DESIGN AND ANALYSIS OF THE PROTECTIVE STRUCTURE OF AN INTERCITY BUS DURING A ROLLOVER ACCIDENT

M.Sc. Çolak N.[1], M.Sc. Şahin U.2, M.Sc[2]. Candaş A.[2], Prof. M.Sc. İmrak C.E. PhD.[2]
Istanbul Technical University, Graduate School of Science Engineering and Technology, Turkey[1]
Istanbul Technical University, Faculty of Mechanical Engineering, Turkey[2]

candas@itu.edu.tr

Abstract: *Vehicles, such as buses which are massive and have a very high centre of gravity, they have a lower resistance to overturning than other vehicles. The studies have shown that deformations can especially occur in the body structure. Some deformations that can occur in carrier elements during an accident make the vehicle a vital danger area for drivers and passengers. The aim of this study is to examine the protection of the passengers in the bus by means of constructive developments to be made within the body structure. ECE R66 legal regulations which are issued by the European Union (EU) and (Economic Commission for Europe Regulation 66- Provisions on the Approval of Major Passenger Vehicles for Resistance to the Construction of the Skeleton) for the buses were developed to protect passengers' habitats in overturning accidents. This work focuses to reach constructive solutions for costing, manufacturing and, safety which provided conditions for the body structure during rollover behaviour of the vehicle. Computer simulations and analysis have been performed to examine the strength of the cross-section of the body structure. The methods specified in the standard for calculating the rollover behaviour of the vehicle have been implemented and concluded. The results obtained from all these analyses produced constructive solutions and optimizations for the design of intercity buses.*

Keywords: BUSES, ROLLOVER, ECE R66, DESIGN OPTIMIZATION

1. Introduction

The fact that they have a large mass and that the center of gravity is located at a very high point on the ground significantly reduces the resistance of the buses and similar vehicles against overturning. Especially considering that buses are used for passenger transportation, it is seen that the loss of life and the amount of damage that can happen in case of a possible accident are quite high. Turkey Statistics Institute (TUIK) when the road traffic accident statistics are examined, it emerges outstanding data related accidents. For example, in 2013, a total of 1207354 casualties lost 3685 people's lives and 274829 people were injured. When we look at the distribution of these accidents by vehicle types, it emerges that 7230 of them were built by buses [1]. Tipping accidents usually take place in the form of step / roll. The wheel interrupts the lateral forces that interact with the object to create the stage, causing it to roll on the axis of that object. Sidewalk edges, ramps, contact with stones make up 90% of the overturns in this category [2]. It may, however, follow an accident such as a frontal collision [3].

In this study, a study was carried out to contribute to the protection of the passengers in a bus by means of constructive developments to be carried out in the body in case of an accident that occurred during the overturning and overturning of these conditions. The carrying elements of the vehicles were subjected to the overturning test specified in the legal regulation by simulation and various reinforcements were made in the sidewall columns, ceiling width wraps, and infrastructural connections in order to provide the determined living area in the calculation.

2. ECE R66 STANDARD AND DESIGN REQUIRMENTS

ECE R66 regulation was first published by the United Nations Economic Commission for Europe in 1986, with the aim of preventing the consequences of overturning and protecting the living area of passengers. Many countries take the bus rollover test as a mandatory certification program of the imported bus, requiring the superstructure of the bus have sufficient strength [4]. The ECE R66 regulation has been issued to prevent the consequences of overturning and to protect the living space of passengers and offers five ways to detect the superstructure strength when the bus rollovers: (1) rollover test; (2) rollover test using body sections; (3) quasi-static loading test of body sections; (4) quasi-static calculation based on testing of components; (5) computer simulation of rollover test of complete vehicles [4].

ECE-R66-02, It entered into force on August 19, 2010. The scope has been expanded to include minibuses (M2). Application to other vehicles in the M2 and M3 categories (e.g. double-decker bus) is optional. The requirements of R 66-01 apply. Valid from 9 November 2017 for all vehicles on transit in the class specified in this standard. TSE ECE R66 was issued by TSE (Turkish Standards Institute) on 01.01.1996 and TSE ECE R 66

(Revision 1) on 31.12.2008 issued the "Provisions on approval of large passenger vehicles on the strength of skeleton structure" standards. However, these standards were removal on 10.08.2016.

