

# Optimization of Barriers Structure Design Based on LS-DYNA Collision Analysis

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**Abstract.** In order to get barriers whose safety performance and landscape design were suited for double-deck viaduct of a highway and conformed to standard specification, barriers structure needed to be optimized. LS-DYNA finite element program was used for simulation analysis, and structural comparison was carried out according to the redirective performance and buffering performance of different forms of concrete slopes, by analyzing the stress and deformation, relative position relationship and working width of the upper column and beam of barriers, the structural strength, height layout and horizontal layout were optimized, and the stress optimization was carried out according to the stress situation of the foundation bolts on the collision side. The analysis results show that the improved slope makes it easier for the vehicle to return to the normal operating posture and the acceleration index is lower. The reasonable arrangement of the horizontal position of the beam can optimize the working width of barriers. The design of the rib plate on the side of the column against the collision can significantly improve the problems of high stress level and large difference of the foundation bolts.

**Keywords:** Traffic and Transportation Engineering; Finite element; Barriers; Optimization analysis; Column; Crossbeam; Foundation bolt.

## 1. Introduction

The double-deck viaduct of a highway adopts the up and down line three-dimensional layout to construct the double-deck viaduct. The total length of the main bridge is about 2085 m, the total length of the upper bridge is about 1526 m, the total length of the lower layer is about 1281 m, the length of the double-deck parallel section is 960 m, and the remaining sections are left and right separated bridges. The upper structure of the double-deck viaduct is a prestressed concrete continuous box girder, the lower structure is a double-layer frame pier, and the rest are double-column piers. The unique structural design of the double-deck viaduct puts forward special requirements for its traffic safety protection facilities. If the safety performance of the anti-collision barriers, the last line of defense for highway safety, is insufficient, it is possible that the vehicle will pass through or over barriers and fall under the bridge, which will not only cause serious secondary accidents, but also damage the main structure of the bridge and cause huge losses.

Finite element collision analysis of display dynamics based on LS-DYNA has been proven to be instructive for the design of new type barriers [1-3]. Therefore, this paper uses LS-DYNA software to carry out finite element simulation calculation and analysis on the matched barriers structure set on the above bridge, and verifies it according to the national standard specification, and gives the optimized structure of barriers.

## 2. Concrete Slope Optimization Selection

The combined barriers is the barriers form adopted by the double-deck viaduct of the highway, which is composed of the upper metal beam column structure and the bottom concrete wall. Through the study, the bottom of the concrete structure retaining wall can adopt single slope type or improved (F type) slope, as shown in Fig.1.

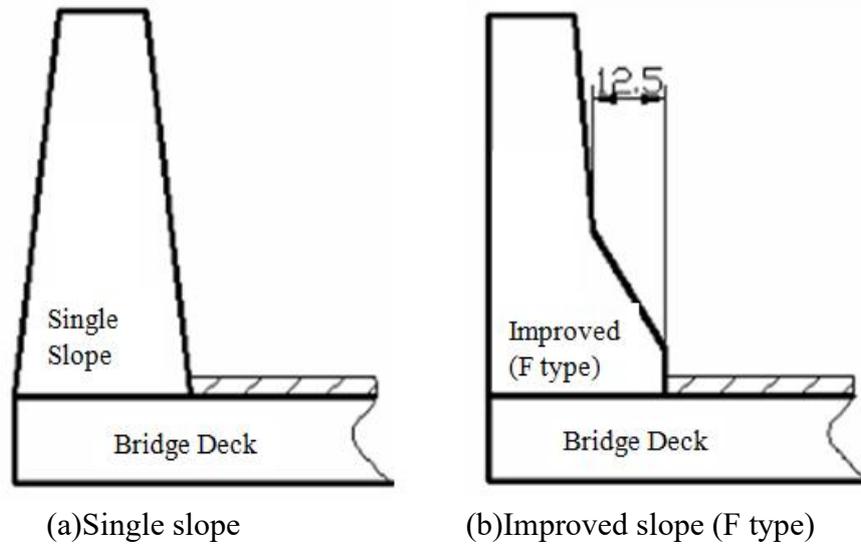


Fig. 1 Combined barriers bottom concrete slope form

Both of the above two slope forms have a certain buffering protection effect on accident vehicles, but further research is needed to determine the advantages and disadvantages of the buffering performance of the two slope forms. The LS-DYNA software is used to optimize the buffering performance of the two slope forms. Firstly, the finite element model of standard passenger car crashing single slope concrete barriers and improved slope concrete barriers is established. In the model, the total mass parameter of the passenger car is 1500 kg, the impact velocity parameter is 100 km/h, and the impact angle is 20°. On the basis of this model, the safety buffering performance of the two slope forms is compared and analyzed.

