

Research on Optimization Design of Front and Side Structures under the 24th Edition of C-NACP Automotive Collision Standard

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ABSTRACT

Structural crashworthiness plays a core role in vehicle safety design, mainly focusing on the maximum impact force that the body structure can withstand in collision accidents, and striving to maximize collision energy absorption to ensure that passengers have sufficient living space. The design of structural crashworthiness needs to consider the deformation mechanism and energy absorption characteristics of vehicles under different collision modes, and improve crashworthiness through material selection, structural optimization, and other means. In addition, the structural crashworthiness is closely connected to the passenger restraint system, which together constitute the key to the passive safety performance of the vehicle. In vehicle safety design, the improvement of structural crashworthiness can significantly enhance the vehicle's ability to protect passengers in collision accidents and reduce the risk of injury. Therefore, in-depth research on structural crashworthiness and the development of efficient crashworthiness structures are important directions for improving vehicle safety performance.

KEYWORDS

Structural Crashworthiness; Vehicle Safety Design; Collision Energy Absorption; Crash Resistant Structure; Risk of Injury.

1. BASIC THEORY OF STRUCTURAL CRASH RESISTANCE

1.1. The Concept, Principle, and Main Indicators of Crashworthiness

Impact resistance refers to the absorption of kinetic energy generated by an object as internal energy consumption, protection of personal safety and reduction of losses at low or high speeds. During this period, the object does not require damage to the material or structure, but requires maximum energy absorption in a way that causes damage.

The principle of impact resistance mainly includes energy absorption and diffusion, deformation of the body structure during vehicle collisions, absorption of impact energy through the elastic plastic deformation of materials, and reduction of impact on passengers. The design of the body structure also takes into account the dispersion of impact force to a larger surface area, reduce local stress and minimize passenger injuries.

The main indicators of impact resistance include the maximum load generated by the structure during the impact process, the energy absorbed per unit of material mass (i.e. not absorbed energy) and the average load throughout the impact process. These indicators may reflect the vehicle's ability to absorb and distribute energy during the impact process, thereby assessing the vehicle's impact resistance.

There are other indicators used to assess the vehicle's resistance to collisions, such as suction, maximum deceleration, average impact force, steering column collapse, firewall intrusion, etc. These indicators can provide a more comprehensive understanding of the vehicle's ability to protect passengers in the event of a collision.

In summary, collision resistance is an important factor in vehicle safety design: reasonable construction and material selection can improve the vehicle's collision resistance and protect passengers from collision injuries.

1.2. Energy Absorption, Deformation, and Failure Modes of Structures During Collision

Workers must have sufficient power, habit, and any radius method to ensure the safety of the most urgent work paths.

When you know that you are using the power of love, it has core activities. As close to the end, the structure of power and the structure of the most common heavy squares. The absorption process helps to enhance the capacity of large-scale production workers to implement and promote the development of large-scale production services. The body part was a steel structure, and the longest gondola had spread to the front race of the most important part, and they had overwhelming power to know that it was weak to the root of the race at the longest.

Deformation is another important reaction of the vehicle structure in the collision process. Deformation of car structures depends on design, material properties, speed and angle effects. If it is known to be a soft machine, the structure must be four types during pause. The most typical plastic load natural load. Elastic deformation is reversible and plastic deformation is irreversible and provides permanent damage to the vehicle body. Make your wooden chassis easier and respect your own self-esteem.

Finally, there are times when you can use multiple ways to support chase. This method is played back at completion of chase. Accuracy is considered a risk. That is, I do not respect the importance of score strength, score strength, importance and severity. The duration of the importance of the score strength structure is not voluntary. In order to avoid or reduce failure mode generation, an automotive designer needs to predict and improve structural performance through modeling, simulation and analysis while selecting appropriate materials and processes to ensure structural strength and hardness.

In short, during the vehicle collision, energy absorption, deformation, and arrangement of interconnects and interrelated structures are not required. Such changes will lead to serious internal change and respect the way to manage the most complex processes and accumulate results.

