Journal of Advanced Sciences and Engineering Technologies (2024); 8(1):1-17

DOI: http://doi.org/10.32441/jaset.8.1.1

Journal of Advanced Sciences and Engineering Technologies

www.jasetj.com

Journal of Advanced Sciences and Eng. Technologies

JASET

Flexural behavior of one-way voided reinforced concrete slabs under the influence of uniformly distributed static loads

Yaseen Ali Saleh*, Aziz I. Abdulla, Muyasser M. Jomaa'h

Civil Eng. Dept., College of Eng., Tikrit University

Keywords:

Deflection, ductility, first crack load, flexural behavior, one-way slab, ultimate load.

Highlights:

- *Study Purpose and Scope: This study examines the bending behavior of voided one-way reinforced concrete slabs under static loads. Six slabs were tested, including one solid and five with different void ratios.*
- *Effect on Cracking Load and Deflection: As the void ratio increased, the initial cracking load decreased by up to 13.43%. Deflection also dropped slightly, ranging from 1.47% to 6.39%.*
- *Impact on Load Capacity and Ductility: Voids reduced the maximum load and deflection by up to 30.44% and 23.64%. Ductility index also declined, with reductions reaching 19.9%.*

ARTICLE INFO

Article history:

Received	24 June	2024
Received in revised form	02 July	2025
Accepted	21 July	2025
Final Proofreading	12 Aug.	2025
Available online	14 Aug.	2025

**Corresponding author:*

Yaseen Ali Saleh

Civil Eng. Dept., College of Eng., Tikrit University.

Abstract:

Voided one-way reinforced concrete slabs represent a specific category within the family of concrete slab systems. Widely used in residential and industrial buildings due to their cost-effectiveness, lightweight, and ease of implementation. The present work focuses on examining the flexural response of one-way reinforced concrete slabs incorporating voids when subjected to uniformly applied static loading. Six slab specimens with specified dimensions were cast for this purpose (40001000180) mm, five of which are voids with proportions of (4.36%, 8.72%, 13%, 17.44%, and 21.8%), in addition to a sixth specimen that is solid without voids representing the reference slab. Through the tests, it was revealed that the first cracking load of voided slabs gradually decreases with an increase in the voids' ratio, with the load value decreasing by a percentage ranging from 3.94% to 13.43% compared to the solid (reference) slab. The deflection values also decreased by a percentage ranging from 1.47% to 6.39% when voids were present. Furthermore, the inclusion of voids resulted in a reduction in both the maximum load and the resulting deflection, with the load value decreasing by a percentage ranging from 3.18% to 30.44%, and the deflection value decreasing by a percentage ranging from 1.35% to 23.64% in comparison with the control slab. Moreover, it was observed that the presence of voids in the slabs resulted in a decrease in the ductility index, with a decrease ranging from 0.8% to 19.9%.

INTRODUCTION

Voided one-way reinforced concrete slabs constitute a commonly adopted structural system in both residential and industrial constructions, primarily owing to their economic efficiency, reduced self-weight, and ease of fabrication and installation.

Previous experimental studies on one-way voided reinforced concrete slabs have demonstrated that the introduction of voids formed by polystyrene balls alters the structural behavior of the slabs, particularly by modifying the failure mode. However, further investigation is still required to better understand the flexural response and performance of such systems under uniformly distributed static loads.

Introducing spherical voids with a diameter equal to 75% of the slab's depth changes the failure mode from flexural to shear. It was also observed that slabs with smaller voids, where the ratio of the diameter of these voids to the slab depth does not exceed 50%, experience almost negligible losses in ultimate strength due to the presence of voids [1].

As for larger voids, the resistance decreased by percentages ranging from 17.7% to 21.3% for void slabs with varying proportions compared to solid reference slabs. However, this decrease can be compensated for by the positive results achieved due to the reduced self-weight of the void slabs, which ranged from 6.4% to 20.6% compared to the reference slabs. Additionally, the void slabs exhibited more ductile deflection-load behavior than solid slabs due to a decrease in flexural stiffness, which ranged from approximately 11.1% to 23.7% [1].

