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# **THESIS OUTLINE**

## **“INNOVATION OF SHEAR IMPROVEMENT IN CONCRETE BEAMS BY INTERNALLY REINFORCING PBO MESH AND CFRP GRID”**

Since the common method for enhancing the shear performance of concrete beams by the reinforcing steel stirrups exhibits an unavoidable disadvantage due to the corrosion problem, the application of Fiber Reinforced Polymer (FRP) becomes extensive and well-known in recent years. Normally, the FRP in a form of sheet is externally attached to the surface of concrete and the third component such as epoxy resin is required for making a bond between the two materials. Although the performance of concrete structures can be enhanced by the externally bonded FRP sheets, they still have some disadvantages due to the usage of epoxy resin which is actually low fire resistance and it can be degraded under UV light.

In order to develop a new challenge of FRP composites for concrete beams, this research presents a new alternative shear improvement by using high performance textile composites such as the Polyparaphenylene Benzobis Oxazole (PBO) fiber mesh and the Carbon FRP (CFRP) grid as a direct replacement of conventional steel stirrups at the shear span inside concrete beams. In fact, the mechanical properties of the PBO fibers are really impressed since the elastic modulus of  $270 \text{ kN/mm}^2$  and the tensile strength of  $5800 \text{ N/mm}^2$  are both fairly higher than those of the high-strength type of carbon fibers.

The experimental programs in this study were separated into three main parts. The first part was the elementary tests for investigating the basic mechanism and the compatibility between the internal mesh/grid and the concrete surrounding them. The bending test of eight concrete elements internally reinforced in flexural direction with PBO mesh and CFRP grid was investigated. The actual tensile strength of the reinforcing mesh/grid from the bending test was compared with their ultimate tensile strengths obtained from the uni-axial test. On the basis of results obtained from the elementary tests, the concrete beam tests were investigated with a total of seventeen RC specimens. The four-points loading tests were conducted until the failure of specimens. The results in terms of shear capacities, shear carried by the internal mesh/grid, load-displacement relationships, cracks patterns, failure modes and shear resisting mechanism were presented and discussed. Lastly, suitable models for evaluating the shear carried by internal PBO mesh and CFRP grid were introduced and

the calculated results were compared with the experimental results. The contents in the thesis were divided into seven chapters as summarized as follows:

**Chapter 1** introduced the origin and the background behind the idea of this study. The research motivation for the replacement of conventional steel stirrups by the high performance textile FRP composites was indicated by depicting results of some previous experimental investigations. In addition, the main objectives of this study and the outline of this dissertation were also mentioned in this chapter.

**Chapter 2** described the development of FRP materials for concrete structures, the limitations of them and also the existing guidelines and standards instructing about the application of RC structures with FRP materials. Moreover, the physical and mechanical properties and also some significant previous studies about the PBO mesh and the FRP grid which were used as reinforcing materials in this study were also provided in this part.

In **Chapter 3**, the elementary test for the internal reinforcing PBO mesh and CFRP grid was presented. This test mainly aimed to obtain the actual tensile strength of the PBO mesh and the CFRP grid when they were used as reinforcing materials inside concrete elements and also to verify whether this internal reinforcing method can be applied in bigger structural concrete member or not. Dimensions and details of concrete elements in each case were described. Fabrication of specimens with internal PBO mesh or CFRP grid was explained step by step before the process of concrete casting.

The results from the bending test showed a good reinforcing efficiency from the internal composites. The failure mode of each specimen was depended on the amount and the coating method of reinforcing composites. The flexural capacity of the specimens with two and three layers of PBO mesh was about two and three times of the specimen with one layer. Besides, the PBO mesh coated by the resin before casting concrete led to a higher tensile resisting ability than the uncoated one.

In concrete elements with CFRP grid, the flexural capacity of the specimen with four strips of internal grid was about double of that of the specimen with two strips, indicating a sufficient reinforcing efficiency from the internal CFRP grid system. In addition, the actual tensile strengths of the internal mesh/grid from the bending tests were not far from their ultimate tensile strengths, resulting that this internal reinforcing system was reasonable for applying to other concrete structures in further studies.

**Chapter 4** focused on concrete beam test with internal PBO mesh, a total of nine concrete beams varying in the number of PBO mesh layers, the width of PBO mesh in the shear span, and the reinforcing configuration of the mesh were tested. The reinforcing meshes were coated by the resin to assemble the small fibers into a group and were wrapped around the compression and tension bars as a replacement of steel stirrups before casting concrete.

The experimental results from the four-point loading test confirmed an ability of the internal PBO mesh for enhancing the shear performance of reinforced concrete beams. The internal mesh displayed its performance after the occurrence of diagonal cracks. The shear performance of concrete beams increased significantly with a higher number of the internal mesh layers. In details, the shear capacity increased by 49% for the specimen with one layer, 73% for the specimen with two layers and 114% for the specimen with three layers when compared with the un-reinforced specimen.

With the second parameter, the shear capacity amazingly decreased when the width of internal mesh in the shear span was expanded. The highest reinforcing efficiency was obtained when the width of the mesh was the shortest one as 280 mm. This phenomenon was happened because the fresh concrete was not able to penetrate perfectly into the holes of PBO mesh. This also caused a horizontal crack in compression zone which can impede the development of shear capacity in beams with a longer width of internal mesh. For the specimens with one layer of internal mesh, the shear carried by mesh increased by 39% with 560 mm-mesh, 42% with 420 mm-mesh and 78% with 280 mm-mesh when compared with the specimen with 700 mm-mesh.

Moreover, the difference in reinforcing configuration of the internal PBO mesh showed a great impact on the shear performance of concrete beams reinforced with internal PBO mesh. The mesh provided at the center of the shear span showed a better shear resisting performance than that of the non-centered one when the same total amount of PBO mesh was provided.

In case of concrete beam test with CFRP grid presented in **Chapter 5**, eight concrete beams with and without CFRP grids in the shear span were tested. The parameters were the number of CFRP grid strips in the shear span and the spacing of grids which was varied between 50 mm and 100 mm. The reinforcing grids were attached at the two sides of the shear span by the binding wires as commonly used for steel stirrups before casting concrete.

The experimental results revealed that the shear capacity and the shear carried by internal CFRP grids were significantly improved with a higher amount of grid strips, however, the increasing ratio of shear capacity was not proportional to the shear reinforcement ratio. The resisting effectiveness of each grid became smaller with a greater amount of internal grid in the shear span. In fact, the specimen with only two strips of the grid exhibited a highest resisting performance among all tested specimens in this study.

Besides, the location of internal grid in the shear span was very important for the shear resisting effectiveness of the reinforcing grids since the more number of grid strips located near the center of the shear span was much more effective to resist the propagation of diagonal crack than the strips near the edge. Because of that, the internal grids with narrower spacing showed a greater resisting ability than the wider one. In addition, the failure of all specimens in this study occurred when the diagonal crack was extended to connect between the loading point and the supporting points and this was considered as the shear compression failure.

**Chapter 6** explained about the truss analogy method for modelling the shear carried by internal PBO mesh and CFRP grid. The shear reinforcing efficiencies ( $K$ ) were added into the equations to limit the shear resisting ability of the internal composites. The validation of the proposed models exhibited a satisfied agreement with experimental results. Discussion about the reinforcing efficiency between the proposed method and the existing methods from the guidelines (JSCE, ACI) was explained in the last section of this chapter.

Finally, the conclusions of this research and the suggestions for the improvement of the proposed internal reinforcing system by FRP composites in further study were given in **Chapter 7**.