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Influences of Rehabilitation Material Parameter on Existing RC Parapets

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ABSTRACT

The durability of existing reinforced concrete parapets degrades because of severe environment influences recently. For example, the protection layer drops and the rebar rusts, which is widespread. At the same time, it also caused the degradation of the anti-collision performance of bridge parapets. Ultra high performance cementitious composites (UHPCC) are applied in the rehabilitation and reinforcement of existing reinforced concrete parapets to obtain the comprehensive rehabilitation including the durability and the anti-collision performance. The influence of the UHPCC rehabilitation layer on the anti-collision performance of bridge parapets was analyzed in this paper based on the nonlinear finite element method. And it was verified by experimental data from other literature. The analysis results revealed the influence of the internal factors (such as the thickness of UHPCC rehabilitation layer and the fiber volume fraction of UHPCC) on anti-collision performance (such as the maximum dynamic deformation and the peak impact load of parapets). The research work may provide a scientific reference for the comprehensive rehabilitation of bridge parapets based on UHPCC.

Key words: Parapets, Rehabilitation, UHPCC, Impact load, Deformation

1. INTRODUCTION

As one of the major forms of the anti-collision guardrails in city bridges and highway bridges, the parapet should meet the aesthetic requirements and the anti-collision design level. The protection layer on bridge parapets drops and the rebar rusts because of the insufficient durability, which is outstanding recently. And the durability and the anti-collision performance of parapets degrade. Comprehensive rehabilitation including these performances for the existing parapets is of significance in the engineering field.

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UHPCC is a new generation of high-performance cementitious composites (Dugat1996), and its mechanics performances and durability are excellent. Strengthening and rehabilitation of existing concrete structures is one of the important engineering applications for UHPCC. For example, in the bridge deck(Brühwiler 2008), prestressed concrete members(Habel 2009), the rehabilitation of the pavement(Schmidt 2008),the composite beams and the composite slabs (Bastien2014), and the rehabilitation of reinforced concrete members(Prem 2015), etc.

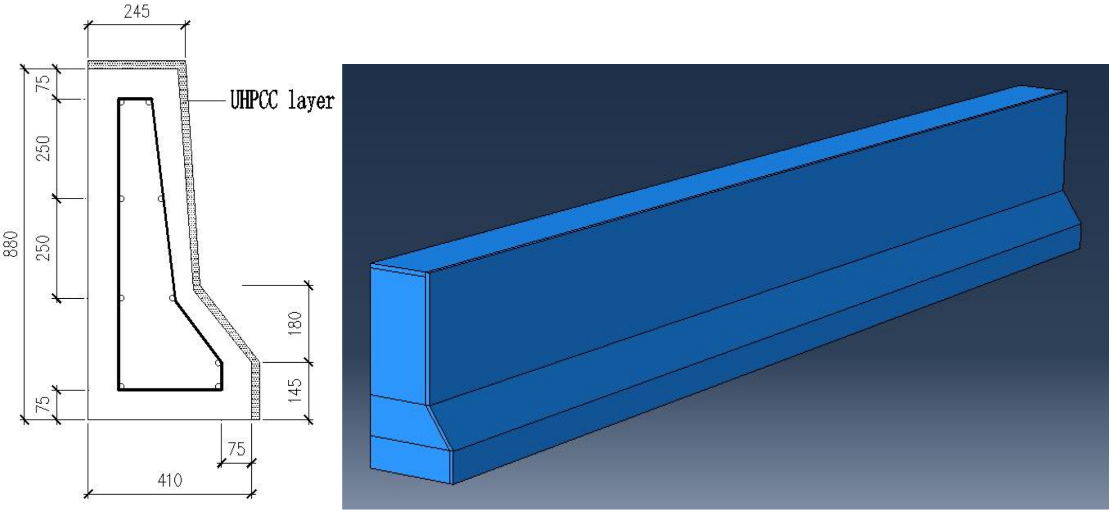
The durability is rehabilitated and the load-carrying capacity is strengthened by UHPCC in existing structures. The composite structure including the UHPCC rehabilitation layer and existing structure members makes the rehabilitation of UHPCC become the comprehensive rehabilitation which contains the rehabilitation of the durability and the load-carrying capacity. For the past few years, some research work were carried out on the composite structural performance of UHPCC and normal concrete(Wu 2014; Wu 2012; Wu 2013; Bruhwiler 2013; Oesterlee 2007;Moreillon 2013;Brühwiler2013).Brühwiler(2013) studied flexural and shear behavior of UHPCC-RC composite beams, and applied it to the engineering rehabilitation of bridge pavement and bridge parapets. In addition, the mechanical properties of the bridge reinforced concrete parapets with a UHPCC overlay were studied (Charron 2011; Duchesneau 2011). However, the research on rehabilitation of existing bridge parapets based on UHPCC is relatively few.