Table 1 shows the comparison table of the vehicle driving posture after the passenger car simulated collision with two barriers (different slope surface). It can be seen that the vehicle has a certain climb. After measurement and comparison, the climb height of the improved slope barriers is smaller than that of the single slope barriers, and the vehicle hits the improved slope barriers more easily to return to the normal running posture and trajectory.

Table 1. Comparison of Vehicle Attitude between Single-slope and Improved Slope Passenger Car Collision

Slope Form	Running posture of the colliding vehicle at each moment					
	Single slope					
	T=0s	T=0.1s	T=0.2s	T=0.3s	T=0.4s	T=0.5s
Improved slope						
	T=0s	T=0.1s	T=0.2s	T=0.3s	T=0.4s	T=0.5s

Table 2 shows the comparison of the maximum acceleration in three directions of the center of gravity position during the collision between the concrete barriers of the single slope and the improved slope by passenger car, including the length direction X, width direction Y and height Z of the car body. It can be seen that the maximum acceleration of the center of gravity generated by the improved slope concrete barriers is smaller than the maximum acceleration of the center of gravity generated by the single slope concrete barriers.

Table 2.Comparison of maximum acceleration of passenger car after collision with barriers of different slope forms.

Acceleration direction	Maximum acceleration of single slope (g)	Maximum acceleration of improved slope (g)	Comparison Results
X direction (vehicle length direction)	15.53	11.25	Improved slope acceleration is smaller
Y direction (vehicle width direction)	19.52	16.8	
Z direction (vehicle height direction)	6.37	6.0	

Note: g is the acceleration of gravity

Through the above finite element analysis, it can be seen that the improved slope has better redirective performance and buffering performance, can better restore the vehicle to the normal driving posture and trajectory, and can effectively reduce the damage degree of the impact to the occupant, so the slope type of the concrete base of the lower part of the double-deck viaduct combined barriers should adopt the improved slope (F type).

### 3. Steel Structure Column Optimization

Steel structure column is one of the main components of the combined barriers, its setting is reasonable or not directly affects the protective performance of the whole barriers, so the finite element simulation method is used to optimize the column structure to improve the overall safety performance of barriers.

Fig.2 shows the time history curve of the impact force of the beam calculated by the finite element model under the impact energy of 640 kJ. Assuming that two columns share the impact force at the same time, the static force model of a single column is set, and the optimized structure of the column is obtained through multiple iterative calculations (Fig.3).

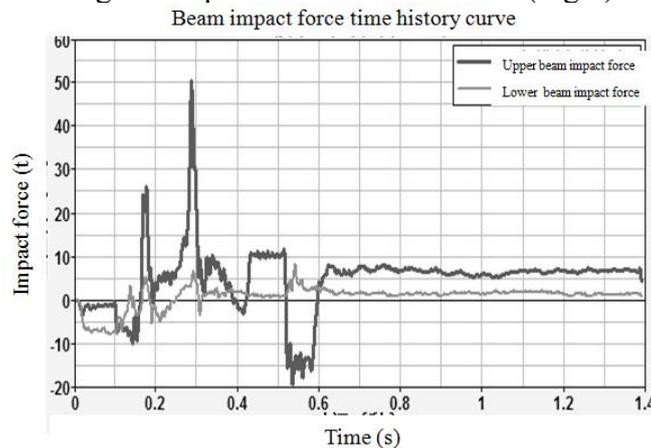


Fig. 2 Time History Curve of impact Force of the Beam at 640kJ Impact Energy.

