International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

A Review Paper on Punching Shear Behavior of Bubbled Slabs

Imtethal H. Jaber[1*], Waleed A. Waryosh[2]

[1]Civil Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq
Email: *emthlal[at]uomustansiriyah.edu.iq*

[2]Civil Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq
Email: *waleedwaryosh[at]uomustansiriyah.edu.iq*

Abstract: ***Bubbled slabs are introduced to decrease the self-weight of the slab by decreasing the amount of concrete in the slab's middle. This decrease results in cost savings, a reduction in the time needed for construction, improvements in structural performance, and an increase in the slab's efficiency. Despite the many benefits that this form of slab offers, it is similar to flat slabs. The more concentrated load at the column connection causes it to experience failure-punching shear. In addition, the design equations for bubbling slabs suggested by building rules derive from experiments conducted on flat slabs. Previous investigations of bubbled slabs have shown that the punching shear of bubbled slabs is different from that of flat slabs.***

Keywords: Bubble slab, flat slab, Punching shear, plastic sphere.

1. Introduction

The span between columns in reinforced concrete structures is the primary design limitation where perimeter beams and thick slabs are required to design a larger slab between columns, which leads to weight gain due to the need for more significant amounts of concrete [1]. The bubbled slab system is the key to resolving such problems in construction. this system was invented in the 1990s by a Danish engineer [2]. That reinforced concrete bubble slab, in general, consists of top reinforcement mesh, plastic balls, and bottom reinforcement mesh [3], as shown in Figure 1–1. These slabs use spherical, doughnut, oval, or cuboid-shaped plastic void formers. [4],[5] and reduce the weight by as much as fifty percent relative to solid slabs while maintaining flexural strength [6],[7]. Slab-column connections and locations where concentrated loads operate are the most hazardous parts of two-way solid and bubbled slabs [8]. The intense shear force and high shear stresses in this region result in the concrete slab being punched [9], [10], [11]. This might result in the gradual collapse of the whole building. If not approached with precision, the structural concept of these systems is severely compromised [12], [13]. Although, there are a number of benefits to bubbled slabs, research on the punching shear behavior of this type of slab is limited. In this paper, previous studied on the punching shear behavior of bubbled slabs are reviewed.

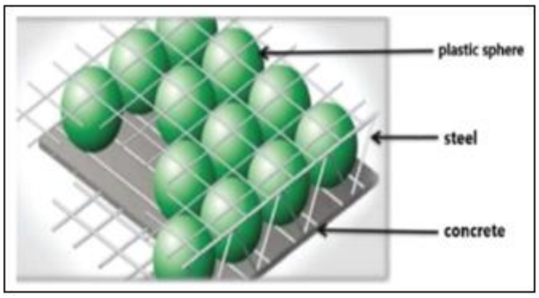
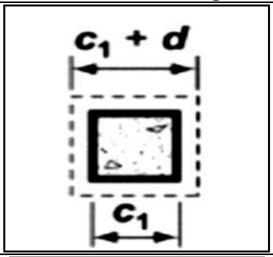
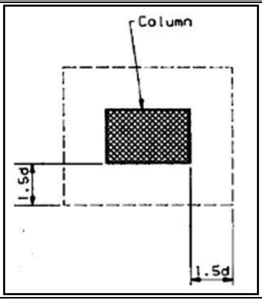
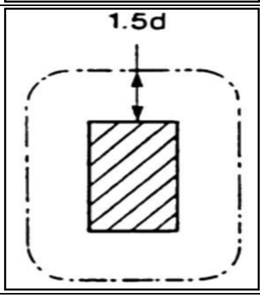


Figure 1-1: Bubble Deck's Design [4]

2. Punching Shear Failure

The punching shear capacity of the bubble deck slab is a main problem due to its small thickness [14]. When implemented without beams, brittle failure (punching failure) at the point of connection between slabs and columns is possible [15]. This kind of failure results in the degradation of the overall resistance. As a result, the structure could collapse [16]. Many experimental studies have assessed the punching shear strength (PSS) of the connection point. Some of these studies and suggestions are shown in Tables 1–1. Including ACI 318-19 [17], BS 8110 [18], and Eurocode2 [19]. Defining the critical section location is a case of dispute among the current design codes, as shown in Tables 1–1. For example, ACI 318-19 specifies a much smaller critical section in comparison with BS 8110 or Euro Code 2. Alexander and Simmonds [20] have discussed three traditional punching shear failure modes. If the structure is loaded symmetrically, the surface of the punching failure occurs in the form of a truncated cone surrounding the column. If an unbalanced load is present, a combination of two modes of failure (punching shear and flexural) will happen. Numerous practical experiments show that shear strength is proportional to the effective mass of the concrete. Estimates suggest that the punching shear of bubble slabs is around 72% to 91% of that seen in solid slabs. The calculations increase the shear capacity of a bubble slab with the same height by 0.6 times. Consequently, a high level of safety is assured. Special care should be taken in regions that are subjected to significant shear forces, such as the vicinity of columns. To resolve this issue, one may eliminate a small number of balls from the crucial region around the columns. This would effectively restore the columns' complete shear capability [21].