The effect of UHPCC rehabilitation on the anti-collision performance of parapets was studied to provide the basis for the comprehensive rehabilitation of parapets based on UHPCC. This paper adopted the nonlinear finite element model established in previous research work and the model was verified by the composite slab impact test of Habel and Gauvreau (Habel 2009). According to the analysis results, this paper revealed the influence of the internal factors (such as the thickness of UHPCC rehabilitation layer and the corrosion rate of rebars) on anti-collision performance including the maximum dynamic deformation and the peak impact load of parapets. The research work may provide a scientific reference for the comprehensive rehabilitation of bridge parapets based on UHPCC.

2. FINITE ELEMENT MODELING OF VEHICLE-PARAPETS

2.1 The parapet model

New Jersey parapets (NJ type)(National Standard of the P.R.C.1994) were adopted in this paper. The section size and finite element model of the parapet rehabilitated by UHPCC were shown in Figure 1. The parapet generally sets a temperature seam along the longitudinal direction every 6m. The lower surface of the parapet and the corresponding upper surface of the bridge deck were connected by the "Tie" way, and a rigid connection was applied to the bottom surface of the bridge deck.



a) Section size b) Finite element model

Fig.1 Sectional dimensions and FEM model

2.2 Material model

In this paper, concrete constitutive model of the parapet was chosen from the Chinese national standard "code for design of concrete structures" (GB50010-2010) (National Standard of the P.R.C. 2010).The standard compressive strength was 33 Mpa and the tensile strength was 3.3 Mpa.The Poisson’s ratio was 0.2.

The main force steel bars of the parapet were vertical steel bars and longitudinal bars when the collision occurred.HRB335 grade hot rolled steel bars were adopted in this paper. The standard value of the steel yield strength was 335Mpa, and the section area of stirrups and longitudinal bars are 70.85mm^2 and 200.96mm^2, respectively. The stirrups spacing is 150mm.

In the numerical analysis, UHPCC adopted the ideal elastic-plastic model (Benjamin 2006), which omitted its strain hardening range, as shown in Figure 2.

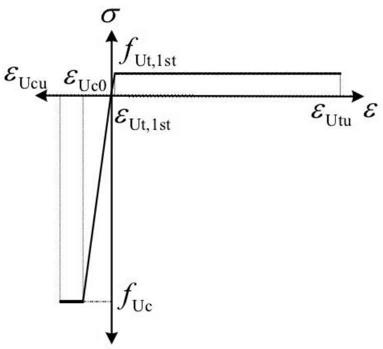


Fig.2 Uniaxial stress-strain relationship of UHPCC

The material parameters were based on the test results of Yang (Yang 2006), as shown in Table 1.

