Using MIDAS software to analyze the reinforced concrete beam reinforcement with pasted carbon fiber reinforced polymers

Luo Yan

Southwest Jiaotong University Hope College, Chengdu 610000, China

977694165@qq.com

Abstract

Carbon fiber reinforced polymers(CFRPs) are excellent materials that possess useful properties. Based on existing research and bridge reinforcement using pasted CFRPs, combined with analysis and reinforcement of Long Tan bridge of the Lanzhou- Chengdu-Chongqing pipeline after an earthquake and application of the bridge structure finite element software MIDAS, this paper develops a finite element model that simulates the reinforcement and design of the bridge with pasted CFRPs, and proposes a reinforcement and design scheme. A finite element analysis model is established using MIDAS/CIVIL software to simulate reinforcement using pasted CFRPs, and the reinforcement design and plan with pasted CFRPs is carried out. This provides useful experience for the research and design of similar reinforcements of old bridges in the future.

Keywords

Bridge reinforcement,Carbon fiber reinforced polymer,Ultimate flexural capacity,Finite element method.

1. Introduction

Since the 1980s, China has entered a period of rapid development and has constructed many types of bridges. The total number of highway bridges currently exceeds 570 000, and China has the second highest number of bridges in the world, after the United States of America. Currently, due to aging, improvements in the loading of structural members, corrosion, floods, earthquakes and other reasons, a large proportion of bridges in China have developed structural damage and thus have reductions in their bearing capacities. Only by analysis, maintenance and reinforcement of the bridges, will they be able to continuously adapt to new loads and provide traffic capacity[1]. The bridges, which were designed and built to old standards, are only designed to carry low loads and have narrow deck widths. With the passage of time and the vigorous developments in transportation, the tasks of maintenance and management of bridges have become increasingly arduous. The technologies of bridge analysis, evaluation, repair, reinforcement, maintenance and management are thus of significant importance. In recent years, reinforcement of bridges has received increasingly urgent attention worldwide, and the focus on construction of bridges has shifted from construction of new bridges to the reinforcement and reconstruction of old bridges.

Depending upon the structure, condition and environment of the old bridges, there are many different options for bridge reinforcement methods. These include using the reinforced reinforcement method, the external pre-stress reinforcement method or the bonded steel plate reinforcement method[2]. There are nine main reinforcement methods currently adopted: adding bridge reinforcement layers, enlarging sections, changing the structural stress system, anchor spraying cement concrete, adding components, adding assistance beams and adding bonded carbon fiber reinforced polymers (CFRPs).

The reinforcement design of an old unsafe bridge should adopt a systemic and repeated method in order to select the reinforcement design with the best possible improvements in the economy, effect, duration and appearance. Owing to their good physical, chemical and engineering application properties, CFRPs have great application potential in all reinforcement methods[3].

2. Earthquake Damage Performance of Long Tan Bridge

The Long Tan bridge is located in the near the Yangba town, Kang county, Gansu Province, China and completed in 2000. It is a reinforced concrete simple T-beam bridge of 3×20meter, bridge width of 8.5 meter, continuous deck and total length of bridge of 75 meter. Beam height of T-beam is 1.3 meter high and single span is 5 spans. The substructure is reinforced concrete double column pier, expanding type pier foundation and gravity type U station. Design load is truck-load 20, trailer 100. The bridge is in the VII basic seismic intensity, which point to the Guangping and Yangba respectively. Bridge graph is shown in Fig.1 and horizontal layout of bridge deck is shown in Fig. 2.

Because the Long Tan bridge was suffered from serious damage in the "5.12" WenChuan earthquake, it was detected and evaluated immediately after the earthquake. Detection work mainly includes: ultrasonic-rebound method detecting concrete strength, crack detection, geometry measurement of all parts of bridge, damage of components and joint position [4].

The comprehensive conclusion of detection and evaluation is bridge span structure beam cracking and crack development by seismic action and having an adverse effects on the bearing capacity of bridge [5]; According to analysis and calculation, actual ultimate flexural capacity of beam of 2033KN.m is lower than ultimate flexural capacity of 2240KN.m required under the action of the original design load truck-load 20, trailer 100. So the bridge has been unable to meet the capacity requirement of original design.