Current Design Methods for Punching Shear [22]

Design Method	PSS (MPa)	Critical Section b0 For Rectangular Columns	Limitations
ACI318-19	Vc is Minimum of: $4\lambda_s\lambda\sqrt{f'_c}$ $\left(2+\frac{4}{\beta}\right)\lambda_s\lambda\sqrt{f'_c}$ $\left(2+\frac{\alpha_s d}{b_o}\right)\lambda_s\lambda\sqrt{f'_c}$		$\sqrt{f'c} \leq 70MPa$ The maximum shear stress does not exceed (1/3 $\sqrt{f'c}$) N/$mm2$ λs is shape factor λ is light weight concrete factor
BS 8110	$Vc = 0.27k(100\rho t)1/3$ $f'c$ 1/3, *cube* $k = 4\sqrt{400/d}$ $\rho t \leq 0.03$		The design of shear for concrete strength (fcu) not greater than (40 N/mm2). (100ρt) should not Be over than (3). (4$\sqrt{400/d}$) should not be below (0.67) for structural elements that are not equipped with shear reinforcement, and not less than (1) for members with shear Reinforcement. ρt is flexural tension reinf. ratio
Eurocode2	$Vc = 0.18k\,(f'c$ $100\rho t)1/3$ $k = 1 + \sqrt{200/d} \leq 2.0$ $\rho t \leq 0.02$		----

3. Literature Reviews

Mihai et al. in 2013 [23] investigated the behavior of five spherical hollow flat slabs of dimensions (1500×2850×310 mm) under concentrated load. The Specimens reinforced with different percentages of steel reinforcement ranges between (0.18 to 0.63 %). Results revealed that failure mode depends mainly on the steel reinforcement ratio. Therefore, the flexural failure mode occurred in slabs with reinforcement percentages less than (0.5%), while in steel reinforcement percentages higher than 0.5%, shear failure would occur.

Sakin in 2014 [24] conducted a study to look into the punching shear of five slabs made of self-consolidating concrete (SCC) with dimensions of (1000×1000×80 mm). While the others were solid slabs, three were bubble decks, which are plastic gaps with a diameter of (40 mm). In this study, steel fibers mixed into the concrete at 0.8 and 1% volume fractions to make the critical perimeter stronger. This perimeter was 2 d from the column faces. Test findings show that using SCC boosts punching shear strength. In addition, punching strength improved, and the angle of punching failure decreased by adding steel fiber in the critical zone.

Ahmed in 2014 [25] Investigated bubbling slab behavior and strength. Three slab samples with dimension1000 mm × 1000 mm Reinforced concrete slab thickness and concrete volume were the study's variables. According to the results, bubble slabs have a 10% lower shear capacity than flat slabs of the same thickness.

Fadhil In 2017 [26] examined the punching shear behavior of bubble slabs employing twenty-four RC slabs (1500x1500) mm with thicknesses of (100 ,130) mm experimentally under concentric and eccentric pressures. The main variables were the type of slab (bubbled, solid), plastic balls diameter (60, 90) mm, the concrete compressive strength (30, 60) MPa, and the bubble location relative to the critical section from the face of the column at (d, 2d). The findings demonstrated a decrease in the ultimate load of the bubble slab in compression with a solid slab of 4-20% and 14.7-29.4% in bubbles placed at (2d) and (d). Furthermore, bubble slabs exposed to eccentric loads exhibit an 11.8-17.6% decrease in ultimate load in compression compared to bubble slabs subjected to concentric loads.

Ibrahim and Hammed in 2018 [27] investigated the efficiency of stirrups and horizontal intermediate mesh reinforcement in enhancing Punching shear resistance and deformation in bubbled slabs at the slab-column connections in bubbled slabs. Ten specimens with dimensions of 1000 × 1000 × 100) mm. The primary factors investigated include slab type (solid, bubbled), shear reinforcement ratio, stirrup type (separated, numerous), number of layers for the middle mesh (one, two), and bubble location relative to the critical zone (inside, outside). Test findings demonstrate that bubbled slabs containing spherical balls within and outside the critical zone have about (69-83%) of a solid slab's ultimate load. This demonstrates that the sample with bubbles beyond the critical zone responds similarly to solid slabs but with a little reduction in punching shear

Al-Gasham et al., in2019 [28] they investigated the punching shear behavior of bubbled slabs using both theoretical and experimental techniques. Within their experimental portion, five samples measuring 1000 x 1000 x 90 mm assessed; two of the samples were solid slabs, and one had bubbles in it. The parametric analysis is carrying out using the ABAQUS software. The results of the investigation showed that the bubbled slab had a lower punching shear capacity than the solid slab.

