Analysis of Seat Belt Anchorage Strength for Vehicles

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Abstract. In order to improve the efficiency of seat design and enhance the safety of vehicle seats, it is necessary to carry out CAE analysis on seat safety before making physical tests. In this paper, the finite element analysis theory and HyperWorks finite element analysis software are applied in the pretreatment of vehicle seats, seat belts, as well as the upper limbs and buttocks of dummies. The loading time and load of the seat are set according to GB 14167-2013 of the People's Republic of China, and CAE calculation is carried out based on LS-DYNA software, obtaining the stress-strain nephogram of the corresponding vehicle seats. An improved scheme is proposed base on the analysis results, and CAE analysis is carried out on the improved seats again. The results of the analysis fully meet the national standard GB 14167-2013 and material strength requirements, which are of important guiding significance in reducing the development costs, shortening the development cycle and improving the passing rate of physical test.

1. Introduction
Vehicle seats not only provide riding comfort for the crew, but also play a role in protecting the life of passengers in vehicle collision; the strength of vehicle seat belt anchorage is an important index of vehicle safety regulations and a mandatory test index of vehicle experiments in Announcements. In the event of a collision, the tearing or rupture surrounding the seat belt anchorages is the main cause of casualties. GB 14167-2013 Safety-belt Anchorages, ISOFIX Anchorages Systems and ISOFIX Top Tether Anchorages for Vehicles requires that the strength of the seat belt anchorage must ensure that the seat belt does not fall off in the specified time and under the test load, but allows permanent deformation at the anchorages or in the surrounding area, including partial breakage or cracking [1]. In order to make the seats better protect passengers in vehicle collision, many seat companies have put higher product performance requirements than the current regulations.

In this paper, a front-row seat for vehicles being developed is taken as the object of study. According to GB 14167-2013 standard, pretreatment of vehicle seats, seat belts, and the upper limbs and buttocks of dummies is conducted through the finite element analysis software HyperWorks, LS-DYNA is used for calculation, and the design scheme is improved to meet the regulatory requirements, reduce the number of physical tests and shorten the design cycle.

2. Passive Safety Simulation Analysis Method
Finite element simulation analysis method is the main method of vehicle passive safety simulation analysis, and the detailed model is obtained by the discrete of CAD model [2-3].

The position and time relationship of each node in the finite element model is expressed as.

\[ x_i = x_i(x_a, t) \]  

(1)

The initial position at moment is
\[ x_i(x, 0) = x_a. \]  

\[ \dot{x}_i(x, 0) = v_i(x_a). \]

Each node and the whole can meet momentum conservation, energy conservation and mass conservation:

\[ \rho \frac{Dv}{Dt} = F + \frac{\partial \sigma_i}{\partial x_i}. \]  

\[ \rho \frac{De}{Dt} = \frac{1}{2} \sigma_{ij} (v_{i,0} + v_{j,0}). \]  

\[ \rho(x_i) = \rho_i(x) \left| \frac{\partial X_i}{\partial X_j} \right|. \]

Where the traction boundary conditions are as follows:

\[ \partial b_i \sigma_{ij} n_j = t_i(t). \]

The displacement boundary conditions are as follows:

\[ \partial b_x x_i (x_a, t) = D_i(t). \]

The contact boundary conditions are as follows:

\[ \partial b_3 (\sigma^\gamma_{ij} - \sigma^\delta_{ij}) n_j = 0(x^\gamma = x^\delta). \]

By substituting the boundary conditions into the nodes, the law of motion and energy changes of each node can be obtained, namely the corresponding relationship of the whole structure in the collision.

The finite element analysis method can provide a more comprehensive and accurate relationship between the energy absorption and deformation response in collision, providing more realistic boundary conditions for the design of the constraint system.

### 3. Finite Element Modeling of Front-row Seat for Vehicles

The geometric modeling of the front-row seat for vehicles, seat belts, as well as the upper limbs and buttocks of dummies is completed via the three-dimensional software CATIA, the finite element model is set up by using the finite element analysis software Hyperworks, and size of the grid for the main components is 5mm. In order to improve the reliability of CAE analysis in some key force components, the grid size may be smaller. The shell cells are mainly divided by grids with main quadrangles and auxiliary triangles, pipes and seat belts mainly adopt beam cells, and solid parts mainly adopt hexahedral grid cells [4-5]. Grid cell quality requirements are shown in Table I.

There are connections between the various parts of the seat, the use of bolts at the anchorage has great impact of stress, so the position of installation holes needs to be carried out with Water treatment in CAE analysis, bolt connection is simulated by Rigid cells, the solder joints are simulated by Beam cells using MAT100 material[6-7]. Fig. 1 is the established seat finite element analysis model.
Table 1. Seat grid cell quality requirements

| Type          | 2D cell | 3D cell |
|---------------|---------|---------|
| Warpage       | <5°     | <5°     |
| Aspect        | <5°     | <5°     |
| Length        | >5mm    | >20mm   |
| Jacobian      | ≥0.7    | ≥0.7    |
| Skew          | <60°    | <60°    |
| Quadrilateral cell |       |         |
| Min angle     | 45°     | 45°     |
| Max angle     | 135°    | 135°    |
| Triangle cell |         |         |
| Min angle     | 20°     | 20°     |
| Max angle     | 120°    | 120°    |

4. Loading Principles and Parameter Settings

4.1. Loading Principles

The four feet of the seat and the floor are connected with beams before loading; SingleSurface is used for the contact between the parts. The equipment for fixing vehicles should be less than 500mm from the front of the measured point or not less than 300mm at the rear, and shall not affect the body structure within the whole width scope. The loading shall follow GB 14167-2013, as shown in Table 2, and the loaded model is shown in Fig. 2.

