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Technique Research on High Strength Low Alloy Structural Steel Used in Semi-Rigid Guardrail

Yu Haixia[1, a], Zhou Zhiwei[1,b] and Zhang Hongsong[1,c]

[1]Research Institute of Highway, Ministry of Transport, No.8 Xitucheng Rd, Beijing, China, 100088

[a]hx.yu@rioh.cn, [b]zw.zhou@rioh.cn, [c]hs.zhang@rioh.cn

Key words: High strength low alloy structural steel, semi-rigid guardrail, finite element simulation, reduce guardrail penetrating, decrease steel consumption

Abstract: The technical and economic feasibility of high strength low alloy structural steel is analyzed used in highway semi-rigid guardrail. In principle of improving safety performance and reducing cost, a kind of high strength low alloy structural steel guardrail is designed. Through the finite element simulation method, the safety performance of this guardrail structure is validated to satisfy the grade-A conditions (160kJ kinetic energy). Compared with the guardrail of same protection level made of ordinary carbon structural steel, high strength low alloy structural steel guardrail can reduce the probability of penetrating when the accident vehicle impact the guardrail and decrease the accident damage, the steel consumption is above 20% lower and the construction cost can be saved as well, thus, remarkable economic and social benefits can be obtained.

1 Introduction

Highway Guardrail includes semi-rigid guardrail, rigid guardrail and flexible guardrail. Most of the structure forms of semi-rigid guardrail are W-beam barrier, thrie-beam barrier or beam-post barrier in China, the barrier material is commonly Q235 carbon structural steel. Semi-rigid guardrail is convenient to product in factory, the construction technology is simple, therefore, it is widely used in highway and plays an important role in road traffic safety protection.

With the rapid development of economy, the highway traffic characteristics have changed speedily in recent years in China, the traffic flow, vehicle speed and heavy vehicle percentage are all increased obviously, which puts forward higher demands on road safety protection level. The safety performance of some semi-rigid guardrail structures in used are limit, which are not match to the increasing protection demands. The accident that vehicle impact the guardrail and run out of the road or run into the opposite direction lane occurred frequently, the subsequent result is many injuries and fatalities, large property damages and serious social influence. To improve the protection capability of semi-rigid guardrail, the steel consumption must correspondingly be increased. So, considering the influence factors of security, economy, environmental protection, and resource saving comprehensively is the trend of sustainable development for semi-rigid guardrail.

Compared with the Q235 carbon structural steel widely used in semi-rigid guardrail material, high strength low alloy structural steel has good comprehensive mechanical properties, especially high impact toughness, superior weld ability and strong corrosion resistant capability [1]. If the key application techniques of high strength low alloy steel used in semi-rigid guardrail could be solved, and the guardrail structure could satisfy the collision protection demand, then high strength low alloy structural steel can replace ordinary carbon structural steel as guardrail material, so as to obtain higher protection performance, improved road security level, less steel consumption and lower construction cost.

2 Technical feasibility analysis for high strength low alloy structural steel used in highway semi-rigid guardrail

Mechanical properties of the material play a decisive role on safety performance of guardrail [2]. Select Q345 high strength low alloy structural steel which is common internationally as the research object.Q345 steel has well comprehensive mechanical properties, low temperature impact toughness, good welding performance and so on, it is widely used in the structure of dynamic loading [3].

For analyzing the technical feasibility that Q345 steel replace Q235 steel as the guardrail material, the static tensile experiments are completed to obtain basic performance parameters of these two kinds of material, thus to analyze their strength and ductility. The impact dynamics experiments are completed with Hopkinson bar equipment to analyze their resistance.

2.1 Static experiments The function of Semi-rigid guardrail to protect accident vehicle is mainly manifested in two aspects, on is protection and guidance function, the other is cushioning function. Protection performance depends on the intensity of guardrail material and cushioning effect depends on the ductility of guardrail material, therefore, semi-rigid guardrail material should have appropriate intensity and ductility.

Make static tensile experiments of Q235 steel and Q345 steel with a universal testing machine and analyze their intensity and ductility. The size of test specimen is shown in Fig. 1.

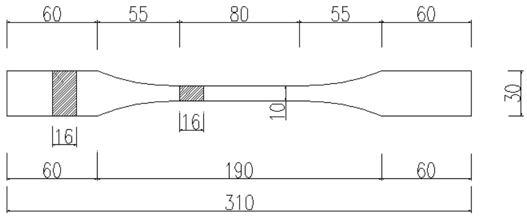


Fig. 1 Size of test specimen [mm]

The test results of static tensile experiments are shown in table 1.

