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Strengthening of RC one-way slabs including cut-out using different techniques ☆

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ABSTRACT

Often, it is essential to introduce a cut-out in an existing reinforced concrete slab for facility requirements. That cut-out poses a break in the continuity of the slab loading trajectories. Hence, a great attention has to be paid to the adopted strengthening approach in order to restore the flexural resistance of the slab included cut-out. To investigate the structural flexural performance of strengthened one-way reinforced concrete slab included cut-out, six slabs including cut-out adjacent to the central patch load in addition to one slab without cut-out as a reference slab were tested up to failure under incremental monotonic loading. The six slabs including cut-outs contained one control un-strengthened slab along with five strengthened slab. These slabs were strengthened using either Near Surface Mounted (NSM) steel bars or Externally Bonded Carbon Fiber Reinforced Polymer (EB-CFRP) at the tension side, while four out of them were strengthened by either NSM-steel bars (one slab) or an overlay of Engineered Cementitious Composites (ECC) material (three slabs) at the compression side. It can be concluded that end anchors for the EB-CFRP sheets along with the surface preparation before installing the ECC overlay are very important parameters in order to guarantee the optimum utilization for both the EB-CFRP sheets and the ECC overlay material. In addition, the test results showed that the hybrid strengthening technique incorporated NSM-steel bars in tension side along with ECC overlay in compression side showed its superiority among all proposed strengthening schemes. It is not only allowed the slab included cut-out to restore its flexural resistance, but also it enabled the slab to outperform its structural performance compared to that of the slab without cut-out.

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1. Introduction

Introducing cut-outs in an existing reinforced concrete slab is necessary in some circumstances as the installation of escalators, elevators or utilities such as air conditioning, heating or wiring ducts. These cut-outs have the advantages of improved air circulation, aesthetics, and improved lighting. However, these cut-outs pose a break in the continuity of the slab causing weak points in the whole structure. They thus require special attention in remodeling of the slab in order to capture the actual behavior of the new slab including cut-out [1–4].

Broad applications of the fiber-reinforced polymer (FRP) materials as new construction strengthening materials have been recently accomplished. FRP materials are lightweight, high strength, and non-corrosive materials. By virtue of these advantages, there are wide ranges of recent, current, and potential applications of these materials that cover both new and existing structures. Among different types of FRP materials, a Carbon Fiber Reinforced Polymer (CFRP) is used extensively in the structural engineering field. The Externally Bonded Reinforcement (EBR) technique has been more generally applied due to its simple installation procedure. Design guidelines and specifications have also been established well for this system [5]. In particular, their practical implementations for strengthening by epoxy bonding are several [6–10].

When compared to the Externally Bonded Reinforcement (EBR) technique, the Near Surface Mounted (NSM) technique assures a higher anchoring capacity to the CFRP reinforcing material. In consequence, a high tensile stress can be mobilized in the CFRP, as long as the member load carrying capacity is not limited by a premature failure mode [11–13]. The Near-Surface Mounted (NSM-CFRP) strengthening technique has been used in the recent years, with remarkable efficiency, in order to increase the flexural strength [14,15]. The use of FRP rods for this application is very new and the Near Surface Mounted (NSM) steel rods have been in Europe for strengthening of RC structures dated back to 1948 [16].

☆ The experimental work had been conducted at Tanta University's Concrete and Heavy Structures Laboratory.

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For RC slabs of low or medium concrete strength, the increment of the flexural resistance that NSM can provide might be limited by the maximum allowable compressive strain in the extreme compressed concrete fiber. This drawback can be overcome by adding a concrete layer in the compression zone of the existing slab [17,18]. In order to achieve the desired full composite action, the new concrete overlay and the existing concrete slab should behave monolithically. A sound bond between the new layer and the existing concrete slab can be guaranteed if a proper epoxy compound is used [19,20].

Another way of strengthening of RC slabs is adding a new concrete layer. The additional concrete overlay increases the lever arm of the moment resisting of the concrete section. Casting an overlay and thus adjoining a fresh material onto an older structure can result in durability problems such as cracking and de-lamination along the transition zone between the two materials. These occurrences are mostly dependent on differential movements, i.e. volume changes, between the base concrete and the overlay caused by shrinkage, temperature variations or both, poor workmanship or external loads [21,22].

