Retrofitting The Punching Shear of Two-Way Concrete Slabs by Using An Innovative Style of Reinforcing

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Abstract

This research introduces a new technique concerning the reinforcing of two-way concrete slabs by using steel plate with an octagonal shape of openings rather than traditional bar reinforcement. The experimental program consists of casting and testing four slab models with overall dimensions of 1050x1050x60 mm. One of these models is reinforced by classical deformed bars, while the other three models are reinforced by perforated steel plate. The adopted shapes of openings in used steel plate were octagonal, and the effects of three sizes were investigated. All models have the same amount of steel and are tested under a punching shear load to provide the same conditions for equitable comparison. The results show that the models reinforced by perforated steel plate display better behavior than the models reinforced by traditional bar reinforcement. The average punching shear loads of small, medium and large openings were 66.67%, 82.05%, and 53.85% greater than the model reinforced by deformed steel bars, respectively. The proposed reinforcing technique can be considered a good solution for increasing the resistance of two-way concrete slabs under punching shear with a relatively small thickness of slabs. As a result, the less amount of concrete with the same amount of steel and more efficient behavior means the proposed technique provides good structural enhancement with economical outcomes.

Keywords: two-way slabs, punching shear, self-compacting concrete, perforated plate, octagonal openings

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1. Introduction

The main structural concept concerning the reinforcing two-way concrete slabs is to provide individual steel elements (steel bar) and then put these elements at suitable distances with suitable connections between them to produce the rebar mesh. In this research, the investigation of the validity of using perforated steel plate instead of normal reinforcement found many advantages, like enhancement in structural behavior (better specification), reducing the amount of concrete (lower cost), and providing an equivalent rebar mesh (perforated steel plate) to reduce the time of implementation (less time). According to previous, the use of perforated steel plate instead of steel bars will satisfy benefits in time, cost, and specification.

The largest structural problem in concrete is the low resistance to tension stress, so the use of steel in the tension zone for the concrete members can be considered one of the keys leading to major developments in the structural concrete branch. The researchers aimed to create a mechanical interlock since the chemical adhesion force between concrete and steel is insufficient for structural purposes. A new type of shear connector was suggested in 1987, which used a steel plate with a suitable number of openings. This type of shear connector is called Perfobond rib [1-5]. Veldanda and Hosain (1992) tested the validity of this type of shear connecter [6], while Oguejiofor and Hosain (1994) tried to establish this type of shear connecter through using a parametric study about it [7]. Al Zahid and Alwash (2022) upgraded the use of this type of shear connector and employed perforated steel plate with circular openings as a reinforcing technique instead of steel bar. The results of

their study refer to the success of this reinforcing technique [8].

This research experimentally investigates the effect of using perforated steel plate, with octagonal openings, as a reinforcing system instead of the traditional reinforcement and then compares the outcome of this suggested reinforcing technique with that model reinforced by normal reinforcement. In addition to the use of different shapes of openings, the type of concrete will be self-compacting concrete to be sure that there are no voids under the plates. The experimental program will consist of casting four slab models with overall dimensions of 1050*1050*60 mm. Three models will be reinforced by perforated steel plate, while the other one will be reinforced by deformed steel bar. All the models will have the same equivalent amount of steel. Each of the three models is reinforced by perforated steel plates with octagonal openings. The selected shapes of openings are octagonal to increase the mechanical interlock between the concrete and steel plate. Each shape will have three sizes: small, medium, and large openings with the same amount of steel. All models will be tested under a punching shear load using 150 * 150 mm at the midpoint of slabs.

2. Materials And Methods

This section includes all of the items that were required to complete the experimental program of this study, as well as the test methodology:

2.1. Type of concrete

The essential key for success this technique of reinforcing is to choose a suitable type of concrete. Casting the concrete without cavitations under the perforated plate is critical here, hence self-compacting concrete is necessary [9-10]. The ratio of used ingredients is clarified in the Table 1.

Table 1 Ingredients ratio of concrete

Materials	Ratio
Cement	1.000
Water	0.350
Sand	1.750
Gravel	2.000
Glenium 54	0.018
Silica Fume	0.050

The average cylindrical compressive strength was 30.07 MPa.