2. PRINCIPLES AND STRATEGIES FOR STRUCTURAL CRASH RESISTANCE DESIGN

2.1. The Basic Principles of Structural Crashworthiness Design

The core principle of structural impact resistance design lies in efficiently absorbing collision energy and ultimately ensuring the safety of passengers. This process begins with the need for the vehicle's structure to convert impact kinetic energy into non-elastic forms, utilizing mechanisms such as material elastic deformation. This is achieved not just by storing elastic characteristics, but by allowing for rapid energy dispersion, thereby mitigating the impact on passengers.

To minimize harm to passengers, it is crucial to meticulously control the maximum reaction force during structural deformation. This involves maintaining the stability of the reaction force and avoiding excessive impact, which could potentially cause serious harm. To achieve this, designers

must carefully consider the material properties, geometry, and arrangement of the vehicle's structural components.

In thin-walled metal structures, the effective absorption of collision energy requires ensuring sufficient deformation travel and stroke efficiency. This means that the structure must be able to deform gradually and evenly during a collision, maximizing the absorption of impact energy. Additionally, the stability of energy absorption is paramount. The vehicle structure must maintain consistent energy absorption characteristics throughout the collision process to prevent any sudden changes that could potentially harm passengers.

From a broader perspective, the overall vehicle design must take into account various structural elements. The front structure, for instance, must possess sufficient plastic deformation capacity to absorb collision kinetic energy. Simultaneously[1], the passenger compartment must exhibit high structural strength to ensure that passengers have a safe and secure living space during a collision. Furthermore, the use of springs and damping devices can help isolate passengers from the interior of the vehicle, reducing the impact of secondary collisions.

In summary, structural impact resistance design is a multifaceted process that involves various considerations such as energy absorption, reaction force control, deformation stroke and stroke efficiency, suction stability, and overall vehicle structural design. The ultimate goal is to comprehensively enhance the protection capabilities of the vehicle's passengers in the event of a collision accident, ensuring their safety and well-being.

3. SIMULATION ANALYSIS AND OPTIMIZATION OF STRUCTURAL CRASHWORTHINESS

Compared to the 21st version, the 24th version of the CYNACP standard has significantly improved both frontal and side collision conditions, which undoubtedly puts higher requirements on the structural crashworthiness of vehicles. Especially in the frontal 100% overlapping rigid barrier collision test, we can observe that the increase in collision speed is quite significant, from 50.1^{+1} km/h in the 2021 version to 55 ± 1 km/h, which means an increase of 21% in collision energy. This change poses great challenges to the safety performance of vehicle structures.

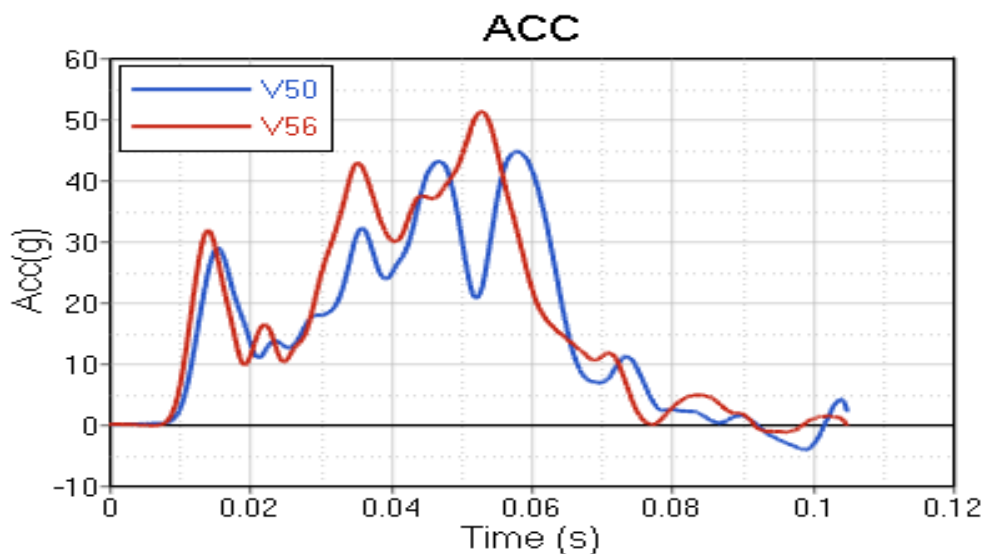


Figure 1. Acceleration Comparison

After the collision speed increases, the dynamic response exhibited by the vehicle body during impact also undergoes significant changes. Firstly, the peak acceleration of the vehicle body significantly

increases, which means that at the moment of collision, the impact borne by the vehicle is more severe. At the same time, the early appearance of peak and pulse width time also indicates that the vehicle structure has reached its maximum impact state in a shorter time, which puts higher requirements on the stiffness and strength of the vehicle structure.