Engineered Cementitious Composites (ECC) is an exceptional representative of the new generation of high performance fiber reinforced cementitious composites, featuring high ductility and durability characteristics [23–26]. ECC's high tensile ductility, deformation compatibility with existing concrete, and self-controlled micro-crack width lead to its superior durability under various mechanical and environmental loading conditions such as fatigue, freezing and thawing, chloride exposure, and drying shrinkage [27–29]. Engineered Cementitious Composites (ECC) is a mortar-based composite that is reinforced with short random fibers, such as polyethylene (PE) or polyvinyl alcohol (PVA). The use of PVA fibers has better tensile crack bridging properties while the use of PE fibers shows a better compressive behavior [30]. ECC is a micromechanically designed material that uses a micromechanical model to tailor-make the required properties. By using this micromechanical tool, the fiber amount used in the ECC is typically 2% by volume. Thus, ECC is designed to resist large tensile and shear forces but at the same time has compatible properties, such as compressive strength and thermal expansion, to ordinary concrete based on Portland cement [31].

Experimental investigations on the structural performance of one-way spanning CFRP-strengthened slabs with cut-outs have been reported by Alkhrdaji et al. [32], Vasquez and Karbhari [33], Casadei et al. [34], Tan and Zhao [35] and Smith and Kim [1]. They concluded that FRP-strengthened slabs achieved a higher load-carrying capacity than their un-strengthened control counterparts. In addition, all strengthened slabs failed by de-bonding initiating at intermediate cracks (IC de-bonding) and in the case of the slabs with cut-outs, the critical cracks were diagonal and originated from the corners of the cut-out. Boon et al. [2] showed that the effect of additional rectangular bars along with diagonal bars surrounding the opening failed to restore the bending capacity of un-cut slab. Seliem et al. [36] showed that the slab included cut-outs strengthened with NSM-CFRP strips had a higher load-carrying capacity in comparison to the slab strengthened with EB-CFRP laminates while using significantly less area of FRP. This behavior is attributed to the improved resistance of the NSM technique to IC de-bonding. Kim and Smith [4] showed that the FRP anchors were found to increase the strength of RC slabs with large penetrations and delay complete loss of the strengthening plates due to de-bonding.

For the made cut-out in reinforced concrete slabs, the common practice is to replace the cut reinforcement around the opening without compensation of the concrete part [3]. However, the cut-out involves both concrete and reinforcing steel. The reinforced concrete section always is designed in order to withstand the applied load and to be failed in a tension-controlled manner [37,38]. Although, the replacement of tension steel only may lead to shifting the neutral axis of the RC section resulting in increased compression zone depth yielding compression-controlled failure that is unfavorable, refer to Fig. 1.

The adopted strengthening methodology in the current research work is based on providing strengthening materials on both tension and compression sides in order to balance the removed forces due to cut-out leading to an adequate global structural performance. Thus, the flexural capacity of the entire slab can be restored thoroughly. The tension side is strengthened by either NSM-steel bars or EB-CFRP sheets at both edges of the cut-out alongside the loading span, while the compression side is strengthened by either NSM-steel bars at both edges of the cut-out or an overlay of ECC material to be casted around the cut-out region.

2. Experimental work program

2.1. Test slabs

The experimental work program consisted of seven one-way slabs divided into three groups: one reference slab without cut-out and one control slab including cut-out referred to as the group No. 1, and five slabs including typical cut-out and strengthened using different techniques represented group No. 2 and group No. 3.

All slabs had the same concrete dimensions and internal steel reinforcement. Each slab had 600 mm width × 100 mm thickness and a total span of 1600 mm, while the center to center span was 1400 mm. The flexural reinforcement of the slabs consisted

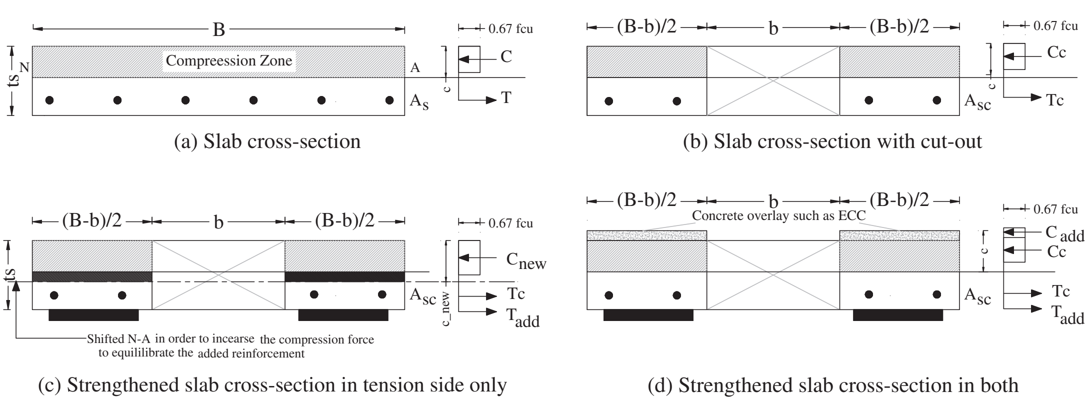

Fig. 1. Internal forces of slab cross-section including cut-out.

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