Rollover event simulation and optimizations of vehicle Design using Finite Element Analysis

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Abstract— *It was found that as per Fatality Analysis Reporting System (FARS) rollover events cover more than 30% of the crashes. A large number of road accidents take place every year causing many fatalities and severe injuries to the vehicle occupants. Over 9 thousand people are killed yearly in rollover crashes. In 2001, 10.5% of all fatal crashes were rollovers, though only 2.2% of all crashes were rollovers. Almost fifty percent of fatalities occurring in Sport Utility Vehicles (SUVs), pickup trucks, and minivans are due to rollovers. This makes rollover a serious threat for all vehicles, but especially larger utility vehicles (NHTSA, 2002). Figure 1.1 graphically illustrates the dangers of rollover accidents. If sufficient attention is given to injury impediment, by building the vehicles innately safer, this problem can be reduced. Among the various modes of vehicle crashes, rollover crashes are often very severe and threatening to vehicle occupants. The rollover crash accident of vehicles, although occurs less frequently than any other type of accident, the fatality rate and severe injuries are highest in rollover crash. Hence the structure of the vehicle needs to be strong enough to ensure the minimum damage and at the same time it should absorb maximum impact energy. In this work numerical simulation of pick-up rollover test using finite element method is followed. As shown in figure 2, during rollover vehicle roof, A Pillar and B Pillar play an imperative role to avoid vehicle collapse. Using Finite element Approach optimizes design of roof and its surrounding systems will be finalized to reduce vehicle collapse during rollover accidents .We have also studied the use of different materials for the top in order to decrease the thickness of sheet metal of top segment while also behaving safe in the regulation. The technique is being carried with the aid of Finite Element Analysis (FEA) and Computer Aided Engineering (CAE) routines to upgrade a roof material.*

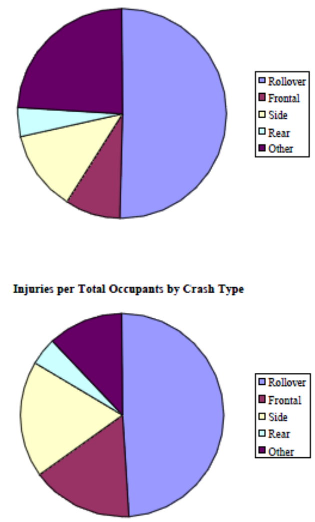


Figure 1: Annual Average in to Tow-away crushes by crush type in the NASS and FARS crush Database, adjusted for unknowns.

