

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

Saeed Sahranavard¹, Hasan Haji-Kazemi^{2*}

¹Department of civil engineering, Ferdowsi university of mashhad, Mashhad, Iran

²Department of civil engineering, Ferdowsi university of mashhad, Mashhad, Iran

ABSTRACT

RC slabs are the structural members responsible for carrying and transferring of 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 concern in using these plates consists 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 easier and more reliable connection. For the purpose of 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 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 strengthening system are studied through load-displacement graphs, and are analyzed in dissipated energy and ductility. The results have shown 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 is 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 show that the failure mode in using epoxy resin is the debonding of the steel plate, while the failure mode in using expansive bolt is pull out of the bolt.

KEYWORDS

Two-way slabs, strengthening RC slabs, punched steel Plate, ductility, failure mode, energy dissipation

* Corresponding Author: Email: hkazemi@um.ac.ir

1. Introduction

Steels plates are the oldest and the most well-known and classic materials in strengthening concrete slabs. The heavy weight of the plates make 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 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 using of steel plates with epoxy resin in 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] experimenting on the bolt and bolt-resin connection approach in order to strengthen concrete elements.

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

2. Methodology

For the purpose of 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's thickness on the strengthening system and focuses on comparing the results from the specimens C, S1 and S2. For the purpose of controlling 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 through 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 is used for the purpose of experiment. All of specimens are simply supported according to the design assumption. In order 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.

3. Discussion and Results

Figure 1 shows load-displacement graphs. G1's graph shows Loading capacity and initial stiffness in both specimens of S1 and S2 is shown to have significantly improved. 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 delay in the plastic behavior of the system. G3's graph shows that while the square arrangement of the holes increasing the loading capacity up to 13.3%, the circular and rhombic arrangement have respectively shown loading capacity increase of 40% and 61.6%.

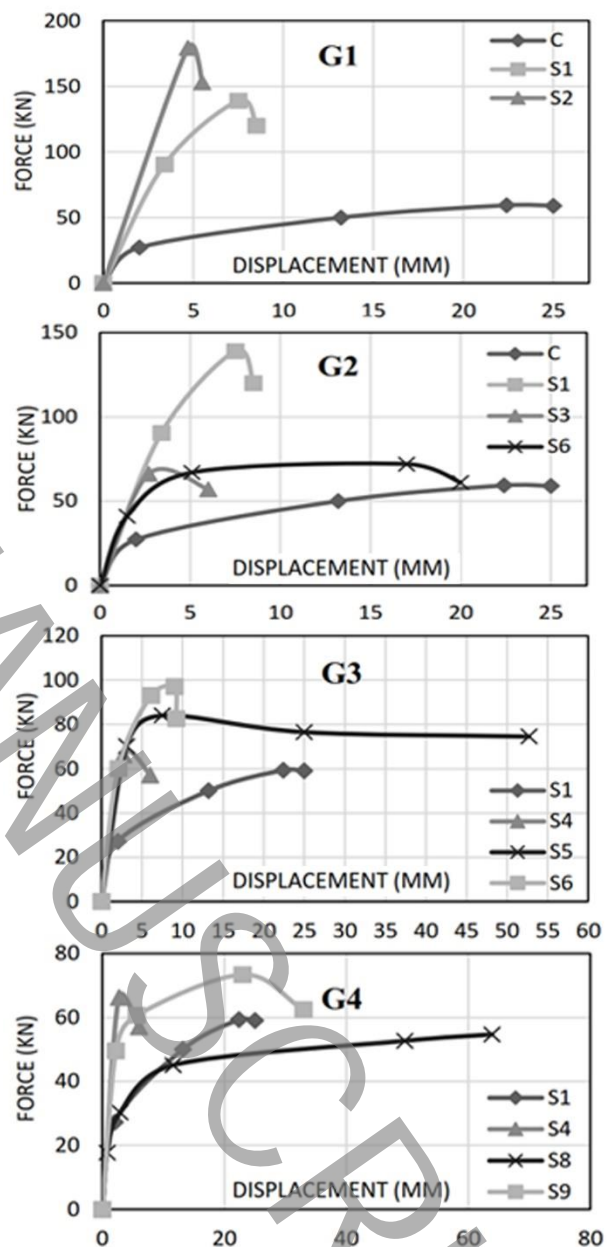


Figure 1. Load-Displacement graph

G4's graph shows that using both epoxy resin and expansion bolts for the strengthening plates with square arrangements of the perforations are the best bonding

method. This method increases the loading capacity by 20% while using epoxy resin alone only increases the loading capacity by 13.3%.

