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Retraction

Retraction: Finite element analysis of two-way hollow core reinforced concrete slab under punching repeated load (*IOP Conf. Ser.: Mater. Sci. Eng.* **1145 012051)**

Published 23 February 2022

This article (and all articles in the proceedings volume relating to the same conference) has been retracted by IOP Publishing following an extensive investigation in line with the COPE guidelines. This investigation has uncovered evidence of systematic manipulation of the publication process and considerable citation manipulation.

IOP Publishing respectfully requests that readers consider all work within this volume potentially unreliable, as the volume has not been through a credible peer review process.

IOP Publishing regrets that our usual quality checks did not identify these issues before publication, and have since put additional measures in place to try to prevent these issues from reoccurring. IOP Publishing wishes to credit anonymous whistleblowers and the [Problematic Paper Screener](#) [1] for bringing some of the above issues to our attention, prompting us to investigate further.

[1] Cabanac G, Labbé C and Magazinov A 2021 arXiv:[2107.06751v1](https://arxiv.org/abs/2107.06751v1)

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Finite element analysis of two-way hollow core reinforced concrete slab under punching repeated load

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Abstract. This research provides information about the finite element analysis of the structural behavior of an innovative new type of two-way hollow reinforced concrete (RC) slabs of two-way plastic piping system under the effects of concentrated punching repeated loads. This new type of two-way hollow slab could be constructed by replacing part of the concrete volume by a continuous network of two-way plastic piping system to cut portion of the dead loads by reducing the self-weight of the created slabs as well as offering networks of voids inside the RC slab which could be valuable for passing utility lines. The reliability of elements forms, material characteristics, types of constants and the convergence study of the proposed finite element model of the new type of two-way hollow RC slabs was confirmed by the outcomes of the numerical study and the experimental results using five different parametric studies. The proposed FE model showed satisfactory accuracy with a maximum variance ratio of about 0.11 in comparison with the ultimate loading capacity of the experimental behavior. The results were demonstrating the efficiency of the new methodology of producing two-way hollow RC slabs using the two-way piping system by reducing the self-weight by about 24% with maintaining about 79% of the total strength. Moreover, the reduction in the strength could be eliminated by locating the networks of plastic pipes out of the locations of the maximum stresses, adding micro steel fiber, using high strength concrete or increasing the reinforcement ratio.

Keywords: Finite element analysis, two-way hollow, piping system, punching, repeated loads.

1. Introduction

Today, one of the requirements of constructing different types of reinforced concrete buildings is providing large spaces with a minimum number of columns. Increasing the clear spacing could lead to several issues such as increasing the slab depth, increasing the self-weight and causing higher cost. A number of choices are offered in practice such as using RC slabs of higher depth, prestressing the reinforcement or replacing RC solid slab by RC hollow slab. The first option of using deeper RC slabs provides higher stiffness that can lead to satisfying the requirements of the serviceability. Unfortunately, using thicker RC slabs could lead to several issues, including producing heavier slabs, which requires bigger structural members (foundations and columns) along with effecting the clear height of floors. The second mentioned option (using prestressed units) also has several issues, including the necessities of highly trained staff and expensive equipment. In contrast, the third option



of using hollow RC slab systems, which usually produced by replacing a portion of the volume of the solid concrete by styro-foam blocks, plastic molds or polystyrene blocks, could provide lower self-weight, thinner columns, smaller foundations, less construction material and lower time of construction [1, 2].

Over the last decades, several types of research were conducted on the structural behavior of hollow RC slab. It has been reported that increasing the hollowness ratio of hollow-core slab led to reducing the ultimate shear strength along with decreasing the ductility [3]. Replacing a portion of the solid concrete by hollow steel pipes increased the ultimate capacity and improving the slab toughness by reducing the deflection [4]. It also was shown that using both cubes and spheres that were made from recycled polypropylene, in fabrication RC hollow slabs led to similar ultimate capacity [5]. Furthermore, the mechanical performance of the hollow-core RC slab was significantly improved by increasing the thickness [6, 7]. The structural performance of hollow-core RC slab has been proved to be improved by using shear reinforcement [8].

