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Strengthening Effects of Steel Truss Bridge Members with Carbon Fibre Reinforced Plastics Sheets

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Abstract

This study conducted finite element (FE) analysis to investigate the effect of seismic strengthening of H-beam members strengthened with carbon fibre reinforced plastics (CFRP). The buckling loads and the amount of the absorbed hysteretic energy were investigated. As a result, CFRP was effective in reinforcing against buckling load. The buckling load was improved more than 20% with CFRP sheets. Reinforcement was also effective in cyclic loadings, decreasing the reduction in load-bearing capacity to less than 12%. Further, reinforcement increased the amount of the absorbed hysteretic energy, especially in the compression region. Under the assumption that the CFRP would not delaminate, CFRP sheets with larger elastic modulus showed higher reinforcement effects.

Keywords: steel truss members, buckling load, finite element analysis, carbon fibre reinforced plastics (CFRP), seismic strengthening, absorbed hysteretic energy.

1 Introduction

Since the 1995 Kobe Earthquake in Japan, seismic strengthening of bridges has been implemented nationwide. However, due to a lack of funds from local governments, reinforcement work on long-span bridges and special bridges has not yet progressed very far. Some of older truss bridges, in particular, do not satisfy current seismic design specifications. The reinforcement of truss members is generally done by attaching the plates or replacing the members. These methods, however, require large equipment such as heavy machinery for installation. They also have disadvantages such as cross-sectional loss of the base material due to bolt holes and/or embrittlement of the heat-affected zone due to welding.

In recent years, the carbon fibre reinforced plastics (CFRP), which has high strength and durability, has been used as one of the repair and reinforcement methods for steel structures. This method allows repair and reinforcement without damaging the base metal, since the steel and CFRP are bonded by resin. Furthermore, it has the advantage of being lightweight and easy to install. Reinforcement using CFRP has been studied for corroded areas and the effect of reinforcement on plate members [1, 2]. However, there have been only a few cases in which the application to truss bridge members was studied.

The purpose of this study is to investigate the effect of seismic reinforcement on truss members subjected to compressive forces. Finite element (FE) analysis and experiments were conducted to investigate the buckling resistance of H-beam steel members reinforced with CFRP and the amount of the absorbed hysteretic energy under cyclic loading.

2 Methods

The analysis was performed using the finite element analysis software Marc [3], and loading experiments were conducted as shown in Figure 1. Focusing on overall buckling in the weak axial direction, the dimensions of H-beam with a length of 2424 mm was used in the experiments and the analysis were determined as follows; the width and thickness of the flange and web sections are 100 mm × 9 mm and 140 mm × 19 mm, respectively.

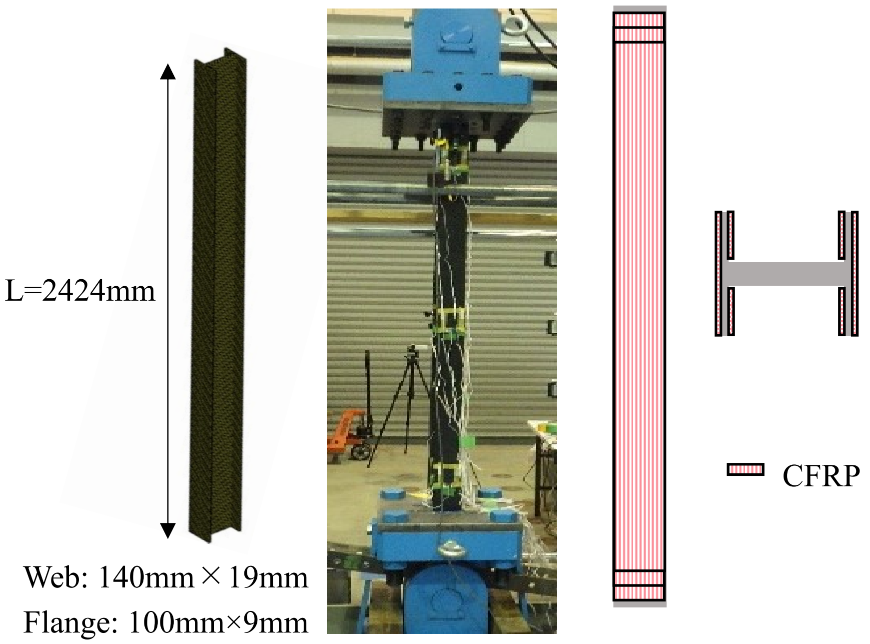

Figure 1: Model overview and loading test setup.

