Experimental Investigation of Slab-Column Connections of Reinforced Concrete Flat Slabs Subjected to Accelerated Corrosion

Hamidreza Samiee[1*], Ali Kheyroddin [2], Mohammad Kazem Sharbatdar[3]

[1] PhD, Faculty of Civil Engineering, Semnan University, Semnan, Iran
hrst19810@gmail.com, hamidreza-samiee@semnan.ac.ir
[2] Distinguished Professor, Faculty of Civil Engineering, Semnan University, Semnan, Iran;
kheyroddin@semnan.ac.ir
[3] Professor, Faculty of Civil Engineering, Semnan University, Semnan, Iran
msharbatdar@semnan.ac.ir

ABSTRACT

Reinforced concrete flat-slab systems are widely used for their architectural flexibility and construction efficiency. However, the lack of distributing beams increases the chance of two-way shear concentrations at slab–column connections, raising the risk of progressive collapse. This study investigates how corrosion affects embedded beams and examines its impact on the structural performance of reinforced concrete (RC) slabs. Seven slab–column connection specimens were built and tested in a two-phase experimental program, including evaluations of bidirectional shear strength. The research analyzed load–deformation behavior, failure modes, crack patterns, material hardness, and absorption properties. Results show that increasing the flexural reinforcement ratio improves the two-way shear capacity: specimens with low, medium, and high reinforcement ratios reached peak capacities of about 234 kN, 272 kN, and 321 kN, respectively. More reinforcement also decreased deformation percentages (from 11.85% to 9.70% and 6.41%) and changed crack patterns from mainly radial to parallel orientations relative to exterior columns. Corresponding changes in failure mode were observed, shifting from flexural to flexural–shear or from flexural–shear to two-way shear as reinforcement increased. Comparing these results with design standards such as ACI 318-19, CSA A23.3-14, Eurocode 2, and BS 8110-97 showed that these codes did not accurately predict the behavior of the tested specimens. The findings highlight weaknesses in current design practices for slab–column joints affected by corrosion and provide insights for developing more resilient detailing and assessment methods for flat-slab structures.

KEYWORDS

Reinforced Concrete Flat Slabs, Flexural Reinforcement Ratio, Accelerated Corrosion, Two-Way Shear Strength, Deflection Capacity.

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1. Introduction

The reinforced concrete (RC) flat slab structure system is widely employed in tall, multi-story buildings because of its large spans, low thickness, easy formwork, and flexible plan layout. However, slab-column connections are vulnerable to brittle two-way shear failure, which is commonly triggered by corrosion of the reinforcement in severe environmental conditions, which leads to a rapid loss of Two-way shear capacity [1].

Several theoretical resistance models have been developed to predict the two-way shear resistance of slab-column connections [2].

Corrosion of embedded reinforcement within concrete is an electrochemical process [3]. The formation of corrosion products (rust) creates expansion stresses within the surrounding concrete matrix. This results in tensile cracking [4]. The ultimate consequences include reduced cross-sectional area of reinforcement [5], and negative effects on the two-way shear failure mechanism and overall structural behavior [6, 7]. Consequently, predicting the two-way shear strength of slab-column connections becomes increasingly unreliable [8, 9].

Current design codes inadequately predict the two-way shear capacity of corroded RC flat slab structures, especially under moderate to severe corrosion. This research proposes initial coefficients to account for corrosion effects and to improve predictions of two-way shear strength in corroded flat slab-column connections.

2. Experimental program

in this study, seven experimental-scale RC slab-column connections with identical structural designs were developed to examine the effects of flexural reinforcement corrosion on the two-way shear strength of flat slab structures. Fig. 1 illustrates the dimensions and reinforcement details of a representative specimen. To simulate corrosion, all specimens were exposed to corrosive conditions for three months.

This experimental study employed an accelerated corrosion technique utilizing the impressed current method, in which an electrical current is passed through the reinforcement to speed corrosion, reducing the test duration. This procedure was executed using a controllable direct current (DC) power supply, as depicted in Fig. 2.

After the accelerated corrosion test, all specimens were subjected to a concentrated load. This assessed the two-way shear capacity using a quasi-static loading method. The specimens were placed on a supporting frame that rested on the strong concrete floor. Four steel rollers supported the four edges, simulating simple supports and allowing corner uplift as the load was applied. The displacement-controlled method maintained the quasi-static load application.

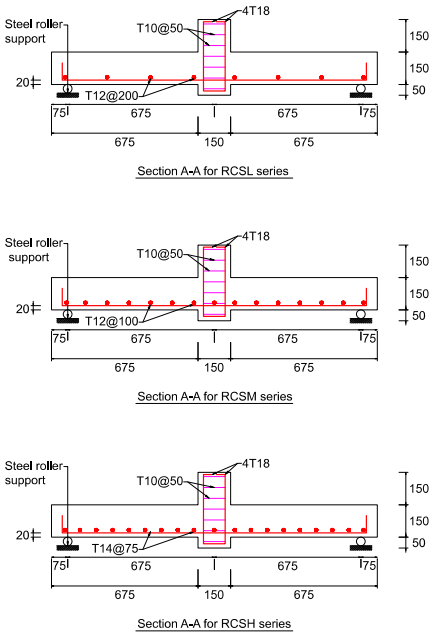

Fig. 1. Dimensions, reinforcement details.