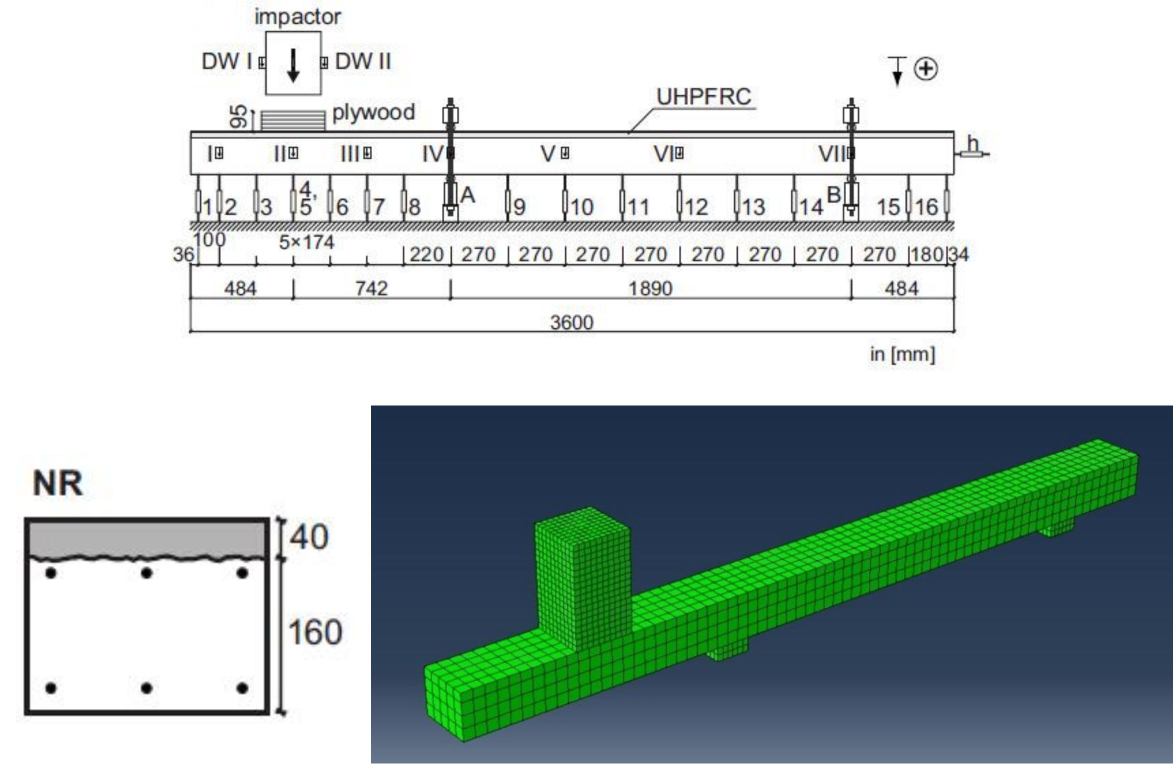
Table 1 Material parameters

Fiber volume fraction (%)	Mass density (kg/m^3)	Poisson's ratio	Compressive strength(MPa)	Tensile strength (MPa)	Modulus of elasticity (GPa)
0	2465	0.18	88	3	50
1	2465	0.18	110	6	50
2	2465	0.18	140	9	50

2.3 Model verification

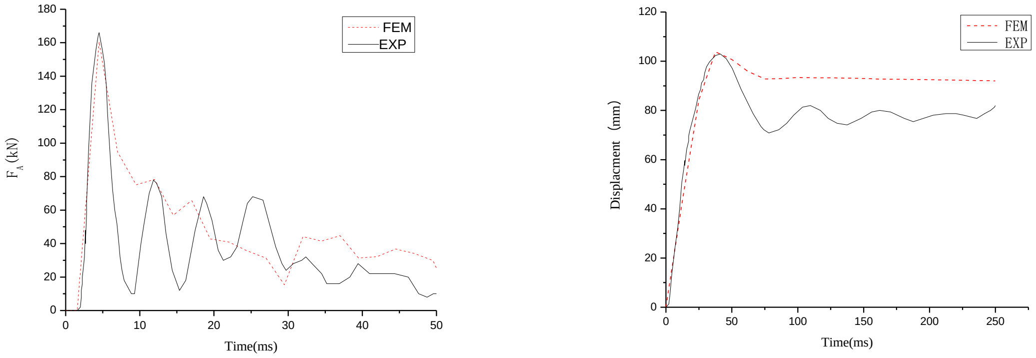
In this paper, according to Habel(2009) the impact test of reinforced concrete composite slab with a UHPFRC overlay, reinforced concrete cantilever slab based on UHPFRC was the modeling verification object. The structural geometry and load characteristic of the parapet rehabilitated by UHPFRC was similar to it. Therefore, it is chosen as the basis of the experimental verification. In the previous research, the finite element model was verified by Habel test. The results of the Habel test and the verification were briefly introduced.