Fig. 1 Long Tan bridge

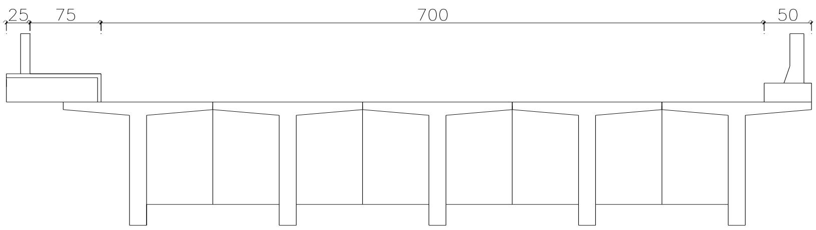

Fig. 2 The cross-section sizing and shaping of bridge (cm)

3. Reinforcement estimation using pasted CFRPs

3.1 Bridge load standard

The bridge was designed and constructed in the year 2000. The original bridge design load of truck-load 20 and trailer 100 was abolished. The load standard is equivalent to the highway-II of "General Code for Design of Highway Bridges and Culverts" (JTG D60-2004)[6]. The bridge corresponds to a standard load of q_k = 7.875 kN/m, p_k = 240 kN/m

3.2 Basic design and calculation parameters

The original geometric parameters of the bridge beam were a rib width of the T-beam of b=180 mm and a section height of the T-beam of h=1300 mm. The cross-section of the T-beam is shown in Fig. 3.

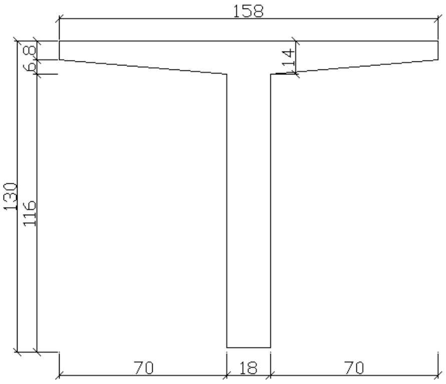

Fig. 3 Geometric size of the Long Tan bridge T-beam (cm)

3.3 Original design material parameters

The tensile reinforcement was 8 roots and the diameter was 32 mm, the design value of the tensile strength was fsd = 280.00 N/mm2, the area of tensile reinforcement was As = 6432 mm2, the resultant force point of the tensile reinforcement to the distance of the close to edge section was as = 114 mm, the area of compression reinforcement was 0.00 mm2, and the resultant force point of the compression reinforcement to the distance of the close to edge section was as' = 40.00 mm.

The strength grade of the concrete was C30, the design value of the axial compressive strength was fcd = 13.8 N/mm2, the standard value of the axial tensile strength was ftk = 2.01 N/mm2, and the design value of the axial tensile strength was ftd = 13.9 N/mm2. The T-beam cross-section of the model is given in Fig. 4[7].

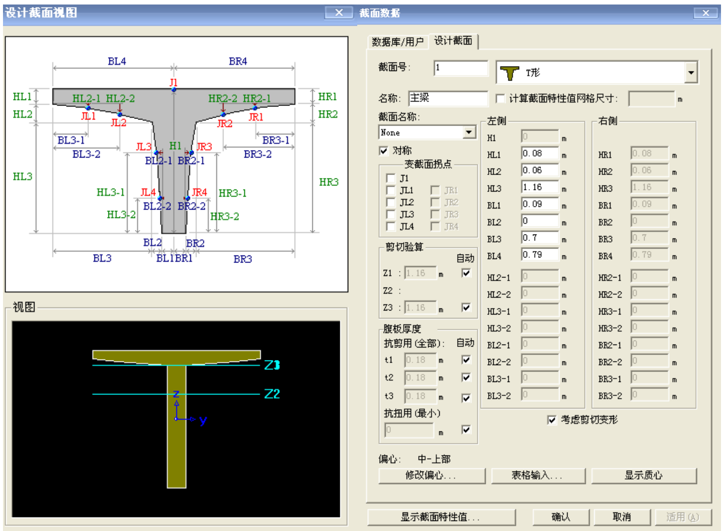

Fig. 4 T-beam cross-section of the model

3.4 Carbon fiber materials and special pasting glue

The mechanical properties of the UT70-30 type CFRPs produced by the Japanese carbon fiber manufacturing company (Dongli) were as per the calculation reference values [11]. The design thickness was 0.167 mm and the elastic modulus Ecf ≥ 2.01×105 MPa. According to the T-beam bottom web with pasting of two layers of CFRPs, the ultimate tensile strength was ff ≥ 3000.00 MPa [8].