The mechanical properties of CFRP sheet and steel used in this study are listed in Table 1. As shown in Table 1, two types of CFRP sheets with different modulus of elasticity were used in the experiments and analyses: the elastic modulus of CFRP Sheet 2 is 1.6 times higher than that of CFRP Sheet 1. Three layers of CFRP sheets were applied to the top and bottom surfaces of the H-beam, as shown in Figure 1. In the CFRP jacketing method, the sheets are attached by shifting the edges of each sheet 25 mm apart to prevent delamination. Hence, the analysis was conducted under the assumption that the CFRP would not delaminate.

	Thickness (mm)	Elastic modulus (GPa)	Poisson's ratio
Steel	9.0	200	0.3
CFRP Sheet 1	0.495	390	0.3
CFRP Sheet 2	0.429	640	0.3

Table 1: Properties of steel and CFRP sheet.

As the modulus of elasticity of adhesive resin is small compared with one of steel, adhesives were not modelled in the analysis. Both steel and CFRP were modelled using the solid elements with a mesh width of 4.5 mm. Initial deflection and residual stresses were introduced into the members as initial imperfections. The beam was fixed at the centreline of the cross-section of one end, and the forced displacement was applied to the other end. In this study, two types of forced displacements were applied to investigate the buckling load capacity: a single compression loading and the cyclic loading. Initial deflections were applied as L/1000 = 2.4 mm from the specifications for Japanese highway bridges [4]. For the cyclic loading, forced displacements were applied in the loading sequence shown in Figure 2, where the displacements were one and two times the yield displacement $\delta_y = 2.8$ mm.

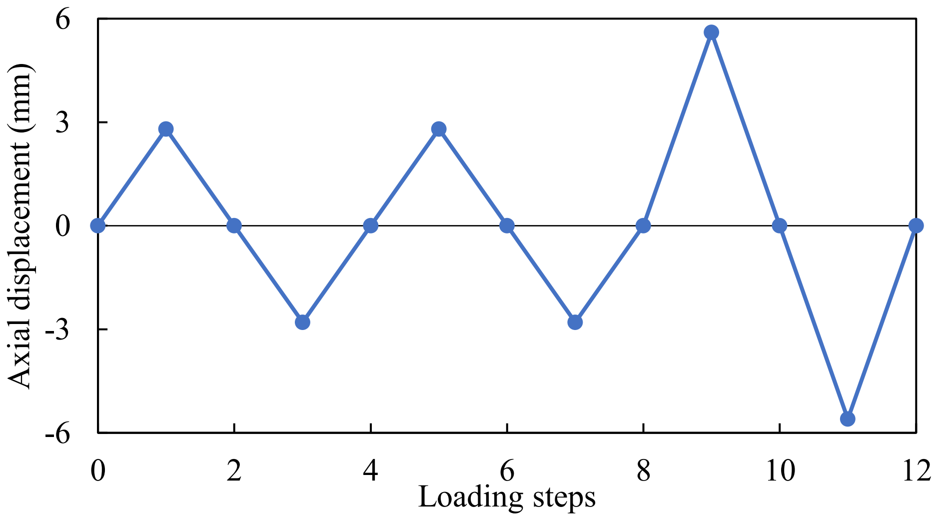

Figure 2: Loading sequence of the cyclic loading.

3 Results

Figure 3 shows the results of a single compression loading analysis. The vertical axis shows the total loads on member end and the horizontal one shows forced displacements. The buckling load in this study was defined as the maximum value of the load. The buckling load of the member reinforced with CFRP Sheet 1 was 20% and CFRP Sheet 2 was 29% larger than that of the unreinforced member. As shown in Figure 3, after buckling, the load-bearing capacity of the unreinforced member is significantly reduced, but the reinforcement causes a smaller reduction. The degree of inclination of reduction in load-bearing capacity after buckling is 42% smaller in CFRP Sheet 2 than the unreinforced member. Under the assumption that the CFRP would not delaminate, CFRP Sheet 2 was highly efficient because of its large elastic modulus.