More importantly, the increase in intrusion of the front bumper is a highly concerning issue. As a key structural component of the front of the vehicle, the increase in intrusion of the front panel means that the passenger compartment is subjected to more severe compression and impact during the collision process. This may not only cause more serious injuries to passengers[2], but also affect the overall safety performance of the vehicle.

Therefore, in the face of the challenges posed by the 24th edition of the CYNACP standard, vehicle designers need to make more efforts to optimize the structural design of vehicles. They need to start from multiple aspects such as material selection, structural design, and force transmission path optimization to improve the structural crashworthiness of the vehicle. At the same time, it is necessary to ensure the effectiveness of the optimized design through extensive simulation analysis and experimental verification.

In summary, the upgrade of the 24th edition of the CYNACP standard has put forward higher requirements for the crashworthiness of vehicle structures, but at the same time, it has also brought greater challenges and opportunities to vehicle design.

4. IMPROVEMENT OF STRUCTURAL CRASHWORTHINESS

With the implementation of the new C-NCAP standard, the existing vehicle design is no longer able to meet the requirements of the new standard in terms of structural crashworthiness. In order to improve the safety performance of vehicles, it is necessary to optimize the design of the frontal structure's crashworthiness. Specifically, we can start from the following four aspects:

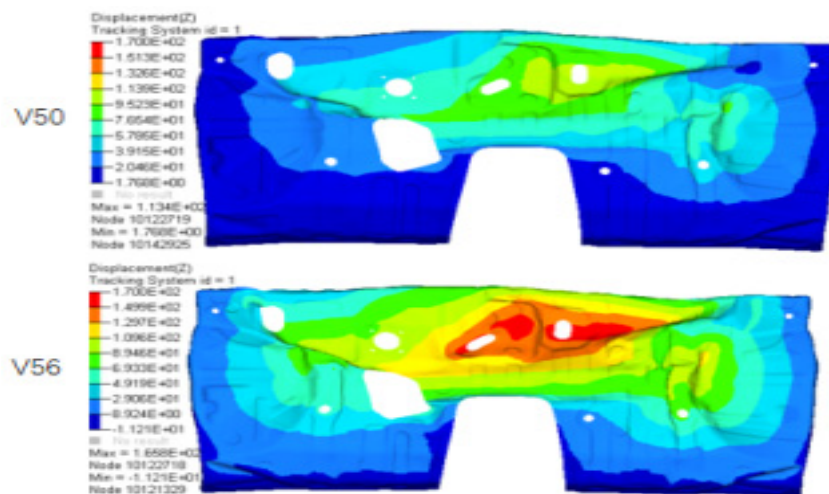


Figure 2. Comparison of intrusion volume into the front bumper

Firstly, increasing the energy absorption space is the key to improving crash resistance. During the collision process, the vehicle structure needs to absorb a large amount of energy to reduce the impact on passengers. Therefore, measures such as increasing the length of the energy absorption box and replacing the smaller moving parts in the X-direction can effectively absorb excess energy. This not only reduces the impact force during collisions, but also reduces damage to the vehicle structure.

Secondly, improving the energy absorption efficiency per unit area is also crucial. To achieve this goal, we can increase the cross-sectional dimensions or thickness of components such as energy

absorption boxes and longitudinal beams. These components play an important role in the collision process, as they can effectively absorb and disperse collision energy. By increasing their size or thickness, their energy absorption capacity can be improved, thereby further enhancing the vehicle's crashworthiness. Reasonable arrangement of power transmission channels is also an important aspect that cannot be ignored in optimization design. During the collision process, a reasonable force transmission channel can disperse the collision force to various parts of the vehicle structure, reducing the impact on a single component. By optimizing the design of the transmission channel, we can allow more energy to be transmitted and decomposed through the upper or lower channels, thereby reducing the risk of injury to passengers. Reasonably designing component failure strategies is also an effective means to improve crashworthiness. During the collision process, the failure of certain components is inevitable. However, through reasonable design, we can control the failure mode and timing of these components to maximize energy release and reduce harm to passengers. For example, strategies such as suspension breakage, detachment of subframe mounting points, and failure of the subframe body can all reduce the impact force during collisions to a certain extent.