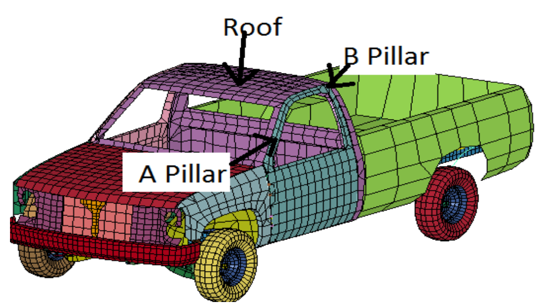


Figure 2: FE Model of Pickup Truck

1. INTRODUCTION

The main objective of this study is to prepare and study the finite element simulation of roof crush test. The data presented in this study should be used just to understand the FE simulation process. One of the most crucial hazards for the safety of passengers and crew ridding in a SUV is the roll-over event. In the years that went it was seen that after the accidents took place the structure of the body that was deformed or the portion of the structure that was deformed seriously threatens the lives of the passengers and hence the roll-over strength became an important issue for the car manufactures. The roll-over strength is the key factor that has to be stressed upon .the consequences of roll over events is very catastrophic and various regulations are there for proper analysis of rollover accidents. In the automotive industry the main topic in case of automotive safety are frontal, lateral and rear end impacts. In case of roll over cases the risk of injury is very high and as in case of rollover accidents the upward tendency of the incidence rate are expected because of increasing sales of passengers cars and SUVs. When we compare other accidents in case of cars with the roll over events, we will come to know that the event of roll over is characterized by a complex vehicle motion having longer durations and linear acceleration is low. The various facts and statistics about accidents have shown that the roll over events occur with relatively lower frequency and considers all kinds of accidents that happens in a SUV'S. The mortality rate in roll over is approximately 5 times greater as compared to any other possible accident typology. This work carried by us presents the finite element simulations of the structural behaviour of the SUV'S in a roll-over accident .the resistance of the structure and the passenger injury risk are evaluated .our main motive was featured on the effect of a roll-over accidents over the structure and passenger. In this work using FEA simulations are carried out for the mechanical behaviour of A and B pillar as well as of the roof of the SUV in case of a roll over events. these simulations will help us to build the best optimized structure of a SUV'S with different material system that could be used so that the best structural behaviour against roll over are achieved .These simulations are based on FMVSS-216 regulations, which gives specifications about roof crash resistance of passengers cars, and light trucks (GVWR 6000POUNDS OR LESS).This standard establishes the requirements for the passengers compartment roof. The main purpose of this standard is to reduce deaths and injury due to crushing of the roof into the occupant compartment in roll-over crashes .this standard applies to passenger's cars and multipurpose passengers vehicles .trucks and buses with GVWR of 2772 kg's or less. The new vehicles entering into the market should be able to pass successfully through a no. of standard tests and the same process should be followed for vertical models also. The accidents occurring due to roll over depend on stability of a vehicle during turns. This vehicle stability is influences by the height of C.O.G and width of vehicle. This narrow track and high C.O.G may make a vehicle unstable when it takes turn at high speeds which results in roll-over accidents. The main reasons for the rollover of a vehicle are:

- Excessive cornering speeds
- Tripping
- Collision with other vehicle or an object
- Sharp changes in direction at high speeds etc.

1. The impact load in case of roll over is very severe which can result in total collapse of the structure

2. Methods:

In this study Chevrolet C2500 Pick truck FE model was used to simulate the FMVSS216 test and offer best optimized vehicle design against the same test. In order to simulate FMVSS216 in FEA our understanding about this test must be clear. The setup of FMVSS216 is shown in figure 2. The device is a rigid unyielding block whose lower surface is a flat rectangle measuring 762mm by 1892mm.the chassis frame of the vehicle is placed on the rigid horizontal surface ,the vehicle is fixed rigidly in position, all windows are closed and doors are locked and any convertible tops are secured or removable roof structure in place over the passenger compartment.

- Its longitudinal axis is at forward angle (side view) of 5 degrees below the horizontal and is parallel to the vertical plane through the vehicles longitudinal centreline.
- The lateral axis is at lateral outward angle of 25 degrees in below horizontal.
- Its lower surface is tangent to the surface of the vehicle and
- Initial contact point is on the longitudinal centreline of the lower surface of the test device and 254mm from forward most point of centreline.
- The force is applied so that the test device moves in a downward direction perpendicular to the lower surface of the test device at a rate of not more than 13mm per second until the force becomes 22.24kN.

- The test device is guided in such a way that throughout the test it moves without rotation in a straight line with its lower surface oriented as specified in test.
- The distance is measured which the test device is moved i.e. the distance between the lower surface of the test device and its location as the force level increases up to the specified level is reached .this distance is measured.

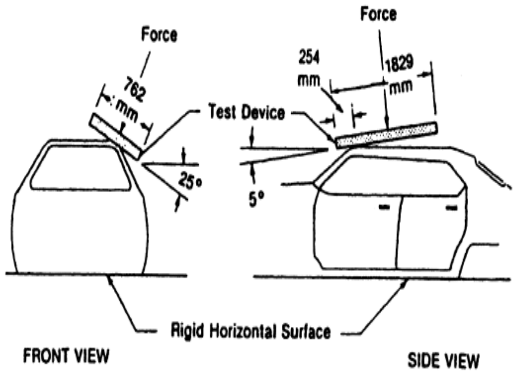


Figure 3: FMVSS216 setup

The test vehicle which we have considered is Chevrolet -C2500of general motors. The FE model of this truck was directly used to setup FE simulations of FMVSS216 roof crush test. The test device is a rigid unyielding block whose lower surface is a flat rectangular plate (impactor plate) measuring 762mm by 1829mm in dimensions. Finite element model of the impactor plate is shown in figure 4.1.

The test device is used to apply the force to either side of the forward edge of a vehicles roof. The lower surface of the test device must not move more than 127m. If the lower surface of the test device moves more than 127mm then the vehicle fails under this test and the vehicle will not pass successfully. Also the force applied in Newton's should be equal to 1.5 times the unloaded vehicle weight of the vehicle measured in kg and multiplied by 9.8.

