

Research Article

Study on Key Technologies Based on the Bus Rollover Security

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Abstract: In order to reduce the traffic accident caused by roller, this study finds out the breakthrough point from the cause-effect relationship and function achievement mechanism aspects and studies key technologies based on the bus rollover security. The research directions mainly include lowering the height of the mass center to the greatest extent, shortening the span between side windows or making improvements on the sectional dimension of side pillars, strengthening the soldering joints of side body, ensuring the continuity of close loop structures and employing high-strength steels. Research results demonstrate that the proposed improvement directions and measures designed to enhance bus rollover security are rational and effective and they can provide beneficial guidance and reference for security design in the bus manufacturing.

Keywords: Bus, middle body frame, rollover

INTRODUCTION

Most of bus accidents are caused by rollover as statistics showed. Some regulations on bus rollover security have been established in international communities, such as ECE R66 in Europe and GB/T17578-1998 in China, which set up rules aimed at enhancing the upper structures of buses. How to improve the rollover-resistance capacity and better protect passengers has become a significant issue nowadays. Buses should ensure sustainable strength and stiffness of the top structures during and after rollover test, specific to the side window pillars, require no part of the vehicle outside the survival space at the start of rollover, is intruding into the survival space and no part of the survival space projects outside the deformed structures. A passenger's survival space is defined as the space retained for passengers during or after the top side rollover test in accordance with enforced regulations (Zhou *et al.*, 2010).

Based on the formation mechanism of bus rollover, the study finds out the breakthrough point from cause-effect relationship and function achievement mechanism aspects and studies key technologies based on the bus rollover security. The research directions mainly include (Mangado *et al.*, 2007; Brown, 1990):

- A Lowering the height of the mass center to the greatest extent
- B Shortening the span between side windows or making improvements on the sectional dimension of side pillars

- C Strengthening the soldering joints of side body
- D Ensuring the continuity of close loop structures
- E Applying high-strength steels

LOWERING THE HEIGHT OF THE MASS CENTER TO THE GREATEST EXTENT

As Fig. 1 shows, CG1, CG2 and CG3 are the positions of the center of gravity. Assuming that the bus is falling down from the highest center of gravity (i.e., CG2 in Fig. 1), initial velocity is zero, calculate the collision energy as follows.

$$E_R = Mg(h_1 - h_2) = Mg(0.8 + \sqrt{h_0^2 + B^2} - h_2) = \int_0^T F ds = \int_0^T a_t V_t dt$$

In the above formula:

where,

- M = Bus mass
- h_0 = Initial position of the center of gravity at the rollover platform
- B = Distance between the rotation axis and the vertical plane of longitudinal central axis
- h_1 = The height of center of gravity at the start of rollover
- h_2 = The position of the center of gravity after bus rollover
- g = The constant of the acceleration of gravity, defined as 9800 mm/s^2

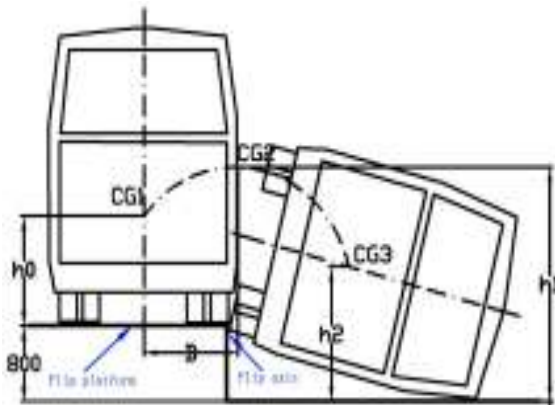


Fig. 1: Changes for the center of gravity during bus rollover

- F = Load bearing during rollover
- T = Crash time
- a_t = Acceleration of mass center during the process of crash
- V_t = Velocity of mass center during the process of crash

The formula indicates that the total energy ER the bus absorbs is a constant; the process of energy absorption is associated with the acceleration of mass center and crash time (Taeg, 1993). The crash process of energy absorption can be reflected from view of the acceleration of mass center and crash time, while the velocity of mass center and crash time are determined by the height of center of gravity. Therefore, the height of the center of gravity should be lowered to the greatest extent to improve the bus rollover security (James, 2000).