Engineers have been concerned in investigating the structural behavior of two types of RC hollow slabs including one-way hollow RC slabs (such as hollow-core slabs) and biaxial voided RC slab systems (such as styro-foam, Airdeck, BubbleDeck, U-boot, and cobiax). Those systems of RC hollow slab could be used only in dropping the self-weight of RC slabs. In contrast, the suggested new category of two-way hollow RC slab decreases the self-weight of RC slabs and providing continuous networks of voids inside the RC slabs that could be used in passing utility. The present paper provides valuable information regarding the finite element analysis of the structural behavior of the new system of two-way hollow RC slab using ABAQUS/Standard 2017.

2. Details of the testing platform

2.1. Materials

Traditional Portland cement, fine aggregates, coarse aggregates and superplasticizer (Sika ViscoCrete® 5930-L) were used in producing concrete mixtures. Moreover, silica fume was used in producing self-compacting high strength mixtures, and limestone was used in manufacture normal strength self-compacting mixtures. Also, fiber reinforced concrete was produced using micro steel fibers. Steel rebar ($\varnothing 6$ and $\varnothing 4$) of diameter (6 mm and 4 mm, respectively) were used as (main and secondary reinforcement, respectively) in producing both the bottom and top layers of reinforcement, respectively. Finally, the two-way piping systems were fabricated using plastic pipes and plastic fittings, as shown in Fig. 1.



Figure 1. Using two-way plastic piping systems in assembling two-way hollow RC slabs.

2.2. Testing parameters

The structural behavior of eight RC slabs (two reference solid RC slabs and six two-way hollow RC slabs of different parameters with dimensions of $(80 \times 880 \times 880 \text{ mm})$ was evaluated under the effects of concentrated punching repeated loads (CPRL). The influences of five variables were evaluated in this study, including the following:

1) Manufacturing two-way hollow RC slabs of two-way plastic piping systems of various hollowness ratio (0%, 16% and 24%) was assessed by testing $C_{65}.F_0.H_{24}.D_{40}.R_1.A_u.L_c$, $C_{65}.F_0.H_{16}.D_{32}.R_1.A_u.L_c$ and $C_{65}.F_0.H_0.D_0.R_1.A_0.L_c$ concrete slabs, as presented in Fig. 2(B, A, and C, respectively).

2) Assembling two-way hollow RC slabs of two-way plastic piping systems with concrete mixtures of strength ($f'_c = 35$ MPa for concrete of normal strength and $f'_c = 65$ MPa for concrete of high strength) was observed through testing $C_{65}.F_0.H_{24}.D_{40}.R_1.A_u.L_c$, $C_{65}.F_0.H_0.D_0.R_1.A_0.L_c$, $C_{35}.F_0.H_{24}.D_{40}.R_1.A_u.L_c$ and $C_{35}.F_0.H_0.D_0.R_1.A_0.L_c$ RC slabs, as presented in Fig. 2(B, C, B, and C, respectively).

3) Producing two-way hollow RC slabs by applying different arrangements of two-way plastic piping systems was evaluated through testing $C_{65}.F_0.H_{16}.D_{32}.R_1.A_{nu}.L_c$, $C_{65}.F_0.H_0.D_0.R_1.A_0.L_c$ and $C_{65}.F_0.H_{16}.D_{32}.R_1.A_u.L_c$ RC slabs, as presented in Fig. 2(D, C, and A, respectively).

4) Constructing two-way hollow RC slabs using concrete mixtures of fiber reinforced concrete and two-way plastic piping systems was examined through testing $C_{65}.F_{1.5}.H_{16}.D_{32}.R_1.A_u.L_c$, $C_{65}.F_0.H_{16}.D_{32}.R_1.A_u.L_c$, and $C_{65}.F_0.H_0.D_0.R_1.A_0.L_c$ RC slabs, as presented in Fig. 2(A, A, and C, respectively).

5) Producing two-way hollow RC slabs of two-way plastic piping systems and a higher reinforcement ratio was evaluated through testing $C_{65}.F_0.H_{16}.D_{32}.R_2.A_u.L_c$, $C_{65}.F_0.H_{16}.D_{32}.R_1.A_u.L_c$ and $C_{65}.F_0.H_0.D_0.R_1.A_0.L_c$ RC slabs, as presented in Fig. 2(A, A, and C, respectively).