Table 1 Test results of static tensile experiments

Material	Specimen number	Diameter	Tensile strength	Lower Yield strength	Elongation after fracture
		D/[mm]	R_m/[Mpa]	R_{eL}/[Mpa]	A/[%]
Q235 steel	1	5	393	237	26
	2	5	397	241	27
	3	5	402	239	27
	Average value	5	397.3	239	26.7
Q345 steel	4	5	514	346	24
	5	5	510	351	26
	6	5	513	353	25.2
	Average value	5	512.3	350	25.1

The experimental results show that the average elongation of Q235 steel is slightly higher than that of Q345 steel, both of the two materials have good ductility, but the intensity of Q235 steel is lower, the average tensile strength is 77.5% of that of Q345 steel, the average yield strength is 68.3% of that of Q345 steel. Applied to semi-rigid guardrail, the distinction of cushioning effect between the two materials is not obvious, but the capability of Q235 steel guardrail for protecting vehicle is markedly lower than that of the Q345 steel guardrail.

2.2 Impact dynamics experiments Metal material will appear strain hardening phenomenon under the action of impact load, deformation resistance ability of material will be enhanced [4]. In the collision processing of vehicle to the guardrail, the more strain hardening of guardrail material occurred, the higher ability to resist deformation obtained. Made impact dynamics experiments of Q235 steel and Q345 steel under three different impact speeds with Hopkinson bar equipment, the total counts of dynamic impact experiments is 18 times, analyze the ability to resist deformation of the two kinds of material under impact load.

The defining impact speed in Specification for Design of highway safety facilities (JTG D81-2006) consists of three kinds of speed: 60 km/h, 80 km/h and 100 km/h, converting to speed 16.7 m/s, respectively, 22.2 m/s, 27.8 m/s correspondingly. Selecting three kinds of impact loading speed as experiment speed, consists of slow speed (v_1 = 12 m/s), medium speed (v_2 = 20 m/s) and high speed (v_3 = 28 m/s), which cover the test collision speed range defined in specification mentioned above. The stress-strain curve of Q235 steel and Q345 steel under the impact load are shown respectively in Fig. 2 and the Fig. 3.

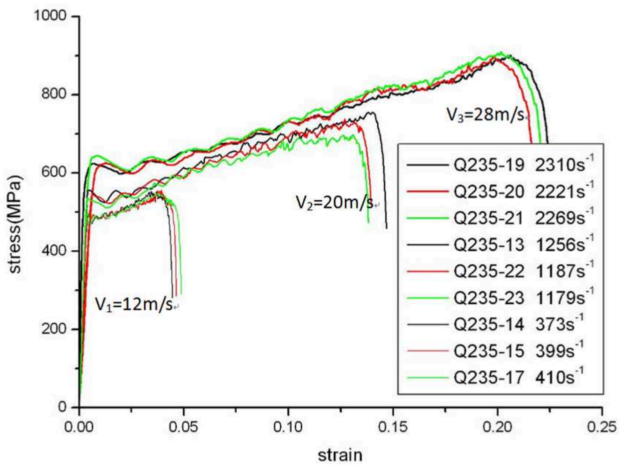


Fig. 2 Stress-strain curve of Q235 steel

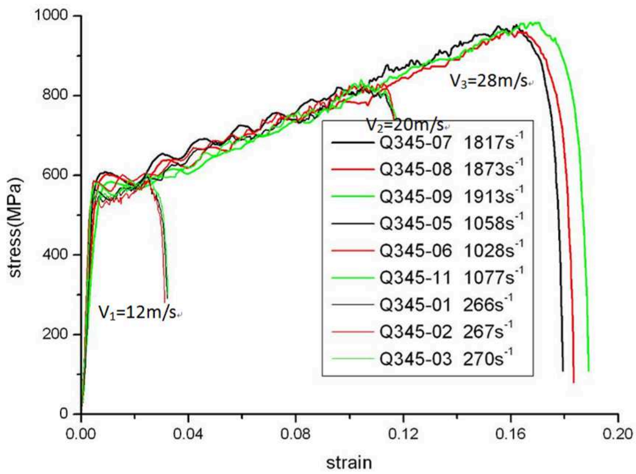


Fig. 3 Stress-strain curve of Q345 steel

The test results comparison between Q235 steel and Q345 steel are shown in table 2.