SHORTENING THE SPAN BETWEEN SIDE WINDOWS OR MAKING IMPROVEMENTS ON THE SECTIONAL DIMENSION OF SIDE PILLARS

Currently many 12 m series of buses are applying 5 side windows, which can hardly fulfill requirements of half bearing rollover even if they are pretty and have a wide vision. Thus, one more close loop should be designed, i.e., 6 side windows. The usual method to improve the stiffness of side pillars is to change sectional dimension, while lightweight should be made into consideration at the same time. It is indicated from Table 1 (is described as the bending-resistance property of rectangle poles) that the bending-resistance property of 40*60*4.0 rectangle poles is nearly the same as that of 50*60*2.0, while material consumption is 1.5 times of the latter one.

It is demonstrated according to literature researches and simulations that 6 windows should be applied as possible in buses of which integral weight exceeds 13000 kg and mass center on condition of no loads

Table 1: Parameters comparison of several sectional materials

Parameter Specifications	Area (A) mm ²	I mm ⁴	Iz mm ⁴
40*60*2.0	384	193152	102272
40*60*4.0	736	345045	178005
50*60*2.0	424	170765	170765
50*60*3.0	624	322632	241672

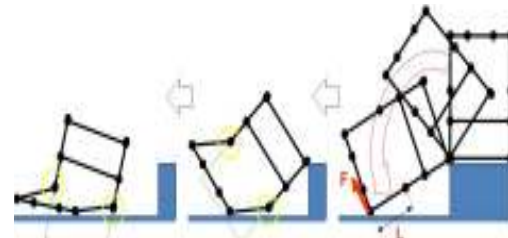


Fig. 2: Process of bus rollover

is higher than 1.4m and cross sections of side pillars should adopt 50*60*3.0 or higher stiffness dimension (ordinary steels) (Larrode *et al.*, 1995).

STRENGTHENING THE SOLDERING JOINTS OF SIDE BODY

Many causes can result in rollover security problems and the design of close-loops is a decisive factor for capacity bearing of the structure. The problem model can be simplified to be built as shown in Fig. 2 for study of bus rollover (Kadir *et al.*, 2006).

It is observed from the above figure that the top side beam is firstly touching the ground, generating huge impact force and creating a bend moment to the side pillar, which will be the most potential reason that causes the damage of soldering joints between side pillars and top side beams or the upper and the lower middle beams.

- **Improvements on joints between side pillars and lower middle beams (floor beams):** During rollover, the deformation of the joints between side pillars and lower middle beams will be magnified and effects the intrusion of top side pillars into passenger's survival space, hence, the deformation of the joints should be lessened to the greatest extent. There are many forms for the damage of soldering joints between side pillars and floor beams, i.e., window pillars bend excessively or even fracture, soldering joints are destroyed or middle beams deform greatly, as shown in Fig. 3. The proposed improvements mainly include designing oblique poles and base plates on the floor beams, increasing sectional thickness of middle beams or adding intensified rectangular poles into the middle beams (Qi *et al.*, 2006; McCray and Barsan-Anelli, 2001)
- **Enhancement on the joints between side pillars and upper middle beams:** In general design of buses, because the stiffness of side pillar structures

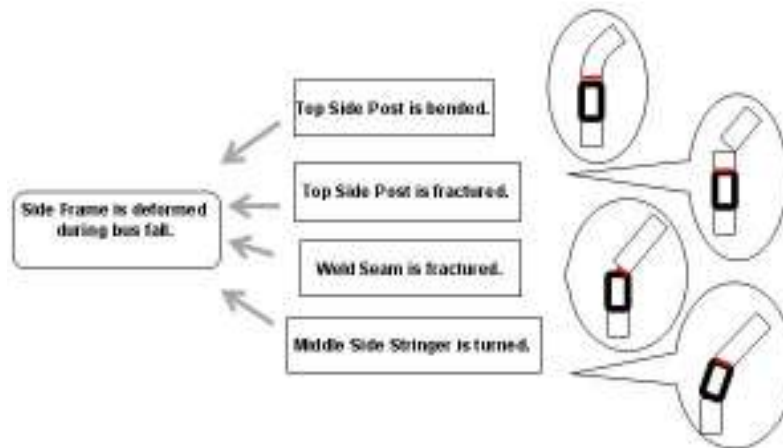


Fig. 3: Deformation modes for the soldering joints of side pillars



Fig. 4: Side pillars become unstable and deform at the joints with the upper middle beams