The size of the specimen was 250mm × 200mm ×3600mm.The geometry size, the detail of the reinforcement and the finite element model were shown in Figure 3. The reinforcing bars cross section is 100 mm^2. Coupon tests indicated the yield strength of 470 MPa with a well-defined yield plateau and an ultimate strength of 750 MPa. The compressive strength, tested on three cylinders (diameter 100 mm), was 128 MPa at 28 days and131 MPa at the age of testing of the composite slab strips(100 days). The uniaxial tensile strength was 11 MPa at a deformation of 0.15% at 28 days. The concrete was a conventional concrete provided by a local ready-mix supplier. It had a compressive strength of 33 MPa after 28 days and 37 MPa at the time of testing of the composite slab strips (250 days).



a) Dimensions and reinforcement b) Finite element model

Fig.3 Geometric dimensions, reinforcement and model of the slab strip



a) Test values and simulation values of the impact load b) Test values and simulation values of the displacement

Fig.4 Comparison of experimental values and simulation values

The impact load test values were compared with the simulated values as shown in Figure 4. The results showed that rise and fall of the impact load test values were smoother, impact time of the test was longer than that of the simulation, but overall, simulation values are in good agreement with the test values. According to Figure 4 a), the greatest impact load test value and simulation value at the support F_A of test specimen was close, respectively is 160.5kN and 166kN ,and the impact load shock wave and the peak of numerical simulation were relatively close.

According to Figure 4 b), the peak value of displacement simulation and the experimental result of composite slab subjected to impact are in good agreement. But the simulation results after the peak value was relatively smoother. It differed greatly from the experimental results. The reasons of the difference between the test value and the simulation value were as follows:

(1)The influence of the secondary impact on the displacement was not considered in the numerical simulation, so the fluctuation and the shock phenomenon of the test results were not reflected..

(2)Drop hammer was supposed to be rigid with certain approximation. In numerical simulation, in order to simplify the calculation and shorten the calculation time, drop hammer was seen as a rigid body. And drop hammer was deformed from the test results. We can see the obvious tremor by high speed camera. It can be presumed, drop hammer itself consumed some energy in the impact process.

2.4 Vehicle model

This paper adopted the vehicle model called cars (Tai 2010).The structure size of the car is 3.6m length, 1.4m wide, 1.5m high, and the vehicle mass is 1.5t. The vehicle total mass is controlled by material density. In the modeling analysis, the vehicle model was considered as the rigid body, and the simplified model of the vehicle was shown in Figure 5.

