Optimal design research structure rollover safety universe coach follow standards European safety ECE R66

Nghiên cứu thiết kế kết cấu tối ưu cho xe khách Universe nhằm bảo đảm an toàn lật nghiêng theo tiêu chuẩn an toàn Châu Âu ECE R66

Hong Thao Pham[1], Van Thoai Le[1], Cao Hieu Le[1], Van Cuong Phi[1], Van Cuong Le[2]

[1] Nguyen Tat Thanh University, Ho Chi Minh City, Vietnam

[2] Binh Duong University, Binh Duong Province

Corresponding author: Le Van Cuong, Email: vancuongbd60@gmail.com

Tóm tắt: Đề tài ứng dụng kỹ thuật máy tính (CAE) xây dựng mô hình phần tử hữu hạn xe khách Universe ghế ngồi. Sau đó mô phỏng phân tích độ cứng khung xương ban đầu của mô hình theo tiêu chuẩn an toàn lật nghiêng Châu Âu ECE R66. Kết quả độ cứng, khối lượng khung xương ban đầu lớn. Tiến hành giảm bề dày theo cách truyền thống để khung xương biến dạng chạm đến không gian an toàn, làm giảm khối lượng khung xương xe khách. Tiếp tục cải tiến bằng việc thay đổi thiết kế về kết cấu khung xương ở những vị trí ảnh hưởng đến biến dạng. Kết quả cải tiến cho thấy khối lượng giảm thêm 5%. Tuy nhiên, phương pháp cải tiến này chưa thật sự tối ưu. Thông qua bài toán tối ưu, tiến hành thiết kế thực nghiệm mô phỏng đưa ra phương trình hồi quy thực nghiệm bằng SPSS. Sử dụng giải thuật di truyền GA trong Matlab để giải phương trình hồi quy thực nghiệm. Kết quả đạt được là tổng khối lượng các biến được chọn giảm 18,5% so với trước khi tối ưu.

Từ khóa: *An toàn lật nghiêng; cải tiến; giảm khối lượng; phần tử hữu hạn; ECE R66; tối ưu hóa*

Abstract: Computer applications modeling finite element universe bus seats are technical topics. Then, skeletal model starting stiffness was analyzed using simulation to meet the European tilt safety requirement ECE R66. As a result, the skeleton's initial volume and hardness are higher. Reduce the volume of the passenger car frame by performing a thickness reduction in the conventional manner until skeletal deformation reaches a safe space. continuing to improve by altering the structural skeleton's design at deformation-affecting positions. Results showed improved volumes decreased by 5%. However, this improved method is not really optimal. Conduct simulation experimental design using optimization problems with an empirical regression equation from SPSS. applying Matlab GA's genetic algorithms to the empirical regression equation. Results achieved as the total volume of the selected variables decreased 18.5% compared to the prior optimization.

Keywords: *Algorithms; ECE R66; element; improve; reduce the volume; safety*

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1. Introduction

Bus accidents are frequently in the world. Of all traffic fatalities in Europe, 150,000 victims are injured and 150 victims die each year due to this accident [1]. In the US in 2004, The National Highway Traffic Safety Administration reports an estimated 16,000 injuries and deaths in bus crashes, of which more than half of the deaths that occur in this accident are not related to a collision [2].

Tomas Wayhs Tech [3] used LS - Dyna software to simulate the safety of passenger car skeleton structure under tilting conditions, based on simulation results, analyze and propose a design plan Improved design to satisfy specified standard requirements, structure optimization has not been implemented yet.

Yu – Cheng Lin [4] used Hypermesh 7.0 software to build a finite element model for a vehicle segment, then used LS - Dyna 970 software to analyze the tilting simulation results. He compared experimental results with simulation results, adjusted the finite element model and technical parameters until the simulation results and experimental results were close to each other, not optimal texture.

In this study, he used Hypermesh software to mesh the model and safely simulate the passenger car skeleton structure in the event of a collision and rollover, based on simulation results, analysis and model improvement satisfy the safety conditions according to the standards, then proceed to optimize the chassis structure and compare the results before and after the optimizationAnother section of your paper.

