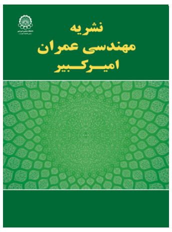

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Experimental Study of Flexural Strengthening of Two-way Reinforced Concrete Slabs Using Punched Steel Plates

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ABSTRACT: RC slabs are the structural members responsible for carrying and transferring loads. RC slabs need to be strengthened as a result of different reasons such as changing of function and corrosion of steel bars. The most widely utilized approach in strengthening these slabs has been the usage of steel plates. However, the concerns in using these plates consist of their immense weight as well as their unreliability in being properly connected to the concrete slabs. This study focuses on using punched steel plates as a strengthening factor for concrete slabs since they have reduced weight and allow an easier and more reliable connection. For the experiment, two-way RC slabs with the dimensions of 120 cm and the thickness of 8 cm are strengthened through punched steel plates and are placed under a semi-concentrated loading effect. The effect of plates' thickness, the arrangement and the area of the punched holes, and the connection type in the performance of the strengthening system are studied through load-displacement graphs and are analyzed in dissipated energy and ductility. The results showed that the punched strengthening plates increase loading capacity, energy absorption, and the ductility of the two-way slabs up to 62%, 253%, and 220%, respectively. Also, it was shown that the arrangement of the holes and the connection type of the strengthening plates have a significant effect on the performance of the strengthening system. Failure state control in experimental models showed that the failure mode in using epoxy resin is the debonding of the steel plate, while the failure mode in using expansive bolt is pulled out of the bolt.

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1. INTRODUCTION

Steels plates are the oldest and the most well-known and classic materials in strengthening concrete slabs. The heavyweight of the plates makes the bonding operation difficult. Also, there is no access to the under of the reinforcing plate, and it is hard to control the amount of epoxy resin used or to remove the excessive resin. Finally, it is not possible to control the state of the slab in service life [1].

Many researchers such as Gemert [2], Yelgin *et al.* [3], Huovinen [4], Rasheed and Al-Azawi [5], and Charif [6] studied the use of steel plates with epoxy resin in the flexural strengthening of the concrete elements.

Most of the researchers who used epoxy resin to bond the strengthening plate reported debonding as the governed failure mode. For this reason, some researchers such as Ebead and Marzouk [7], Gomes and Appleton [8], and Subedi *et al.* [9] evaluated the bolt and bolt-resin connection approach to strengthen concrete elements.

In this research, the flexural strengthening of two-way RC slabs with punched steel plates was experimentally performed for the first time, and the limitations of steel plates have been overcome by creating openings in the steel plates.

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2. METHODOLOGY

For this experiment, 9 square RC slabs with the dimensions of 1200 mm and thickness of 80 mm have been built. These specimens are studied in 4 general groups. Group 1 (G1) studies the effect of plate thickness on the strengthening system and focuses on comparing the results from specimens C, S1, and S2. To control the area's effect on the behavior of the strengthening system, the second group, G2 is used for collecting results from the specimens C, S1, S3, and S6. The third group, G3, studies the outcome of perforation arrangement on the potency of the strengthening plate by comparing the results from specimens C, S3, S4, and S5. Finally, the last group, G4, compares the results from C, S3, S7, and S8 to study the connection method used in bonding the punched strengthening plate.

A hydraulic Jack with 500 kN capacity, course of 400 mm, and loading rate of 1 mm/min are used for the experiment. All the specimens are simply supported according to the design assumption. To record the behavior of the slab a load cell is used at the center, two LVDT on the upper side of the slab – at the 1/4th of each diagonal length of the specimen – as well as a laser to record the displacements below of slab at the center of it.