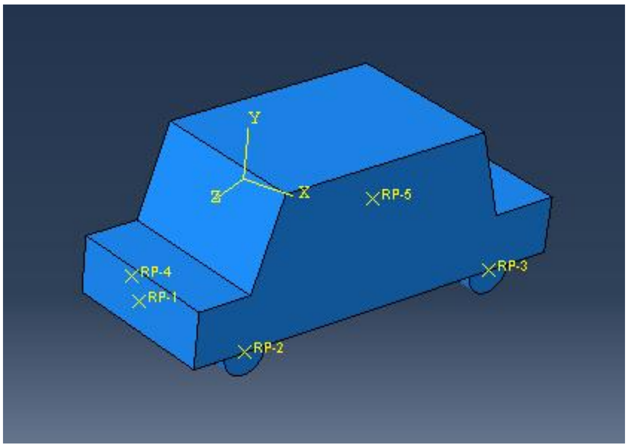


Fig.5 Finite element model of the vehicle

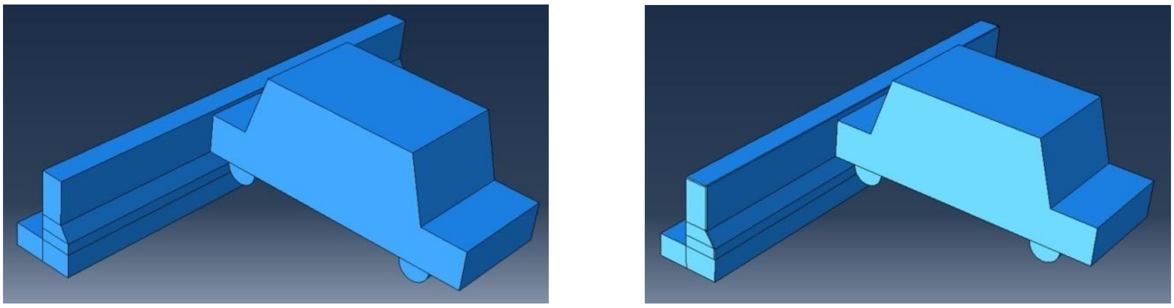
3. Influence factors consideration

Through the vertical collision simulation process between the vehicle and the parapet, the effects of the parameters(such as the thickness of UHPCC rehabilitation layer and fiber volume fraction)on the anti-collision performance of the parapet were considered, as shown in Figure 6.The thickness of UHPCC rehabilitation layer was respectively 20 mm, 30mm, respectively. The fiber volume fraction was 0%, 1%, 2%, respectively. The test specimen information were shown in Table 2.

Table 2 Test specimen names and influence considerations

Name	Thickness of the rehabilitation layer(mm)	Fiber volume fraction(%)
UT20-0	20	0
UT30-0	30	0
UT20-1	20	1
UT30-1	30	1
UT20-2	20	2
UT30-2	30	2

The rules of test specimen number in Table 2 were as follows: "UT" represented the thickness of UHPCC rehabilitation layer, subsequent number 0, 20, 30, meant that the thickness of UHPCC rehabilitation layer was 0 mm (the parapet was not rehabilitated), 20 mm, 30 mm, respectively.



a) Original parapet b) The parapet rehabilitated by UHPCC

Fig. 6 Finite element model of vertical impact process

4. RESULTS ANALYSIS

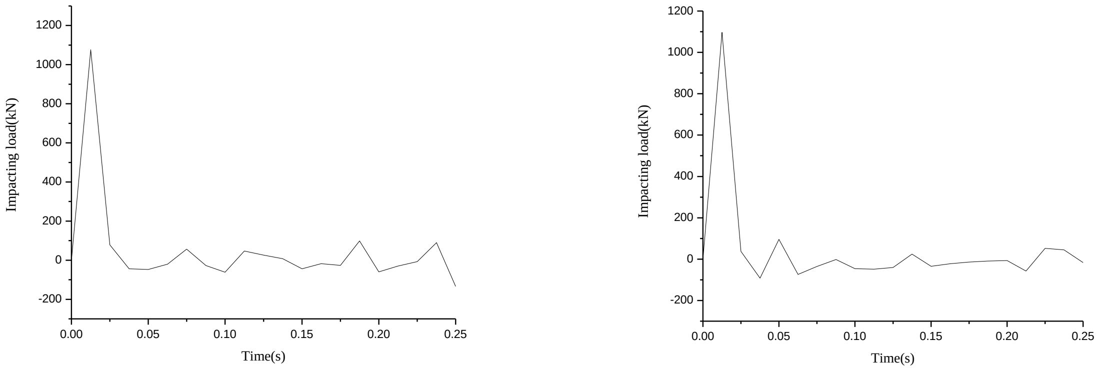
4.1 Influence of UHPCC rehabilitation layer thickness

The analysis results showed that when the corrosion rate of the steel bar was 25%, the anti-collision performance can't meet the requirement of Chinese national standard (National Standard of the P.R.C. (2004)). UHPCC was used to rehabilitate parapets which achieved the threshold value of steel bar corrosion rate. Through the vehicle collision, we can get peak impact load and the maximum dynamic deformation of parapets of different UHPCC rehabilitation layer thickness. The numerical results were shown in Table 3.