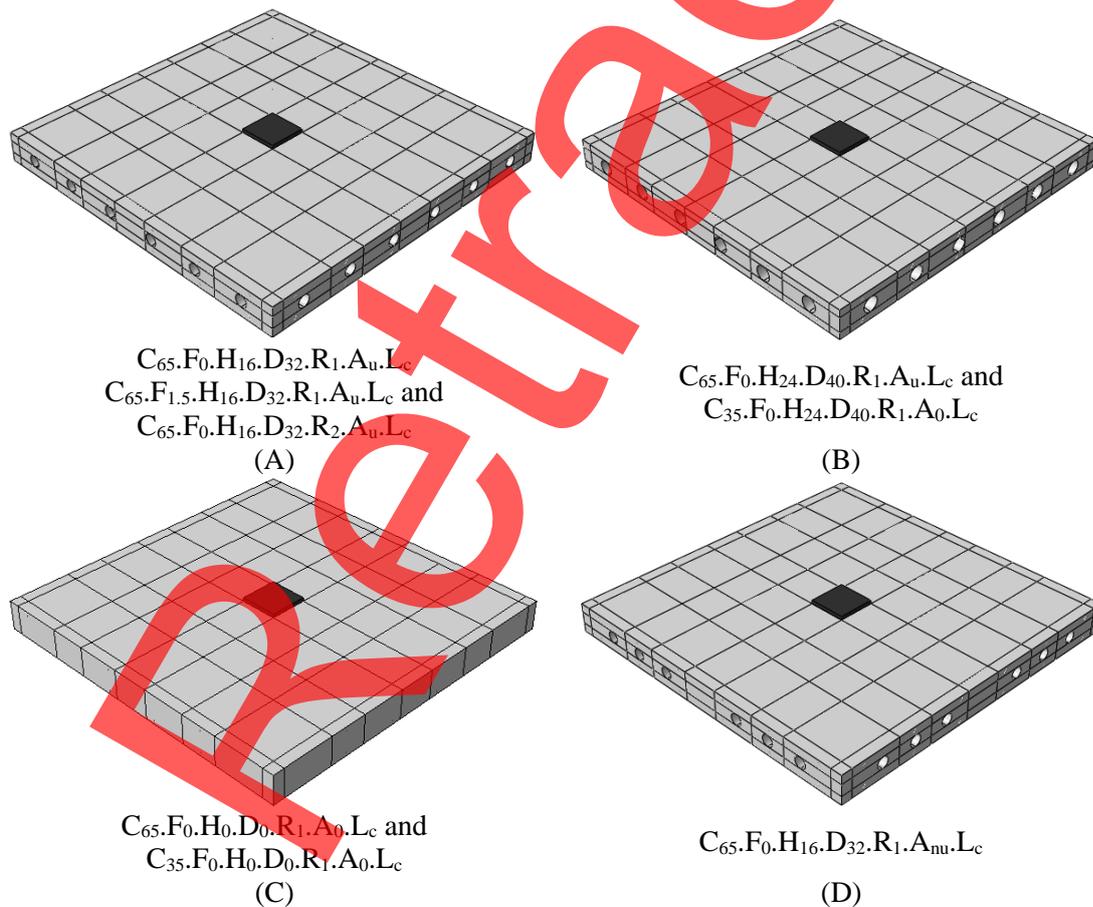


Figure 2. Details of RC slabs.

2.3. Details of reinforcement

All RC concrete slabs were reinforced by a bottom layer of $6\phi 6@150$ cm c/c and a top layer of $6\phi 4@150$ cm c/c in two orthogonal directions excluding two-way hollow RC slab C₆₅.F₀.H₁₆.D₃₂.R₂.A_u.L_c of 16% of voids that had a bottom layer of $12\phi 6@75$ cm c/c and a top layer of $6\phi 4@150$ cm c/c in two orthogonal directions. A clear uniform cover of 1 cm was used for RC slabs.