Figure 1. Seat finite element model

Figure 2. Seat post-loading model
Table 2. Model loading principles

| Loading object     | Direction                                                                 | Force value     |
|--------------------|---------------------------------------------------------------------------|-----------------|
| Dummy’s shoulder   | Parallel to the longitudinal plane of the vehicle and 10±5° to the horizontal plane | 13500N±200N     |
| Dummy’s buttocks   | Parallel to the longitudinal plane of the vehicle and 10±5° to the horizontal plane | 13500N±200N     |
| Seat               | Forward vertically and horizontally                                        | 2550N           |

4.2. Parameter Settings

The material constitutive is an important parameter in the finite element calculation, and only the correct material parameters can be input to get the accurate calculation result. Under normal circumstances, the stress-strain relationship of the material under one-dimensional ideal condition is measured experimentally, and the relationship in the complex case is obtained by substitution or replacement [8-9].

In this paper, the seat is mainly a thin plate stamping part, so it conforms to the MAT24 material model. In the MAT24 material model, since the stress-strain curve slope is the same in the elastic strain stage, so only the plastic section stress-strain curve needs to be input in the material stress-strain curve. Fig.3 shows the transformation chart of the input curve.

\[
\sigma_{\text{eff}}(\varepsilon_{\text{eff}}^p, \dot{\varepsilon}_{\text{eff}}^p) = \sigma_y(\varepsilon_{\text{eff}}^p) + SIGY(\dot{\varepsilon}_{\text{eff}}^p)^\frac{1}{p} \tag{10}
\]

By setting the values of C and p, we can obtain the dynamic stress-strain relationship.

The setting of time step plays a large role in the calculation accuracy. The time step is the length of time for each step of finite element integration. The display center difference method is used in LSDYNA software calculation, the stability of the algorithm depends on the time Length, if the integral step is greater than formula (11), the calculation is unstable, resulting in decreased accuracy of the calculation.

\[
2(\sqrt{1 + \xi^2} - \xi) / \theta_{\text{max}}. \tag{11}
\]
Where $\xi$ is the system damping ratio, $\omega_{\text{max}}$ is the system’s maximum natural frequency.

5. CAE Analysis Results

5.1. Results Evaluation Criteria

It is more reasonable to judge whether the material is broken or not through the deformation of the material, because analyzing the strength of the seat belt anchorages by using the display center difference method and by merely taking the size of the stress as a reference standard will miss/reduce the fracture standard or some other factors.

In the CAE analysis process, the minimum spacing of the lower effective anchorages shall be such that there are two anchorages A and B passing through the seat belt, and the distance between the through A and B point two vertical planes parallel to the longitudinal center plane of the vehicle shall be at least $L_1=350\text{mm}$. The upper effective anchorage Q shall be above the horizontal point R, and $L_2=450\text{mm}$, as shown in Fig. 4[10-11].

5.2. Strain Nephogram

The model is submitted to the LS-DYNA for calculation, and the overall deformation of the seat as shown in Fig.5 is obtained. The force strain diagram of other key components is shown in Fig.6-Fig.9. Fig.6 is the strain nephogram of the lower anchorage parts of the seat belt. It can be seen that the maximum plastic strain of the part is 0.35 and the maximum plastic strain of the material is 0.3. Fig. 7 is the anchor strain nephogram, it shows the maximum plastic strain of the part is 0.87, and the maximum plastic strain of the material is 0.3. Fig.8 is the outer slide strain nephogram, it shows the maximum plastic strain of the part is 0.68 and the maximum plastic strain of the material is 0.12. Fig.9 is the connecting rod strain nephogram, it shows the maximum plastic strain of the part is 0.17 and the maximum plastic strain of the material is 0.12.

Figure 4. Geometric position of seat belt anchorages

Figure 5. Calculation results
5.3. Result Analysis
According to Fig. 5-Fig. 9, the seats collapsed and the strain of the lower anchorage parts of the seat belt as well as of some important parts have exceeded the maximum shaping strain of the material, so the seat structure is unreasonable. The main reason is that when the lower anchorage parts of the seat belt bear a large tension, as shown in Fig. 10, point C produces a larger torque (relative to point M), so that the rails occur upturned deformation and cause the overall seat force change, resulting in collapse as shown in Fig. 5.