Previous investigations comparing slabs incorporating spherical voids with conventional solid slabs revealed that the bending stresses in the voided slabs were approximately 6.43% lower than those observed in the solid counterparts. Moreover, finite element simulations carried out for both slab types indicated an increase in deflection of about 5.88% in the voided slabs, attributed to the reduction in overall stiffness resulting from the presence of voids.

In addition, experimental findings indicated noticeable reductions in strength, stiffness, ductility, and energy absorption capacity of the voided slabs when contrasted with the solid specimens used as reference slabs[2].

The studies conducted on void concrete slabs, in which the results obtained from laboratory work were analyzed and compared with both the European Standard EFNARC (European Federation of National Associations Representing for Concrete, 2005) and the American Standard ACI 318M-19, revealed that the former was more accurate and less conservative in predicting the bending and shear strength of reinforced concrete slabs with varying proportions of voids [3].

It should be noted that all the above-mentioned results were obtained from specimens designed following the requirements of the American Standard ACI code.

The variation in compressive strength values of the concrete used in casting voids reinforced concrete slabs has a significant effect on the load, leading to the formation of the first crack. This load decreased by a percentage of 15% to 62% for concrete with moderate compressive strength not exceeding 30 MPa. Meanwhile, the reduction percentage ranged from 5% to 40% for high compressive strength concrete, around 60 MPa. Additionally, increasing the reinforcement ratio from 0.2% to 0.26% in void concrete slabs resulted in a reduction of deflection by approximately 1.6% to 35.9% for samples with high compressive strength.

Decreasing the void size also led to a reduction in deflection for the same load stages, with a range of approximately 20% to 35.7% for high-compressive-strength void slab samples [4].

If void slabs containing openings are subjected to high stresses due to the nature of the applied loads, leading to the entry of the stress block into the voided region, studies have shown that if the entry does not exceed 20% of the void volume, its effect on the behavior of these slabs is minimal [5].

Many studies have found that the deflection of these slabs is influenced by the presence of voids compared to solid slabs, with a reduction in deflection ranging from 10.3% to 11.1% depending on the void size, and it can reach up to 67% if the ratio between the void diameter and the slab thickness reaches 75%. It is recommended to use voids with a size equal to 50% of the slab thickness, as there is no significant loss in maximum resistance, and the reduction in stiffness, deflection, and toughness of the slabs is limited and not substantial [2].

The main objectives of this study are:

- To investigate the flexural behavior of one-way voided reinforced concrete slabs subjected to uniformly distributed static loads.
- To evaluate the effect of internal voids on the load-carrying capacity, deflection response, and crack propagation of the slabs.
- To compare the structural performance of voided slabs with that of conventional solid reinforced concrete slabs under similar loading conditions.
- To provide experimental insights that may contribute to the development of more efficient slab systems with reduced self-weight and improved structural behavior.

EXPERIMENTAL PROGRAM

In this study, the effect of varying void ratios on the flexural behavior of reinforced concrete slabs under uniformly distributed static loads was investigated. Slabs with different void percentages were tested, which were 0%, 4.36%, 8.72%, 13%, 17.44%, and 21.8%. These slabs were respectively denoted as SSS, SSV1, SSV2, SSV3, SSV4, and SSV5. These void ratios were achieved by placing PVC pipes with a diameter of 100 mm and a length equal to the total length of the slab (4000 mm) in varying numbers. The selection of these ratios was based on the lowest achievable void ratio (4.36%) achieved by placing only one plastic pipe and the highest possible void ratio (21.8%) meeting the requirements of the ACI318M-14 code by placing five pipes. This method of creating voids in slabs represents the most realistic scenario and can be encountered in real-life situations, especially in the construction of bridges. These voids can be utilized for the passage of electrical, water, and communication services, in addition to the benefits achieved through weight reduction.