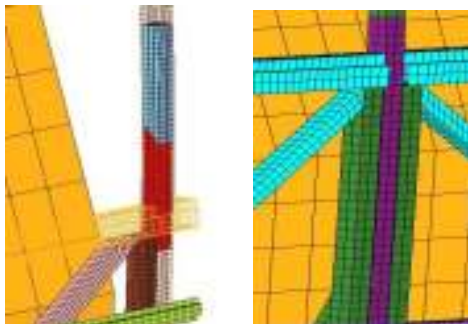


Fig. 5: Insert rectangle steels to the side pillars at the upper middle beams

generate mutation on the upper middle beams nearby and therefore easily becomes unstable and deform, the effective force of the structures is influenced significantly consequently, as shown in Fig. 4. Hence, the proposed measures include adopting through side pillars, inserting two rectangle steels to the side pillars at the upper middle beams or inserting a through pole to the upper side of the upper middle beams, as shown in Fig. 5.

The reasons for designing two intensified poles are as follows:

- Avoid too long inner intensified pole so as not to be easy to run through the curved side pillars
- The thicknesses of cross sections of the upper intensified rectangular pole and the lower one are different, which will make the side pillars produce variable stiffness effect
- Design the connectors of the two rectangular steel poles as wedge shape so that the two poles can penetrate from upside and downside respectively and come into being self-locked
- **Enhancement of the joints between side pillars and top side beams:** Motion is relative. Providing the joint between side pillars and top side beams of the crashing side as the origin of a relative coordinate, whose deformation will also be magnified and effect the deforming intrusion of the lower part of side pillars and in the meantime obviously effect the crashing force delivering to the other side of side body. Therefore, the strength design of the joint between side pillars and top side beams is also significant. Enhanced measures cover increasing the thickness of top side beams, adding a parallel rectangular pole or cutting through side pillars which will be welded to upper top side beams then.

CONTINUITY ASSURANCES OF THE CLOSE LOOP STRUCTURES

The main element for improving bus rollover security performance is the close loop structure design. Every close loop structure basically contains one roof arc rod, two side pillars, two baggage compartment pillars and floor beams. The close loop structure is the decisive factor for strength bearing and rollover prevention, thus its continuity must be ensured.

Take the original side body structure of a production bus as an example (the left structure in Fig. 6), side pillars and baggage compartment pillars

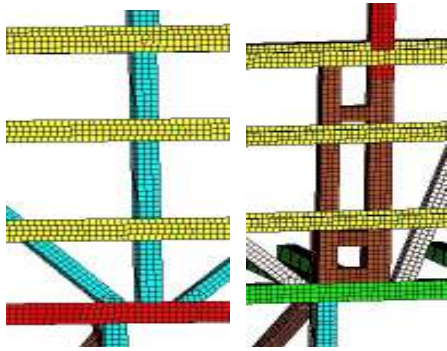


Fig. 6: Side pillars and baggage compartment pillars stagger by each other and the corresponding improvement measures

stagger each other, which would easily cause the upper structure of side pillars to lose stability. The major improvement approach to assure the continuity of close loop structures is to prevent the poles staggering in close loop structures, such as adding baggage compartment pillars and corresponding oblique poles. If the staggering can hardly be avoided due to needful structure design, adjacent short pillars and connection beams can be added to guarantee the continuity of close

loop structures (as displayed in the right picture of Fig. 6).

ADOPTION OF HIGH-STRENGTH STEELS

With an increasingly tough environment and energy crisis the world encounters, energy saving and emission reduction have been becoming a big challenge for bus manufacturers nowadays. Light weight technology has proved to be a trend among automotive industry and attracts wide attention. High-strength steels has obtained sound effects in applications of bus weight reduction and safety improvements and been utilized more and more in bus body manufacturing.

This study carries out the study and demonstration of high-strength steels applications in bus rollover (the ultimate tensile strength of high-strength steels is 1180 MPa, which is simplified as 1180#); the material parameters are provided by one domestic steel industry.