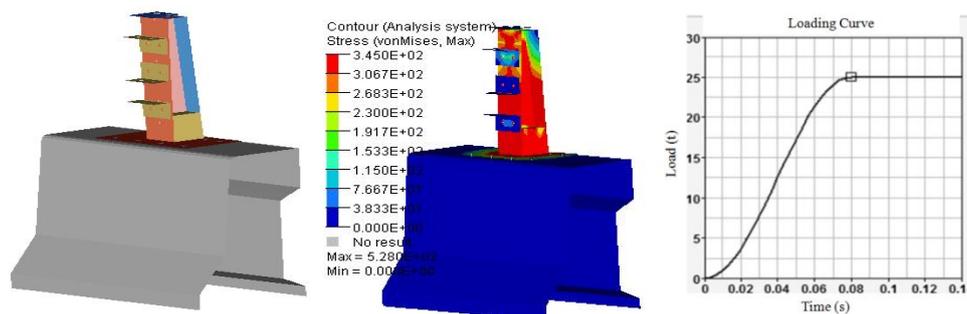


Fig. 3 Column Optimization

Fig.4 is the oblique H-shaped column structure after finite element simulation and optimization the material is Q345, the thickness of the wing, web and top plate are 12mm, the thickness of the bottom plate is 28mm, the column not only meets the structural strength requirements, but also facilitates the bracket connection between the beam.

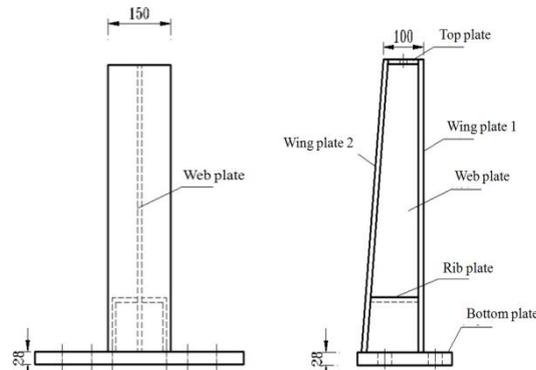


Fig. 4 Optimized Oblique H-shaped Column

#### 4. Beam Section Optimization

According to previous experience of the full-scale impact test with real vehicle, the farther the beam collision face from the column, the better the redirective performance of barriers. For the combined barriers, the distance between impact surface of the steel structure beam and the column is 160mm, which can effectively reduce the risk of vehicle tripping, so the cross-sectional size of the beam is 160 mm long  $\times$  100 mm wide, but the cross-sectional thickness of the beam needs to be determined through optimization research.

Fig.5 is the deformation diagram of barriers under the same beam thickness under different collision conditions. It can be seen that the deformation degree of the collision barriers of the large bus (the total mass of the vehicle is 25000kg, the impact velocity is 80km/h, and the impact angle is 20°) is small. This is because the rigidity of the large bus body is smaller than the rigidity of the truck, and the mass distribution is uniform. At the same time, because there is skin around the car body, good redirective performance, so the damage to the barriers is small; The deformation of the barriers when the truck collides with barriers is large, and the deformation of the barriers when the integral type truck (vehicle total mass 40000kg, impact velocity 60km/h, impact angle 20°) and saddle type truck (vehicle total mass 55000kg, impact velocity 60km/h, impact angle 20°) collides with is close, after analysis, this is because compared with the integral truck, the saddle truck is a hinged structure between the front and the cargo box, the vehicle collides with barriers is easier to drive away from barriers, at the same time, because the saddle type truck body is longer, and barriers collision time is longer than the integral type truck, therefore, although the impact energy of the saddle type truck is greater than the integral type truck, but the impact force and the damage to barriers is similar to the integral type truck.

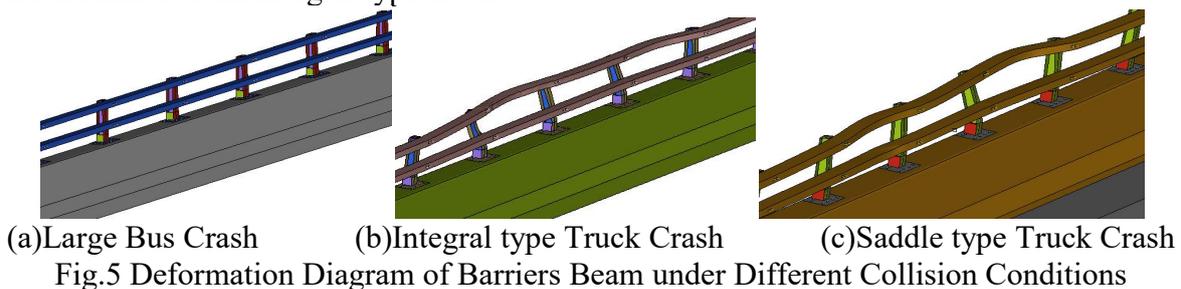
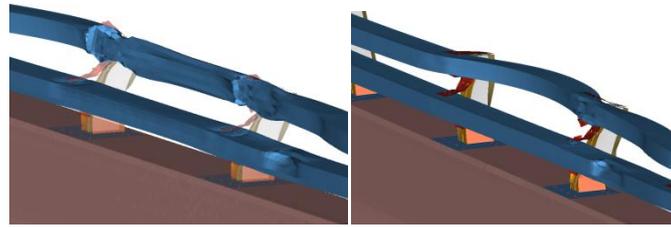