The force should not exceed 22.24 KN for passenger cars. As the total GVW measured of the vehicle was found to be higher than the given limit hence 22.24KN maximum force was applied with the help of rigid plate. The vehicle is constrained on its sills or chassis frame on a rigid horizontal surface, the vehicle is rigidly fixed in position, all windows are closed, all doors are closed and locked and any convertible tops are secured over the passenger's compartment. The complete setup of FE model of FMVSS216 roof crush model is also given in figure 4.2.

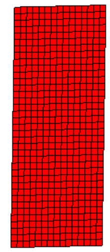
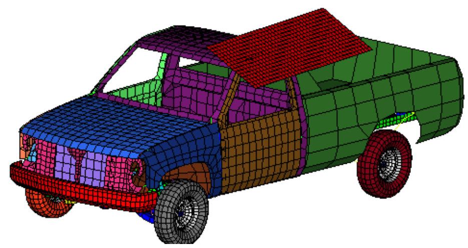


Figure 4 4.1) Impactor plate FE model



4.2) full simulation & testing setup

3. <u>Results and Discussions:</u>

The results section is divided into two sections. First baseline and other is optimization process. Figure 5 shows the displacement contour of the model after applying maximum force. As shown in figure after application of the maximum force of 22.24 kN, the rigid plate was travelled about 30 mm. It clearly shows that with the baseline design FMVSS216 roof crush model can be cleared successfully. Figure shows the strain and stress results on the roof region. Maximum strain was found around 0.08% and maximum stress found around 200MPa

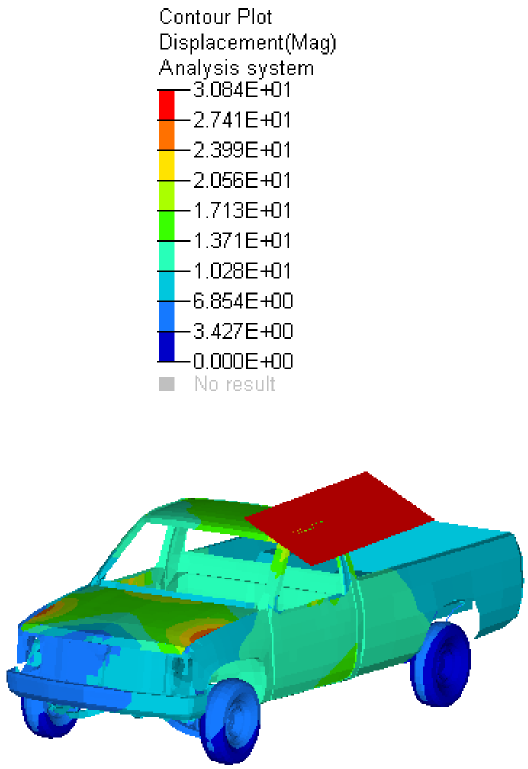


Figure 5: Contour showing Displacement of the rigid impactor after application of full load

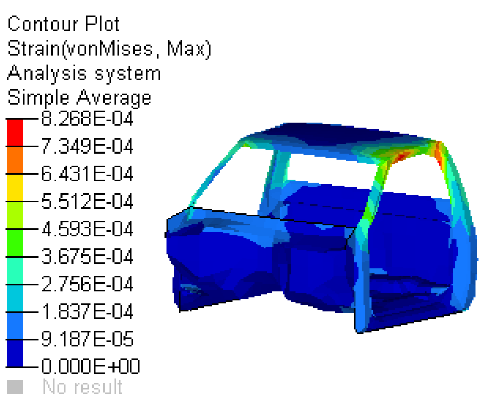


Figure 6.1: Contour showing strain induced in roof truss due to displacement of impactor after application of full load