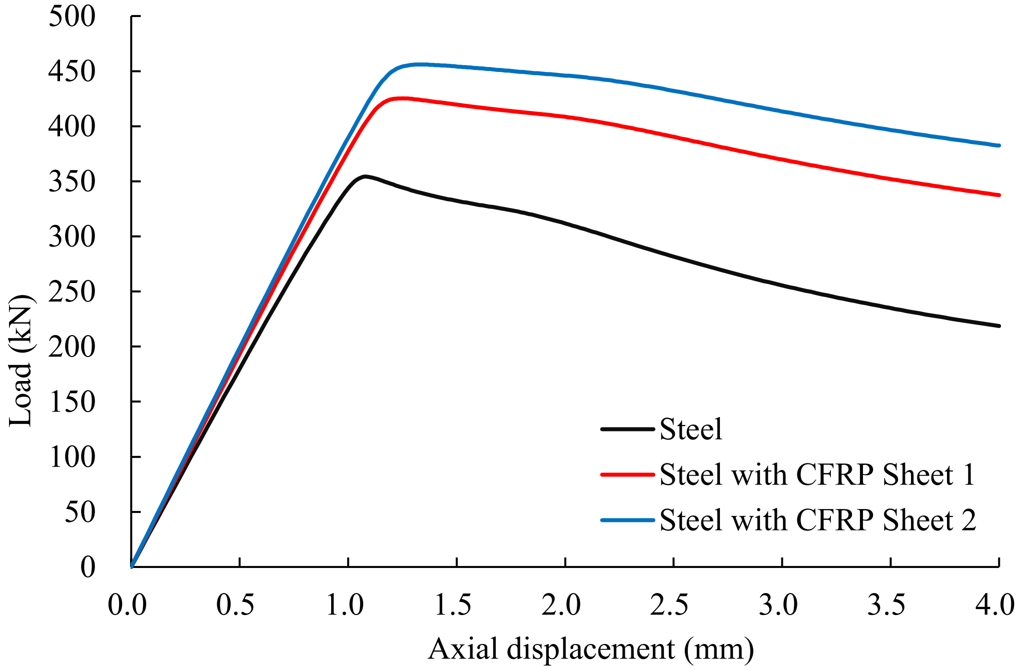

Figure 3: Load-displacement relation for a single compression loading.

Figure 4 shows the results of the cyclic loadings. While the load-bearing capacity of an unreinforced member is decreased by 29% after repeated compression, the CFRP reinforcement reduces the decline rate to 12% for CFRP Sheet 1 model and 8% for CFRP Sheet 2 model. Figure 5 shows the total amount of the absorbed hysteretic energy per loading step obtained from the area enclosed by the hysteretic curves in Figure 4. The absorbed hysteretic energy is an important index of damage of the structural members during earthquake responses. The amount of the absorbed hysteretic energy was larger in the tensile region than in the compressive region (positive load range in Figure 4). Reinforcement increased the amount of the absorbed hysteretic energy, especially in the compressive region, increasing the total absorbed hysteretic energy of the CFRP Sheet 1 model by 21% and the CFRP Sheet 2 model by 29 % over the unreinforced model.