Gharbi and Mahmoud in 2020 [29] Punching shear in reinforced concrete slabs subjected to fire was examined. Temperature distribution of the slab thickness, failure type, punching strength, and deformation were all anticipated using finite element analysis. Finite element transient thermal-structural analysis performed under fire circumstances using ANSYS. Concrete compressive strength, fire area, fire temperature, length-to-thickness ratios, and support type were all take into account in this parametric study. The result demonstrates the potential of finite element analysis to predict punching shear in reinforced concrete slabs subjected to fire. Furthermore, fire-exposed reinforced concrete slab punching shear is influence by the length-to-thickness ratio.

Jawad in 2021 [30] Investigated the punching shear behavior of reinforced geopolymer concrete bubbled slabs exposed to a real fire flame. 28 samples of (450 x 450 x 70) mm have been tested. Twenty-one slabs exposed to real fire flame, and seven specimens kept without burning as reference specimens. All samples tested under concentrated load at mid-span. The variable of experimental works is concrete types (geopolymer, normal, high strength and Reactive powder) with compressive strength (30, 30, 60 and 90) MPa, respectively, glass fiber content (0, 0.5, 1, and 1.5) %, fire flame temperature (150, 300 and 450) °C, fire flame duration 30-minutes, cooling methods gradually by air. The results show that geopolymer concrete bubbled slabs behave similarly to RC bubbled slabs at 150 °C. In (300 and 450) °C, the ultimate load decreases by (22 and 34) % concerning control slabs. When the glass fiber content increases, the ultimate load increases by (14 to 25) % for geopolymer concrete bubbled slabs without exposure to fire flame.

Al-Fwadhil and Waryosh In 2022 [31] studied the punching shear behavior of a Self-Compacted bubble Reinforced Concrete slab after burning it in a real fire test until it reached 300 C° and cooling it with air and water. All specimens tested under concentrated load at mid-span by testing ten specimen slabs with dimensions of (450 x 450 x 70) mm. The main studied variables are the type of concrete, normal-strength concrete (NSC) and self-compacted concrete (SCC), and the method and duration of cooling. Results show that using SCC improved the punching failure zone.

4. Conclusions

A literature review Was conducted on the punching shear behavior of bubbled reinforced concrete slabs, and numerous samples of bubble concrete slabs were studied. Each sample was constructed, each of which built using a variety of test parameters. Each of these slabs failed under the punching shear. The presence of plastic balls in the middle depth resulted in a reduction in the quantity of concrete where the stress is at a minimum.

References

[1] Singh, M., & Saini, B. (2019). Analytical and experimental study of voided slab. In Proceedings of the 1st International Conference on Sustainable Waste Management through Design: IC_SWMD 2018 1 (pp. 438-448). Springer International Publishing.

[2] Hai, L. V., Hung, V. D., Thi, T. M., Nguyen-Thoi, T., & Phuoc, N. T. (2013). The experimental analysis of bubbledeck slab using modified elliptical balls. In Proceedings of the Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13) (pp. G-6). The Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13).

[3] Ibrahim, A. M., Oukaili, N. K. A., & Salman, W. D. (2013). Flexural behavior and sustainable analysis of polymer bubbuled reinforced concrete slabs. In Fourth Asia Pacific Conference on FRP in Structures (APFIS 2013) (pp. 11-13).

[4] Bubbledeck, U. K. (2008). BubbleDeck voided flat slab solutions—Technical Manual & Documents. BubbleDeck UK head office, Jersey.

[5] Valivonis, J., Jonaitis, B., Zavalis, R., Skuturna, T., & Šneideris, A. (2014). Flexural capacity and stiffness of monolithic biaxial hollow slabs. Journal of Civil Engineering and Management, 20(5), 693-701.

[6] Björnson, G. (2003). BubbleDeck-Two-Way Hollow Slab.

[7] Sagadevan, R., & Rao, B. N. (2021). Experimental and analytical investigations on two-way flexural capacity of biaxial voided slab. In Advances in Structural Technologies: Select Proceedings of CoAST 2019 (pp. 233-247).

[8] Habibi، F.، Cook، W. D.، & Mitchell، D. (2014). Predicting post-punching shear response of slab-column connections. ACI Structural Journal, 111(1), 123.