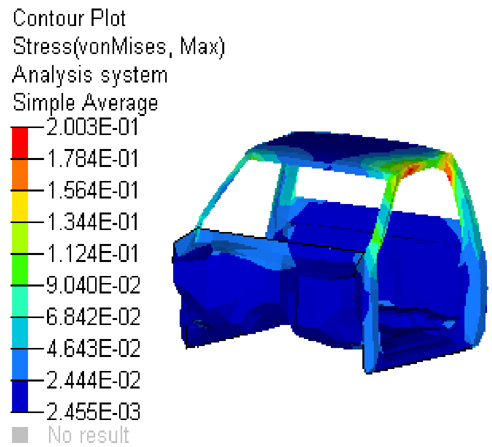
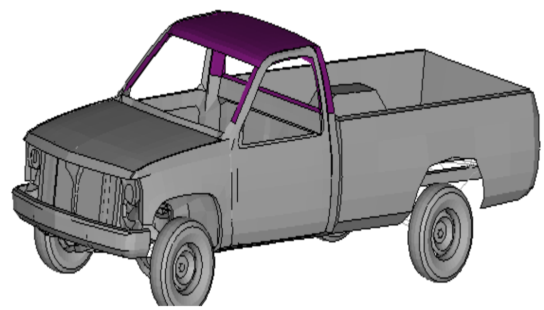


Figure 6.2: Contour showing stress induced in roof truss due to displacement of impactor after application of full load



As the rigid plate can travel maximum of 127mm, weight optimization of the roof was performed using FE modelling. The baseline roof model is having the thickness of 2.5mm with total roof weight of 214kg. Weight optimization was performed with reduced thickness of 2mm as shown in figure 7.

Figure 7: Weight optimized FE Model of the vehicle

Results of weight optimized design are shown in figure 8, 9.1 & 10.2. Figure shows the displacement contour of the model after applying maximum force. As shown in figure after application of the maximum force of 22.24 kN , the rigid plate was travelled about 33 mm. It clearly shows that with the weight optimized design FMVSS216 roof crush model can be cleared successfully. Figure shows the strain and stress results on the roof region. Maximum strain was found around 0.1% and maximum stress found around 228MPa.

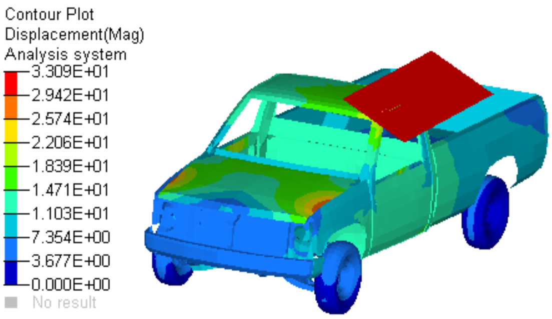


Figure 8: Contour showing Displacement of the rigid impactor after application of full load on optimized roof design

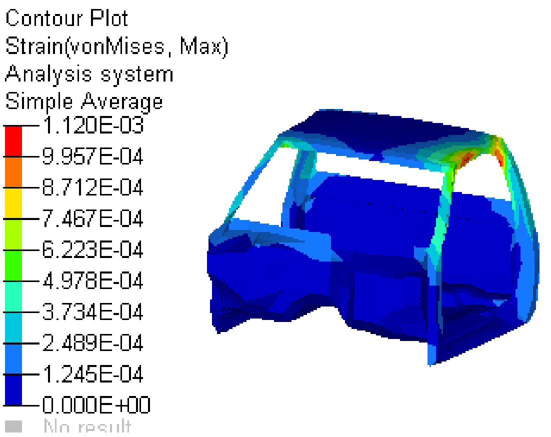


Figure 9.1: Contour showing strain induced in roof truss due to displacement of impactor after application of full load on optimized roof design

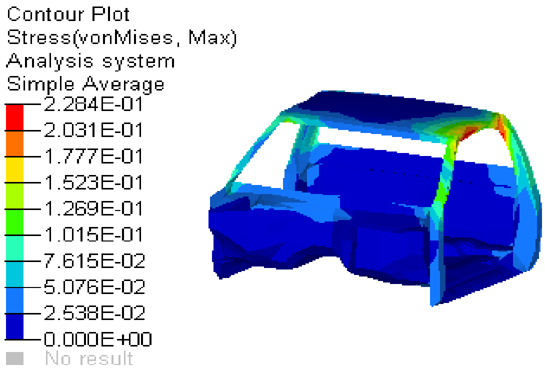


Figure 9.2: Contour showing stress induced in roof truss due to displacement of impactor after application of full load on optimized roof design

After analyzing the result we have observed the loop holes which cause major rollover accidents. Fatigue cracks are major cause of fatal in any vehicle body. Fatigue crack simulation can be observed by the mesh generation over the vehicle body[7]. Then, we have concluded car roof, side rails and pillars of a car are the major components which can give strength to a car and enhance the safety[8]. So, our first approach was to use best possible material which can enhance the strength of a car body. Further, we performed some iteration by taking 4 different grades steel and used dynamic transient analysis method to obtain the results[9].