3.5 Estimation of reinforced area with pasted CFRPs

The cross-sectional area of the CFRPs at the bottom of the beam was AS = 60.12 mm2. Considering the second-order bending moment, the practical initial moment of the section of calculation was M1 =852 kN.m before reinforcement, which was caused by dead loads of the bridge span structure itself before reinforcement. Under the action of the initial moment before reinforcement, the initial strain of the concrete cross-section tensile edge was ε1 = 0.0002. Considering the second-order bending moment, a concrete strength of no more than C50 and εcu = 0.00033, the ultimate strain of the CFRPs at the bottom of the beam was εf = 0.047, and the height of the compression zone was x =68 mm, $x \leq 2as'$ = 80 mm. Because the ultimate flexural capacity of M = 2413 kN.m was larger than the M = 2240 kN.m required after reinforcement, the estimation meets the initial design requirement [9].

4. Finite element simulation and calculation analysis of Long Tan bridge flexural strengthening with pasted CFRPs

MIDAS is a finite element analysis software in three-dimensional space [10]. By the three-dimensional modeling analysis cannot it calculate transverse distribution coefficient as the two-dimensional program, modeling and post-processing more visual. By adding various kinds of nonlinear factors in the finite element library and combining with structural analysis theory of the construction stage, the time dependency and nonlinear of set, can it be able to calculate accurate and practical analysis results. MIDAS is the same as other finite element analysis software, and mainly contains three basic modules: the preprocessing mode, the solver and the post-processing mode. The input of the modeling process is completed in the preprocessing mode. The viewing and arrangement of analysis results of load combination, reaction, displacement, component internal force and stress are completed in the post-processing mode. The post-processing mode provides two forms of graphics and text to analyze and calculate the results [11].

The CFRP finite element simulations of this paper adopted plane stress elements. The mechanical parameters of the CFRPs, such as thickness, width, elastic modulus, shear modulus, tensile strength and Poisson's ratio, can be randomly set up in the "Material" and "Element modeling" options [12].

This paper selected a four-node unit to simulate. The degrees of freedom of the unit were based on the unit rectangular coordinates, and each node only had the degree of freedom of the line displacement in the X, Y directions.

4.1 T-beam modeling

The bridge was modeled as a simply supported bridge system and adopted the T-grillage method to construct the analysis model of the main girder of the single span of the whole bridge. The fundamental method was to replace the upper structure of the bridge with an equivalent beam grillage and focus the flexural rigidity and torsional rigidity dispersed in each section of the T-beam on the nearest equivalent beam grillage. The longitudinal and lateral rigidity of the actual structure focused on the longitudinal and lateral beam grillage, respectively. The equivalent principle of ideal rigidity is that when the actual prototype structure and corresponding equivalent beam grillage bear the same load, both deflections are equal, and the moment, shear and torque of each beam grillage is equal to the corresponding internal force of the actual structure represented by the beam grillage. Because of the differences in the structural characteristics between the actual structure and the beam grillage system, the equivalence was approximate, but in terms of the general design, the calculation accuracy of the grillage method was adequate [13]. The T-grillage method model of the main beam of a single span of the whole bridge can be seen in Fig. 5.