2.4. Supporting and loading conditions

The supporting system was designed to provide a simply supporting condition by utilizing four solid steel circular shafts of diameter (20 mm) that setting on a rigid I-section steel frame, as presented in Fig. 3. As demonstrated in Fig. 3, the concentrated punching repeated load (CPRL) was applied to the RC slabs using a steel plate of dimensions (100 × 100 × 10 mm). The concentrated punching repeated load was applied over five phases with a set of ten intervals with an increment of about 20% of the expected ultimate loading capacity. Finally, steel C-clamps were utilized to prevent the uplifting of the corners.

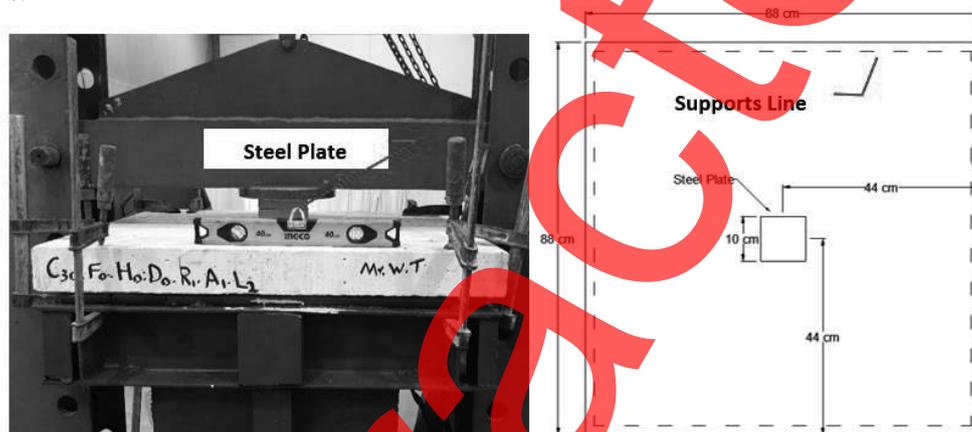


Figure 3. Details of the supporting and loading parameters.

3. Finite element model of two-way hollow slab

Nonlinear FEA was performed to analyze the mechanical behavior of two-way hollow RC slabs under the effects of concentrated punching repeated load using an advanced three-dimensional FE engineering computer program (ABAQUS/Standard 2017) and as follows:

3.1. Convergence study

The suitable mesh of two-way hollow RC slab model was conducted by performing a convergence study by assessing the effects of using different mesh sizes ranging from (100 mm to 15 mm) on the ultimate carrying capacity. The convergence study showed insignificant influences on the load vs. carrying capacity for mesh sizes ranging between 15 mm and 30 mm. As a result, an element size of 20 mm was used in this research, as presented in Fig. 4.