4. Analysis using Steel AISI 4000:

After that we have changed the material of individual components and we have used AISI 4000 steel to strengthening the car roof and pillars. W e have updated the material and its respective properties in the components and performed some iteration. By varying the thickness of components finally we have achieved the displacement of plate which is below 127mm of the plate and final thicknesses of components are being shown in table-1. Resultant displacement of force plate is shown in figure-4.Further, we have randomly performed some iteration over different grades of steel such as, ASTM A36, Molly- Chrome steel with the same thickness and following are the results are shown in figure-5.Finally, after performing innumerable iteration ns over these steel grades we have observed better strength can be provided to vehicle by using steel grade AISI 4000.

5. Bead Design and Modelling: Now, we have continued our research in order to ameliorate the strength of roof of a car. To increase the strength of a car we have modelled the solid bead over the car roof and assigned the proper material and respective property to the bead component. Design of car component is in such a way that it can also be beneficial for the car aerodynamics point of view and also enhance the strength of car roof. Air can easily pass through the car bead which is good for vehicle aerodynamics. We have design the bead in such a way that it can mitigate the effect of s tresses and can enhance the strength of roof which is a major cause of roll over fatal. Design of roof bead is shown in figure-6.After creating the bead component we have again done simulation over the same car and performed the iteration by taking the material AISI 4000 and same optimized thickness of component and following Resultant Displacement vs. Time graph has been plotted in figure-7.

6. Advanced Octa Grid Design and Modelling:

Advanced grid structure is an evolution of early aluminium iso-grid stiffening concepts. These structures have broadly being used in aeronautical and civil engineering applications because of its high impact strength and fatigue resistance. The other real characteristic of this network is high quality energy assimilation. Energy engrossing materials are generally being utilized as a part of car commercial ventures in light of the fact that; inhabitant's security majorly relies on the retention of accident vitality of vehicle structure [10].This octa grid is made up of two major components stiffeners and skin. In which, stiffener is ribs and skin is car roof. Further, this octa grid is installed over car roof and simulation is performed. Octa grid over car is shown in figure 8 and simulation result has been shown in figure-9.