Table 3 Numerical results of NC parapets for different UHPCC thickness

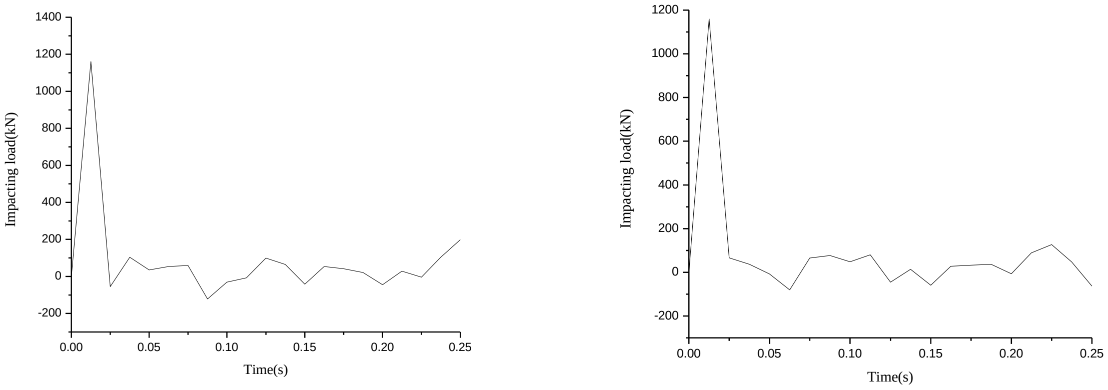
Name	Fiber volume fraction (%)	UT (mm)	Impact load(kN)	Deformation(mm)
T0	0	0	1076	100.4
T20-0		20	1097	74.01
T30-0		30	1160	66.2
T0	1	0	1076	100.4
T20-1		20	1159	64.4
T30-1		30	1215	55.3
T0	2	0	1076	100.4
T20-2		20	1209	57.04
T30-2		30	1244	48.56

According to the above simulation results, the impact load versus time curve and the displacement versus time curve for different UHPCC rehabilitation layer thickness were obtained, and as shown in Figure 7 and 8.