2. Safe space according to ECE R66 standard

The ECE R66 standard [5] (Economic Commission of Erope, Regulation 66), conducting safety studies of chassis structure under rollover conditions, has the following provisions:

+ The displacement of any part of the chassis must not encroach into the safe space.

+ Any part in the safe space is not allowed to protrude outside the chassis structure after being deformed.

+ The distance between the inclined plane and the plane of impact is 800 mm, the vehicle is stationary on the overturned plane, tilt this plane with an angular velocity lower than 0.087 (rad/s) until the vehicle begins to overturn. The initial angular velocity ω_0 = 0 (rad/ms).

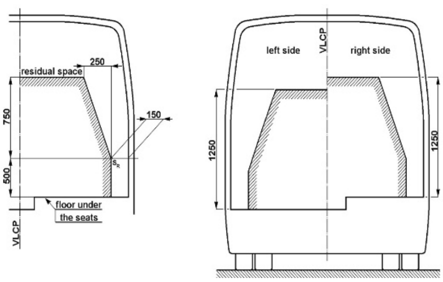

Figure 1. Safe space in cross-section

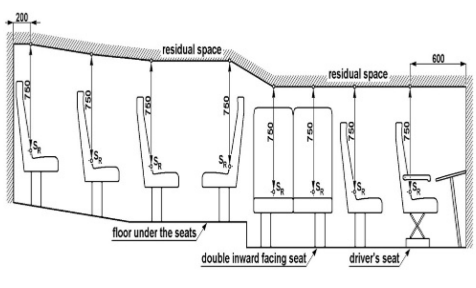

Figure 2. Safe space in longitudinal section

3. Building a research model

From drawings on 2D CAD software provided by Tracomeco manufacturer, use ThinkDesign software to design 3D models and then put them into Hypermesh environment to mesh and edit mesh objects. Choosing the grid type and mesh size is very important, greatly affecting the simulation results, in order to limit the number of error grids and energy loss in the simulation process in this study, we choose the square grid with the size of 10x10 mm for the whole model.

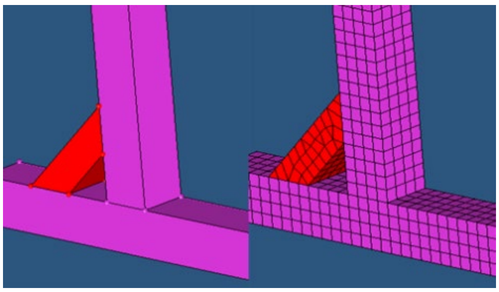

Figure 3. Before and after object meshing

To ensure accurate simulation results, the entire mesh on the model must be closely linked together by mesh welding, the details of the chassis model, the axle and the wheel rim must be linked using the CONTRAINED EXTRA NODES OPTION method.

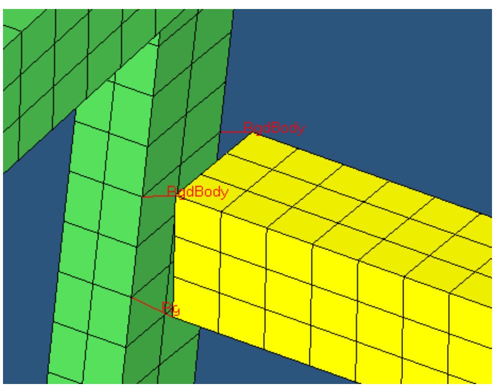

Figure 4. Before and after welding the structure for the model

4. Design rollover models, create materials and assign conditions of variables according to standards

- Standard rollover model design:

Place the vehicle on an overturned plane 800 (mm) away from the collision plane, at this time the vehicle's center of gravity is at position G, slowly tilting this plane, the angular velocity is lower than 0.087 (rad/s) to the limit angle of inclination (40,90), at this time the model overturns itself thanks to the action of gravity at the center of gravity position G' with no initial angular velocity (ω0 = 0 (rad/ms)), the angular velocity increases slowly until The collision process starts at the center of gravity G". In this model, the angular velocity at impact is calculated as 0.00206 (rad/ms), rotates about an axis and is under the influence of gravity, the maximum weight of the model is calculated to be 11400 kg.