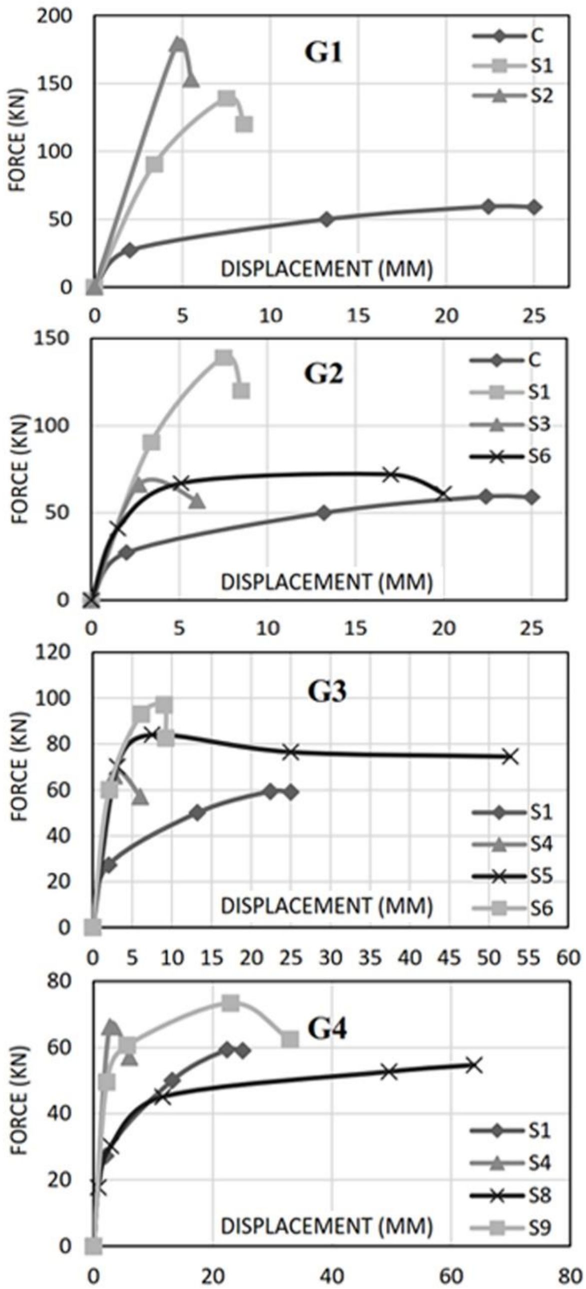

Fig. 1. Load-displacement graph

3. RESULTS AND DISCUSSION

Fig. 1 shows load-displacement graphs. The G1's graph shows loading capacity and initial stiffness in both specimens of S1 and S2 are shown to have significantly improved. The G2's graph shows that the punched strengthening plates of S3 and S6 have increased the maximum loading capacity up to 13.3% and 25% while causing a delay in the plastic behavior of the system. The G3's graph shows that while the square arrangement of the holes increasing the loading capacity up to 13.3%, the circular and rhombic arrangements have respectively shown loading capacity as 40% and 61.6% increment.

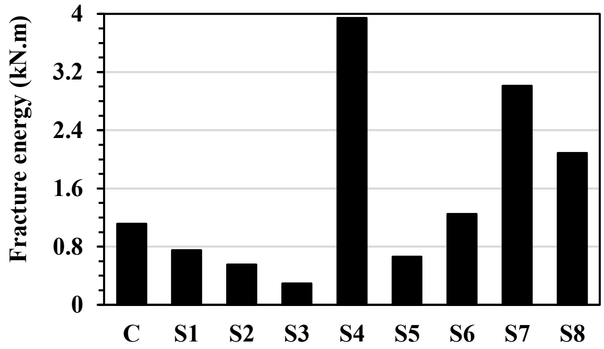

Fig. 2. Energy absorption of experimental specimens

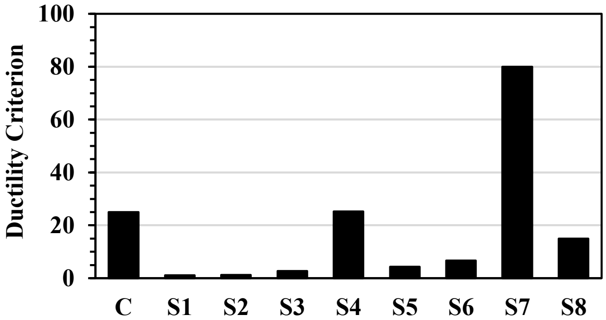

Fig. 3. Ductility criterion of experimental specimens

G4's graph shows that using both epoxy resin and expansion bolts for the strengthening plates with square arrangements of the perforations is the best bonding method. This method increases the loading capacity by 20% while using epoxy resin only increases the loading capacity by 13.3%.

Fig. 2 displays the fracture energy in the specimens. Fracture energy for each specimen is represented by the area under the total load-displacement curve. It is observed that the fracture energy in S4 has a 253% increase compared to the C specimen. Therefore, the arrangement of the perforations plays an important role in the performance of the perforated plates. The results also showed that using bolts to bond the strengthening plate cannot improve the loading capacity and the stiffness of the slab, hence, displays great functionality and increased energy dissipation of 170%.

Fig. 3 shows the ductility criterion for all the specimens. The ductility criterion for each specimen is represented by the ultimate displacement to elastic displacement ratio. Comparing these criteria revealed that using in-depth embedded anchorage bolts does not improve stiffness and ultimate strength, they increase ductility significantly up to 220%. The results also showed that using epoxy resin has no positive effect on ductility. The ductility of S4 is equal to the control specimen, while S1 and S2 with non-perforated strengthening plates have low ductility criteria. Comparing the ductility values of S3, S4, and S5 revealed that choosing proper arrangement in the strengthening plate highly affects the ductility of the strengthening system.

4. CONCLUSION

In this research, punched steel plates were used for the first time to strengthen two-way concrete slabs. RC slabs with 1200×1200×80 mm were studied. The results were categorized and compared into four groups. The G1's results showed non-perforated steel plate with 2 mm thickness improved initial stiffness and loading capacity up to 200%, while showing a decrease in energy absorption and ductility. The G2's results demonstrated that punching the steel plate decreased its effectiveness on the loading capacity, even though it could improve loading capacity and energy absorption up to 25% and 12%, respectively. The G3's results showed selecting the right arrangement can significantly affect its behavior and effectiveness. The rhombic arrangement with 62% improvement in loading capacity and circular arrangement with 253% improvement in energy absorption showed the best performance. Finally, the G4's results showed that using expansion bolts instead of epoxy resin for the plate connection resulted in the reduction of loading capacity, but increased ductility criterion up to 220%. Studying the connection types of the strengthening plate also disclosed that using epoxy resin and bolts simultaneously resulted in the best performance in the strengthening system.

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