All the slabs were supported simply by parallel placement along the shorter side of the slab on two parallel walls made of concrete blocks, specially constructed for this purpose, with a height of 1800 mm. This setup was designed to closely simulate real-world conditions, with a clear distance between the two walls of 3600 mm and each support having a width matching that of the concrete block wall, which is 200 mm wide. Consequently, the total length of the slab was 4000 mm, and it had a width of 1000 mm.

A formwork was created using white wooden panels to match the requirements of the work for the underside of the slab, mimicking precisely what occurs at the construction site. All the details of the support walls and the wooden formwork are illustrated in Figure (1).

Figure (1) shows the details of the support and the wooden formwork.

Concrete Mixture

The specifications of the concrete mix used for casting the slabs were determined by selecting a compressive strength for the concrete of approximately 30 MPa at 28 days, considering it to be a moderate value. Table (1) represents the proportions of the concrete mix components used in casting, including cement, fine aggregate, coarse aggregate, and the weight of water used in the concrete mix, all of which had previously undergone complete laboratory testing.

Table 1. Weight of concrete components

Material	Cement	Fine aggregate	Coarse aggregate	Water
Weight (Kg/m^3)	315	810	1040	140

Casting of reinforced concrete slabs

The slabs were reinforced with a reinforcement consisting of 6 bars of 12 mm diameter steel in the longitudinal direction of the slab, which had a length of 4000 mm (Ø12 @ 190 mm C/C). Additionally, the steel required for resisting temperature and shrinkage effects in the transverse direction of the slab, which had a width of 1000 mm, was provided as (Ø12 @ 246 mm C/C), following the requirements of the American Concrete Institute ACI 318-14 code (ACI 318-14 2014), as illustrated in

Figure (2).

The loading method used in this research was carried out by loading the slabs, as happens in practical situations when load testing of slabs is required. This was achieved by using the method of placing concrete blocks with a known weight (25 kg per block) distributed evenly over the entire surface of the slab until the desired load was reached. All the stages of casting the slabs are illustrated in Figure (3).

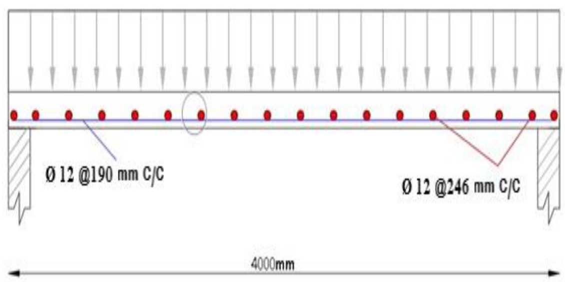

Figure (2) Details of reinforcing the slabs.

The amount of load was calculated by the concrete blocks with known weights distributed over the specimens. The deflection, on the other hand, was measured using an LVDT (Linear Variable Differential Transformer). The inspection results, specifically the deflection values obtained in the slabs, were recorded and stored using a computer connected to the LVDT. Subsequently, load-deflection curves were plotted based on the examination of these slabs.

Figure (3) shows casting the concrete for the slabs.

RESULTS AND CALCULATIONS

The evaluation of the slabs was conducted using load–deflection curves measured at the mid-span. Key parameters, including the first cracking load, the ultimate load, and the overall structural response of the slabs, were determined.