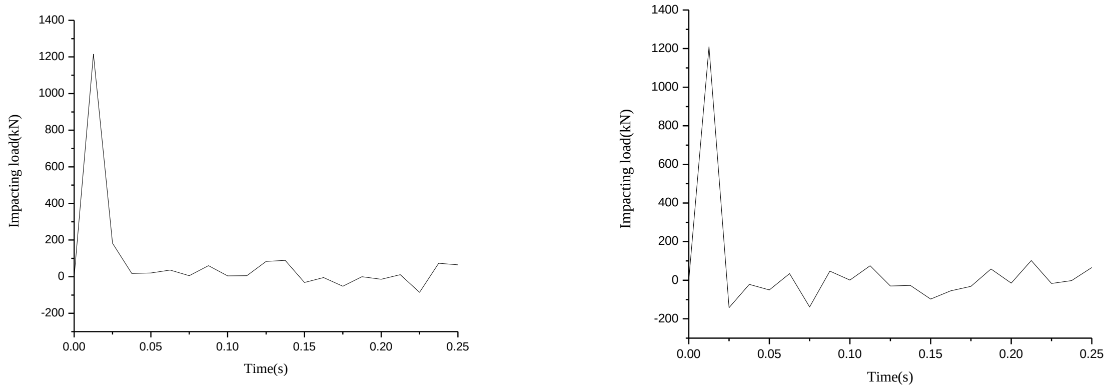
a) T0

b) T20-0



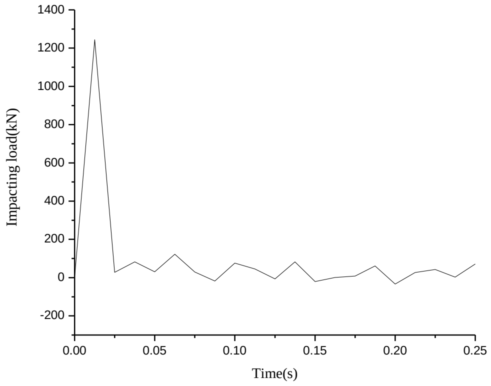
c) T30-0

d) T20-1



e) T30-1

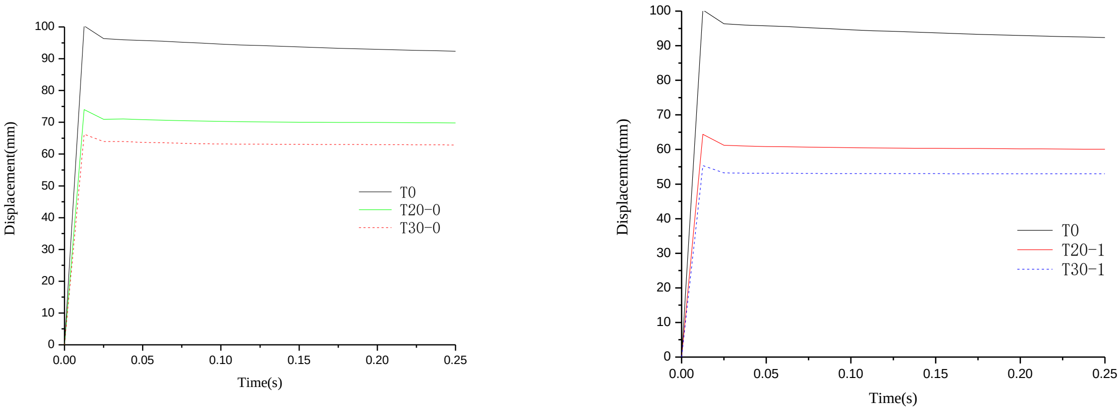
f) T20-2



g) T30-2

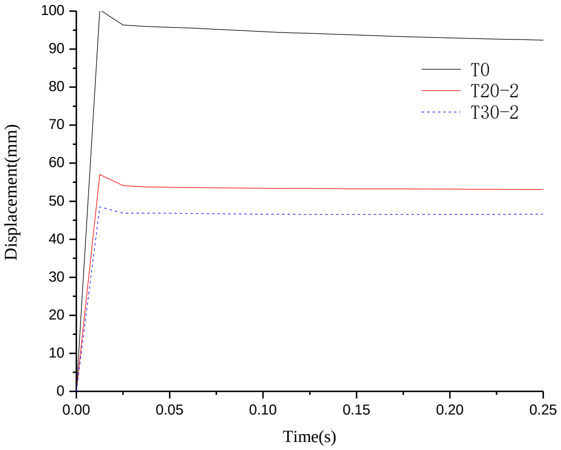
Fig.7 Impact load-time curve for different models

According to Figure 7, when the fiber volume fraction of UHPCC was 0%,1%,2%, with the increase of UHPCC rehabilitation layer thickness, the impact load increased gradually. But the growth rate is smaller. When the fiber volume fraction was 0%, the parapets of 20mm, 30mm thickness of UHPCC rehabilitation layer were compared to original parapets that were not rehabilitated by UHPCC and the impact load increased by 1.95%, 7.8%, respectively; when the fiber volume fraction was 1%, the parapets that used 20mm, 30mm UHPCC rehabilitation layer thickness under the vehicle impact were compared to the above normal parapets, the impact load increased by 7.7%, 12.9%, respectively; when the fiber volume fraction was 2%, the impact load increased by 12.36%, 15.6%, respectively.



a) V_f 0%

b) V_f 1%



c) V_f 2%

Fig.8 Comparison of displacement-time curve for different influence considerations