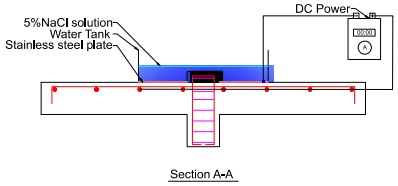

Fig. 2. Accelerated corrosion method.

3. Test results and discussion

The most severe corrosion was observed around the edges of the column stub. This is likely because initial cracks in the RC flat slab allowed the NaCl solution to penetrate more easily, leading to the accumulation of corrosion products around the corroded reinforcements and accelerating the corrosion process. By contrast, uncorroded reinforcements and the surrounding concrete provide a confining effect, which results in considerably thinner or fewer cracks in the concrete near the edge of the corrosion area. The reinforcements embedded within the corrosion area were extracted from the specimens after the loading test was completed. This procedure aimed to evaluate the actual corrosion levels and material properties. The actual corrosion level was ultimately quantified based on Eq. 1.

$$\eta = \frac{\Delta m}{m_i} \times 100\% = \frac{m_i - m_f}{m_i} \times 100\% \quad (1)$$

Table 1 summarizes the corrosion levels measured in the samples. Notably, the RCSL series exhibited the

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highest corrosion levels. The RCSL-C and RCSM-C series exceeded initial predictions, while the RCSH-C series demonstrated lower levels than anticipated. The discrepancy in corrosion levels can be attributed to the influence of flexural reinforcement density in the corrosion area: increased density enhances the concrete's ability to confine, thereby minimizing the formation of fine cracks. This, in turn, limits the penetration of corrosive solutions, resulting in reduced corrosion levels.

Table 1
Material properties of corroded reinforcements.

Specimen ID	$\bar{\eta}$ (%)	η_{max}(%)
RCSL	20.2	21.5
RCSM	19.9	21.7
RCSH	11.7	13.1

Note: $\bar{\eta}$ and η_max are the average and maximum measured corrosion level, respectively

As illustrated in Table 2, the observed two-way shear strengths for the specimens RCSL, RCSM, RCSH, RCSL-C, RCSM-C, and RCSH-C were recorded as 234, 272, 321, 136, 228, and 304 kN, respectively. Notably, as the flexural reinforcement ratio increases, the two-way shear strength is enhanced for all specimens. Specifically, the results show that the two-way shear capacity of the uncorroded specimens RCSM and RCSH exceeds that of the RCSL specimen by factors of 1.16 and 1.37, respectively. Similarly, for the corroded specimens RCSM-C and RCSH-C, the two-way shear capacities are increased by factors of 1.68 and 2.24, respectively, relative to RCSL-C. Furthermore, specimen RCSL-C behaves differently compared to RCSM-C and RCSH-C, as it shows early deviation from the uncorroded curve, whereas the others show sudden drops at failure. This early deviation can be related to a lower flexural reinforcement ratio, more extensive corrosion, and yielding of all the flexural reinforcement before failure; these factors result in a predominantly flexural failure mode. Conversely, the corroded specimens exhibit a reduction in shear strength compared to the control, with decreases of 42, 16, and 5% for RCSL-C, RCSM-C, and RCSH-C, respectively. This observation indicates that the adverse effects of corrosion on two-way shear strength diminish significantly as the flexural reinforcement ratio increases.

Table 2
Summary of test results.

Specimen ID	Δ_{cr} (mm)	V_{cr} (kN)	Δ_y (mm)	V_y (kN)	Δ_u (mm)	V_u (kN)
RCSL	0.92	74	2.12	113	11.85	234
RCSM	1.06	69	5.85	232	9.70	272
RCSH	1.60	109	5.28	291	6.41	321
RCSL-C	0.20	27	1.10	76	6.97	136
RCSM-C	1.82	102	3.44	163	5.85	228
RCSH-C	1.63	138	3.24	221	5.73	304
RCSH-C	1.63	138	3.24	221	5.73	304

Note: Vcr, Δcr, Vy, Δy, Vu, and Δu are the loads and deflections corresponding to the appearance of the first crack, the first yielding of flexural reinforcements, and the two-way shear failure, respectively;

4. Conclusion

- Corrosion significantly reduced the two-way shear capacity and deflection compared to uncorroded specimens. The lesser impact on higher reinforcement specimens results from increased reinforcement density. This enhances concrete confinement, mitigates cracking, and slows corrosion.

5. References

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