別紙４－１（課程博士（英文））

Date of Submission (month day, year) : July 8, 2022

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Abstract (Doctor)

Title of Thesis	Applications of thin fiber reinforced polymer (FRP) materials for the strengthening of structures in the civil engineering field

Civil infrastructure plays a key factor in the development of the economy and human life. The infrastructures of constructed facilities for the transportation and housing of people, goods, and services, which were remarkably expanded in recent years are now reaching a critical age with widespread signs of deterioration and inadequate functionality. Designing efficient methods for rehabilitating, rebuilding, and maintaining civil infrastructure is very essential to ensure the sustainable development of the economy and health infrastructures. At the same time, fiber-reinforced polymers (FRPs) composites have emerged as excellent construction materials for the renewal of existing structures.

This thesis is presented as a compilation of different investigations. Part 1 of the thesis describes the strengthening effects of carbon fiber reinforced polymers (CFRPs) for the thin-walled steel structures under various loading conditions: (1) axial compression (chapter 3 and 4), (2) bending shear load (chapter 4), (3) shear load (chapter 5), and (4) dynamic load (chapter 6). Part 2 of the thesis investigates the strengthening effects of glass fiber sheets (GFSs) on the strength of pultruded glass fiber reinforcement polymer (PGFRP) single bolted connections.

The strengthening effects of circumferential CFRP layers on the increasing load-carrying capacities of thin-walled steel cylinders (TSCs) under compressive load through finite element analysis (FEA) and experiments are presented in Chapter 3. The results showed that circumferential CFRP layers reveal their significant effects on the increased load-carrying capacity of TSCs. In addition, good correspondences were found between experimental and FEA results regarding deformation behavior, load-carrying capacity, and strain and stress relations.

In the next investigation, the effects of carbon fiber orientations for the strengthening of TSCs under compressive and bending shear loads are described in Chapter 4. In the first stage, the validation of the accuracy between experimental and FEA was conducted for small-scale TSCs. The FEA method was then used to analyze the effects of fiber orientation for the strengthening of full-scale TSCs. The results indicated that circumferential CFRP layers reveal their significant effects on the increased load-carrying capacity of TSCs under axial compression. In addition, circumferential 0° and 0°/90° CFRP layers proved the better strengthening effects than 90° CFRP layers for TSCs under bending shear loads.

The effects of CFRP strengthening on the shear strength of thin-walled steel plates (TSP) are experimental

and numerical investigations in Chapter 5. The results reveal that CFRP layers can be effectively used to increase the ultimate shear strength of the TSPs. The strengthening effect was better if the width-to-thickness ratio of the CFRP layer was low. Moreover, equations using the lamination theory of composite materials can be used to predict the critical and ultimate shear load for strengthened TSPs with high accuracy.

The effects of CFRP strengthening for thin-walled storage tanks (TST) under dynamic loads are presented in Chapter 6. A new experimental method using small-diameter steel balls to create internal pressure for the TSTs is applied. In the next steps, the strengthening effects of two types of externally bonded CFRP sheets, including the circumferential CFRP layer (0°) and two-directional CFRP layer (0°/90°), on the performance of TSTs under dynamic loads were investigated. The consequences show that CFRP layers can restrain both static and dynamic hoop strains in TSTs, especially the 0° CFRP layer. The restraint levels of static strains can be up to 65% for the 0° CFRP layer and 62% for the 0°/90° CFRP layer.

In part 2 of the thesis, a series of experiments were conducted to consider the strengthening effects of GFS on the strength of pin-bearing PGFRP single bolted connections. In addition, the FEA method was also used to confirm the strengthening effects. According to a series of material tests, the equations were proposed to predict correctly failure modes and ultimate loads of GFS-strengthened pin-bearing PGFRP single bolted connections. Three types of GFS, which were molded by the Vacuum transfer molding method, were used for the strengthening: 0°/90° GFS, ±45° GFS, and chopped strand mat (CSM) GFS. The research results indicated that all three types of GFSs could effectively increase the maximum failure loads of the PGFRP connections. The effect of all types of GFSs on the reinforcement was proportional to the decrease in the ratios of end distances to bolt diameter (*e/d*), whereas the effect of the ratios of width to bolt diameter (*w/d*) on the connection strength was not significant if the $w/d \geq 3$. In almost all cases, CSM GFSs proved the best strengthening effects compared to ±45° GFSs and 0°/90° GFSs. Relating the effects of GFS thickness on the connection strength, the strengthening effects per GFS layer decreased when increasing the number of strengthening GFS layers. Finally, when the same modes of failure were obtained for the specimens having the same parameters, the strengthening effects were higher for the large-diameter bolts.

From this overall research program, it can be concluded that thin FRP materials can be used effectively to strengthen various structures in civil engineering to improve the load-carrying capacity and performances of steel structures or PGFRP connections. The research results and proposed equations in this study can help to encourage the practical applications of advanced material (FRP) in the civil engineering field.