2.2. Details of reinforcing models

The reference slab was reinforced by traditional steel bars with a minimum amount of steel, Asmin of 0.0018Ag [11], where the diameter of the used bar was 6 mm. The yield strength of steel bars was 590 MPa. The significant part is to provide the same amount of steel in the form of perforated steel plate with the same value of yield strength, but this point is not applicable. So, a mathematical strategy is needed to solve the previous problem and provide an equivalent amount of steel in all models.

2.3. The mathematical modeling of equivalent reinforcement

The basic concept on which the structural engineer relies for calculating the quantity of steel is the ratio of steel to concrete, which is denoted by the Latin symbol Rho (ρ):

$$\rho = \frac{Area\ of\ steel\ (As)}{Area\ of\ concrete\ (bd)} \qquad (1)$$

However, there is a hidden value in the above equation that represents one unit length from each steel reinforcement and concrete cross section, which can be mathematically translated as:

$$\rho = \frac{As*1}{bd*1} \qquad (2)$$

Alternatively, the above equation can be rewritten as:

$$\rho = \frac{Volume\ of\ steel}{volume\ of\ concrete} \qquad (3)$$

The amount of steel in slabs reinforced by perforated steel plate will be evaluated using the preceding equation. Because of the difference in yield strength between steel reinforcements and perforated steel plate, an equivalent amount of perforated steel plate will be necessary here as:

Generally, in case of $f_{y_{psp}} = f_{y_{tr}}$

$$\rho_{psp} = \rho_{tr} \qquad (4)$$

Note that :

f_y = yield strength of steel

psp = perforated steel plate

tr = traditional bar reinforcement

But anyway, the yield strength of classical deformed bar reinforcement and steel plate have not the same value, so

(ρ_{tr})= Equivalent ρ_{tr} (5)

The primary aim that should be satisfied is

$$As * fy_{psp} = As\, fy_{tr} \quad (6)$$

Substitute Eq. (6) in Eq. (4) and Eq. (2)

$$\frac{As * fy_{psp} * 1}{bd * 1} = \frac{As\, fy_{tr} * 1}{bd * 1} \quad (7)$$

$$\frac{Volume\ of\ PSP * fy_{psp}}{volume\ of\ concrete} = \frac{Volume\ of\ tr * fy_{tr}}{volume\ of\ concrete} \quad (8)$$

$$Volume\ of\ PSP * fy_{psp} = Volume\ of\ rs * fy_{sr} \quad (9)$$

According to the previous, the details of the perforated steel plate were in Table 2.

Table 2 Details of used perforated steel plates

Describe of openings	Octagonal openings	
	Side length mm	Distance between openings' edges mm
Small opening (12*12)	27.4	17.1
Medium opening (8*8)	41.1	25.7
Large opening (4*4)	82.3	51.3

The plates were 1000*1000*1 mm in size and were adopted as a reinforcement rather than traditional steel bars for the models. Fig. 1 depicts the perforated steel plate employed in the current work.

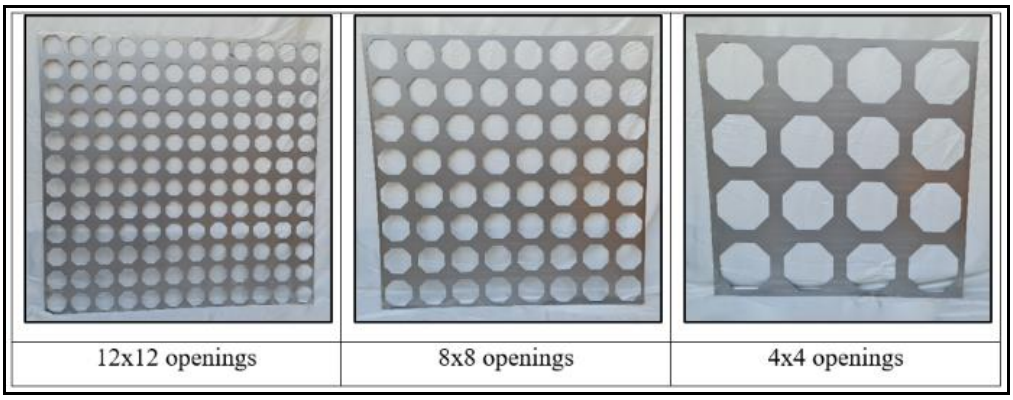

Fig. 1 Perforated steel plate – Octagonal openings

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2.4. Loading and Supporting Conditions