From the Hypermesh program, center coordinates G (XG, YG, and ZG) are exported. The following is the sequence of execution:

Post → summary → load → ls-dyna971→ ctr_of_gravity → summary → Open the critical level message dialog using Notepad after exporting it.

29_8_trongtam - Notepad

File Edit Format View Help

Center of Gravity

Component	ID	MASS	NS-MASS	Total Mass	X	Y	Z
hansan	22	0.0	0.0	N/A	N/A	N/A	
handauchassis	23	0.0	0.0	N/A	N/A	N/A	
hankhungiuavoida	24	0.0	0.0	N/A	N/A	N/A	
hankhunggiuavoid	25	0.0	0.0	N/A	N/A	N/A	
hankhunggiuamoih	26	0.0	0.0	N/A	N/A	N/A	
hankhunggiuavoih	27	0.0	0.0	N/A	N/A	N/A	
hankhunggiua	28	0.0	0.0	N/A	N/A	N/A	
handuoichassis	29	0.0	0.0	N/A	N/A	N/A	
hanchupdau	32	0.0	0.0	N/A	N/A	N/A	
hanmangtraivoidu	33	0.0	0.0	N/A	N/A	N/A	
hanmangphaivoidu	34	0.0	0.0	N/A	N/A	N/A	
handauchassisvoi	35	0.0	0.0	N/A	N/A	N/A	
DONGCO	36	981.44995271	0.0	981.44995270794	4.466265E+03	-4.92585E+01	-1.04000E+02
hanmangvoichupda	39	0.0	0.0	N/A	N/A	N/A	
Hanchupdauvoicha	43	0.0	0.0	N/A	N/A	N/A	
handuoichassisvo	44	0.0	0.0	N/A	N/A	N/A	
x1	45	57.711985258	0.0	57.71198525778	5.281092E+01	-4.99498E+01	9.496688E+02
x2	46	37.085377385	0.0	37.085377384734	4.220915E+03	-4.92581E+01	5.787122E+02

LS-DYNA Page 3

Center of Gravity

Component	ID	MASS	NS-MASS	Total Mass	X	Y	Z
x3	47	15.19794484	0.0	15.197944839878	4.377274E+03	-4.90193E+01	5.969893E+02
x4	48	34.076406439	0.0	34.076406438759	5.329033E+03	-4.84321E+01	5.801825E+02
giacuong	50	0.4625353294	0.0	0.4625353294028	4.058711E+03	-5.18862E+01	9.029192E+02
gianlanh	51	240.0	0.0	-2.88207E+03	-4.92545E+01	2.164554E+03	
kinhbenhong	52	100.0	0.0	8.542081E+01	-4.92475E+01	9.384326E+02	
kinh_chan_gio	53	140.0	0.0	-2.17008E+03	-1.78916E+01	6.712400E+02	

Number of Components: 42

Total Structural Mass: 6274.98

Total Non-Structural Mass : 0.0

Total Mass of Model (Structural + Non Structural) : 6274.98

Center of Gravity for Model -- X: 3.782306E+02 Y: -4.70426E+01 Z: -4.13351E+01

Figure 5. The information provides the center of gravity's coordinates

From figuring out where the center of gravity is. It aids in establishing the height of the computed model's center of gravity.

$$\beta_{t\,max} = \arctan\left(\frac{c}{2h_g}\right) = \arctan\left(\frac{1850}{2.1096}\right) = 40^{o}9'$$

$$\omega = \sqrt{\frac{2Mg(h_1 - h_2)}{J}} = \sqrt{\frac{2Mg\Delta h}{J}}$$

$$\omega = \sqrt{\frac{2.11400.0,00981.751}{3,96.10^{10}}} \approx 2,06.10^{-3}$$

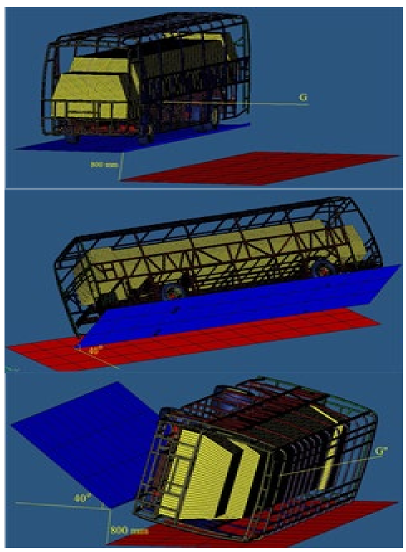

Figure 6. Standard rollover model

- Design safe space according to standard: based on the size specified in the standard safe space, we use HYPERMESH software to design safe space Figure 7.