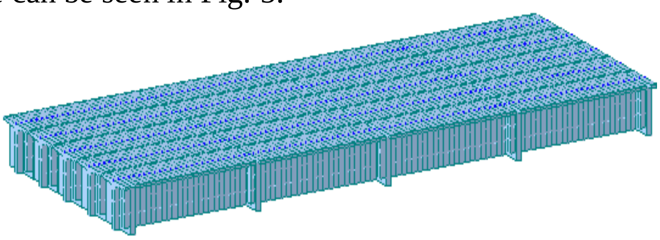

Fig. 5 MIDAS model of the Long Tan bridge single-span main beam

4.2 Simulation of carbon fibers

The CFRPs that were pasted at the bottom of the T-beam were simulated by a plane stress element and the material property parameters of the CFRPs, which were used in the design of the reinforcement as input by the user-defined material and section function [14]. The bond between the

CFRPs and the main girder reinforced concrete was simulated by setting the boundary conditions of the nodes. Selecting the rigid connection mode in the elastic connection options, the connecting node of the CFRP element unit and the T-beam in the corresponding position achieved coordination of the deformation and displacement and prevented bonding failure and sliding failure, see Fig. 6.

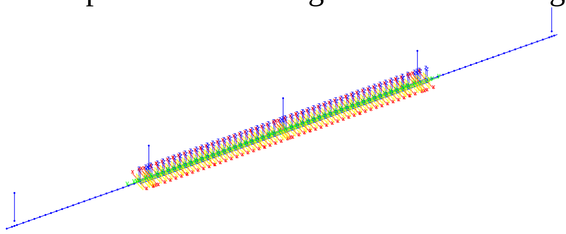

Fig. 6. Connections of carbon fiber unit node and the main beam node

4.3 Analysis of model calculation results

Before the completion of the structural boundary conditions, static load, moving load and definition of construction stage, the completion of the software preprocessing mode phase is end[15]. The next step was to calculate and enter the post-processing stage to view the analysis results. The main inspection was whether the girder deflection, cross-sectional moment, flexural capacity of the normal section, cross-section stress and girder crack meet the requirements.

1. Structural reaction: the maximum reaction of the support was 517.2 kN/m.

2. Deflection checking calculation.

The maximum deflection appeared in the mid-span, which was 0.020 m in length and met the code requirement (≤ l/600). The beam deflection output results are given in Table 1.

Table 1 Maximum deflection

Node	Load	DX (m)	DZ (m)	RY (rad)
2	cLCB2(Max.)	0.00000	0.00000	0.00683
52	cLCB2(Max.)	-0.00127	-0.01980	0.00045
53	cLCB2(Max.)	-0.00129	-0.01981	0.00037
54	cLCB2(Max.)	-0.00130	-0.01981	0.00029
55	cLCB2(Max.)	-0.00135	-0.01978	0.00010
102	cLCB2(Max.)	-0.00261	0.00000	-0.00312

From Table 1, the minimum deflection value appeared at the end of the fulcrum section, which was 0, and the maximum deflection value appeared in the mid-span section, which was 1.98 cm. Flexural capacity checking calculation of normal section[16].

Under the action of the highway-II load, the maximum and minimum moments of the main girder section are given in Fig.7. The maximum moment of the mid-span section was 2286.3 kN.m.

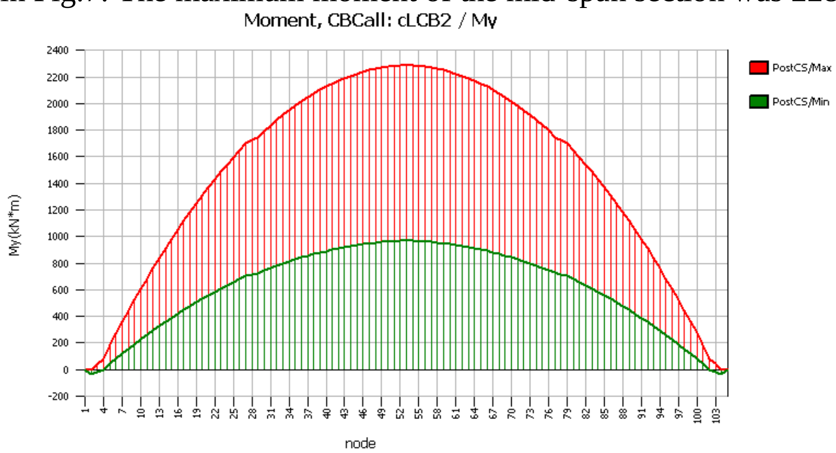

Fig. 7 Main girder section moments under loading

After the Long Tan Bridge was reinforced with pasted CFRPs, the maximum moment value was 2285.8 kN.m under the action of the highway-II equivalent load, and the corresponding section flexural capacity value was 2464.5 kN.m, which meets the design requirements and is improved by 21.2%.