[9] Acciai, A., D'Ambrisi, A., De Stefano, M., Feo, L., Focacci, F., & Nudo, R. (2016). Experimental response of FRP reinforced members without transverse reinforcement: Failure modes and design issues. Composites Part B: Engineering, 89, 397-407.

[10] Sprince, A., Fischer, G., Pakrastinsh, L., & Korjakins, A. (2014). Crack propagation in concrete with silica particles. Advanced Materials Research, 842, 470-476.

[11] Caratelli, A., Imperatore, S., Meda, A., & Rinaldi, Z. (2016). Punching shear behavior of lightweight fiber reinforced concrete slabs. Composites Part B: Engineering, 99, 257-265.

[12] Schnellenbach-Held, M., & Pfeffer, K. (2002). Punching behavior of biaxial hollow slabs. Cement and concrete composites, 24(6), 551-556.

[13] [13] Oukaili, N. K., & Hussein, L. F. (2020). Experimental and Analytical Study on Punching Shear Strength of BubbleDecks. ACI Structural Journal, 117(2).

[14] Nicácio, W. G., Barros, J. A., & Melo, G. S. (2020). Punching behavior of BubbleDeck type reinforced concrete slabs. Structural Concrete, 21(1), 262-277.

[15] Alsheameri, A. M., Rasheed, L. S., & Alsaad, A. J. (2023). Enhancement of flexural behavior of hybrid flat

slab by using SIFCON. Open Engineering, 13(1), 20220487.

[16] Muntadher Kadhim Abdul Hassan, (2022) "Effect of Water Cooling on Punching Shear Behavior of Reinforced Concrete Bubbled Slabs after Fire", A Thesis Submitted to the Civil Engineering Department, College of Engineering, Mustansiriyah University.

[17] ACI CODE-318-19: Building Code Requirements for Structural Concrete and Commentary". (2019). American Concrete Institute, Farmington Hill, MI.

[18] British Standards Institution (B.S.8110). (1997). "Code of Practice for Design and Construction", Part 1, London.

[19] Eurocode 2, "Design of Concrete Structures Part I. (2002) .General Rules and Buildings". European Committee for Standardization Brussels.

[20] Alexander, S. B., & Simmonds, S. H. (1987). Ultimate strength of slab-column connections. Structural Journal, 84(3), 255-261.

[21] Bubbledeck, U. K. (2007). BubbleDeck voided flat slab solutions—Technical Manual & Documents. BubbleDeck UK head office, Jersey.

[22] Yahya S. Ali. (2016). "Temperature Effects on Punching Shear Enhancement in Reinforced Concrete Slabs", A Thesis Submitted to the Civil Engineering Department, College of Engineering, Mustansiriyah University.

[23] Bindea, M., Zagon, R., & Kiss, Z. (2013). Flat slabs with spherical voids. Part II: Experimental tests concerning shear strength. Acta Technica Napocensis: Civil Engineering & Architecture, 56(1), 74-81.

[24] Sakin, S. T. (2014). Punching shear in voided slab. Civil and Environmental Research, 6(10), 36-43.

[25] Ahmed, Q. W. (2016). Punching Shear Behavior of Bubbled Reinforced Concrete Slabs. Diyala Journal of Engineering Sciences, 9(1), 55-66.

[26] Luma Fadhil, L.F. (2017). "Punching Shear Behavior of Bubble Decks under Eccentric Loads", Ph.D. thesis, University of Baghdad, Baghdad, Iraq.

[27] Harba, I. S., & Hameed, M. A. (2018). Shear behavior of self-compacted reinforced concrete two-way bubble slabs. International Journal of Civil Engineering and Technology (IJCIET), 9(12), 1117-1127.

[28] Al-Gasham, T. S., Mhalhal, J. M., & Jabir, H. A. (2019). Improving punching behavior of interior voided slab-column connections using steel sheets. Engineering Structures, 199, 109614.

[29] Gharbi, A. H., & Mahmoud, A. S. (2020). Punching shear behavior of reinforced concrete slabs under fire using finite elements. Journal of Engineering, 26(5).

[30] Hussain kadhum Jawad, "Punching Shear Response of Glass Fiber Geopolymer Bubble Slabs After High Temperatures Effects", A Thesis Submitted to the Civil Engineering Department, College of Engineering, Mustansiriyah University, 2021.

[31] Al-Fwadhil, M. K., & Waryosh, W. A. (2022). PUNCHING SHEAR BEHAVIOR OF A SELF-COMPACTED BUBBLE DECK SLAB SUBJECTED TO FIRE AND WATER COOLED. Journal of Engineering and Sustainable Development, 26(2), 40-55