A universal machine with a capacity of 2000 kN was used to test the models. A rigid steel frame was used to provide simple support. The load condition was created to simulate a punching shear load by subjected 150*150 mm on the top face of the models [12], The loading status is illustrated in Fig. 2.

Fig. 2 Testing models under punching load

3. Experimental Results

The results comprise three main categories, as stated below.

3.1 Load deflection curves

In this study, three sizes of octagonal openings were considered: PSPO1-Co with a side length of 27.4 mm and 12x12 openings, PSPO2-Co with a side length of 41.1 mm and 8x8 openings, and PSPO3-Co with a side length of 82.3 mm and 4x4 openings. As illustrated in Fig. 3, all previous models were compared to a reference one reinforced by a normal deformed bar, Re-Co.

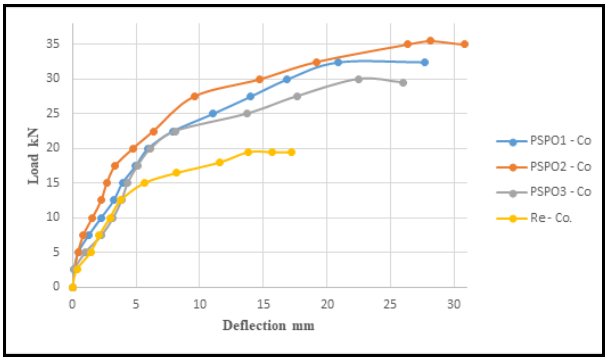

Fig. 3 Effect of change size opening for octagonal shape

3.2 First crack load and crack width

A monotonic load was applied to the slab models till the first visible cracks were observed. The load continued to increase up to the ultimate load. The crack widths were recorded at the stage that the first visible cracks appeared, in addition at the ultimate load. Moreover, crack width was taken between these two stages. Table 3 elaborates on the recorded results.

Table 3 Loads and corresponding crack's width – uniform load

No.	Model's name	Load kN	Crack's width mm
1	Re - Co	10	0.482
		15	3.17
		19.5	9.52
2	PSPO1 – Co	10	0.89
		25	2.42
		32.5	3.28
3	PSPO2 – Co	10	0.71
		20	1.84
		35.5	4.00
4	PSPO3 – Co	10	0.81
		22.5	2.35
		30	4.11

3.3 Crack pattern

A methodology for tracing the crack development process was considered since the proposed method for reinforcing two-way concrete slabs is still under research. The green cracks occurred at the load where the first visible crack appeared, while the red cracks occurred at the ultimate load. Blue was used to highlight the cracks between these loads. A computer mapping was prepared to clarify these stages. Fig. 4, 5, and 6 show the cracks forming in these three stages of the Re-Co, PSPO1-Co, PSPO2-Co and PSPO3-Co, respectively.