Requirements of ECE R66

“The worst situation case” describes the type of vehicle that at least fulfills the ECE R 66 requirements for superstructure strength within a vehicle type. The three parameters that define the worst case are structural strength, reference energy, and residual space. "Empty vehicle mass" (Mk) is the mass calculated with the weight of the vehicle in addition to the empty weight of 75 kg, weight of the fuel tank when 90% full, refrigerant gas, oil, spare wheel if the vehicle is used. For "total vehicle mass" (Mt) passenger and hostess weights are added to empty vehicle weight. The weight of the seated passengers is assumed to be 34 kg, the weight of the standing passengers is 68 kg, assuming that the seats are connected with the seat belt.

$$E_R = M.g.h_1 = M.g[0.8 + \sqrt{{h_0}^2 + (B \pm t)^2}] \qquad (1)$$

The reference energy is calculated as follows; Figure 1 shows the starting position of the vehicle, the moment it begins to topple, and the positions of the final center of gravity. The parameters to be used in the reference energy calculation are again shown on Figure 1.

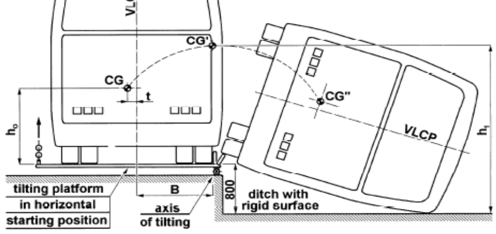


Fig. 1 *The centre of gravity positions for rollover test in ECE R66 [4].*

The application methods specified in the standard to calculate the rollover behavior of the vehicle are as follows *(Figure 2)*. Basic approval method: Overturn of a completed vehicle under specified conditions and evaluation of the results. Equivalent validation method: Tilt test on trunk section, semi-static loading test on trunk section, semi-static calculation based on component tests, numerical simulation based on roll-over test the vehicle is placed on the tipping stand with the suspensions removed and slowly rotated to the axis of rotation of the stand until the equilibrium equilibrium point. The test begins with zero angular velocity at the equilibrium point and the rotation axis will be the wheel ground touch point. The energy of this vehicle is reference energy given in Eq. 1. The car is tilted to a dry and flat concrete floor over a step of 800 mm height.

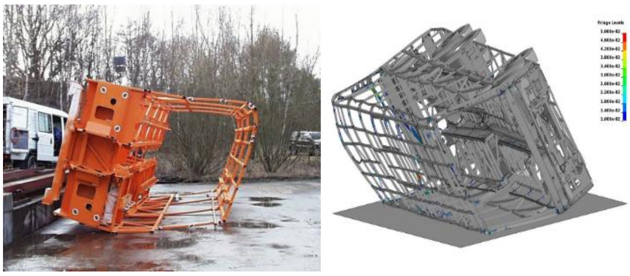


***Fig. 2** Rollover test of a passenger bus.*

3. MODELING AND ANALYSIS OF THE STRUCTURE

The precise criterion for meeting the standard requirements is the protection of the criterion habitat. At this point; during the change of shape the bus superstructure carrier elements should be checked to see if they are attempting to this area which protects the passengers. The living area is defined between two boundary points (Figure 3). Reference point for these boundary points; the intersection of the inner surface of the side wall and the floor. The upper and lower limit points are determined from this reference point.

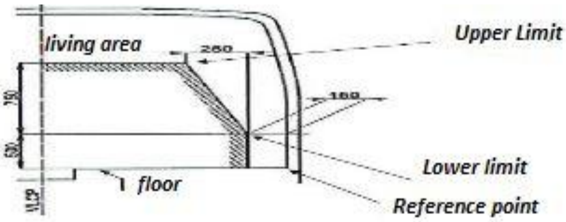


***Fig. 3** Living area.*

During the pre-processing fillets and small holes have been deleted in the modeling program (Catia and Siemens NX). After the profiles' middle surfaces were created, weld relationships were modeled, material and thickness information were processed and converted to model "step" (*.stp) file format (Figure 4). LS-DYNA was used to analyze the structure.