Figure 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 253% increase compared to C. Therefore, the arrangement of the perforations play an important role in the performance of the perforated plates. The results also shows 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%.

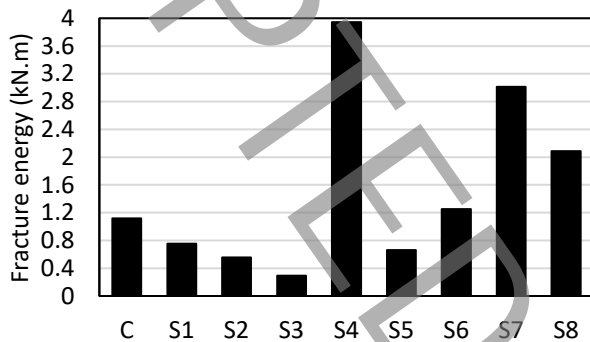


Figure 2. Energy absorption of experimental specimens

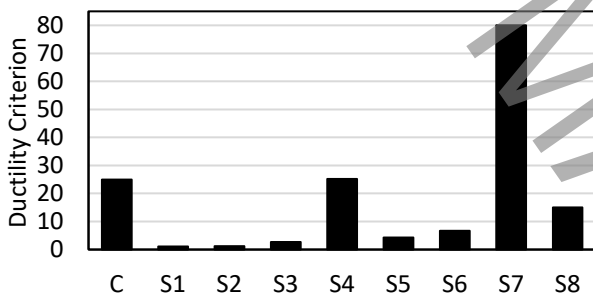


Figure 3. Ductility Criterion of experimental specimens

Figure 3 shows the ductility criterion for all the specimens. Ductility criterion for each specimen is represented by ultimate displacement to elastic displacement ratio. Comparing this criterion shows that using in-depth embedded anchorage bolts do not improve stiffness and ultimate strength, they increase ductility significantly up to 220%. Results also show that using epoxy for connection has no positive effect on ductility. Ductility of S4 is equal to control specimen, while S1 and S2 with non-perforate strengthening plates have low ductility criterion. Comparing the ductility of S3, S4 and S5 reveals 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 in order to strengthen two-way concrete slabs. RC slabs with 1200×1200×80 mm were studied. The results were categorized and compared in four groups. G1's results showed non-perforated steel plate with 2 mm thickness improved initial stiffness and loading capacity up to 200%, while showing decrease in energy absorption and ductility. 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. G3's results showed selecting the right arrangement can significantly affect its behavior and effectiveness. Rhombic arrangement with 62% improvement in loading capacity and circular arrangement with 253% improvement in energy absorption have shown the best performance. Finally, G4's results showed that using expansion bolts instead of epoxy resin for connection of the plate resulted in the reduction of loading capacity, but increased ductility criterion up to 220%. Studying the connection types of the strengthening plate also showed that using epoxy resin and bolts simultaneously resulted in the best performance in the strengthening system.

5. References

- [1] D. Banu, N. Taranu, Traditional Solutions For Strengthening Reinforced Concrete Slabs, The Bulletin of the Polytechnic Institute of Jassy, 3 (2010).
- [2] D.A.V. Gemert, Repair and Strengthening of Reinforced Concrete Plates by Epoxy-Bonded Steel Plates, 509-516.
- [3] A.N. Yelgin, H. Kasap, M.Z. Ozyurt, Strengthening of reinforced concrete slabs by thin steel plates glued with epoxy, Sakarya University journal of science SAUJS, 3 (1999) 25-34.
- [4] S. Huovinen, Action of Glued Steel Plates In Strengthening of Structures, Rakenteiden Mekaniikka, 29 (1996) 69-74.
- [5] L.S. Rasheed, T.K. Al-Azawi, Experimental Analysis Of Reinforced Concrete Slabs Strengthened With Steel Plates, The Iraqi Journal For Mechanical And Material Engineering, 13 (2013).
- [6] A. Charif, Structural Behaviour of Reinforced Concrete Beams Strengthened by Epxy Bonded Steel Plates, University of Sheffield, 1983.
- [7] U.A. Ebead, H. Marzouk, Strengthening of two-way slabs using steel plates, Aci Structural Journal, 99 (2002) 435-444.
- [8] A. Gomes, J. Appleton, Strengthening design of concrete beams by addition of steel plates, Technical University of Lisbon, Lisbon, Portugal.
- [9] N.K. Subedi, Member, ASCE, P.S. Baglin, External Plate Reinforcement For Concrete Beams, Journal Of Structural Engineering, 124 (1998) 1490-1495.