First Cracking Load

The first cracking load (Cracking Load) and the corresponding deflection for the slab specimen were determined during the inspection of the specimens. This involved observing the initial crack formation or occurrence on the specimen and noting the load at that point. All the results of the first cracking load and the accompanying deflection for each load type for this type of slab are illustrated in Figure (4). From the results obtained from the deflection inspection, as shown in Figure (4) for the slab specimens (SSV1, SSV2, SSV3, SSV4, and SSV5), in comparison with the solid reference concrete slab specimen SSS, it was observed that the first cracking load for these specimens gradually decreases with an increase in the void ratio in these specimens. The load values decreased by percentages of (3.94%, 7.19%, 10.74%, 11.02%, and 13.43%) for slabs (SSV1, SSV2, SSV3, SSV4, and SSV5), respectively, compared to the reference slab SSS. Additionally, the deflection value at the first crack for the same slabs decreased by percentages of (1.47%, 3.69%, 4.18%, 5.65%, and 6.39%) compared to the reference slab SSS. The reason for the decrease in the first cracking load and deflection values is attributed to the reduction in the cross-sectional area of concrete in the tension zone, which is subjected to initial stresses and reactions at the beginning of the test. As the loading continues, fine cracks begin to appear at the bottom of the specimen, and these cracks widen and increase until they become visible on the lower surface of the specimen, along the span of the applied load. This is how the first cracking load for the specimen is recorded.

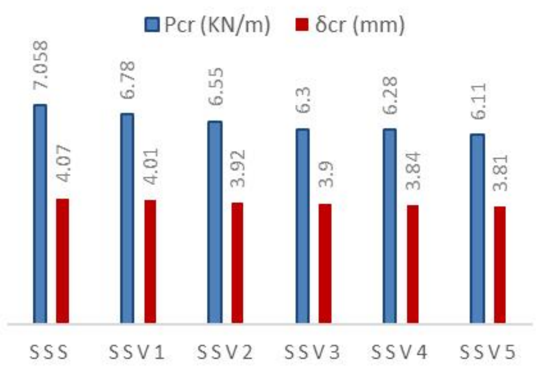

Figure (4) Values of the first crack load and deflection in void slabs.

Ultimate Load

The ultimate load values, which were obtained, represent the results of deflection tests on the reinforced concrete slab specimens. The data includes the load values applied to the specimen along with the corresponding deflection until the specimen fails.

All reinforced concrete slab specimens were intentionally designed to exhibit deflection-controlled failure. Upon loading, cracks initiated within the tensile zone at the slab's bottom surface and extended across its width within the region influenced by the applied load. This was accompanied by an upward shift of the neutral axis toward the compression zone. With further load increase, the reinforcement bars reached their yielding stage, and continued loading caused the cracks to propagate, widening and deepening until they extended into the compression zone at the top of the slab, ultimately leading to the failure of the specimens.

Figure (5) represents the results of deflection tests for the reinforced void concrete slabs with different void ratios. It can be observed that the maximum load required for the failure of the reference solid slab SSS (which does not contain voids) was approximately 23.15 kN/m with a deflection of 164.3 mm. The maximum load values decreased by percentages of (3.18%, 6.31%, 9.4%, 22.28%, and 30.44%) for the slabs (SSV1, SSV2, SSV3, SSV4, and SSV5), respectively, compared to the reference slab SSS. In addition, the corresponding maximum deflection values for each peak load in the tested slabs exhibited reductions of approximately 1.35%, 2.67%, 4.12%, 23.64%, and 6.64% relative to the deflection observed in the reference slab SSS. These results indicate that increasing the void ratio in the reinforced concrete slab specimens leads to a decrease in their ultimate load capacity, primarily due to the reduced concrete area in the tensile zone. Upon loading, cracks were observed to initiate within the tensile region at the bottom surface of the slab and propagate across its width in the zone subjected to the uniformly distributed load. This phenomenon was accompanied by an upward shift of the neutral axis toward the compression zone. As the load increased further, the reinforcement bars reached their yielding stage, and continued loading caused the cracks to widen and deepen until they extended into the compression zone at the top of the slab, ultimately failing the voided slab specimens.

Table (2) provides a simple numerical comparison between the value of the first cracking load and the ultimate load for these slabs, indicating the percentage of the first cracking load to the ultimate load. It is evident from the table that the ratio of the first cracking load to the ultimate load is approximately 30.3% for the reference slab SSS, while it is (30.1%, 30%, 29.86%, 34.7%, and 37.7%) for the slabs (SSV1, SSV2, SSV3, SSV4, and SSV5), respectively. These ratios are very close and represent a value slightly less than one-third of the ultimate load value.

