別紙４－１（課程博士（英文））

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Abstract（Doctor）

Title of Thesis	Improving Buckling Behavior of Steel Members using Unbonded Carbon Fiber Reinforced Polymer (CFRP) Laminates

Approx. 800 words

A Carbon Fiber Reinforced Polymer (CFRP) laminates has been increasingly favored as a material for strengthening steel structures replacing conventional methods of bolting or welding additional steel plates. The CFRP is chosen as it offers several advantages such as high strength-to-weight ratio, excellent fatigue behavior, resistance to corrosion (excellent durability), light weight, and ease of handling and installation. In recent decades, many research programs on strengthening steel structures with CFRP have been conducted. However, the main focus of the previous researches has been limited to strengthening with an adhesive-bonding technique. This research program investigates a new and promising method of strengthening steel using unbonded CFRP laminates which is manufactured through a process of Vacuum-assisted Resin Transfer Molding (VaRTM). The main advantage of this strengthening method is that steel surface treatments are completely no longer needed. This method of strengthening does not rely on the bond strength between steel and CFRP because these two materials are separated by an unbonded layer. The CFRP is expected to contribute only through its flexural rigidity because elastic modulus of carbon fiber is much higher than steel. The proposed unbonded CFRP strengthening is intended to be used for improving buckling performance of axial compression steel members.

The first experiment was conducted to axial compression steel bars with a diameter of 32 mm. A total of eight specimens were prepared consisting of six strengthened specimens and two control specimens. The CFRP requirements for strengthening were derived through analytical models. Three conditions considered included stiffness, strength, and circumferential strength. The unbonded CFRP was applied to only a part of length of the steel bar and positioned at center. Variation of specimens was made for buckling length, CFRP length, and number of CFRP layers. However, the number of specimens prepared was limited as it was a preliminary investigation. The test results showed that the proposed unbonded CFRP strengthening succeeded to increase the buckling capacity of the steel bars. The strengthening effect can even reach almost 50%. Besides that, the CFRP suffered no damage at all. Buckling curvature of the specimen changed from plastic hinge at middle height of specimen to plastic hinge at around the end of CFRP.

A method of equivalent slenderness ratio was then proposed to determine a design (recommendation) strength of the unbonded CFRP strengthened specimens. The effectiveness of

this method was confronted against the performed experimental results and the results of numerical simulations developed for 30 strengthened models. It was clear that the proposed method of equivalent slenderness ratio provides very good results and can be used to determine the recommended strength of axial compression steel bars strengthened with unbonded CFRP laminates.

The next experiment was carried out to angle steel. This program aimed to explore the potential use of the proposed unbonded CFRP to strengthen a real or large-scale steel member. Angle steel is chosen because it is very popular for lateral resisting element in steel buildings. Thus, it is very prone to buckling failure. The strengthening scheme was still same with that applied to the steel bars where CFRP was applied to cover the entire steel surface along the strengthening area (angle steel fully-jacketed cross section). Besides that, the CFRP was also installed at middle span of the specimen through the VaRTM process. A total of twelve specimens, including two control un-strengthened angle steels, were prepared and tested. They were allowed to buckle in their weak axis only. The specimens were divided into two different groups based on the specimen length, i.e., 1618 and 1218 mm. In the first group, in addition to bare steel, three specimens were strengthened with 1000 mm length CFRP, and the other three were strengthened with only 500 mm length CFRP. However, in Group 2, with also one control un-strengthened angle steel, the other four specimens were strengthened with the same CFRP length, namely, 500 mm. It could be confirmed that the CFRP created from the VaRTM process in this study has higher fiber content, at approximately 60%. This described the advantage of VaRTM over hand layup process which is commonly used in adhesive bonding strengthening techniques. The test results showed that the buckling performance of the angle steel can be well improved. Load-bearing capacity of the angle steel can be increased by 8.5%-54.3%. The increase in load-bearing capacity occurred as increasing number of CFRP layers and CFRP length. However, for strengthening with the same number of layers and CFRP length, a greater capacity increase was attained in specimens with smaller angle steel slenderness ratios. Validation of the effectiveness of the equivalent slenderness ratio method in determining strength recommendation of the angle steel strengthened with unbonded CFRP showed that this method gives better results. The safety factor fell within the range of 1.14-1.34 with coefficient variations of 2.2%, 0.6%, and 5.2% depending on strengthening variations.

The final investigation also involved angle steel with the same properties but its strengthening scheme is slightly different from the previous research. The unbonded CFRP was only applied to both legs of the angle steel (angle steel partially-jacketed cross section). This experimental program was conducted to explore another alternative strengthening scheme that allows reduction in amount of CFRP usage. The test results also showed that the proposed unbonded CFRP strengthening can improve the buckling performance of angle steel. The buckling capacity of angle steel could be increased by up to about 69%.

In conclusion, the investigation results presented in this dissertation clearly prove that the proposed unbonded CFRP strengthening method can be used for improving buckling behavior of axial compression steel members. However, there are some topics that have not been explored within this study and the author has identified them as recommendations for future research.