4.4 Stress checking calculation

The maximum stress of the main girder section can be seen in Fig. 8 under loading. The value meets the material allowable stress requirements.

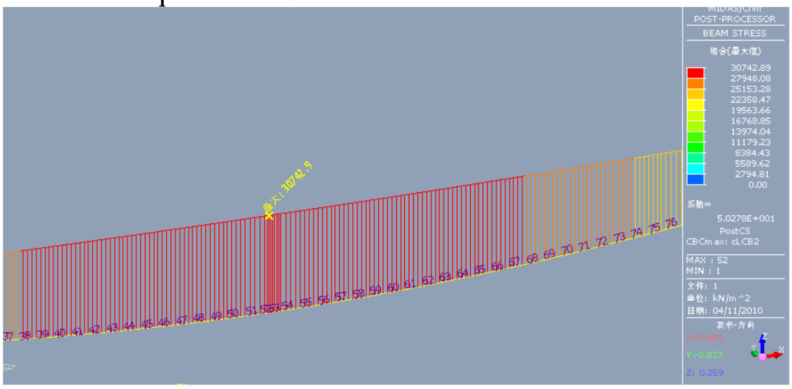

Fig. 8 Maximum stress values of the main girder section under loading

5. Reinforced design scheme of the whole bridge

Two layers of CFRP were pasted at the bottom of the T-beam and folded up 20 cm along the two sides of the web. As the flexural capacity of the beam still met the requirements from the beam end to 1/4 span, there was no need for reinforcement [17]. The range pasted could be selected as 1/5 to 4/5 span.

In view of the deficiency of the shear capacity of the bridge, the bridge was reinforced using a U-shaped hoop method in the beam web with pasted CFRPs. That is, the horizontal pasting layer was on the middle and upper of both sides of the web to achieve the reinforcement effect of a U-type hoop. The CFRP U-type hoop adopted a single-layer distribution of width 20 cm. As the maximum shear effect appeared in the beam end to 1/4 span, the clearance of the U-type hoop was 20 cm. However, the clearance of the U-type hoop was 60 cm from the 1/4 span to the 3/4 span. The width of the CFRP was 10 cm.

Structural cracks were disposed by restoring the material of the concrete structure crack. The beam cracks must be disposed before reinforcement with pasted CFRPs [18]. The treatment measures included the following. When the crack width was less than 0.15 mm, the close method was chosen, where a modified epoxy clay mortar properly sealed cracks and prevented leakage and steel corrosion. When the crack width was greater than 0.15 mm, the automatic low-pressure infiltration injection method was chosen, which continuously injected mending clay into the crack at a constant low pressure.

The honeycomb and pitted surface of the local concrete was directly chiseled, the corroded steels were derusted and sprayed with a rust retardant agent, and then an epoxy mortar with micro expansion was used for repair of the concrete surface.

After the bridge pier crack sealing treatment, a layer of carbon fiber plate of density 1500 g/m2 was pasted into the crack. The diaphragm of the joint fracture was chiseled to an appropriate size of rectangle hole and concrete was poured after installation of the reinforcement on the side. The sinking and spalling abutment cone slope was removed and according to the original design drawings, the bridge was reconstructed after the compaction treatment of the bottom of the slope [19]. The deformation and swell rubber strips were replaced in the expansion joints.

6. Conclusion

Based on existing research and bridge reinforcement using pasted CFRPs, combined with analysis and reinforcement of Long Tan bridge of the Lanzhou-Chengdu-Chongqing pipeline after an earthquake and application of the bridge structure finite element software MIDAS, this paper developed a finite element model that simulated the reinforcement and design of the bridge with pasted CFRPs, and proposed a reinforcement and design scheme. By combining post-seismic analysis with engineering research of reinforcement with pasted CFRPs and considering the reinforcement mechanism, material properties, calculation results and construction characteristics, the method of reinforced concrete bridge flexural strengthening with pasted CFRPs has been shown to be convenient and effective in the case of damage caused by earthquake. It is of great significance to repair bridges and ensure a traffic "lifeline" after earthquakes. This provides useful experience in the research and design of similar reinforcement of old bridges in the future.

