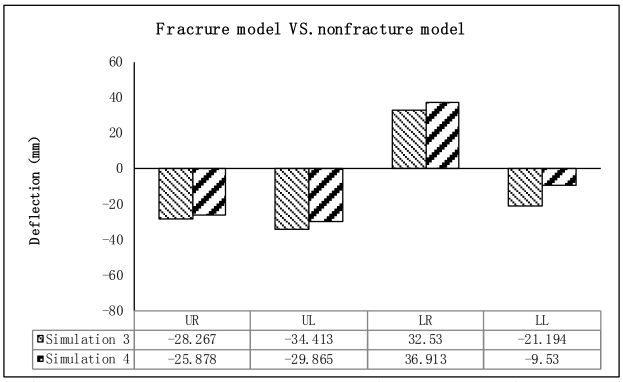

Figure 3: Deflection comparison with and without fracture in the force limiting seatbelt

In the force limiting seatbelt simulations, if the fracture happened, all the compression deflections of the chest would become larger (**Figure 3**), even in the UR. Usually, there is not quite a difference with the regular seatbelt, even though a slight change can be identified. The left side is, likewise, more sensitive than the right side, which is the same as the deflection conclusion of the regular seatbelt. Both the deflections in two sides of the "fracture" HBM are greater than those in the "non-fracture" one. The biggest difference also happened in the LL, about 12 mm, which is a significant change in the deflection compared with all the other three measurement points. The increase of the LR, about 4 mm, should be noticed, which means the rib in this area will go outside in the "non-fracture" model. This will increase the strain of the rib, which may increase fracture risk because of the high strain even though it may give more space to the organs.

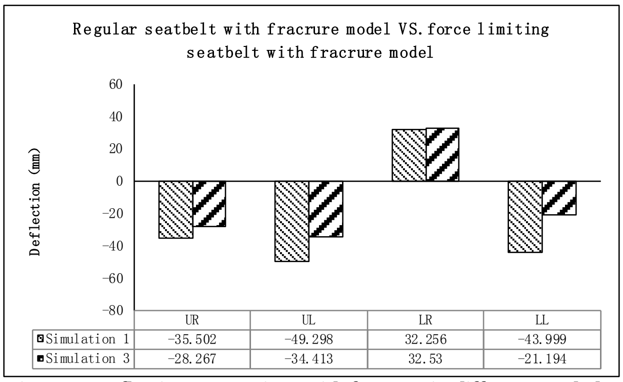

Figure 4: Deflection comparison with fracture in different seatbelts

Judging from the "fracture" HBM simulations, the force limiting seatbelt is much safer than the regular seatbelt because that all the deflections are smaller than those with regular seatbelt and there is no increase of the LR expansion (Figure 4). The reason might be that the compression change is so small or all the four points are independent, which means there is not much connection between each two measurement points. The biggest difference is about 22 mm in LL, also at this point, the largest change will usually be identified. This might be the result of the protection of the force limiting seatbelt. Also the change of the upper body is about 8 mm, which is not as much as the no fracture one and all the compression points are found less deflected with force limiting seatbelt.

If there is no fracture in the simulation, the change of deflections is much more than there are fractures, which means the "non-fracture" simulation condition should be paid more attention to when the study with chest injury is carried out (**Figure 5**).

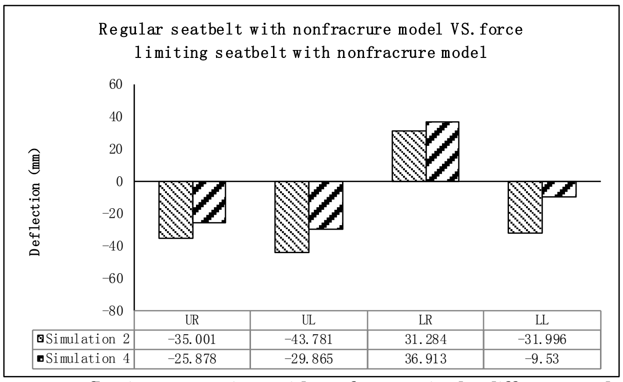

Figure 5: Deflection comparison without fracture in the different seatbelts

Chest deflection outcomes in force limiting seatbelt simulations were much better than that in the regular seatbelt simulations. First, all the compressions of the chest are small, and the expansion will become larger. In this case, the chest injury will be small. The biggest difference is founded in the LL which is about 20 mm gap. This means more safety space for the lung and the organs in the abdomen. Also the compressions become smaller on both sides of the upper torso. And the gap between these two simulations is beyond 10 mm, which is also substantial. There is also a slight increase of the LR due to the reduction of the compression. Because the increase is so negligible, the increased strain will not have so much influence on the rib fracture.

4 Discussion

In the current study, an HBM was settled on a simplified whole-body frontal sled test for the study of two different types of seatbelts on the chest injury. To study the influence of fracture, the rib fracture was set in "fracture" and "non-fracture" conditions to check the effect caused by the fracture setting on the chest deflection. A total of four simulations were applied with two factors (seatbelt and fracture) at two levels each (regular and force limit, yes or no), which is a full factorial (two by two) experimental design study. All the seatbelts were positioned in the same location, and waypoints of the seatbelt were kept in the identical location according to the sled through the entire simulations. The unique curves for the seatbelt materials were the only difference of the simulation.

Compared the chest deflections between simulations with force limiting seatbelt and regular seatbelt, the deflections with force limiting seatbelt is much smaller. It demonstrates that the force limiting seatbelt is better in protecting the chest from serious injury, because that the less deflection can keep more saving space to the occupant and make a reduction of rib fracture risk.

The biggest change regularly happens in the LL, and the values are always more than 10 mm. The reason might be that most fractures happened around this point. And this result also indicates that this point is more likely to get the better protection, so this area should be first considered when it comes to reducing the chest deflection.

The LR will become larger in the “fracture” HBM with the force limiting seatbelt. However, it will become smaller with the regular seatbelt. It may stem from the fact that the number of fractures would reduce, and the ribcage would be safer when force limiting seatbelt was applied. Because the rib fractures around LR are less, the stiffness will keep the same, and the quantitative value will become larger.

The left-hand side of the body is more sensitive to the chest deflection in this study. Both in “fracture” and “non-fracture” HBM, the left side deflection will change more than the right side when the seatbelt type is changed. And for each seatbelt type, the left side will change more from “fracture” to “non-fracture” HBM.

The force limiting seatbelt should be carefully used with the “non-fracture” HBM. Because the difference between “fracture” and “non-fracture” models is very huge with the force limiting seatbelt. Force limiting seatbelt should be carefully modified if applied to the “non-fracture” HBM.

When examining the “fracture” model, regular seatbelt is more suitable than force limiting one. The difference between “fracture” and “non-fracture” models with regular seatbelt is acceptable, but should be carefully applied in the simulation.

5 Conclusion

According to the results, the fracture happened earlier would affect the ribcage stiffness so that the deflection (compression) of the chest would definitely increase no matter what types of the seatbelt. This deflection increase was more noticeable with the force limiting seatbelt. Regardless of the fracture types, the HBM with rib fracture model was more suitable for the simulation study with force limiting seatbelt. The chest deflection change of the “non-fracture” model was not so obvious, which means both the “fracture” and “non-fracture” human models could be used in simulation with the regular seatbelt, although the difference should be noticed and a small modification should be made if the results were to be used.

The results demonstrate that the “non-fracture” FE model should be carefully utilized because of the error when studying the chest injury with force limiting seatbelt.

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