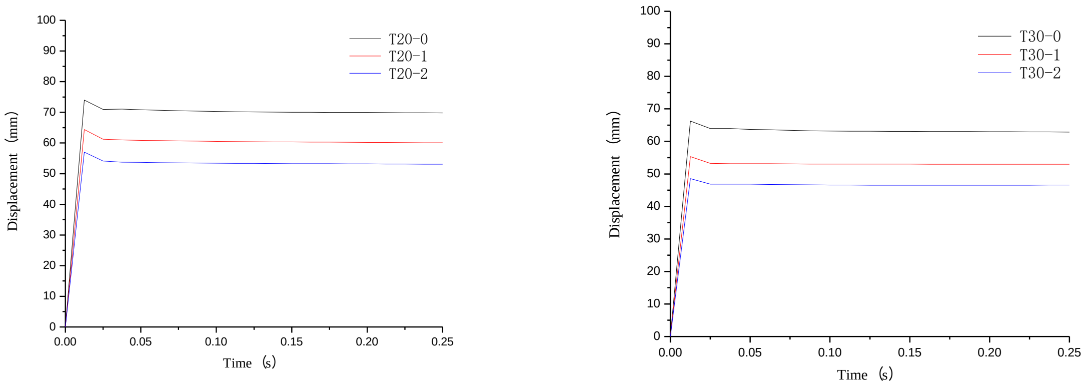
According to Figure 8, with the increase of UHPCC rehabilitation layer thickness, the maximum dynamic deformation of the vehicle impact on the parapet decreased gradually. When the fiber volume fraction was 0%, the parapets of 20mm, 30mm thickness of UHPCC rehabilitation layer under the vehicle impact were compared to original parapets that reached the threshold value of the rebars corrosion rate, and the maximum dynamic deformation decreased by 26.2%, 34%, respectively; when the fiber volume fraction was 1%, the parapets that used 20mm, 30mm UHPCC rehabilitation layer thickness under the vehicle impact were compared to original parapets that reached the threshold value of the rebars corrosion rate, the maximum dynamic deformation decreased by 35.8%, 44.9%, respectively; when the fiber volume fraction was 2%, the parapet that used 20mm, 30mm UHPCC rehabilitation layer thickness under the vehicle impact were compared to the above original parapets, the maximum dynamic deformation decreased by 43.2%, 51.6%, respectively.

4.2 Influence of UHPCC fiber volume fraction

For different fiber volume fraction, the peak impact load and the maximum dynamic deformation of the parapets rehabilitated by UHPCC precast element were shown in Table 4.

Table 4 Numerical results of NC parapets rehabilitated by UHPCC for different fiber volume fraction

Name	UT（mm）	Fiber volume fraction（%）	Impact load（kN）	Deformation（mm）
T20-0	20	0	1097	74.01
T20-1		1	1159	64.4
T20-2		2	1209	57.04
T30-0	30	0	1160	66.2
T30-1		1	1215	55.3
T30-2		2	1244	48.56



a) T20　　　　　　　　b) T30

Fig. 9 Comparison of displacement-time curves for different influence considerations

The numerical results of the peak impact load were compared to show that when the thickness of the UHPCC rehabilitation layer was certain, the peak impact load of parapets increased gradually with the increase of fiber volume fraction. And the maximum dynamic deformation increased obviously. When the thickness of the UHPCC rehabilitation layer was 20mm, the maximum dynamic deformation of parapets rehabilitated by UHPCC of 0%, 1%, 2% fiber volume fraction decreased by 26.3%, 35.9%, 43.2%, respectively; When the thickness of the UHPCC rehabilitation layer was 30mm, the maximum dynamic deformation of parapets rehabilitated by UHPCC of 0%, 1%, 2% fiber volume fraction decreased by 34.1%, 44.9%, 51.6%, respectively.

5. CONCLUSION

Through the vehicle-parapets vertical impact process, with the increase of UHPCC rehabilitation layer thickness, the peak impact load of rehabilitated parapets increased gradually, but the growth rate was smaller. At the same time, the maximum dynamic deformation of rehabilitated parapets decreased obviously.

The peak impact load of parapets increased gradually when UHPCC fiber volume fraction increased, and the maximum dynamic deformation decreased obviously. The analysis results of the peak impact load and the maximum dynamic deformation of the impact position showed that the anti-collision performance were obtained well in the degraded parapets rehabilitated by UHPCC.

Overall, the UHPCC prefabricate element had certain stiffness because of high strength and high modulus of elasticity, and the anti-collision performance of the original parapets was improved.

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