In addition to frontal collisions, side barrier collision tests are also an important indicator for evaluating vehicle crashworthiness. Side barrier collision test, collision speed increased from 50_{0}^{+1} in the 2021 version to 60_{0}^{+1} km/h; The honeycomb aluminum model at the front end of the mobile barrier has been replaced from AE-MDB barrier to SC-MDB barrier. The weight of the trolley has increased from 1400kg to 1700kg, and the collision energy has increased by about 75%. From the performance of the existing SC-MDB model, the intrusion of the side body has significantly increased, and the risk of B-pillar cracking and failure has significantly increased. In order to meet the higher requirements for vehicle crashworthiness in the new version of CNCAP, we must optimize the design from multiple aspects. By increasing energy absorption space, improving energy absorption efficiency per unit area, arranging transmission channels reasonably, and designing component failure strategies reasonably, we can effectively improve the vehicle's crashworthiness and provide safer and more reliable protection for passengers. Crash test verification

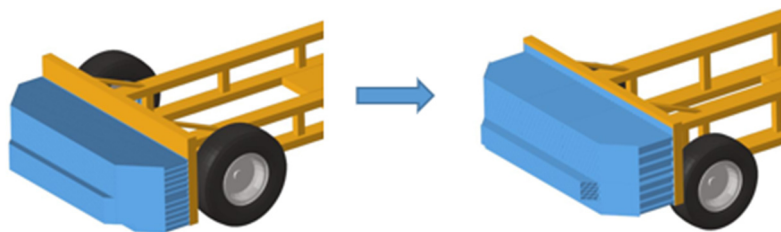


Figure 3. Wall Barrier Comparison

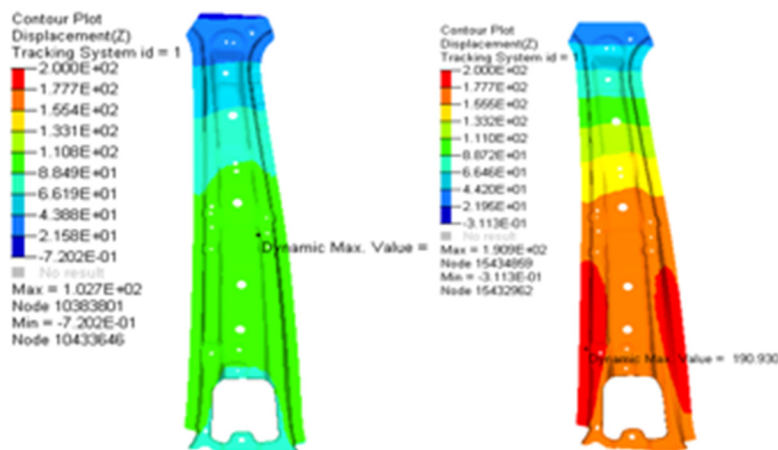


Figure 4. Comparison of column intrusion volume

5. PURPOSE, METHODS, AND STANDARDS OF STRUCTURAL CRASHWORTHINESS TESTING

The main purpose of structural crashworthiness testing is to study the deformation mechanism and energy absorption characteristics of vehicle structures under various collision modes, and to seek improvements in crashworthiness in terms of vehicle materials, structural characteristics, energy management, and collision waveform control. Through such experiments, the aim is to maximize collision energy absorption and ensure that passengers have sufficient living space in the event of a traffic accident.

In terms of testing methods, structural crashworthiness testing usually includes two forms: actual collision testing and simulation. Actual collision testing simulates real collision scenarios, observing and recording the deformation, energy absorption, and passenger protection of the vehicle during the collision process. Simulation uses computer technology and collision analysis software to simulate the collision process and predict the results, in order to optimize during the vehicle design phase.