Table 2 Test results comparison between Q235 steel and Q345 steel

Material	Intensity (average) / [Mpa]	Static experiments	Impact dynamics experiments		
			v_1=12m/s	v_2=20m/s	v_3=28m/s
Q235 steel	Yield strength	239	480	550	630
	Tensile strength	397.3	530	700	880
Q345 steel	Yield strength	350	540	580	600
	Tensile strength	512.3	590	800	970

The experimental results show that the yield strength and tensile strength of the two materials are all increased obviously under impact dynamics experiments compared with the condition under static experiments. With the increase of impact loading speed, the yield strength and tensile strength of Q235 steel both grown, but for Q345 steel, there are some differences. The yield strength growth of Q345 steel is slightly, but the tensile strength growth of that is significantly. The tensile strength results of Q345 steel are all higher than that of Q235 steel obtained under three kinds of impact speed. That means the higher speed when vehicle impact guardrail, the more performance superiority for Q345 steel to prevent vehicle from penetrating guardrail compared with Q235 steel.

Above all, it is technologically feasible for using then high strength low alloy structural steel with superior material properties instead of ordinary carbon structural steel to be guardrail material, it can improve the structure intensity of guardrail, reduce the probability of penetrating when the accident vehicle impact the guardrail.

3 Design of high strength low alloy structural steel guardrail

In order to compare with the existing guardrail structure expediently, the design of high strength low alloy structural steel guardrail retains the common post-beam structure. Considering the convenience of processing and construction, make the wave beam rail, pipe posts and hexagonal block to be the main components of new guardrail, and the structure will be optimized on size and material.

Select a kind of Q235 steel thrie- beam guardrail as a reference structure, which was validated to satisfy grade A (160kJ kinetic energy) [5]. The constructed contents of Q235 steel thrie-beam guardrail structure include:

(1) 3-mm thick thrie-beam rail made of Q235 steel.

(2) 4.5-mm thick pipe post made of Q235 steel, the diameter of post is 114 mm ,the distance of adjacent post is 2m and the depth of post under the ground is 1100mm.

(3) 4.5-mm thick hexagonal block made of Q235 steel with length of 400mm [6].

Design a new thrie-beam guardrail structure made of Q345 steel, the constructed contents of it include:

(1) 2.5-mm thick thrie-beam rail made of Q345 steel.

(2) 4.5-mm thick pipe post made of Q235 steel, the diameter of post is 140 mm ,the distance of adjacent posts is 4m and the depth of post under the ground is 1100mm.

(3) 4-mm thick hexagonal block made of Q345 steel with length of 400mm.

The new design make Q345 steel as material of thrie-beam rail and block and reduce the material thickness. For beam and block, the change of material thickness can be realized easily just by adjusting the existing mould space during new guardrail processing. But for the post, because of different processing craft, it will spend large cost to build a new mould to realize the change of material thickness. Considering this factor, the design of thickness and material for post did not changed. The diameter and distance of adjacent posts is increased.

The two guardrail structures are shown in Fig. 4 and Fig. 5.