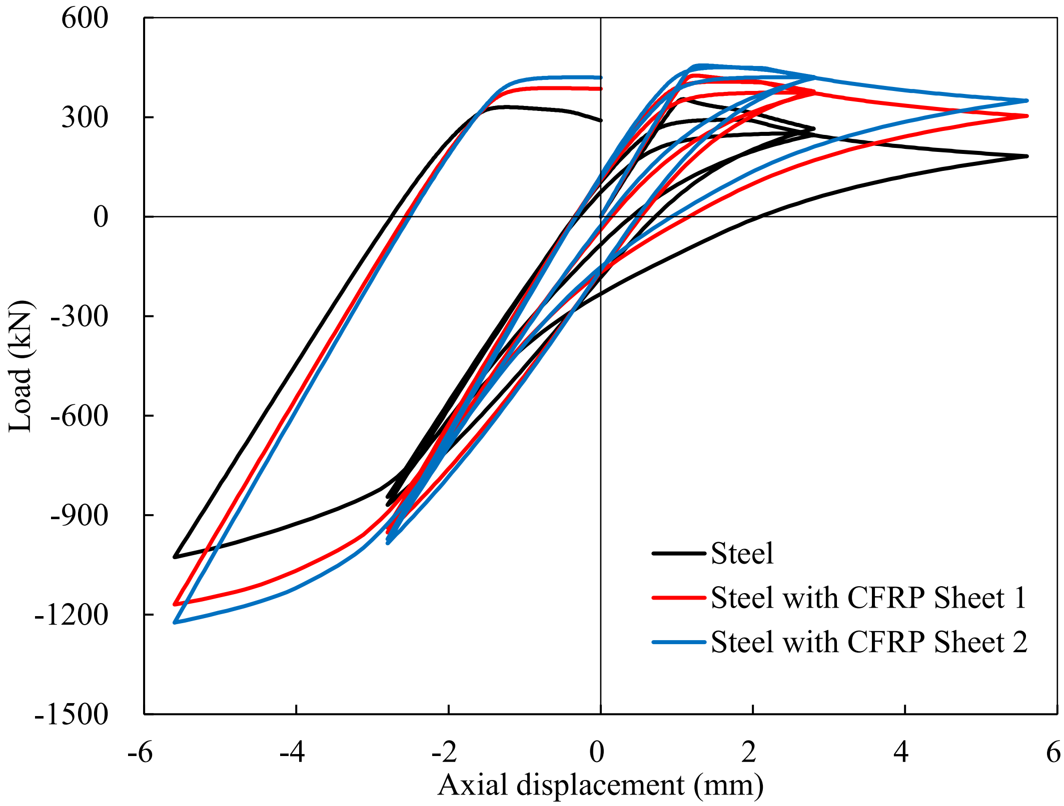

Figure 4: Hysteretic response for the cyclic loadings.

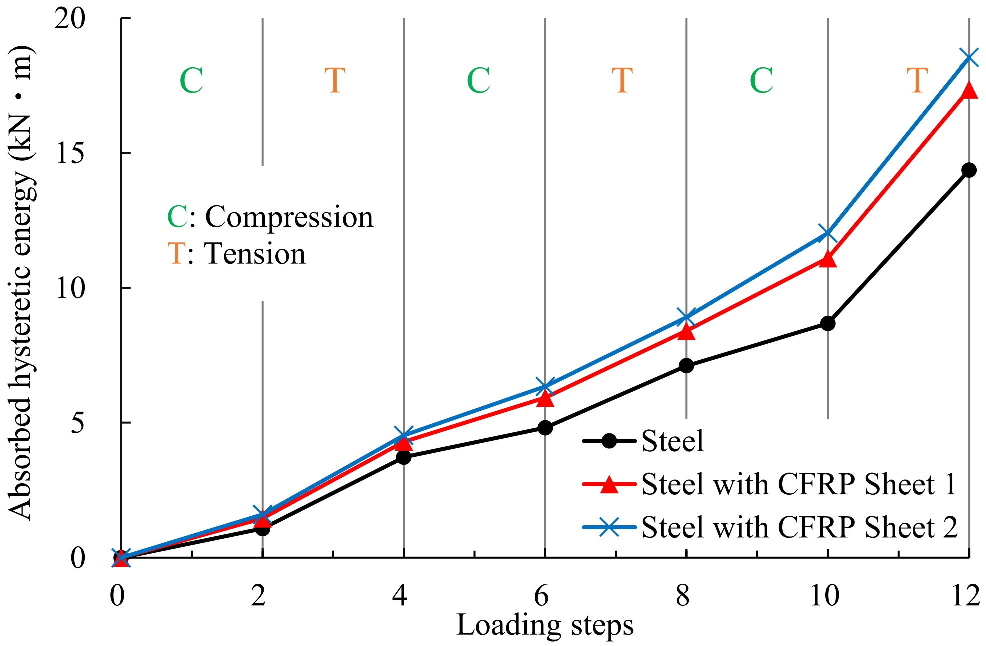

Figure 5: Absorbed hysteretic energy at each step.

4 Conclusions and Contributions

CFRP jacketing method has been adopted as one of the repairs and reinforcement methods for steel structures. This method allows repair and reinforcement without damaging the base metal, since the steel and CFRP are bonded by resin. This study conducted FE analysis to investigate the effect of seismic strengthening of H-beam members reinforced with CFRP.

Under the assumption that the CFRP would not delaminate, CFRP was effective in reinforcing against buckling load, and the buckling load of the member reinforced with CFRP Sheet 2 was 29% larger than that of the unreinforced member. CFRP sheets also improve post-buckling behaviour. The degree of inclination of reduction in load-bearing capacity after buckling is 42% smaller in CFRP Sheet 2 than the unreinforced member. While the load-bearing capacity of an unreinforced member was decreased by 29% after repeated compression, the CFRP reinforcement reduces the decline rate to 8% for CFRP Sheet 2 model. Reinforcement increased the amount of the absorbed hysteretic energy, especially in the compressive region, increasing the total absorbed hysteretic energy of the CFRP Sheet 2 model by 29 % over the unreinforced model.

This study focused on the load-bearing capacity and the absorbed energy of a single truss member and found that CFRP was effective for seismic strengthening of truss bridges. However, it is necessary to consider the bridge responses to earthquake motions based on the results of this study in the future.

Acknowledgements

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