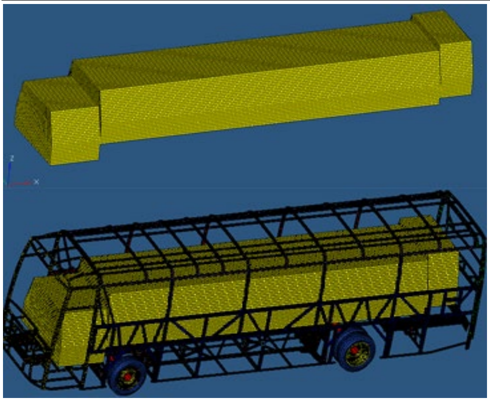

Figure 7. Safe space

- Creating materials, attributes and assigning variable conditions to the model: In this study, the frame structure uses Q235 steel, the chassis uses Q345 steel, the flip plane and the collision plane use hard materials to model simulation, material properties are shown in Table 1

Table 1. Material properties [6]

Steel material	Modulus of Elasticity [Gpa]	Poisson's ratio	Specific weight [kg/mm^3]	Stress limit [Mpa]
Q235	210	0,3	7,85.10^{-6}	235
Q345	210	0,3	7,85.10^{-6}	345

- Create the direction of gravity, use LOAD - BODY - Y, create contact surface for the whole vehicle with the collision plane, use SURFACE TO SURFACE to set. After creating materials, attributes and assigning variable conditions, we proceed to place mass parts such as passengers, luggage, fuel tanks, batteries... on the model.

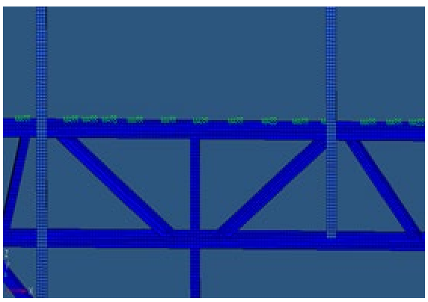

Figure 8. Put weight on the model

5. Simulate, display and analyze the results of the original chassis model simulation

Using LS - DYNA software to simulate, HYPERVIEW software to display and analyze the simulation results of the original chassis model under rollover conditions.

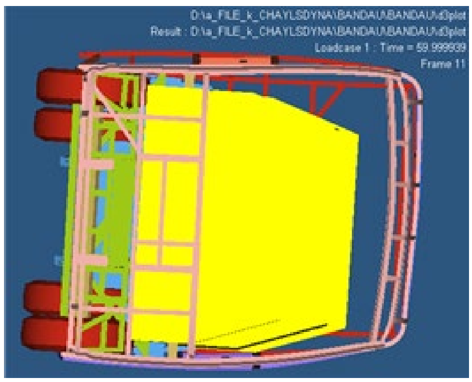

Figure 9. Simulation results of the original chassis model

After displaying the results in Hyperview (Figure 9), the model of the chassis in the event of a collision and tilting is almost not deformed, proving that the chassis has excess durability, making the distance D (the distance from the safe space to the upper body position of the vehicle) large.

6. Reduce the thickness in the traditional way and improve the chassis model according to the safety standard ECE R66

Reduce dimensions in a traditional way so that the deformed chassis reaches a safe space (Figure 9).

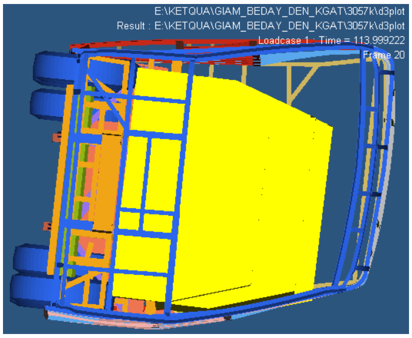

Figure 10. Results after reducing the thickness

Chassis weight reduced from 3270 kg to 3057 kg Figure 11.