Load-deflection

Load-deflection curves are the primary input in studying the deflection behavior of reinforced concrete members under static loads until failure. In general, deflection cracks begin to form in the mid-span region of void-reinforced concrete slab specimens under the influence of uniform load. Figure (6) illustrates the effect of increasing void ratios on the load-deflection curve for one-way void-reinforced concrete slabs reinforced with regular reinforcement bars, compared to the solid concrete slab specimen SSS, which serves as the reference slab. As previously demonstrated, an increase in void ratios in slab specimens leads to a reduction in their maximum load capacity. Consequently, these void ratios have a clear effect on the load-deflection curve at all loading stages.

The load-deflection curve for the reference solid concrete slab SSS is linear until the appearance of the first crack. Then, the second part begins in the post-cracking stage, which is almost linear and slightly less steep than the first part due to the loss of a significant portion of the slab's stiffness resulting from the cracks that have occurred. The post-cracking stage ends when the reinforcement steel yields, entering a new stage, which is the post-yielding stage. In this stage, the deflection increases significantly until reaching the ultimate load Pu = 23.29 kN/m, after which the specimen fails.

As for the load-deflection curve for one-way void reinforced concrete slab specimens, it appears to be less steep than the curve of the solid reference slab throughout the loading duration of the specimens until failure. The reason for this is the decrease in the maximum load and first cracking load of the specimens due to the increased void ratio.

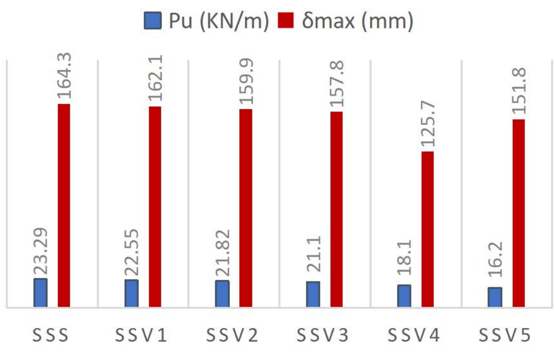

Figure (5) Ultimate load and deflection in voided slabs.

Table (2) Values of the ultimate load and deflection in voided slabs

Spe.	P_{cr} (KN/m)	δ_{cr} (mm)	P_u (kN/m)	Δmax (mm)	(P_{cr}/P_u)
SSS	7.058	4.07	23.29	164.3	30.3%
SSV1	6.78	4.01	22.55	162.1	30.1%
SSV2	6.55	3.92	21.82	159.9	30%
SSV3	6.30	3.90	21.1	157.8	29.8%
SSV4	6.28	3.84	18.1	125.7	34.7%
SSV5	6.11	3.81	16.2	151.8	37.7%

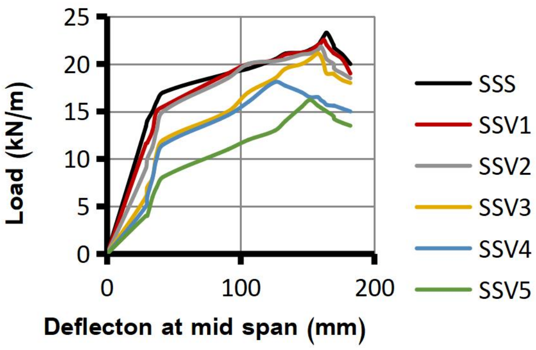

Figure (6) load-deflection curve for voided slabs.

Ductility

Reinforced concrete members can withstand additional loads in the plastic state before failure due to the reinforcement steel reaching the yield point before failure occurs. Consequently, these members exhibit ductile behavior. Structures are described as having ductile behavior when their ductility index (μ_d) is greater than 5 [6].

