Behaviour of One-Way Reinforcement Concrete Cantilever Slabs with Openings

Aws Nabeel Yaseen¹, Ali Hussein Ali Al-Ahmed²

¹M.Sc. Student, Civil Engineering Department, University of Baghdad, Iraq
²Assistant Professor, Civil Engineering Department, University of Baghdad, Iraq

Email: aoussalzaedi@gmail.com, dr.ali-alahmed@coeng.uobaghdad.edu.iq

Abstract. In some concrete structures, openings are placed because of the need for several utility requirements. These openings could affect the strength of the structural members. So the behavior of reinforcement concrete (RC) cantilever slab containing openings and its effect is the subject of the study. Opening shapes, numbers and sizes are the main variables that have been studied in this research. Five RC cantilever slabs were cast and tested; one is without openings and the other four slabs are with openings. It is found that there is a significant effect of openings on the behavior of these slabs. Where, the decrease in the ultimate load (from 39kN to 24.7kN), while the decrease in the deflection at ultimate load (from 67 mm to 35 mm).

Key words: Reinforced concrete, cantilever slabs, openings, square, circular.

1. Introduction

In order to pass sewage pipes, internet lines and water supplies, it has become necessary to make openings in the slabs and roofs in concrete structures. These openings may be of large sizes sometimes, such as elevators or emergency stairs, and may be placed in a dangerous location in the structure for reasons related to the architectural design, whose construction requires special measures. The openings in concrete structures may lead to many problems, including reducing the stiffness of the structural member, as well as its resistance, increasing the deflection and developing many cracks around the openings. This complex behavior may be performed by the structural member due to decrease the area of concrete in the cross-sectional dimension [1-4]. Boon [5] prepared an experimental study on one-way reinforced concrete (RC) slabs that contains openings, and additional reinforcement was used to strengthen it. He noticed that the slabs without additional reinforced, the ultimate load was decreased by about 37% relative to the slab without opening. While for slabs which designed with additional reinforced around the opening, the ultimate load was decreased in a range between (26-34)%.

Afefy and Fawzy [6] carried out a study on one-way RC slabs with openings using various techniques for strengthening. They used NSM (Near Surface Mounted), ECC (Engineered Cementitious Composites) and EB-CFRP (Externally Bonded Carbon Fiber Reinforced Polymer). The researchers noticed that the strengthened slabs gave a higher resistance than the unstrengthened slabs by about 50%. Al-Hafiz [7] conducted an experimental study on one-way RC slabs containing openings using steel plates as a strengthening technique. The main variable was the thickness of the steel plates (2, 4 and 6) mm and the thickness of the slabs were (40, 60 and 80) mm. The researcher noticed that when the thickness of the steel plate increases, the decrease in resistance due to the opening is small.
Aman et al. [8] tested ten RC slabs containing openings except one as a reference slab. The dimensions of the openings were different. Several layers of CFRP strips were used to strengthen these slabs. The researchers noticed that when the openings area was increased from 5% to 20%, the ultimate load was decreased by about 7%. When 3 layers of CFRP were used instead of one layer leads to an increase in the ultimate load up to 9%. In general, openings lead to a decrease in the resistance; therefore, it is necessary to compensate for the decrease in resistance by taking special measures. Because of the lack of research and studies related to the cantilever slab, as well as the difference in the shape and number of openings are not studied in previous researches. This research aims to study the behavior of the cantilever slab that contains openings of different numbers and different shapes.

2. Experimental Program

Five RC cantilever slab models were cast and tested up to failure. These models were made with the same dimensions as follows: length= 2100 mm, width=600 mm and thickness=140 mm. All models have the same reinforcement details with main steel bars of 10 mm and secondary steel bars of 6 mm. Only one model was without opening (solid slab). Whereas, all the other four having openings. The edge of the openings was 150 mm away from the center of the interior support. The models were differed in the shape of the openings and their number as listed in Table 1.

It is worth to mention that the experimental program and materials tests were conducted at the laboratory of civil engineering department of the University of Baghdad.

Table 1: Description of tested slab

| Slab designation | Slab shape | Opening dimension (mm) | Opening shape | Number of openings |
|------------------|------------|------------------------|---------------|--------------------|
| SS               |            | N. A                   | N.A           | N.A                |
| SCO              |            | 280                    | Circular      | 1                  |
| SSO              |            | 250×250                | Square        | 1                  |
| SDCO             |            | 200                    | Circular      | 2                  |
| SDSO             |            | 175×175                | Square        | 2                  |

Where: SS refers to solid slab, SCO refers to slab with circular opening, SSO refers to slab with square opening, SDCO refers to slab with double circular opening and SDSO refers to slab with double square opening.