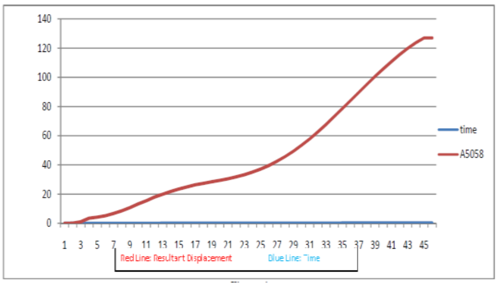


Figure 10 Resultant displacement Vs. Time Graph of steel grade AISI 4000

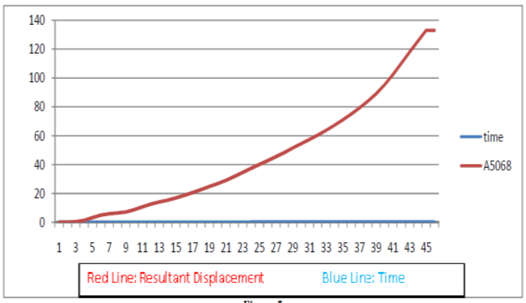


Figure 11 Resultant displacements Vs. Time Graph of Steel ASTM A36 grade

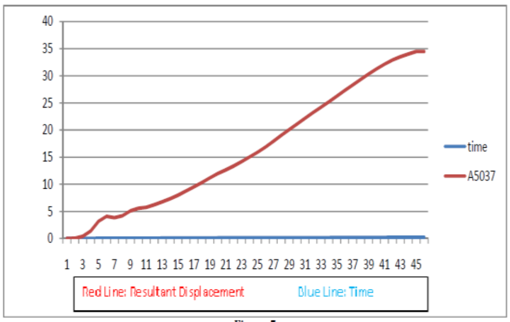


Figure 12 Resultant vs. Time Graph of roof bead

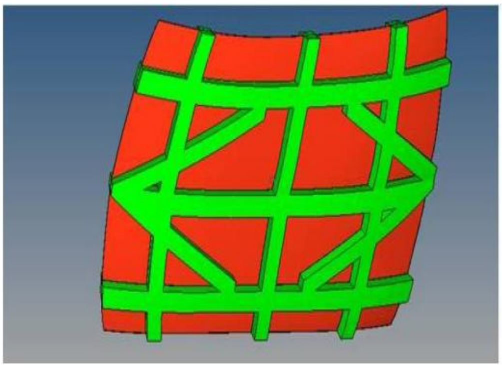


Figure 13 Formation of advanced Octa grid over the roof

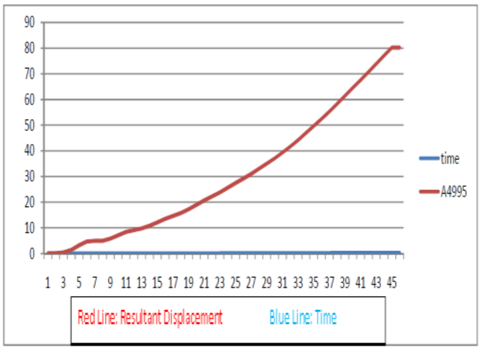


Figure 14 Resultant displacement vs. Time Graph of Advanced Octa Gr

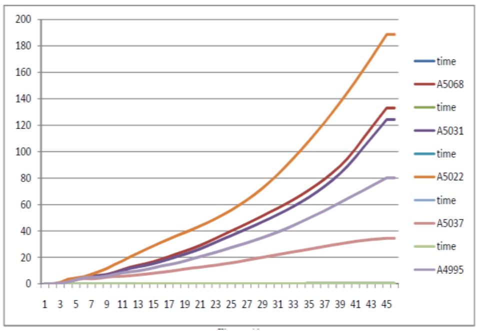


Figure 15 Combined Simulation result of different steel grades, bead formation and octa grid.

7. Results and Discussion

First we have performed the iterations over the different steel grades and following results have been found is shown in table-2. Second, we have done some modifications over roof component of a car and created solid bead and then, designed advanced octa grid and performed simulation over it. Following the results shown in table-3. We have performed several iterations on different steel grades and then finalized the final steel grade AISI 4000 which best suited material for the car body. Further, to enhance the car safety in rollover crashes we have observed that key components are car pillars, roof, side rails and rocker arm and we have to provide strength to these components to design our vehicle durable. However, roof is the major part which plays vital role during rollover crashes and by strengthening the roof part we can enhance the safety of whole vehicle. So, we have designed bead over roof and analysed the result and further created advanced octa grid over the roof with proper analysis. Later, we compared the result by measuring the displacement of force plate which should be less than 127mm. The combines result has been shown in figure 10. In which, above 180 mm displacement had been shown by curve 1 which is of linear steel and 133.8mm displacement shown by curve 2 which is of steel grade ASTM A36. Hence, these materials are not suitable for the safety point of view because displacement of plate should be less than 127mm. Furthermore, steel grade AISI 4000 has shown the optimized result in curve 3 which is 124.3mm. Curve 4 and 5 are of advanced octa-grid and bead formation respectively and showing 80.mm and 34.8mm displacement.

Material	Resultant Displacement (in mm)
AISI 4000	122.8
ASTM A 36	133.2
Molly chrome steel	143.8
Kevlar composite	217.6

8. Conclusion

Roof plays the major role during the rollover crashes and it has been found that strengthening the roof component of the car we can make car durable and safe. To increase the thickness of the component is not the only option because; it will increase the cost of the vehicle. So, with the help of software i.e. Hypermesh we have played with the roof geometry and performed some iteration by employing bead and advanced octa grid over the roof. Furthermore, Results were positive in both the cases and this can be executed by industries to avoid rollover crashes. This study clearly demonstrated the role of Fe process in automobile and mechanical world. This research work still needs validation with experiments. With the complete understanding of this weight saving process individual can learn and enhance their role in vehicle design using Finite Element Analysis.

9. References

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