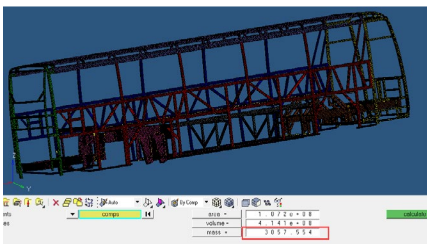

Figure 11. Frame weight after traditional method thickness reduction

Carry out structural improvement in critical positions affecting deformation and reinforce plate-shaped panels as shown in Figure 12.

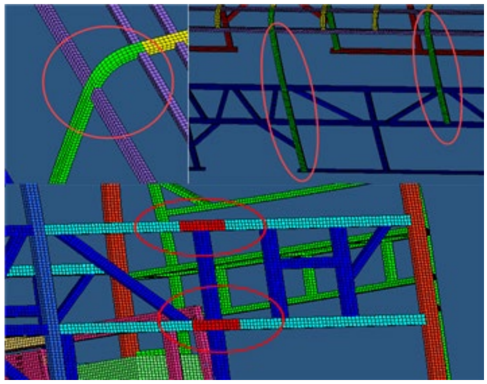

Figure 12. Improvements to the original chassis structure

The result is a 5% reduction in weight compared to before the improvement, Figure 13 (reduced from 3057 kg to 2918kg).

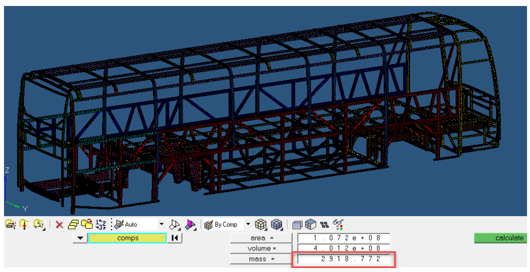

Figure 13. Weight after improvement

Table 2. Compare vehicle chassis mass before and after the improvement

Vehicle chassis mass	Before the improvement	After improvement	Percentage decrease
M [kg]	3057	2918	5 %

7. Optimizing chassis structure

7.1. Choose the optimization variable

Based on the simulation results, select design variables corresponding to the bars with the greatest stress and strain concentration, and optimize the structural thickness so that it meets the requirements:

- The total mass of bars after optimization is smaller than before optimization;
- No intrusion into safe space D according to Figure 14.

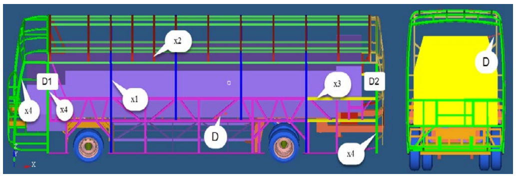

Figure 14. Choose the optimal design variable

- x1 includes 8 vertical bars on the left and right sides of the bus
- x2 includes 12 C-shaped curved bars on the roof of the bus
- x3 consists of 4 bars at the tail of the left and right hip array
- x4 includes 4 vertical bars in the rear and front of the car.
- D1 is the distance from the front reinforcement bar of the left and right hips with the safe space.
- D2 is the distance from the rear reinforcement bar of the right hip and left hip to the safe space.

Design variable:

$$\min F(y) = \sum_{j=1}^{n_e} M_j^e$$

Condition:

$$D_1 \geq 0 \text{ , } D_2 \geq 0$$

$$2 \leq x_1, x_2, x_3 \leq 4{,}5$$

$$3{,}5 \leq x_4 \leq 6$$

In there:

- F(y): objective function
- n_e: entire optimized texture radix.
- M_j^e : weight of j[th] optimized structural bar assemblies.
- x: the thickness of box steel in millimeters.

In this simulation experiment, there are a total of 4 variables. Therefore, the uniform experimental design U6*(64) [7] was selected with 06 experiments being conducted.

For the minimum and maximum values of the 4 variables, we divide each variable into the 6 values shown in Table 3.