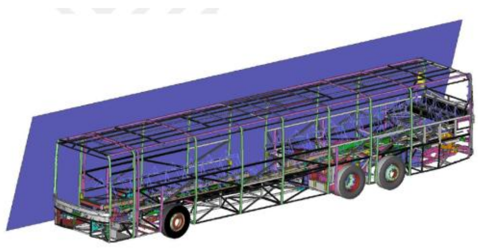


***Fig. 4** A model of a three-axle interurban vehicle.*

The same outer contour and the same loading direction but different constructions. In the following figures (Figure 5), three comparative examples are shown.

***Fig. 5** Different profiles of structures after rollover.*

The deformations determined in the reference model simulation are shown in Figure 6.

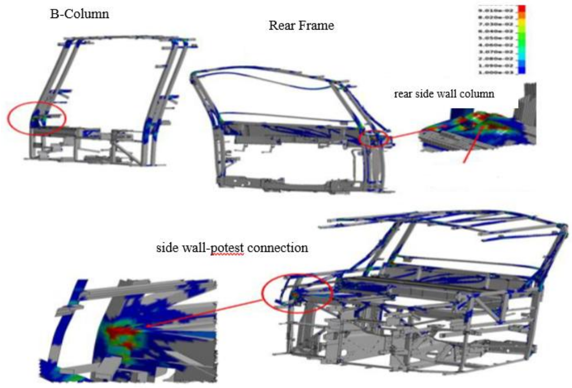


***Fig. 6** Structure deformations.*

4. RESULTS AND DISCUSSION

The main goal of the work is to reach constructive solutions for cost, weight and production optimizations, ensuring safety conditions within the body. Modeling is done in computer environment by using the data obtained from experimental studies focused on section and weight optimization. The methods specified in the standard were applied and finalized to calculate the rollover behavior of the vehicle. The results obtained by applying the rollover test specified in the legal regulations to the vehicle by simulation are calculated. Through these obtained data, the possibilities of developing different solutions have been searched and the protection of the residual space by supporting elements has been tried to be provided by strengthening the sidewall columns, roof cross bows and body connections. This results fulfill both ECE R66 requirements and keep weight increase on vehicle below the targeted level.

Below are examples (Figure 7) of retrofit studies made on a 14 m long 4 m high 3-axle intercity vehicle. Considering the standard requirements 30, the substructure is considered to be rigid. Vehicle weight is calculated with 50 passengers.

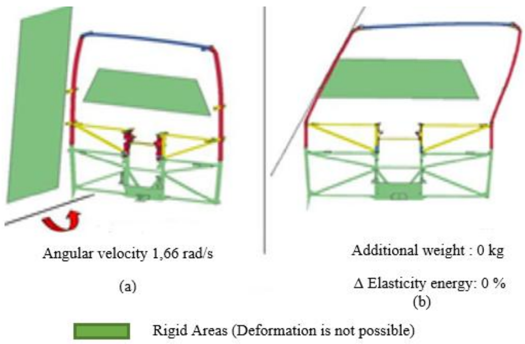


***Fig. 7** a) Base model b) Reference deformation model.*

Considering the weight and dimensions in the selection of the vehicle to be calculated, a three-axis interurban vehicle was first modeled and reinforcement studies were carried out on the reference model to produce solutions that would protect the living area in case of overturning (Figure 8).