The ductility index (μ_d) is defined as the ratio of the deflection at the ultimate load to the deflection at the yield load of the reinforcement steel [7]. It can be obtained from the load-deflection curve of the specimen when the curve transitions from the elastic phase to the plastic phase. It's worth noting that ductility is a desirable characteristic when ensuring greater safety conditions for concrete structures. It provides early warning signs of impending failure, preventing sudden collapse.

Table (3) represents the nature of calculations for the ductility values of one-way reinforced concrete slabs with regular reinforcement bars and containing voids at different ratios. It is observed that the presence of voids in the concrete slab affects its ductility. The ductility index for the reference solid concrete slab SSS was 3.92, and then this value increased with the presence of voids in the void concrete slabs (SSV1, SSV2, SSV3) by 10.1%, 6.89%, and 4.4%, respectively. However, it decreased again for slabs (SSV4 and SSV5) by 19.9% and 0.8%, respectively. This indicates that the presence of voids in concrete slabs at high ratios leads to a decrease in the ductility index.

The reason for this decrease is that the presence of voids at high ratios increases the susceptibility of the slab to breakage, making it more brittle under the influence of various loads. Large voids, even if they are close to the neutral axis, tend to be inert because the stresses around them are generally low, both in tension and compression. However, voids occupy space within these two regions, reducing the area available for resisting tension and compression stresses. Thus, the specimens become more brittle, reducing their ductility, which is evident from the values of both the maximum load and the load required to reach the yielding stage.

Table (3) ductility index for void slabs

Spe.	δy (mm)	δu (mm)	Ductility index ($\mu_{d=\delta_u/\delta_y}$)
SSS	41.9	164.3	3.92
SSV1	37	161.2	4.36
SSV2	38	159.9	4.21
SSV3	38.5	157.8	4.1
SSV4	40	125.7	3.14
SSV5	39	151.8	3.89

Toughness

Toughness refers to the capacity of a concrete specimen to absorb energy, which is typically quantified by the area beneath the load–deflection curve, or equivalently, the total energy required to induce failure in the specimen.

The toughness index represents the ratio between the area under the load-deflection curve at the deflection corresponding to a specific criterion (δcr) to the area at the deflection where the first crack appears. According to the American standard (ASTM C 1018) [8], toughness indices (I5, I10, I20, I30, etc.) are calculated by taking the ratio of the area under the load-deflection curve at the specific ($3\delta_{cr}$, $5.5\delta_{cr}$, $10.5\delta_{cr}$, $15.5\delta_{cr}$) to the area at the deflection where the first crack appears.

In the case of ordinary concrete, low toughness indices are relied upon, while high toughness indices are used for high-strength concrete, especially when using additives [9]. Table (4) illustrates the toughness at the first crack, at the yielding of the reinforcement, and at the ultimate deflection, along with the toughness indices (I5). It demonstrates the effect of increasing the void ratio on toughness. The toughness index was recorded as 4.72 for the reference solid concrete slab SSS, while its value increased for the void concrete slabs (SSV1, SSV2, SSV3, SSV4, and SSV5) by 13.9%, 14.2%, 9.6%, 8.2%, and 6.3%, respectively, compared to the reference slab SSS. The results of toughness for the reinforced void concrete slabs used in the current study can be attributed to the failure characteristic in these specimens. This is due to the increase in the void ratio, which increases the ductility of the specimen but also reduces the resistance to the first crack, yielding, and maximum resistance upon failure in these specimens.

Table (4) Toughness in void slabs

Spe.	First crack toughness kN-mm	Yield toughness kN-mm	Ultimate toughness kN-mm	Toughness index (I_5)
SSS	13.66	50.14	132.7	4.72
SSV1	11.35	58.98	87.97	5.48
SSV2	12.81	57.1	91.3	5.5
SSV3	12.75	33.2	115.6	5.22
SSV4	12.8	55.1	126.8	5.14
SSV5	10.4	44.6	102.7	5.04

Stiffness of slabs

The stiffness of reinforced concrete slabs can be defined as their resistance to deformations resulting from the applied loads, and it serves as a measure of their resistance to deflection caused by these loads. It is closely related to the elasticity modulus of these slabs.