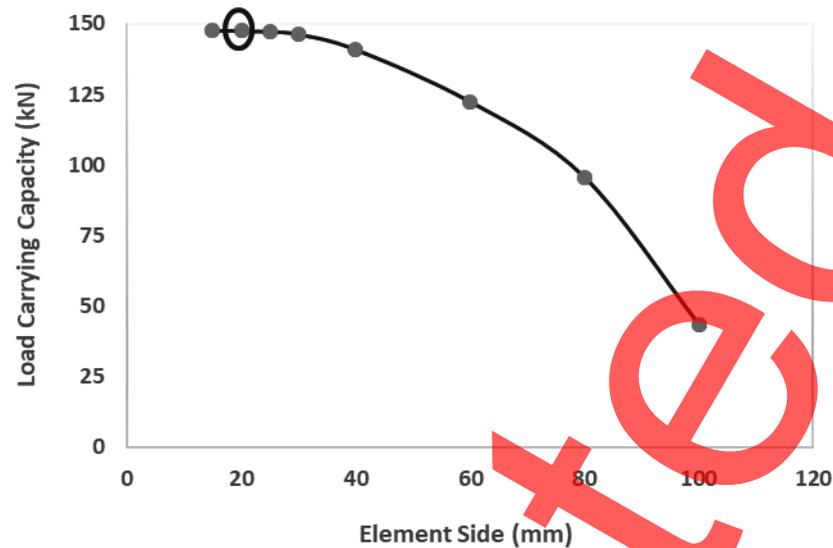


Figure 4. The convergence study

3.2. Assembly of parts

Assembling the two-way hollow RC slab model required five parts, including RC slab, solid steel shafts for supports, a bearing steel plate for loads and rebar for reinforcement. 3-D linear truss (T3D2), which could be defined as 2-node element, was assigned for meshing the rebar while a linear hexahedral element (C3D8R, solid brick element), which could be defined as a 8-node linear brick, was assigned for meshing both of two-way hollow RC slabs, steel bearing plate and solid steel shafts.

3.3. Interaction

Two types of constraints were considered in this study, including an embedded constraint for the reinforcing rebar (Fig. 5(A)) and the surrounding concrete along with a tie constraint for both of the supporting shafts (Fig. 5(B)) and the bearing plate with the surrounding concrete (Fig. 5(C)).

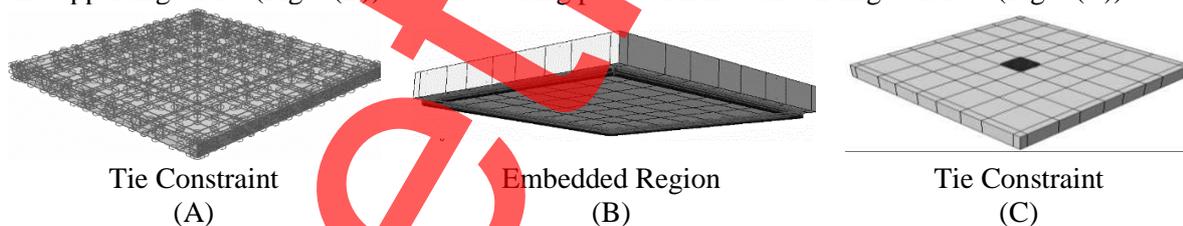


Figure 5. Details of the constraint

3.4. Supporting and loading conditions

In this study, the supporting conditions were applied in two parts. The first was representing the simply supporting condition that was achieved through applying displacement constrained at the solid steel shafts while the other part of the constraint was accomplished through using spring elements at the RC slab corners to prevent the uplifting of the corners, as shown in Fig. 6(A and B, respectively). The punching repeated load was assigned by applying uniform pressure on the bearing steel plate (as shown in Fig. 6(C)).