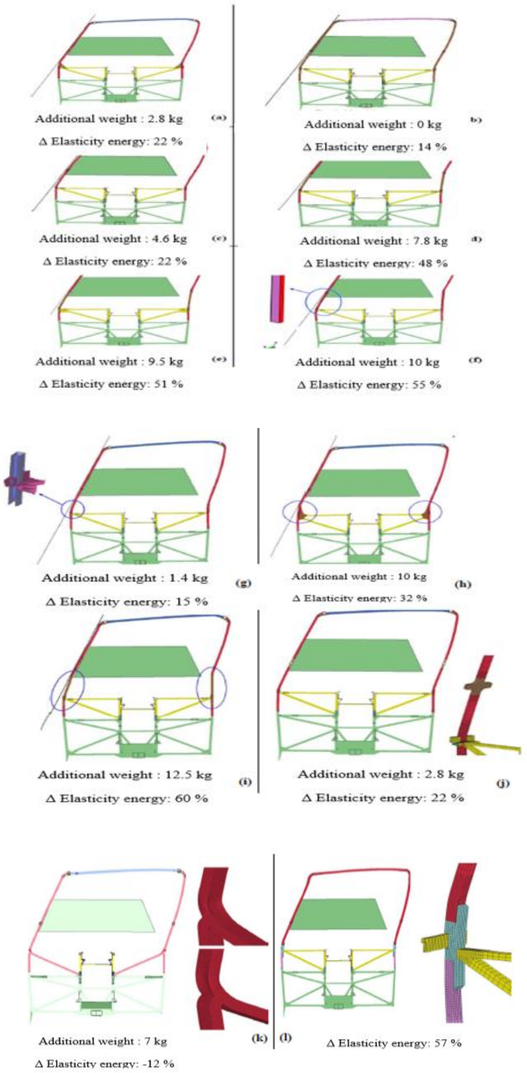


Fig. 8 *The effects of different connection points, cross section and material change.*

The explanations for Figure 8 are as follows:

a) Additional triangular reinforcement piece in podest and side wall connection

b) Use of high strength steel S500 MC in side wall pillar

c) 70x30x2 curved support pieces between the ceiling sidewall

d) Side wall column between bottom of window and top of luggage 6 mm wall thickness

e) Side wall column between bottom of window and top of luggage 6 mm wall thickness + 2 mm bottom triangular reinforcements

f) Side-wall column between the bottom of the window and the top of the luggage.

g) 6 mm sheet metal support in the side wall pipe

h) Cast parts connections

i) 8 mm thick casting pipe piece on the side wall

j) t reinforcement piece in the glassy tube

k) Side wall - podest under coupling pipes

l) 8 mm die casting on the side wall.

Energy time graph of the profiles in different cross sections shown in Figure 9. When evaluated the 60x50x4 mm sections shown in V19 of the circles with side wall column sections of 70x40x3 mm and 60x50x3 mm used in the reference model show about 40% less energy damped.

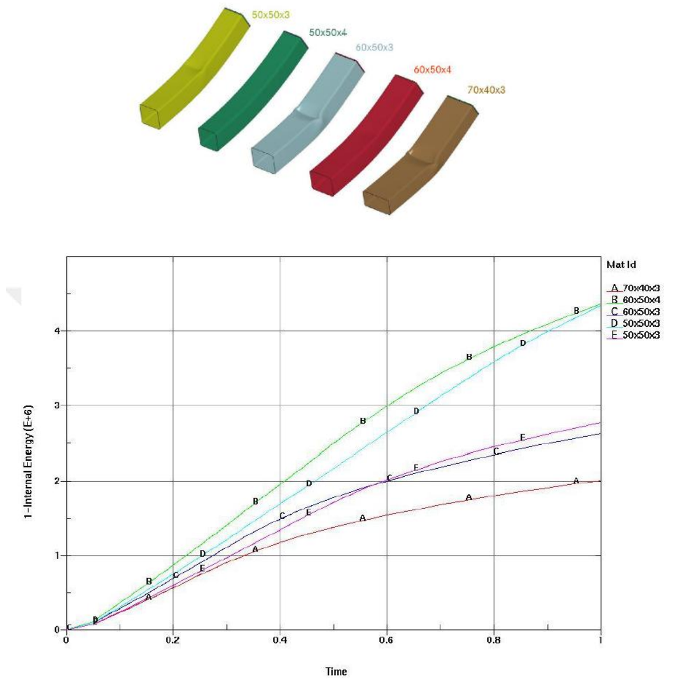
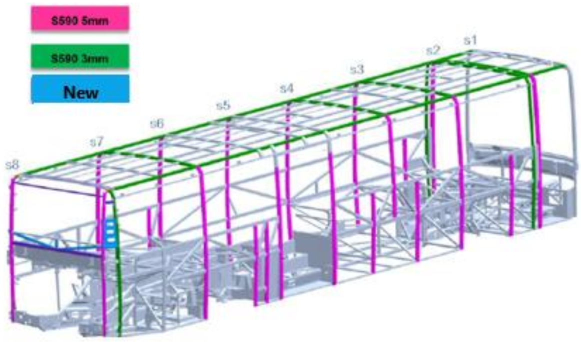