Regarding test standards, different countries and regions may have differences, but they usually involve regulations on collision speed, collision angle, collision object, and other aspects. Taking the 24th edition of the CNACP standard as an example, compared to the 21st edition, it has upgraded both the front and side working conditions, and put forward higher requirements for structural crashworthiness. The collision speed of the frontal 100% overlapping rigid barrier collision test has been increased from 50₋₁⁺¹ in the 2021 version to 55₋₀⁺¹ km/h, and the collision energy has increased by 21%. This upgrade makes the test more closely related to actual collision scenarios, and the evaluation of the vehicle's structural crashworthiness is more rigorous[3].

It should be noted that the specific purpose, methods, and standards of the experiment may vary depending on the research purpose and vehicle type. Therefore, when conducting structural crash resistance tests in practice, appropriate test plans and standards should be developed based on specific circumstances. Meanwhile, with the continuous development of automotive technology, the standards and methods for structural crashworthiness testing are constantly being updated and improved to meet new safety requirements and technological challenges.

6. ANALYZE EXPERIMENTAL DATA AND EVALUATE THE CRASH RESISTANCE PERFORMANCE OF THE STRUCTURE

Table 1. Evaluation of Structural Crash Resistance Performance

Experimental project	Collision velocity (km/h)	Energy absorption (EA) (kJ)	Specific energy absorption (SEA)	Average collision force (MCF) (kN)	Front panel intrusion volume (mm)
Experiment 1	55	120	0.65	80	80
Experiment 2	55	135	0.72	75	75
Experiment 2	55	110	0.60	85	85

In order to analyze the experimental results and evaluate the crashworthiness of the structure, we can draw a table based on specific data and explain in detail how these data reflect the crashworthiness

of the structure. The following is an example table that includes some key crash performance indicators and their corresponding data:

In this table, we assume that three tests were conducted, each with a collision speed of 55km/h. We recorded the energy absorption (EA), specific energy absorption (SEA), average collision force (MCF), and intrusion of the front bumper for each experiment. These data can directly reflect the impact resistance performance of the structure.

The larger the energy absorption (EA) data, the more energy the structure can absorb during the collision process, which is beneficial for reducing the damage to passengers caused by the collision.

The closer the SEA data is to 1, the higher the efficiency of the structure in absorbing energy, and it can absorb more energy per unit of input energy.

The smaller the average collision force (MCF) data, the better the structure can disperse and cushion the impact force when subjected to impact, reducing the harm to passengers.

The smaller the intrusion data of the front bumper, the less compression and impact the passenger compartment is subjected to, and the better the protection performance for passengers.

Based on the data in the table, we can find that:

The energy absorption and specific energy absorption data of Experiment 2 are the highest, while the average collision force and front[9] panel intrusion data are relatively low, indicating that the structural crash resistance performance is the best in Experiment 2. The energy absorption and specific energy absorption data of Experiment 3 were the lowest, while the average collision force and front panel intrusion data were relatively high, indicating that the structural crash resistance performance was poor in Experiment 3.

By comparing these data, we can determine the differences in crash resistance performance of the structure under different test conditions, providing reference for structural optimization and design. It should be noted that actual experimental data may be more complex and diverse, and only a simple example table is provided here to illustrate how to analyze experimental results. In practical applications, it is necessary to develop appropriate evaluation methods and standards based on specific experimental conditions and vehicle types.

7. ACTUAL CASE ANALYSIS

7.1. Case Background

Recently, a renowned automobile manufacturer has embarked on a comprehensive and rigorous set of structural crash resistance tests for its newly developed SUV model. The SUV, boasting a sleek design and advanced technological features, places a paramount emphasis on enhancing the safety performance of its passengers. Given the ever-increasing demand for safer vehicles and the rising concerns surrounding road accidents, the evaluation of the SUV's structural crashworthiness has become a crucial aspect of its development process.

The manufacturer understood that in order to ensure the highest level of safety for its customers, it was imperative to conduct these tests under various conditions and scenarios. Therefore, a diverse range of crash tests were designed, simulating different types of collisions that could potentially occur on the road.

Firstly, the SUV underwent a frontal full-width rigid barrier crash test, where it collided with a fixed barrier at a predetermined speed. This test evaluated the SUV's ability to absorb and distribute impact forces, ensuring that the passenger compartment remains intact and the occupants are protected.