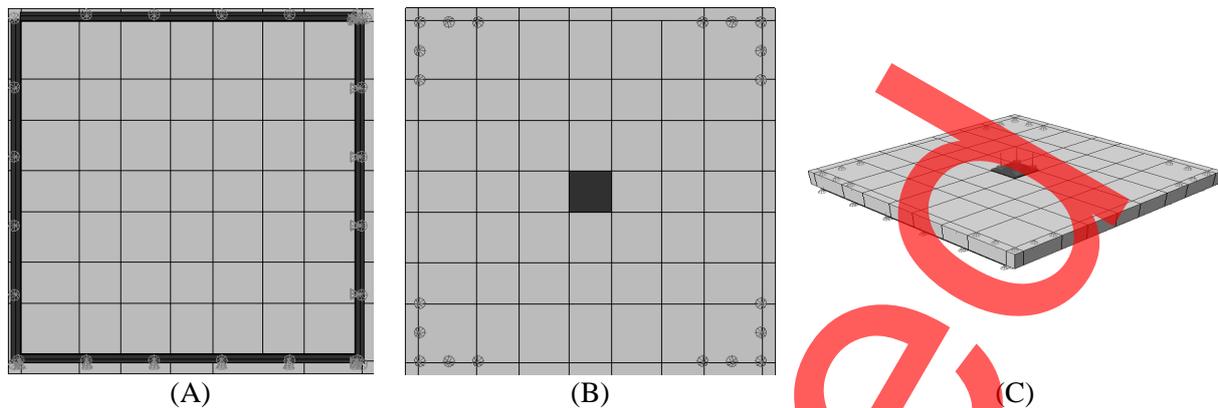


Figure 6. Details of the supporting and loading conditions

4. Results and discussion

Typical behavior of three main levels was experienced during the test of two-way hollow RC slabs under the effects of concentrated punching repeated loads. First of all, a linear relationship (elastic range) was experienced between loads vs. deflection curves from zero loadings until crack initiation. After crack initiation (elastic-plastic level) that happened at a load level ranging from 25.8% to 38.8% of the ultimate loading capacity, more cracks were initiated and propagated following diagonal paths towards the four edges due to increasing the magnitude or the number of cycles of CPRL. In this level of loading, a linear relationship with different slopes was distinguished in load-deflection curves. Also, cracks width was raised and moved to the corners of the RC slabs. The final stage (plastic stage) was spotted with a higher level of loading with significant reduction in the stiffness. A test was terminated at the failure of RC slabs, which could be experienced as a punching shear failure.

The laboratory results exposed that about 21% reduction in ultimate loading capacity was reported due to using two-way plastic piping systems in the production of two-way hollow RC slabs with hollowness ratio as high as 24% [8]. The research outcomes also proved the effectiveness of using a higher ratio of the reinforcement, adding micro steel fiber, allocating two-way plastic piping systems far from the area of maximum stresses or using high strength concrete to eliminating the decline that happens in the mechanical behavior of two-way hollow RC slabs [8].

A satisfactory agreement was observed between the 3-D nonlinear finite element analysis and the mechanical behavior of the two-way hollow RC slabs that conducted by the laboratory work. Fig. 7, presented a comparative study between the deflection shape of the FE models and the experimental models of $C_{65}.F_{0}.H_{16}.D_{32}.R_{1}.A_{u}.L_{c}$ two-way hollow RC slab as an attempt to verify the adequacy of the proposed FE model. The FE analysis also stated that loads that corresponding to the first crack and the ultimate level were higher than the experimental loads by about (14% and 11%, respectively) except for $C_{65}.F_{0}.H_{24}.D_{40}.R_{1}.A_{u}.L_{c}$ that had lower ultimate loading capacity by about 4.5%. Besides, the ultimate central deflection of FE analysis was lower than the experimental deflection by about 15% except for $C_{35}.F_{0}.H_{0}.D_{0}.R_{1}.A_{0}.L_{c}$ that showed higher deflection by about 4.5%. Moreover, a stiffer behavior was observed by the models of finite element method, as demonstrated in Fig. 8 and Table 1.