Fig.5 Deformation Diagram of Barriers Beam under Different Collision Conditions

Fig.6 shows the deformation simulation results of beams with different thicknesses under 640 kJ collision energy. It can be seen that the 8 mm thick rectangular tube beam has a large deformation

at the column connection and may be broken, so it is not suitable to use for the new anti-collision barriers. The thickness of 10mm rectangular tube beam deformation smooth, can be used in the new anti-collision barriers.



(a)8mm Thick Beam(b)10mmThick Beam  
 Fig.6 Beam Simulation Deformation Comparison

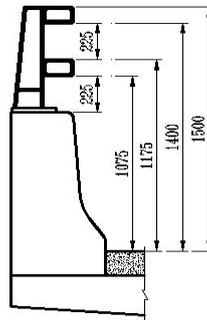
Through the above optimization analysis, the bridge combined barriers in the design can be made of Q345 cross-sectional size of 160 mm × 100 mm × 10 mm rectangular tube as the beam.

## 5. Beam Layout Optimization

The layout of the beam has a great impact on the overall landscape effect and safety protection performance of barriers, so optimization research is needed.

### 5.1 Vertical direction optimization

Aiming at the high anti-collision grade bridge barriers and the special protective bridge barriers passing through the pier set on the double-deck viaduct, the width of the upper and lower beams is adjusted to ensure the permeability and the landscape coordination. Fig.7 shows the vertical layout of the beam after adjustment.



(a)High anti-collision grade bridge barriers

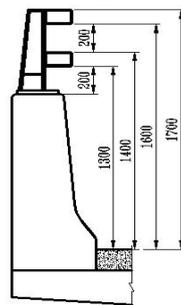


Fig.7 Vertical direction layout of beam (dimension unit: mm)

In order to reduce the safety risk of the head of the occupant in the out-of-control vehicle directly hitting barriers, the arrangement of the beam with height of less than 1290 mm should meet the requirements of 《Design Specifications for Highway Safety Facilities 》 JTG D81-2006 Figure 5.4.1-1 (Fig.8). The upper beams of the high anti-collision grade bridge barriers and the upper and lower beams of the special protective bridge barriers passing through the pier are greater than 1300 mm in height, and the head of the occupant will not collide with barriers; the lower beam of

the high anti-collision grade bridge barriers is located at the position of 1075mm to 1175mm, between 1040mm and 1290mm as specified in the specification, which meets the requirements of the specification and therefore ensures the safety of the occupants.

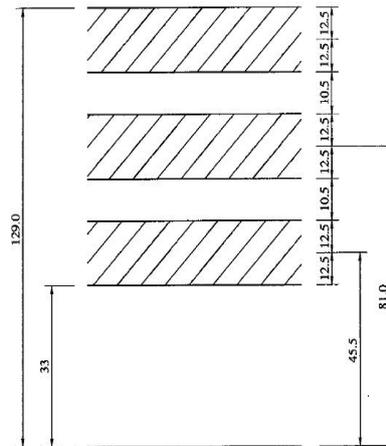


Fig.8 Vertical direction beam layout requirements of the specification (Dimension unit: mm)

## 5.2 Horizontal direction layout

The finite element simulation calculation shows that the horizontal arrangement of the beam has a significant effect on controlling the working width of barriers [6-9]. Fig.9 shows the comparison of the working width of combined barriers after the horizontal arrangement of the beam is changed.