Table 3. The level of the variables

Experimental level	x_1 [mm]	x_2 [mm]	x_3 [mm]	x_4 [mm]
Level 1	2	2	2	3,5
Level 2	2,5	2,5	2,5	4
Level 3	3	3	3	4,5
Level 4	3,5	3,5	3,5	5
Level 5	4	4	4	5,5
Level 6	4,5	4,5	4,5	6

Therefore, Orthogonal Experiment Design U6*(64), it is necessary to conduct a total of 6 test simulations shown in Table 4.

Table 4. Experimental design table according to U6*(6^4)

Serial	x_1 [mm]	x_2 [mm]	x_3 [mm]	x_4 [mm]
1	2	2,5	3	6
2	2,5	3,5	4,5	5,5
3	3	4,5	2,5	5
4	3,5	2	4	4,5
5	4	3	2	4
6	4,5	4	3,5	3,5

7.2. Simulation test results

The test simulation results are shown in Table 5.

Table 5. Experimental data collection results

Serial	x_1 [mm]	x_2 [mm]	x_3 [mm]	x_4 [mm]	D_1 [mm]	D_2 [mm]	M [kg]
1	2	2,5	3	6	69,480	-32,745	233,341
2	2,5	3,5	4,5	5,5	75,871	-7,042	297,024
3	3	4,5	2,5	5	77,183	-16,109	317,441
4	3,5	2	4	4,5	79,904	6,560	258,723
5	4	3	2	4	81,202	-6,137	279,139
6	4,5	4	3,5	3,5	82,273	23,687	342,822

7.3. Using SPSS to set up empirical regression equation

In the process of linear regression analysis, the correlation coefficient R did not meet the requirements. It is recommended to proceed to raise the order of 2 regression equations [8] under the form:

$$y = a_0 + \sum_{i=1}^{s} a_i x_i + \sum_{i=1}^{s} a_{ii} x_i^2 + \sum_{i<j}^{s} a_{ij} x_i x_j$$

In there:

- y: the second-order response surface regression function.

- a0, ai, aii, aij: regression coefficients.

- x1,x2,…,xj:design variables.

- The second-order reaction surface regression setup is shown in Table 6

Table 6. Table of setting the second-order response surface regression of variables

x_1^2	x_1x_2	x_1x_3	x_1x_4	x_2^2	x_2x_3	x_1x_4	x_3^2	x_3x_4	x_4^2
4	5	6	12	6,25	7,5	15	9	18	16
6,25	8,75	11,25	13,75	12,25	15,75	19,25	20,25	24,75	30,25
9	13,5	7,5	15	20,25	11,25	22,5	6,25	12,5	25
12,25	7	14	15,75	4	8	9	16	18	20,25
16	12	8	16	9	6	12	4	8	16
20,25	18	15,75	15,75	16	14	14	12,25	12,25	12,25

- The regression equation exported from SPSS by volume M and distance D1, D2 is as follows:

M = 139,7 + 32,063x2 + 2,878x12 + 2,909x1x3 – 2,647x1x4 + 1,018x42

D1 = 52,118 – 0,453x2 + 0,672x12 – 0,015x1x3 + 0,979x1x4 + 0,259x42

D2 = – 58,246 + 0,101x2 + 1,938x12 + 2,981x1x3 – 0,664x1x4 + 0,474x42

- The above regression equation is evaluated through the correlation coefficient R according to Anova of 1.1 and 1, respectively.

7.4. Solving regression equations using GA genetic algorithm [9] in Matlab

- Code Matlab main program:

```
ObjectiveFunction =
@simple_fitness_m;
nvars = 4;
LB = [2 2 2 3.5];
UB = [4.5 4.5 4.5 6];
ConstraintFunction =
@simple_constraint_d;
rng(1,'twister')
[x,fval] =
ga(ObjectiveFunction,nvars,...
[],[],[],[],LB,UB,ConstraintFunction)
```

- Code Matlab program:

+ Objective function M:

```
function y = simple_fitness_m(x)
y = 139.7 + 32.063*x(2) + 2.878*x(1)^2 + 2.909*x(1)*x(3) - 2.647*x(1)*x(4) + 1.018*x(4)^2;
```

+ Conditional function D:

```
function [c, ceq] = simple_constraint_d(x)
c=[-52.118 + 0.453*x(2) - 0.672*x(1)^2 + 0.015*x(1)*x(3)- 0.979*x(1)*x(4) - 0.259*x(4)^2;
 58.246 - 0.101*x(2) - 1.938*x(1)^2 - 2.981*x(1)*x(3) + 0.664*x(1)*x(4) - 0.474*x(4)^2];
ceq=[];
```

- The results of the thickness of the selected variables (mm) from Matlab are summarized in Table 7, the M values are min, and the distances D1 and D2 satisfy condition ≥ 0.