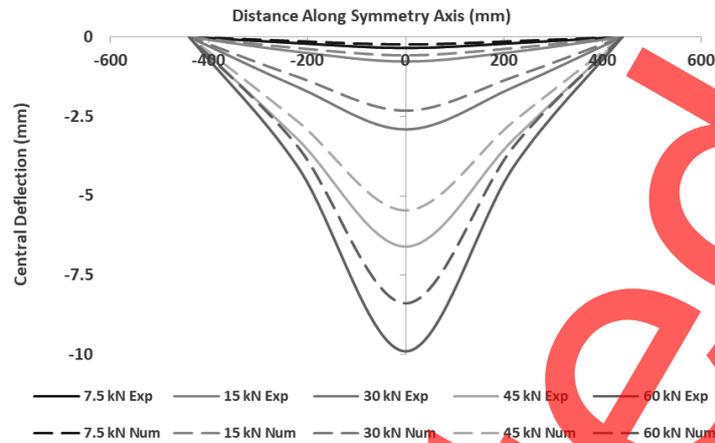
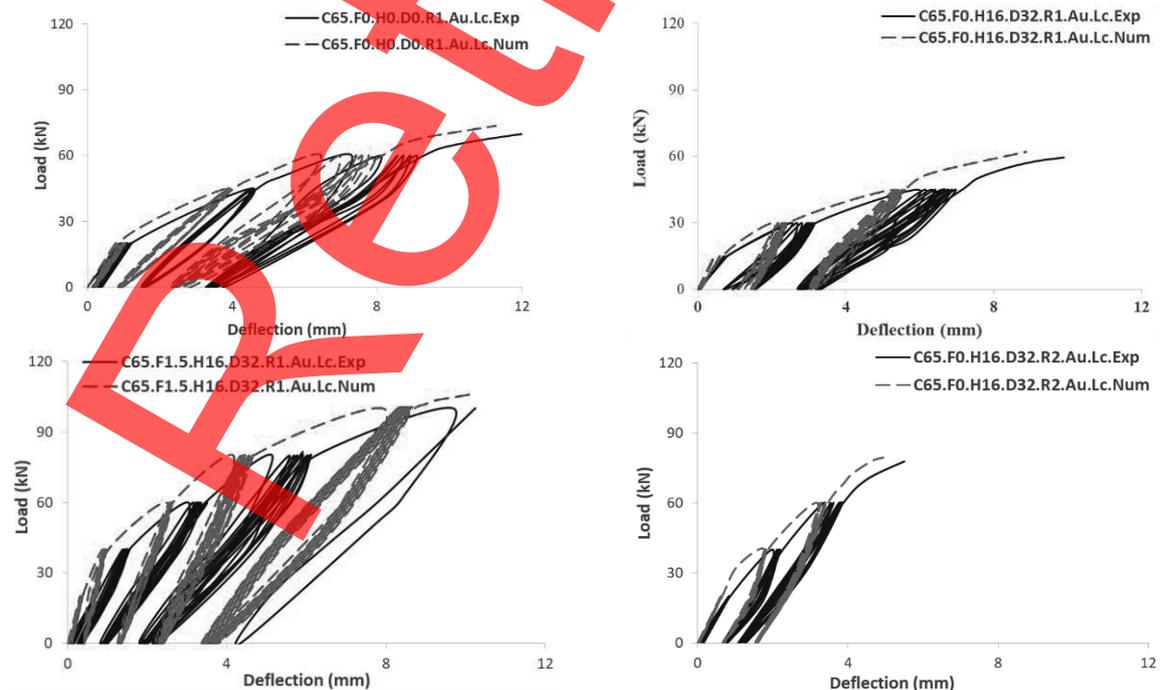


Figure 7. Experimental vs. numerical deflection profile for C₆₅.F₀.H₁₆.D₃₂.R₁.A_u.L_c.

Table 1. Experimental vs. numerical structural behavior.

Model ID	P_{cr_Exp} (kN)	P_{cr_Num} (kN)	$\frac{P_{cr_Num}}{P_{cr_Exp}}$	P_{u_Exp} (kN)	P_{u_Num} (kN)	$\frac{P_{u_Num}}{P_{u_Exp}}$	δ_{cu_Exp} (kN)	δ_{cu_Num} (kN)	$\frac{\delta_{cu_Num}}{\delta_{cu_Exp}}$
C ₆₅ .F ₀ .H ₁₆ .D ₃₂ .R ₁ .A _u .L _c	15.5	17.38	1.121	59.5	62.20	1.045	9.90	8.89	0.898
C ₆₅ .F ₀ .H ₀ .D ₀ .R ₁ .A ₀ .L _c	21.6	23.13	1.071	71.3	73.49	1.031	13.10	11.28	0.86
C ₆₅ .F ₀ .H ₁₆ .D ₃₂ .R ₂ .A _u .L _c	30.2	32.98	1.092	77.77	79.30	1.020	5.50	4.93	0.90
C ₆₅ .F _{1.5} .H ₁₆ .D ₃₂ .R ₁ .A _u .L _c	32.2	35.13	1.091	100.2	106.24	1.060	10.24	10.12	0.99
C ₆₅ .F ₀ .H ₂₄ .D ₄₀ .R ₁ .A _u .L _c	14.5	16.49	1.137	56.3	53.82	0.956	10.23	8.74	0.85
C ₆₅ .F ₀ .H ₁₆ .D ₃₂ .R ₁ .A _{nu} .L _c	18.2	20.48	1.125	61.4	65.33	1.064	8.78	7.85	0.89
C ₃₅ .F ₀ .H ₂₄ .D ₄₀ .R ₁ .A _u .L _c	13.7	15.22	1.111	46.2	50.31	1.089	9.50	8.42	0.89
C ₃₅ .F ₀ .H ₀ .D ₀ .R ₁ .A ₀ .L _c	17.3	19.17	1.108	61.2	67.93	1.110	7.03	7.36	1.05