Fig. 9 *Deformation behaviors under load of pipes in different sections.*

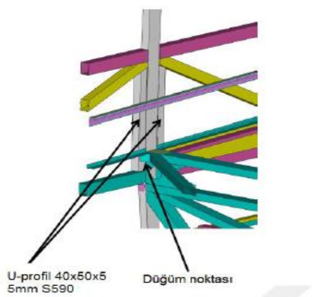
Examination of an intercity vehicle, it was observed that the first overturn test was not able to pass the test and reinforcement measures were investigated (Figure 10).



Right Overturn	c1	c2	c3	c4	c5	c6	c7	c8
Bottom Distance	100	38	30	7	9	-10	-15	-2
Top Distance	88	51	49	33	60	72	55	50

Fig. 10 *The overturn test was not able to pass the test in some sections.*

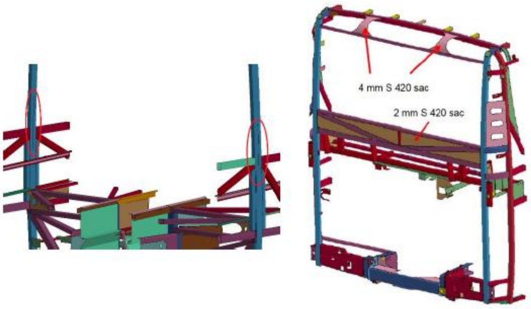
U-profilers (S590 MC 5mm) were placed on both sides of the column first to prevent interference in column 7 (Figure 11).



Right Overturn	c1	c2	c3	c4	c5	c6	c7	c8
Bottom Distance	100	40	32	11	14	-2	-22	4
Top Distance	88	51	49	33	60	72	55	50

Fig. 11 *U profiles*

In addition to the U-profiles, the sheet pieces shown in Figure 11, V8 (6 mm - S420) are added to the 7th column. Column 8 is reinforced with 4 mm sheet metal parts in the rear skeleton roof joint and 2 mm composite sheet under the glass (Figure 12).



Right Overturn	c1	c2	c3	c4	c5	c6	c7	c8
Bottom Distance	92	32	31	16	24	15	7	48
Top Distance	86	48	48	35	62	82	73	75

Fig. 12 *The reinforced U profiles.*

U-Profiler S 420 has been replaced with 6 mm sheets of steel and V8 parts have been canceled during the optimization work for manufacturing.

Right Overturn	c1	c2	c3	c4	c5	c6	c7	c8
Bottom Distance	85	18	25	12	35	11	2	45
Top Distance	84	32	44	28	48	78	70	74

Left Overturn	c1	c2	c3	c4	c5	c6	c7	c8
Bottom Distance	84	18	18	10	24	33	12	66
Top Distance	85	42	39	30	35	67	72	80

5. CONCLUSION

As a result of all these experimental studies, constructive solutions were produced with the data obtained. The results and optimizations obtained by applying all reinforcements to the vehicles are shown. In this way, solutions can be produced to contribute to the protection of passengers in buses resulting from rollover accidents.

12 different designs applied to the safety circle were analyzed and energy fading rates were taken as evaluation criterion. The different materials and sections were compared, the most suitable options were determined in terms of the amount of elasticity energy provided and the amount of additional weight added.

The applications in the vehicle safety circle were extended to two different intercity buses, and after the standard requirements were met, optimizations were made to ease manufacturing and reduce weight. At the end of the study, both the ECE R66 requirements and the vehicle weight difference were kept below the targeted 200 kg level.

5. REFERENCES

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