Secondly, a side impact crash test was conducted to assess the SUV's resistance to collisions from the side. This test was designed to simulate a collision with another vehicle or a stationary object, evaluating the strength and integrity of the SUV's side structure.

In addition, offset crash tests were also performed, simulating collisions where the SUV impacts an object at an angle[4]. These tests were crucial in assessing the SUV's structural performance in non-symmetric collisions, which often occur in real-world accident scenarios.

Throughout these tests, the SUV's front, side, and other critical structural components were carefully monitored and analyzed. Data such as energy absorption, specific energy absorption, and average crash forces were recorded and evaluated. The manufacturer also paid close attention to the deformation of the SUV's structure, ensuring that it remained intact and did not collapse under the impact forces.

The results of these tests were highly encouraging. The SUV demonstrated excellent crash resistance, with its structure effectively absorbing and distributing the impact forces. The passenger compartment remained intact, and the SUV's safety features such as airbags and seatbelts functioned as expected, providing additional protection to the occupants.

Overall, the manufacturer's rigorous testing of the SUV's structural crash resistance has not only validated its safety performance but also reinforced its commitment to providing customers with safe and reliable vehicles. This SUV model serves as a testament to the manufacturer's dedication to innovation and safety, setting a new benchmark in the automotive industry[10].

7.2. Test Method

In order to comprehensively evaluate the structural crashworthiness of this SUV, the testing team adopted various testing methods, including frontal 100% overlapping rigid barrier collision test, side collision test, and multi angle offset collision test. These experiments were conducted at different speeds and angles to simulate various actual traffic accident scenarios.

7.3. Experimental Results and Data Analysis

Analysis of frontal collision test

In the frontal 100% overlap rigid barrier collision test, the SUV collided with the rigid barrier at a speed of 55km/h. The test results indicate that the front structure of the vehicle has successfully absorbed most of the impact energy, the intrusion of the front bumper is controlled within a reasonable range, and the passenger compartment remains intact without severe compression. At the same time, the vehicle's energy absorption (EA) and specific energy absorption (SEA) indicators have reached excellent levels, demonstrating good energy absorption performance.

Analysis of Side Impact Test

In the side impact test, the SUV collided with another vehicle at a certain angle and speed. The test results show that the side structure of the vehicle performs excellently, effectively resisting external impact forces and protecting passengers from injury[5]. In addition, key components such as the B-pillar and doors of the vehicle remained intact during the collision process without significant deformation or fracture.

Analysis of Multi angle Bias Collision Test

The multi angle bias collision test simulates the asymmetric collision situations that vehicles may encounter during actual driving. The experimental data shows that the SUV exhibits good crashworthiness in biased collisions at different angles and speeds. Especially in the design of the bumper, its durability is sufficient to cope with various collision scenarios, effectively protecting key components in the front of the vehicle.

7.4. Conclusion

By conducting a series of comprehensive structural crashworthiness tests on this SUV model, several noteworthy conclusions can be drawn.

Firstly, the SUV has shown remarkable crash resistance capabilities in a range of scenarios, including frontal, side, and multi-angle offset collisions. This is a testament to the meticulous design and engineering that has gone into its key structural components such as the front fascia, side panels, and bumper. These elements are able to effectively absorb and distribute impact energy, greatly reducing the risk of passenger injury in the event of a collision.

Furthermore, the SUV's performance in terms of energy absorption, specific energy absorption, and average collision force is commendable. These metrics, which are widely used in the automotive industry to assess a vehicle's crashworthiness, have all reached exceptional levels in this SUV. This not only speaks to the high quality of the vehicle's materials and construction but also reflects the manufacturer's commitment to safety.

This case study highlights the significant strides that automobile manufacturers are making in enhancing vehicle safety. It serves as a valuable example for other manufacturers, demonstrating the importance of rigorous testing and continuous innovation in ensuring the safety of their products. As automotive technology continues to evolve, it is anticipated that even more models with exceptional safety features will emerge, providing motorists with greater peace of mind and safer travel experiences.

In conclusion, the exceptional crash resistance demonstrated by this SUV model is a clear indication of the progress being made in automotive safety. It is a testament to the dedication and expertise of the manufacturer and a promising sign for the future of safer vehicles on our roads.

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