The stiffness of reinforced concrete slabs is calculated based on the ultimate load of the slab, by taking 45% of the ultimate load and projecting this value onto the load-deflection curve. Subsequently, the corresponding deflection value is determined. To calculate the stiffness of void-reinforced concrete slabs with conventional reinforcement in this study, three loading stages were adopted: at the first crack, at 45% of the ultimate load, and at the ultimate load [9]. This calculation is detailed in Table (5).

Generally, it is natural for the stiffness of reinforced concrete slabs to be high at the loads that cause cracking, with values for the reference slab (SSS) around 3.99 KN/mm. However, they quickly decreased by percentages of (40.6%, 39.8%, 37.8%, 38.8%, and 37.3%) for the slabs (SSV1, SSV2, SSV3, SSV4, and SSV5), respectively, compared to the reference slab (SSS). This implies that the presence of voids has a negative effect on the stiffness of the slabs. Moreover, the stiffness values continued to decrease with an increasing number of cracks and their propagation, which, in turn, reduced the moment of inertia, resulting in decreased slab stiffness. This is especially evident when observing the stiffness values at 45% of the ultimate load. At this point, the stiffness decreased to 2.07 KN/mm for the reference slab (SSS), which represents a 48% reduction. The same trend of reduction is observed for the other slabs (SSV1, SSV2, SSV3, SSV4, and SSV5), with percentages of (29.5%, 45.4%, 56.9%, 61.9%, and 68.4%) reduction, respectively, compared to the stiffness value at the first crack, corresponding to each slab.

All the slabs exhibit the same stiffness as the reference slab (SSS) in the initial loading stages before the appearance of initial cracks. However, as cracks develop in the concrete and transfer loads to the reinforcement bars, slab stiffness decreases. An increase in crack growth occurs at a slower rate, and the stresses transferred from the concrete to the reinforcement bars continue until they reach the yield stress. As the load continues to increase, the number of cracks in the reinforced concrete slabs increases at the expense of crack growth. When reaching the maximum loading stage and after the cracks have widened and reduced the moment of inertia for all the slabs, the results indicate that the stiffness values tend to converge with each other. For instance, the stiffness value at the ultimate load for the SSS slab was 0.57 KN/mm, while this value decreased slightly for the slabs (SSV1, SSV2, SSV3, SSV4, and SSV5) by percentages of (3.5%, 5.2%, 7%, 1.7%, and 26.3%), respectively.

Table (5) Stiffness for void slabs

Spe.	Stiffness at (Pcr/ δcr) (kN/mm)	Stiffness at P45% (kN/mm)	Stiffness at Pu (kN/mm)
SSS	3.99	2.07	0.57
SSV1	2.37	1.67	0.55
SSV2	2.4	1.31	0.54
SSV3	2.48	1.07	0.53
SSV4	2.44	0.93	0.58
SSV5	2.5	0.79	0.42

CONCLUSION

Based on the results and discussions presented, the significant effects of uniformly distributed static loads on one-way reinforced and voided concrete slabs with different void ratios are summarized as follows:

The initial cracking load for these slabs gradually decreases with an increase in the void ratio in these specimens. The load values decreased by percentages of (3.94%, 7.19%, 10.74%, 11.02%, and 13.43%) for slabs (SSV1, SSV2, SSV3, SSV4, and

SSV5), respectively, compared to the reference slab (SSS). Additionally, the corresponding deflection values at the first crack for the same slabs decreased by percentages of (1.47%, 3.69%, 4.18%, 5.65%, and 6.39%) compared to the reference slab (SSS).