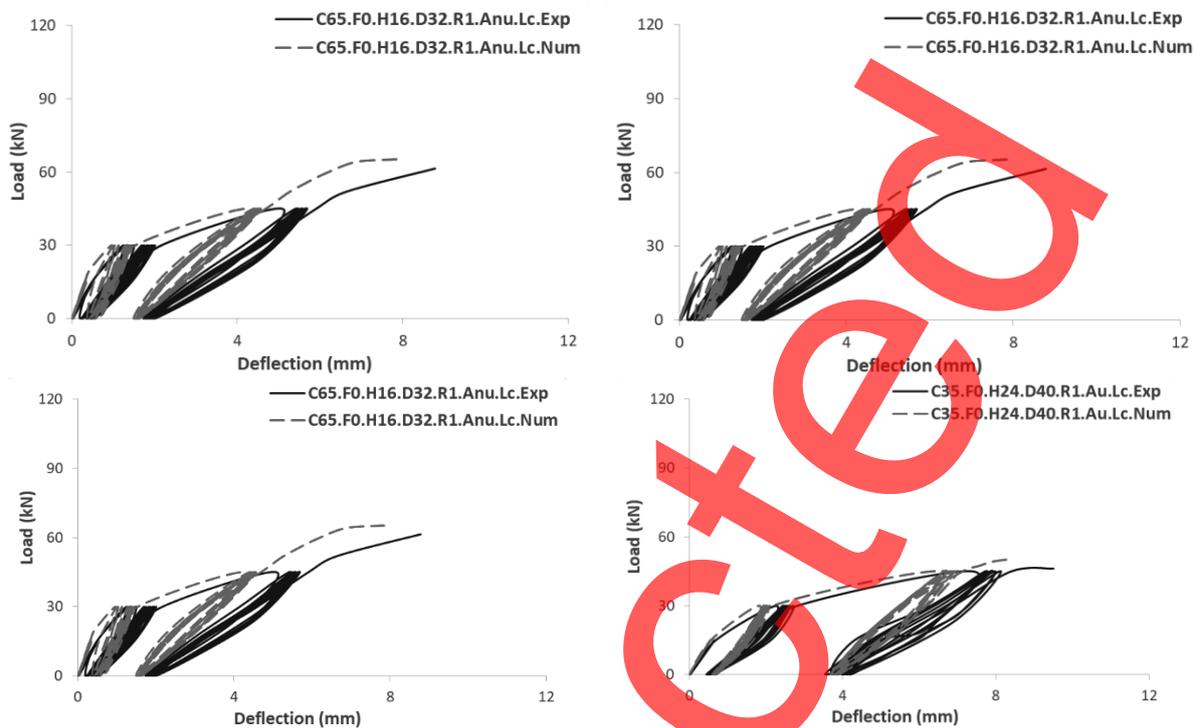


Figure 8. Experimental vs. numerical load-deflection curves.

5. Conclusions

This research was prepared for conducting the mechanical behavior of two-way hollow RC slabs of two-way piping systems, which could be made-up by networks of plastic pipes and fittings, under the effects of concentrated punching repeated loads using ABAQUS/Standard 2017. Eight RC slabs of dimensions (80 × 880 × 880 mm) were tested in this research. Main findings include:

- 1) Using two-way piping systems of about 24% of voids in producing two-way hollow RC slabs could lead to reducing the self-weight of RC solid slab with keeping about 79% of the original ultimate strength along with providing useful networks of voids that could be used for passing utility lines.
- 2) The reduction in the strength of two-way hollow RC slabs could be eliminated by different options, including adding micro steel fiber, distributing two-way plastic piping systems far from the position of maximum stresses, increasing the ratio of the main reinforcement or using high strength concrete.
- 3) Conducting the structural performance of two-way hollow RC slabs under the effects of CPRL by nonlinear FEAs showed satisfactory outcomes in comparison with the experimental results with a maximum difference in the ultimate loading capacity, cracking loads and central deflection by about (11%, 14% and 15%, respectively).

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