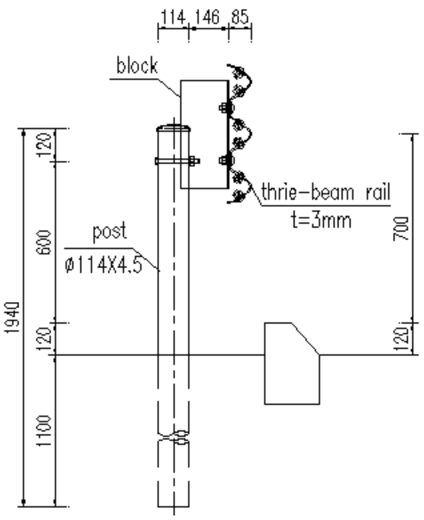


Fig. 4 Thrie-beam guardrail made of Q235 steel

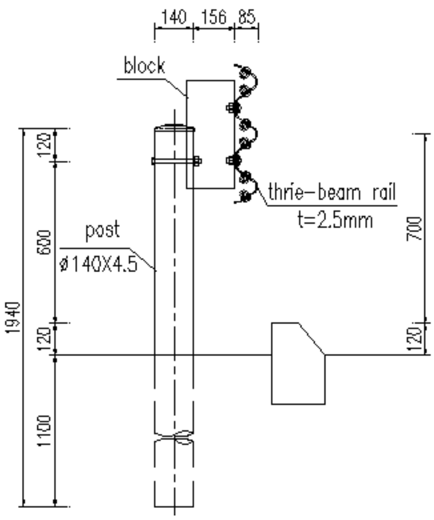


Fig. 5 Thrie-beam guardrail made of Q345 steel

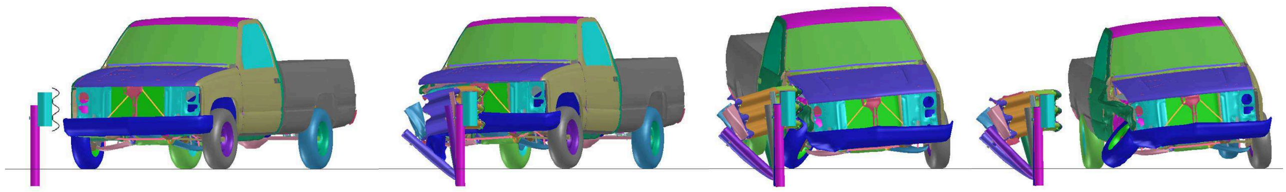
4 Safety performance verification

The finite element simulation method is adopt to verify the safety performance of thrie-beam guardrail made of Q345 steel, the collision test conditions of grade-A is shown in table 3.

Table 3 Collision test conditions of grade-A

Vehicle Type	Vehicle Mass [t]	Impact Speed [km/h]	Impact Angle [°]	Kinetic Energy [kJ]
Car	1.5	100	20	-
Bus or truck	10	60	20	160

4.1 Collision test with car The vehicle trajectory of the car during impacting is shown in Fig. 6.



a) Initial time b) Head impact c) End impact d) Run off

Fig. 6 Vehicle trajectory of the car during impacting

Simulation results show that the thrie-beam guardrail made of Q345 steel has a good performance of protection and redirection. The test car doesn't penetrate, under-ride, or over-ride the test guardrail and remains normal driving posture. The maximum of occupant ride-down acceleration is 12.16g, the exit angle is 11.6°and the maximum of dynamic deflection is about 580mm. The guardrail deformation and stress nephogram crashed by car is shown in Fig. 7.

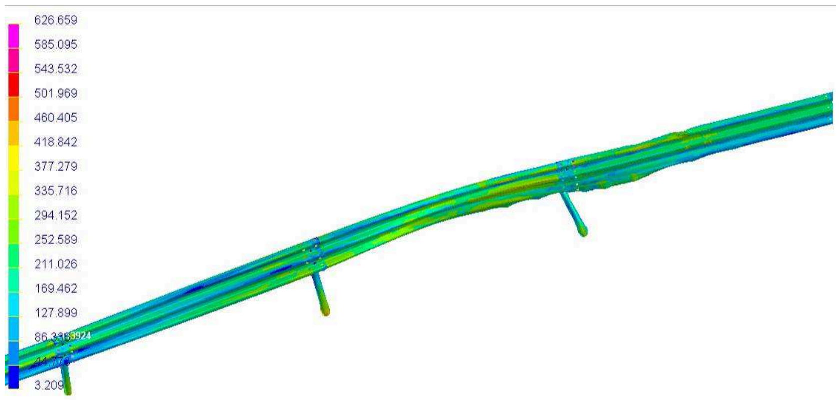
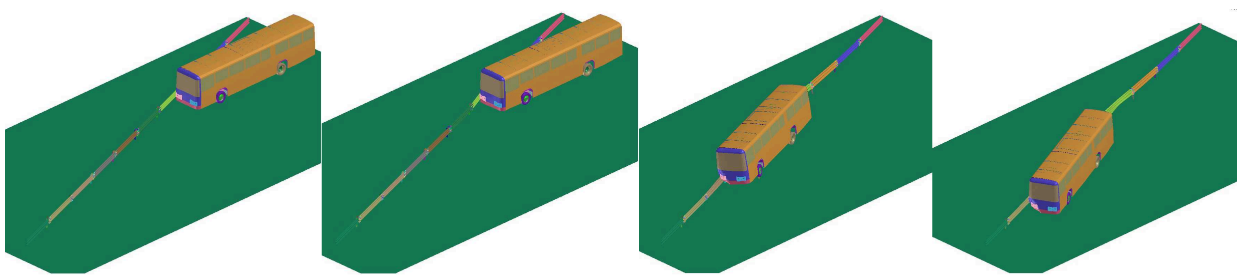


Fig. 7 Deformation and stress nephogram of guardrail crashed by car

4.2 Collision test with bus The vehicle trajectory of the bus during impacting is shown in Fig. 8.



a) Initial time b) Head impact c) End impact d) Run off

Fig. 8 Vehicle trajectory of the bus during impacting

Simulation results show that the test bus doesn't penetrate, under-ride, or over-ride the test guardrail and remains normal driving posture. The exit angle is 5.3°and the maximum of dynamic deflection is about 870mm. The guardrail deformation and stress nephogram crashed by bus is shown in Fig. 9.