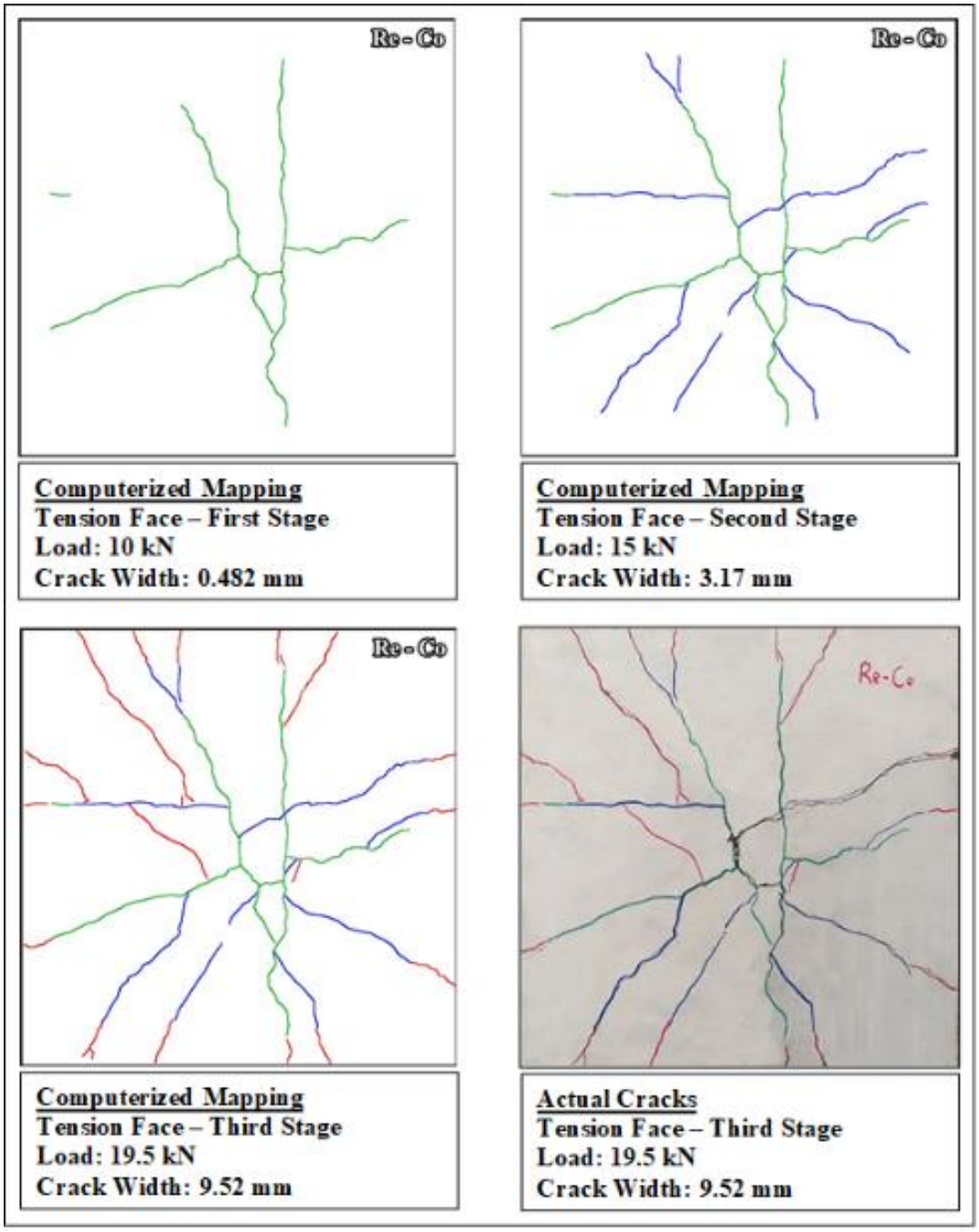

Figure 5. Cracks propagation in Re-Co

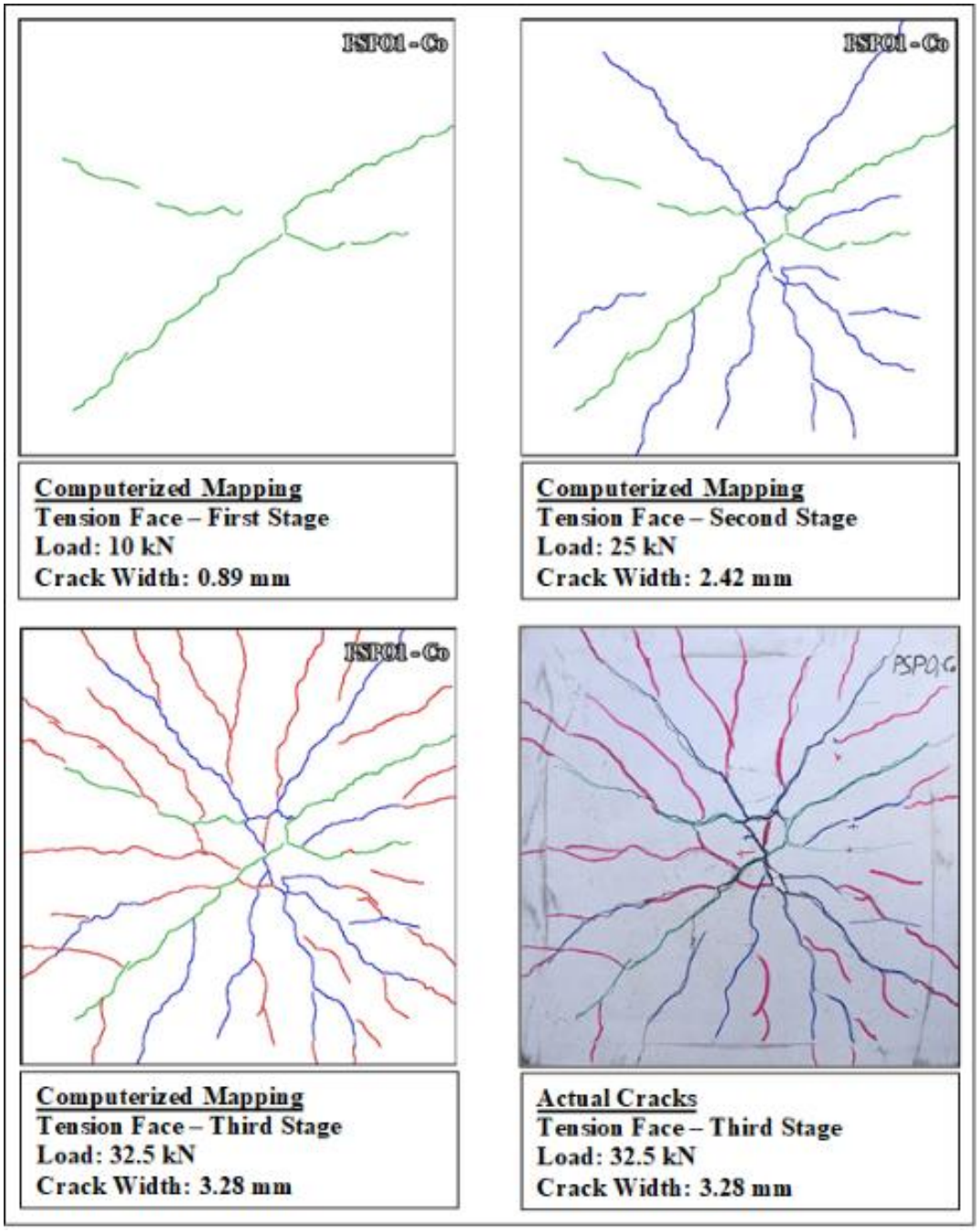

Figure 6. Cracks propagation in PSPO1-Co

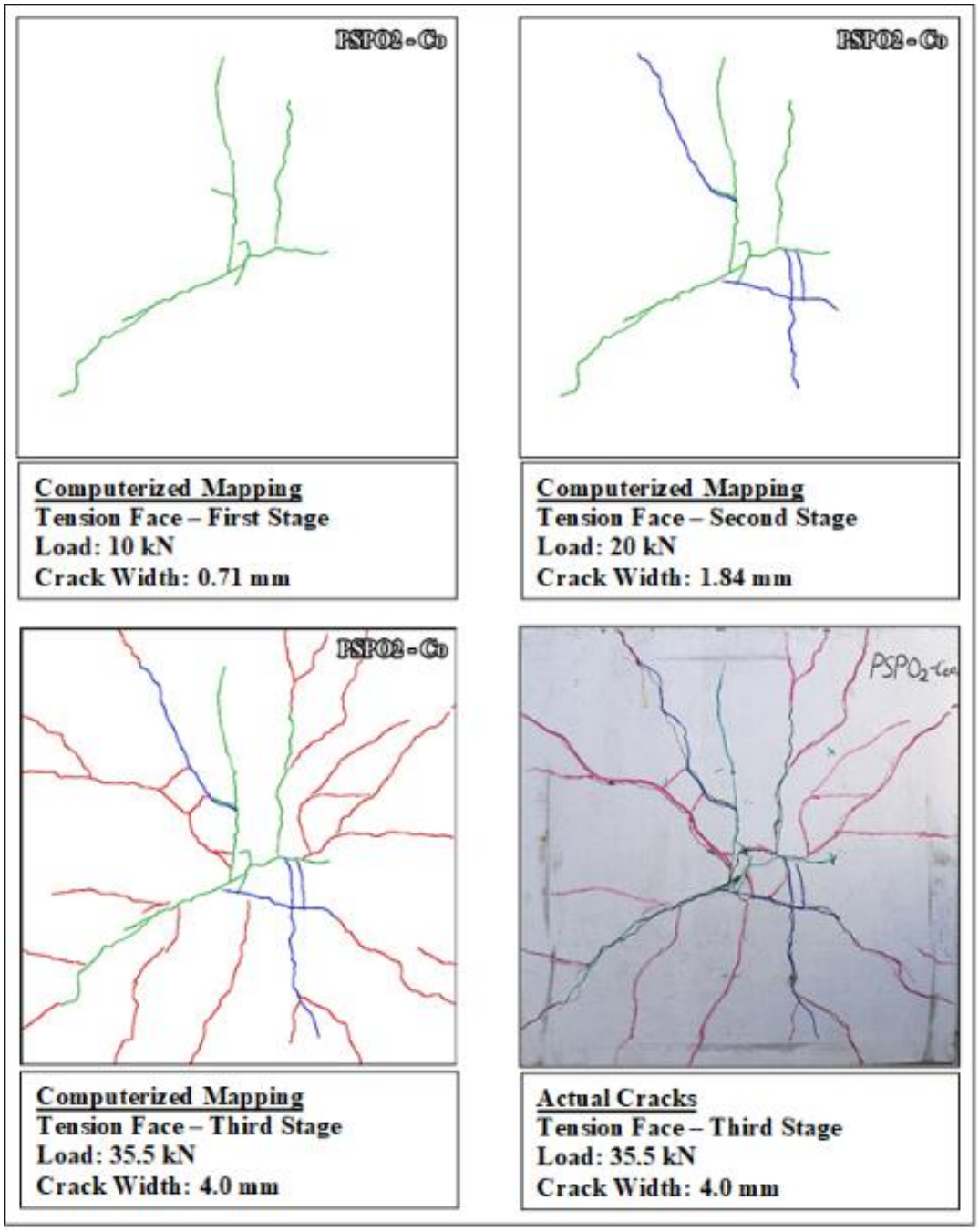

Figure 7. Cracks propagation in PSPO2-Co

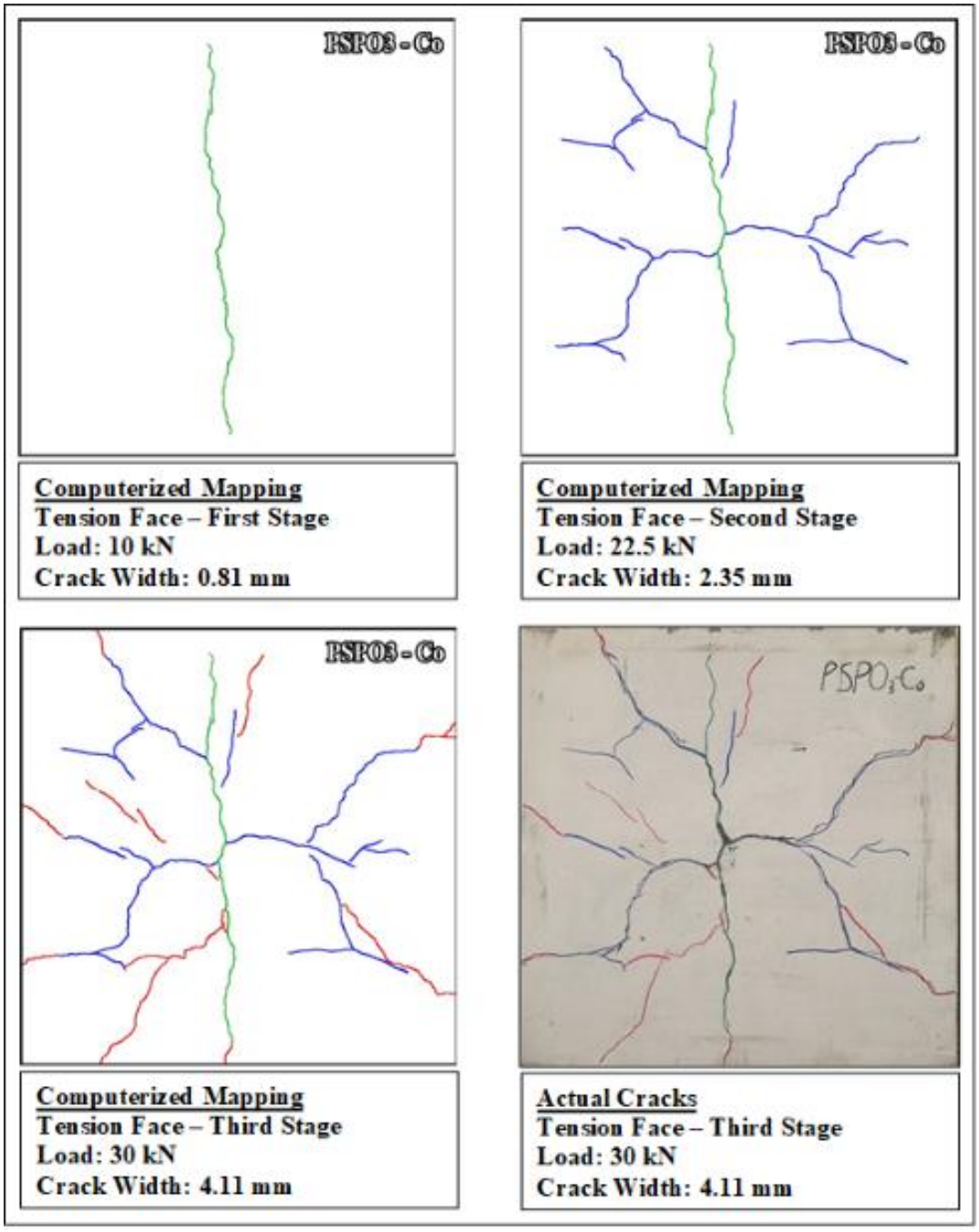

Figure 8. Cracks propagation in PSPO3-Co

4. Results Discussion

The PSPO1-Co, PSPO2-Co, and PSPO3-Co, ultimate loads were 32.5 kN, 35.5 kN and 30 kN, respectively, while the models were reinforced by normal steel bars Re-Co has an ultimate load equal to 19.5 kN. As a result, the specimens PSPO1-Co, PSPO2-Co, and PSPO3-Co had greater ultimate loads than Re-Co by about 66.67%, 82.05% and 53.85%, respectively.

In addition, slabs reinforced by medium-sized openings were stiffer than other models, as shown in Fig. 3.

The first visible crack load in all models has approximately the same value. At a load of 10 kN, the cracks are noticed by monitoring, but in developing the load, the response of slabs reinforced by perforated steel plate shows a lesser crack width than slab reinforced by normal deformed bars.

5. Conclusions

The proposed reinforcing technique, which

uses perforated steel plate as reinforcement rather than steel bars, has a greater ultimate load and stiffer behavior than the traditional method, which uses deformed steel bar. Furthermore, the proposed method eliminates several phases in the implementation process, such as spreading the bar reinforcements and combining them to form the rebar mesh. It is regarded to be easier for the site's supervising engineer to check. The octagonal medium openings (64 openings as 8*8) outperform the small size (144 openings as 12*12) and the large size (16 openings as 4*4). Based on previous results and more future studies, the suggested method of reinforcing the two-way concrete slabs may change the style of reinforcing slabs due to improved outcomes.

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