On the basis of the suggested measures stated above, a FE model of middle body frame rollover is set up (ECE R66, 1998). In the model, the materials of the main bearings of side body utilize Q345 and 1180# high-strength steels respectively, accordingly, the comparison results of the deformation of body frame

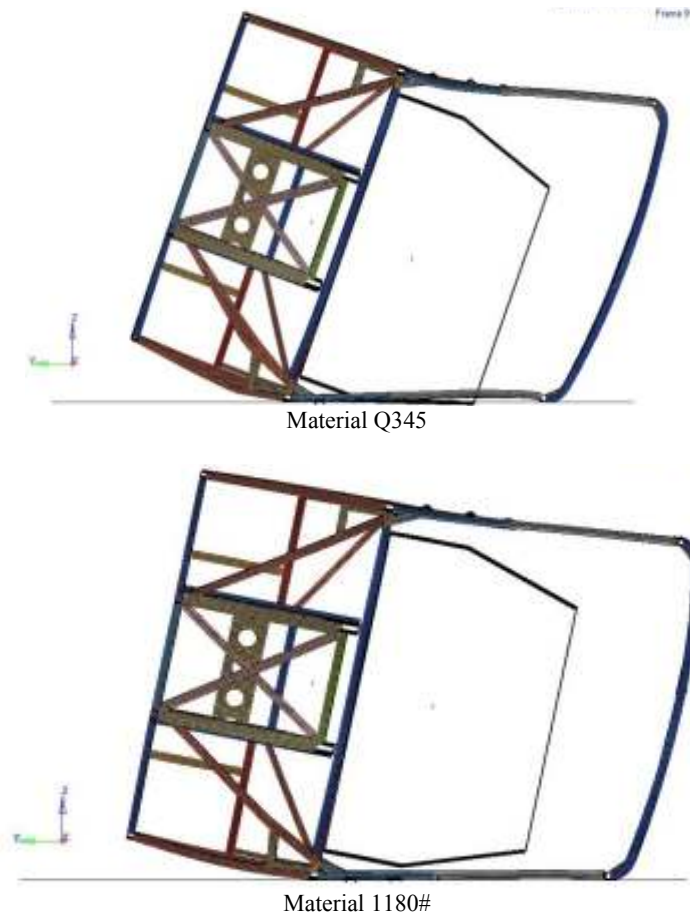


Fig. 7: Deforming comparisons when applying material Q345 and 1180# respectively

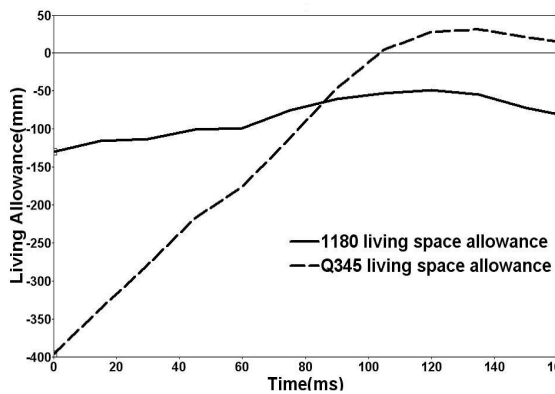


Fig. 8: Comparisons for survival space surplus when applying material Q345 and 1180# respectively

during rollover and the extent of intrusion into survival space are obtained as Fig. 7. It is observed that with the utilization of Q345 type of materials, the survival space has been intruded with 100mm at the forepart and 40mm at the rear part, which obviously cannot fulfill the laws and regulations. However, when applying 1180# high-strength steels, the survival space has allowed some surplus; the deformation comes to the maximum extent at 120 ms, with the minimum surplus approximately 26 mm at the forepart of middle body frame and about 49.5 mm surplus at the rear part (Fig. 8).

CONCLUSION

A great deal of destructive traffic accidents is caused by bus rollover, which is mainly due to poor rollover security of the main body frame of buses. This study performs analyses on the core safety technologies during bus rollover which include lowering the height of mass center to the greatest extent, shortening the span between side windows or enhancing the cross section of side pillars, promoting the strength of joints of side body, assuring the continuity of close loop structures and adopting high-strength steels. Based on the improvement directions and measures as stated above, a FE model of middle body frame rollover is set up. The simulation results indicate that the deformation extent and deformation modes of side pillars have been greatly improved after the improvement, which satisfies the requirements of ECE R66 regulations and verifies the correctness of the suggested approaches.

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