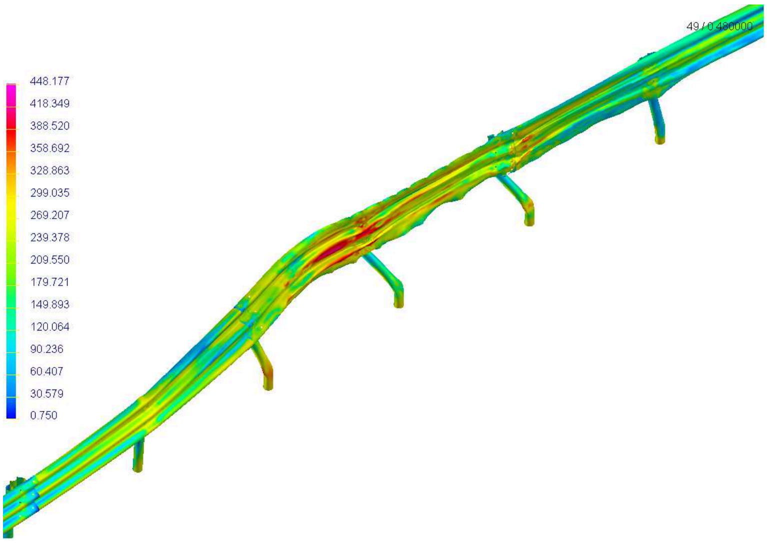


Fig. 9 Deformation and stress nephogram of guardrail crashed by bus

4.3 Simulation results analysis Simulation test results indicate that the thrie-beam guardrail made of Q345 steel can satisfy the protection demand of grade-A, all the evaluation index results meet the criteria limits of Evaluation Specification for Highway Safety Barriers (JTG/T F83-01-2004).

The comparison of simulation test results between thrie-beam guardrail made of Q345 steel and Q235 steel is shown in table 4.

Table 4 Comparison of simulation test results

		Q345 steel thrie-beam guardrail	Q235 steel thrie-beam guardrail
Kinetic Energy [kJ]		160	160
Car	Vehicle trajectory	normal	normal
	Maximum ride-down acceleration [g]	12.16	14.3
	Exit angle [º]	11.6	11.2
	Maximum dynamic deflection [mm]	580	592
Bus	Vehicle trajectory	normal	normal
	Exit angle [º]	5.3	7.4
	Maximum dynamic deflection [mm]	970	892

The maximum of occupant ride-down acceleration show that thrie-beam guardrail made of Q345 steel has an advantage of protecting occupant and reducing injuries. The deformation resistance capability of Q345 steel guardrail with 4m-distance post is similar to that of Q235 steel guardrail with 2m-distance post.

5 Economic analysis

The production process of high strength low alloy structural steel is similar to carbon structural steel, therefore, the price of the two materials is similar as well. The market price of Q345 steel is about CNY6400 /ton and the market price of Q235 steel is about CNY6000 /ton. The economic contrast of Q345 steel thrie-beam guardrail and Q235 steel thrie-beam guardrail is shown in table 5.

Table 5 Economic contrast of the two guardrails

	Q345 steel thrie-beam guardrail	Q235 steel thrie-beam guardrail
Q235 steel consumption [kg/m]	34.8	8.2
Q345 steel consumption [kg/m]	0	17.2
The total steel consumption [kg]	34.8	25.4
Cost of guardrail [CNY/m]	208.8	159.28

The economic contrast results show that, in condition of same kinetic energy, the Q345 steel thrie-beam guardrail can reduce steel consumption about 27.01% and decrease cost about 23.72% compared to Q235 steel thrie-beam guardrail.

6 Conclusion

Through static tensile experiments and impact dynamics experiments, the technical feasibility of high strength low alloy structural steel is analyzed used in highway semi-rigid guardrail. In principle of improving safety performance and reducing cost, a kind of thrie-beam guardrail made of Q345 steel is designed. Through the finite element simulation method, the safety performance of this guardrail structure is validated to satisfy the grade-A conditions (160kJ kinetic energy), which is defined in Specification for Design of highway safety facilities (JTG D81-2006). Compared with the guardrail of same protection level made of ordinary carbon structural steel, high strength low alloy structural steel guardrail can reduce the probability of penetrating when the accident vehicle impact the guardrail and decrease the accident damage, the steel consumption is above 20% lower and the construction cost can be saved as well, thus, remarkable economic and social benefits can be obtained.

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