Acknowledgements

Luo Yan, female, born in 1990, Graduated from Southwest Petroleum University, master. Foundation Project The country`s top work safety science and technology project. The key to control of major accidents scientific and technologic project in the safety production.

References

[1] Xiao Yan, Wu H, Ma R. Prefabricated glass fiber composites jackets for retrofitting reinforced concrete columns. Proceedings of the sixth ASCCS International Conference on Steel Concrete Composite Structures[J]. Composed and Hybrid Structures, USA: Los Angeles, 2000: 952-958.
[2] Clarke J. FRP reinforcement for concrete[J]. Concrete,2000, (5): 21-22.
[3] De Lorenzis L, Nanni A. Bond between near-surface mounted fiber-reinforced polymer rods and concrete in structural strengthening[J]. ACI Structural Journal, 2002, 99(2): 123-132.
[4] J. G. Teng, S. T. Smith, J. Yao, J. F. Chen. Intermediate crack-induced debonding in RC beams and slabs[J]. Construction and Building Materials, 2003,17(6-7): 447-462.
[5] LV Wei-rong. Paste reinforcement bearing capacity of normal section flexural member performance study.Master's Dissertation, Hunan University, 2003.
[6] A. Hansbo, P. Hansbo. A finite element method for the simulation of strong and weak discontinuities in solid mechanics[J]. Computer Methods in Applied Mechanics and Engineering, vol. 193(33–35): 3523–3540, 2004.
[7] Shuenn-Yih Chang, Yeou-Fong Li, Chin-Hsiung Loh. Experimental study of seismic behavior of as-built and carbon fiber reinforced plastics repaired reinforced concrete bridge columns[J]. Journal of Bridge Engineering, 2004, 9(4): 391-402.
[8] LIU Lai-jun, ZHAO Xiao-xing. Design and construction technology of bridge reinforcement. Beijing: China Communications Press, 2004.
[9] Ministry of Communications. JTG D60-2004 General code for design of highway bridges and culverts .Beijing: China Communications Press, 2004.
[10] Wang Bo, Ou Jinping, He Zheng, Zhang Xinyue, Qian Minzhong. Load-Deflection Response of Concrete Beams Reinforced with FRP Bars[J]. Advances in Structural Engineering, 2004,7(5): 427-436.
[11] Wang Bo, Ou Jinping, Zhang Xinyue, He Zheng,Qian Minzhong. Composites Fiber Reinforced Polymer Rebar for Concrete Structures[J]. Proceedings of the Eighth International Symposium on Structural Engineering for Young Experts, 2004, Xi'an, China,704-711.
[12] ANSYS, Inc.Release 10.0 Documentation for ANSYS[R].2005.
[13] MIDAS/CIVIL Analysis for Civil Structures, MIDAS.IT (Beijing) Corporation, 2006.
[14] Novidis,D.,Pantazopoulou, S. J. and Tentolouris, E. Experimental study of bond of NSM-FRP reinforcement[J]. Construction and Building Materials, 2007,21: 1760-1770.
[15] De Lorerizis, L, Teng, J. G.. Near-surface mounted FRP reinforcement: an emerging technique for strengthening structures[J]. Composites: Part B, 2007, 38: 119-143.

[16] Togay Ozbakkalogu, Marut Saatciogolu. Seismic performance of square high-strength concrete columns in FRP stay-in-place formwork[J]. ASCE Journal of Structural Engineering, 2007, 133(1): 44-56.
[17] Jin Feng, Fang Xiu-jun. The contact of the extended finite element method and other numerical methods[J]. Engineering Mechanics, 2008(S1): 1-17.
[18] Sun Hong-ling, Zhang Ai-ping, Cao Jiang-tao. Applications of Carbon Fiber Reinforced Polymer about Bridge Reinforcement Engineering[J]. Electronic Journal of Geotechnical Engineering, 2013 (18): 5075-5083.