3. Material Properties

3.1. Concrete

Concrete was poured by a mixture track at the work site to avoid the difference in the resistance of the models due to the error of making various mixtures, and the target cube crushing strength was 27 MPa after 28 days of casting.
3.2. Steel bars reinforcement

Two diameters of steel reinforcement were used, the main longitudinal rebars of 10 mm and the secondary distribution rebars of 6 mm. The yield stress was 610 MPa and 515 MPa for rebars of 10 mm and 6 mm respectively.

4. Test Setup and Procedure

The load was placed on the free end of the model as a knife edge load with a load cell with a maximum capacity of 500 kN. Linear variable differential transformer (LVDT) was placed under the load to measure the amount of the free-end deflection during the test. At a distance of 850 mm from the free end, a roller-support was placed under the slab, while the other end was supported using a steel frame to make a fixed support. Figure 1 shows the layout of the reinforcing steel and specimen setup of a typical tested slab. While figure 2 shows the steel reinforcement distribution of the tested slabs.

![Figure 1: Typical details and loading setup](image-url)

![Figure 2: Steel reinforcement distribution of the tested slabs](image-url)
5. Test Result and Discussion

After observing the results of the tested slabs, it was found that the slabs with one opening showed least degradation in strength than the slabs with double openings compares with the solid slab. Generally, slabs with circular opening showed better strength than the companion slabs with square openings. It is noticed that the shape of the opening has a significant effect on slabs strength.

Table 2 illustrates the first cracking load, the ultimate load, and the deflection at the ultimate load. While, figures 3 to 7 show the failure and cracking pattern of the tested slabs.

**Table 2**: Details of the first cracking load, the ultimate load, and the deflection at the ultimate load.
Table 2: Summary of first cracking and ultimate loads and deflection at ultimate load of all tested slab

| Slab designation | Ultimate load (kN) | First cracking load (kN) | Deflection at ultimate load (mm) |
|------------------|--------------------|--------------------------|---------------------------------|
| SS               | 39.0               | 7.5                      | 67                              |
| SCO              | 35.5               | 6.7                      | 70                              |
| SSO              | 32.2               | 7.5                      | 52                              |
| SDCO             | 26.8               | 6.3                      | 35                              |
| SDSO             | 24.73              | 6.2                      | 37                              |

Figure 3: Crack pattern for slab SS at ultimate load.

Figure 4: Crack pattern for slab SCO at ultimate load.

Figure 5: Crack pattern for slab SSO at ultimate load.
6. Load Deflection Response

Figure 8 shows the load-free end deflection responses of the tested slabs. From this figure it could be noticed that slab model SCO showed a high resistance compared with the other models and was most close to the SS reference model. The ultimate resistance of this model was 35.5 kN compared with the reference model of 39 kN. The deflection was 70 mm, which is higher than the reference model by 3 mm. For slab model SSO, the ultimate load decreased and reached to 32.2 kN. For the deflection, this model showed high value than the other models which was 52 mm. The ultimate load of slab model SDCO was 26.8 kN. The deflection amount of this slab was very little which about 30 mm is. While, SDSO model which is the weakest model that failed at load of 24.73 kN and with maximum deflection of 37 mm.

In general, from the experimental results, it can be noticed that increasing the number of openings with a small diameter greatly reduces the resistance of the model.
Figure 8: Load deflection curves for all tested slabs.

7. Conclusion

Openings in concrete structure have a significant effect on the resistance, as the ultimate load drop was in the range of 8.97% to 36.58% relative to (SS) reference slab. The number of openings had a significant effect. When comparing the two models (SSO and SDSO) with each other, it's found that the SDSO model that contains two openings had a decrease in its resistance relative to the reference slab by 36.58%, while the SSO model had a decrease in the percentage of 17.45%, comparing with the two models (SDCO, SCO) It is also noticed that the decrease in the SDCO model containing two openings amounted to 31.28% of the SS slab. From this it appears that the increase in the number of openings leads to a significant decrease in the ultimate load. The shape of the openings has an effect on the ultimate load. When comparing (SSO, SCO) it was found that the decrease in the ultimate load in the SCO model was 8.97%, while in the SSO model it was 17.43%, and the same for the (SDCO, SDSO). The ultimate load drop (31.28%, 36.58%) respectively. And this decrease in resistance of slabs with square openings due to a sharp edges at the corners of openings, and this causes develop a more cracks.

8. References

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