Table 7. Optimum results for thickness of variables and min M values and distances D1, D2

Value	x_1 [mm]	x_2 [mm]	x_3 [mm]	x_4 [mm]	M [kg]	D_1 [mm]	D_2 [mm]
Optimal	3,5289	2,0000	3,0526	5,6187	250,6563	87,0069	$0{,}86.10^{-4}$

Because the thickness of steel (mm) on the market has a standard thickness parameter:1, 1.5, 2.0, 2.5, 3.0, 3.5, 4, 4.5,..; thickness of variables selected by standard: x1 = 3,5 ; x2 = 2 ; x3 = 3 ; x4 = 5,5.

7.5. Check optimal results by simulation

From the values of the found variables, set the properties of the variables in Hypermesh and then run the test simulation again for the results as shown in Figure 15.

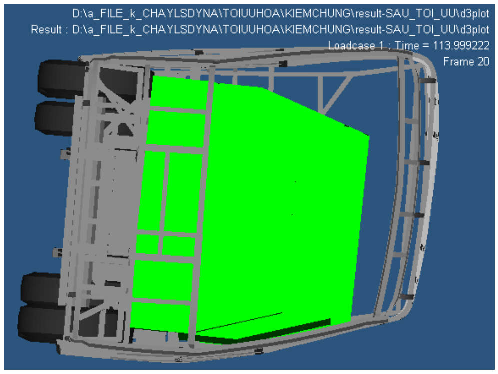

Figure 15. Results displayed after optimization

The simulation results after optimization show that the chassis model deforms after the collision but no longer violates the safe space.

7.6. Compare results before and after optimization

The values of distance and weight measured through simulation experiments are given for comparison before and after and when optimizing are shown in Table 8.

Table 8. Table of test values before optimization and after optimization

Serial	Value	Pre-optimum	Post-optimization
1	x_1 [mm]	3,0	3,5
2	x_2 [mm]	3,0	2,0
3	x_3 [mm]	3,0	3,0
4	x_4 [mm]	5,0	5,5
5	M [kg]	313,004	254,880
6	D_1 [mm]	68,494	80,193
7	D_2 [mm]	-41,111	3,547

From the table collecting simulation results after optimization, the total weight of bars selected for optimization is reduced by 18.5% compared to before optimization, and the safe space at positions D1 and D2 is not damaged intrusive, satisfies the safety condition of rollover according to ECE R66 standard.

8. Conclusions and recommendations

- In the process of studying the rollover safety of the original Universe seat frame model, the simulation results do not guarantee the rollover safety conditions according to ECE R66 standards. The upper body frame and side panels have great rigidity due to the high thickness of the steel. Heavy chassis weight is not necessary.

- The author proceeds to reduce the thickness of the objects in the side array in the traditional way to deform when the collision reaches the safe space according to the simulation results. From this result, further refinement of the chassis model in places of great influence on deformation was achieved by modifying the original design and reinforcing the steel panels. As a result, the weight after improvement is reduced by 5% compared to before the improvement.

- After improving to reduce the number, optimize the structure by experimental simulation according to the U6*(64) model, giving the empirical regression equation. Apply the GA genetic algorithm in Matlab to find the optimal thickness size of the selected variables. Comparing the weighted sum of the post-optimal variables with the pre-optimal variable reduced by 18.5%, the safe space is not compromised according to the European transitional safety standard ECE R66

- The successful project helps to propose to Tracomeco company to reduce input costs and improve the quality of passenger car products. On the other hand, it adds diversity to a new research direction related to vehicle rollover safety according to the European standard ECE R66.

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