Increasing the void ratio leads to a reduction in both the maximum load capacity and the corresponding deflection. The maximum load capacity required for slab failure (SSS) was 23.15 KN/m, and it decreased by percentages of (3.18%, 6.31%, 9.4%, 22.28%, and 30.44%) for slabs (SSV1, SSV2, SSV3, SSV4, and SSV5), respectively, compared to the SSS slab. The corresponding maximum deflection values for each maximum load in the same slabs also decreased by percentages of (1.35%, 2.67%, 4.12%, 23.64%, and 6.64%), respectively, compared to the deflection values in the reference slab (SSS).

The presence of voids in the concrete slabs, especially at high void ratios, leads to a decrease in the ductility index. The ductility index value for the reference slab (SSS) was 3.92, and this value increased due to the presence of voids in the void slabs (SSV1, SSV2, SSV3) by percentages of (10.1%, 6.89%, and 4.4%), respectively. However, it decreased for the slabs (SSV4 and SSV5) by percentages of 19.9% and 0.8%, respectively, compared to the reference slab (SSS).

An increase in the void ratio has a clear effect on the toughness values of the slabs. The toughness index recorded a value of 4.72 for the reference slab (SSS), while this value increased for the void slabs (SSV1, SSV2, SSV3, SSV4, and SSV5) by percentages of (13.9%, 14.2%, 9.6%, 8.2%, and 6.3%), respectively, compared to the reference slab (SSS).

All slabs have the same stiffness as the reference slab in the initial loading stages and before the stage where initial cracks appear. However, as cracks develop in the concrete and transfer loads to the reinforcement bars, slab stiffness decreases. This is especially evident as cracks grow slowly, and the stresses continue to transfer from the concrete to the reinforcement bars until they reach the yield stress. The recorded stiffness for the slabs (SSV1, SSV2, SSV3, SSV4, and SSV5) decreased by percentages of (29.5%, 45.4%, 56.9%, 61.9%, and 68.4%), respectively, compared to the stiffness value at the first crack, corresponding to each slab.

ACKNOWLEDGMENTS

The researchers wish to express their sincere thanks and appreciation to the Chair of the Civil Engineering Department at the College of Engineering, Tikrit University, for their assistance in providing the requirements to complete this research.

References

[1] Al-Gasham, T. S., Hilo, A. N., & Alawsi, M. A. (2019). "Structural behavior of reinforced concrete one-way slabs voided by polystyrene balls", Case Studies in Construction Materials, 11, e00292.

[2] Mathew, R., & Binu, P. (2016) "Punching shear strength development of bubble deck slab using GFRP stirrups", IOSR J. Mech. Civ. Eng. (IOSR-JMCE), 01-06.

[3] Salman, W. D. (2015) "Strengthening of reinforced concrete one-way slabs with opening using CFRP strip in flexural", Int. J. Sci. Res, 4, 4-438.

[4] Nimnim, H., & Alabdeen, Z. Z. (2019). "Structural behavior of voided normal and high-strength reinforced concrete slabs", Kufa Journal of Engineering, 10(2), 1-11.

[5] Oukaili, N. K., & Merie, H. D. (2021). "CFRP strengthening efficiency on enhancement punching shear resistance of RC bubbled slabs with openings", Case Studies in Construction Materials, 15, e00641.

[6] Janet, M.L. and Chris, J.B., (1999) "Experimental Study of Influence of Bond on Flexural Behavior of Concrete Beams Pretensioned with Aramid Fiber Reinforced Plastics", ACI Structural Journal, Vol. 96, No. 3, 377-385.

[7]Elshalaby, Ibrahim, Ibrahim Elgendy, and Ahmed Elsawak. (2021) "Strengthening of Reinforced Concrete one-way Slabs", Menoufia University-Reinforced Concrete Research Group.

[8] Papakonstantinou, C. G., Petrou, M. F., & Harries, K. A. (2001) "Fatigue behavior of RC beams strengthened with GFRP sheets", Journal of Composites for Construction, 5(4), 246-253.

[9] Savoia, M., & Ferracuti, B. (2006) "Strengthening of RC structure by FRP: Experimental analyses and numerical specimen ling", Giugno 2006. DISTART.

University of Bologna.