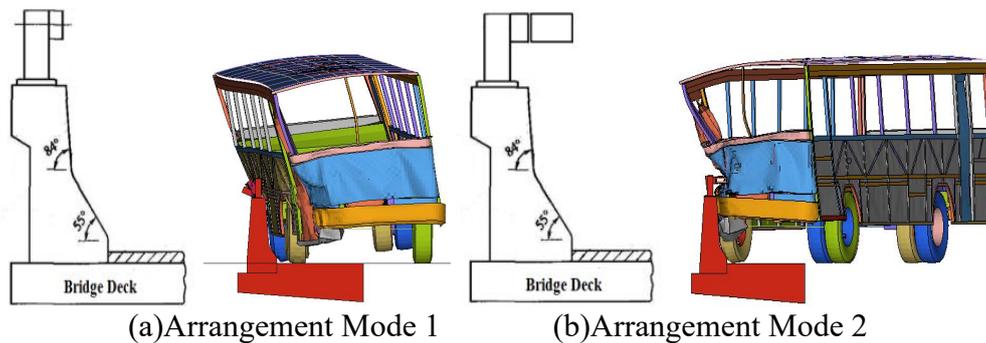
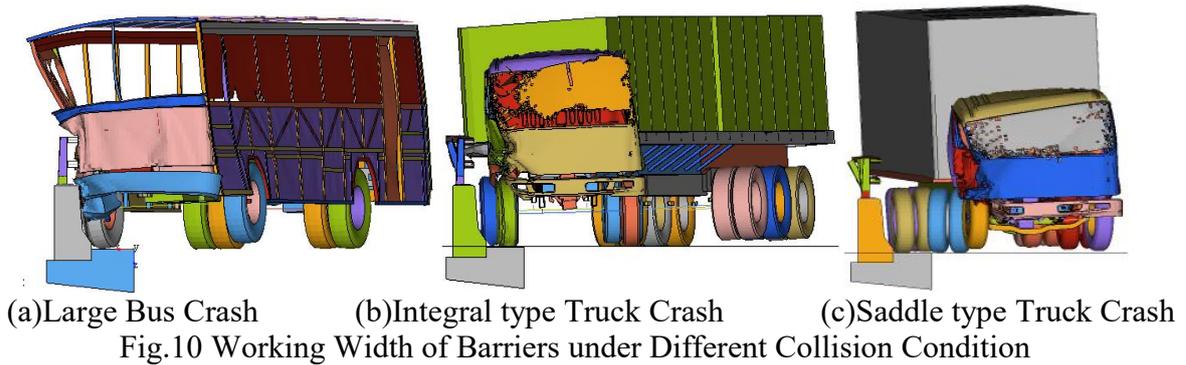


Fig.9 Comparison of Working Width of Barriers Arranged in Different Horizontal Direction of Beam

High anti-collision grade bridge barriers has no specific requirements for its working width, at the same time, because the height of the lower beam is less than 1290mm, the beam should not protrude from the bottom concrete collision surface (such as protrusion, it is not good for the head of the vehicle occupants), so ensure that the collision surface of the beam of the high anti-collision grade bridge barriers is flush with the innermost side of the bottom concrete collision surface.

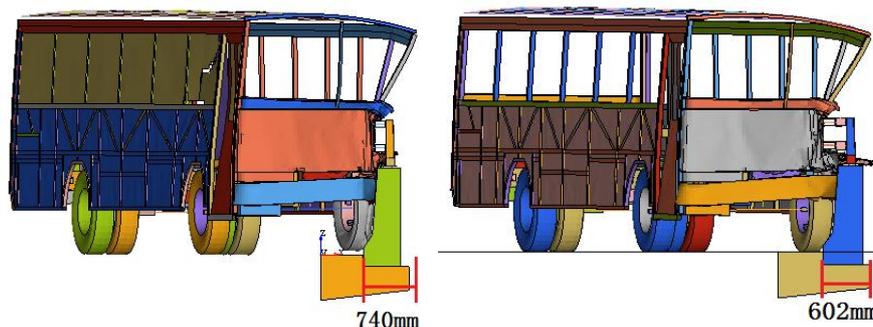
For the special protective bridge barriers passing through the pier, since the height of the beam is greater than 1300mm, its horizontal position can protrude the bottom concrete wall collision surface. However, due to barriers work width index is not more than 650mm high standard requirements (to avoid vehicle colliding pier bridge main structure is damaged), so the need for finite element simulation study to determine the horizontal arrangement of the beam to make barriers work width index to meet the requirements.