6. Structural Optimization
According to the above analysis results, the following improvements of the seat structure are proposed:

1. Improve the structure where the lower anchorage parts of the seat belt locate, the improved structure is shown in Fig. 11.
2. The slide rail moves forward by 30mm, shortening the distance between point C and point M to reduce the torque.
3. The left end of the connecting plate is increased by 10mm to reduce the torque of the end of the slide rail and of the connecting plate, as shown in Fig. 11.
4. The front and sides of the anchor are slotted to reduce the anchor’s concentrated stress.
5. Increase flanging on the connecting rod to enhance the structural strength of it.
The optimized seat model is submitted again to the LS-DYNA software for calculation. The results are summarized in Table 3 and the strain nephogram of some important parts is given, as shown in Fig.12-Fig.15. The results show that the optimized seat completely meet regulatory requirements and material performance constraints.

Table 3. Summary of the improvements

| Parts                        | Material | The maximum material plastic strain/% | Before optimization | After optimization |
|------------------------------|----------|---------------------------------------|---------------------|--------------------|
| The lower anchorage parts of the seat belt | SAPH440 | 30                                    | 35                  | 9                  |
| Anchor                      | SAPH440  | 30                                    | 87                  | 10                 |
| Outer slide             | S500MC   | 12                                    | 68                  | 15                 |
| Connecting rod           | 980DP    | 12                                    | 16                  | 0.03               |

The optimized seat model is submitted again to the LS-DYNA software for calculation. The results are summarized in Table 3 and the strain nephogram of some important parts is given, as shown in Fig.12-Fig.15. The results show that the optimized seat completely meet regulatory requirements and material performance constraints.
The CAE analysis results show that the minimum spacing between the lower effective anchorages A and B is greater than \( L_1 = 350 \text{mm} \), as shown in Fig. 16. The effective anchorage Q is greater than \( L_2 = 450 \text{mm} \) above the point R plier, as shown in Fig. 17. The results meet regulatory requirements.

**7. Conclusion**

HyperWorks finite element analysis software is applied in the accurate pretreatment of the front-row seat for vehicles, and the relevant parameters of the seat model are set according to the requirements of GB 14167-2013 Safety-belt Anchorages, ISOFIX Anchorages Systems and ISOFIX Top Tether Anchorages for Vehicles, and LS-DYNA software is applied to solve the model formula, according to the results obtained that the strength of the seat does not meet the requirements of the regulations, indicating that the seat structure needs to be improved. An improved scheme is proposed base on the test results, and CAE analysis is carried out on the improved seats again. The results of the analysis fully meet the national standard and material strength requirements. The method of seat safety used in this paper can which is of great significance in reducing the development costs, shortening the development cycle and improving the passing rate of physical test.

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9. References

[1] Safety-belt Anchorages, ISOFIX Anchorages Systems and ISOFIX Top Tether Anchorages for Vehicles[S].GB 14167-2013 of the People's Republic of China, 2013.(In Chinese)

[2] Hyun-sik Kim, yoon-sun Lee, Sung-mo Yang, Hee Yong Kang. Structural Analysis on Variable Characteristics of Automotive Seat Frame by FEA[J].INTERNATIONAL JOURNAL OF PRECISION ENGINEERING AND MANUFACTURING-GREEN TECHNOLOGY 2016, 11:75-79.

[3] Chen, H.N., Chen, H. and Wang, L.J. Analysis of Vehicle Seat and Research on Structure Optimization in Front and Rear Impact[J]. World Journal of Engineering and Technology, 2014, 2: 92-99.

[4] Liang Renshuo. Research on Strength of an Automobile Front Seat [D]. JILIN UNIVERSITY-CHINA, 2014. (In Chinese)

[5] Lu Jiao. System Strength Analysis of Vehicle Seatbelt Anchorage [D].SHENYANG UNIVERSITY OF TECHNOLOGY, 2016. (In Chinese)

[6] Wei Guanlin. SIMULATION RESEARCH ON SAFETY OF CAR REAR SEAT FRAME[D]. Beijing University of Chemical Technology, 2013. (In Chinese)

[7] Ramanathan, B., Hu, J. and Reed, M.P. A computational study of seat and seatbelt performance for protecting 6–12 year-old children in frontal crashes[J]. Int. J. Vehicle Design, Vol. 70, No. 1:29–44, 2016.

[8] Sung Yuk Kim , Oh Hwan Jeon , Key Sun Kim. Characteristics of Vibration and Noise from Vehicle Seat Rail[J]. Advanced Science and Technology Letters Vol.120 (GST 2015), pp.239-242.

[9] S Himmetoglu, M Acar , K Bouazza-Marouf , and A J Taylor. Car seat design to improve rear-impact protection[J]. Proceedings of the Institution of Mechanical engineering. Part D, Journal of automobile Engineering, 225(4), PP.441-459, 2011.

[10] Hou Yanjun, Zhou Li, Cui Dong, Xie Shugang. Research on Child Seat ISOFIX Based on LS-DYNA[J]. Automobile Technology, 2016, 01: 42-46. (In Chinese)

[11] Dang Xuemang. The Study of Vehicle Seat Safety With LS-DYNA[D]. Ningbo University, 2014. (In Chinese).