Fig.10 shows the working width of barriers under different collision conditions. It can be seen that the working width of the large bus is the largest, while the working width of the truck is smaller. Therefore, the optimization study of barriers structure based on the working width index can be carried out through the large bus collision.



In the finite element model of the large bus collides with the special protective bridge barriers passing through the pier, the horizontal distance between the beam and the column is increased by setting a pad between the beam and the column. Through multiple iterative calculations, the working width meets the requirement of not exceeding 650 mm.

Fig.11 shows the comparison of the simulation results of the beam and the column with and without the pad. It can be seen that by adding a pad with width of 140 mm (10 mm thick) between the beams, the working width of barriers can be optimized from 740 mm to 602 mm. At this time, the collision surface of the rectangular beam is flush with the collision surface of the concrete base.



(a) no pad between the beam and column      (b) A pad between the beam and column

Fig.11 The Working Width of Barriers Beam with or without Pad Is Compared

## 6. Structural Optimization Based on Bolt Checking

The concrete wall at the bottom of the combined bridge barriers is connected to the upper steel structure by foundation bolts, which are key components for the combined barriers to achieve stiffness matching and effective protection against accident vehicles, and therefore need to be optimized. Through the finite element simulation calculation analysis, in the process of the saddle truck collides with the special protective bridge barriers passing through the pier, the foundation bolts bear the maximum tension, so the foundation bolts are checked and optimized.

Fig.12 shows the axial force curve of foundation bolts during the collision of the saddle truck with the special protective bridge barriers passing through the pier. It can be seen that the maximum axial force of the two foundation bolts near the column is 700kN, and the maximum axial force of the two foundation bolts far away from the column is 150kN. The force of foundation bolts is not uniform, so it needs to be optimized.

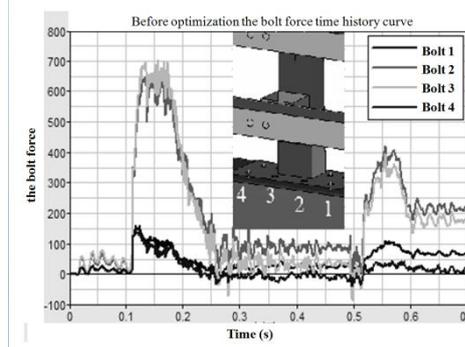


Fig.12 Before optimization the bolt force time history curve

Through the finite element simulation analysis, it can be seen that adding rib plates at the wing plate of the column near the collision surface can effectively enhance the uniformity of the bottom foundation bolts. Fig.13 shows the optimized bolts force time history curve. It can be seen that the maximum bolt force is reduced from 700kN to 500kN by adding rib plates.

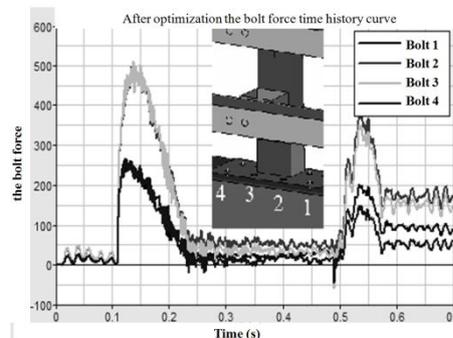


Fig.13 After optimization the bolt force time history curve

## 7. Conclusions

1) Improved slope concrete barriers compared to single slope concrete barriers has a better redirective performance and buffering performance, can better make the vehicle back to normal driving posture and trajectory, can effectively reduce the damage degree of the impact to the occupant.

2) The horizontal position of the beam significantly affects the working width of barriers when the vehicle collides, and the design optimization can be achieved by adjusting the horizontal layout position of the beam with special requirements for the working width of barriers, such as the position of the bridge pier.

3) Adding rib plates to the column near the collision surface can effectively enhance the uniformity of the foundation bolts force, reduce the maximum value of bolts force, and improve the reliability of the structural connection.

4) Barriers structure optimization, need to consider the impact of vehicle collision, climbing, steering, barriers force, deformation, coordination, landscape, as well as the protection of the occupants and other factors, is through the system coordination and optimization of each component structure of barriers to achieve.

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