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Punching Shear Strength of Bubbled Deck Slabs

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

[1,2]Civil Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq

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Abstract: Bubbled slabs are used to reduce the overall weight of the slab by minimizing the volume of concrete in the central portion of the slab. This drop leads to cost savings, a decrease in building time, enhancements in structural performance, and an improvement in the efficiency of the slab. Although this slab style has several advantages, it is comparable to flat slabs. The higher stress concentration at the column connection leads to failure due to punching shear. Furthermore, as recommended by construction regulations, the design equations for bubbling slabs are based on experimental data obtained from flat slabs. Prior studies on bubbled slabs have shown that the punching shear behavior of bubbled slabs differs from that of flat slabs.

Keywords: Bubbled slab, plastic balls, Punching shear strength, Reinforced concrete slab, Solid slab.

1. Introduction

The primary design constraint in reinforced concrete buildings is the distance between columns. When perimeter beams and thick slabs are necessary to create a larger slab between columns, this increases weight owing to the need for a greater volume of concrete [1]. Implementing the bubbling slab system is crucial for effectively addressing construction-related issues. This technique was developed in the 1990s by a Danish engineer [2]. The reinforced concrete bubble slab typically comprises a top reinforcement mesh, plastic balls, and a bottom reinforcement mesh [3], as seen in Figure 1. These slabs use plastic void formers in spherical, doughnut, oval, or cuboid shapes. The weight of the slabs may be reduced by up to fifty percent compared to solid slabs while still preserving flexural strength [6],[7]. The slab-column connections and areas where intense loads are applied are the most dangerous sections of two-way solid and bubbled slabs [8]. The concrete slab in this location is subjected to tremendous shear force and high shear stresses, causing it to be punched [9], [10], [11]. This could lead to the progressive structural failure of the whole structure. If the structural notion of these systems is not treated with accuracy, it is significantly degraded [12], [13]. However, the study on the punched shear behavior of bubbled slabs still needs to be expanded despite the many advantages associated with this form of a slab. This study reviews prior studies on the punched shear behavior of slabs with bubbled slabs.Sample text inserted for illustration. Replace with article text, including headings where appropriate. Figures and tables can be single- or double-column width as appropriate. During the production process they will be placed at the top or bottom of columns, after they are first cited in the text.

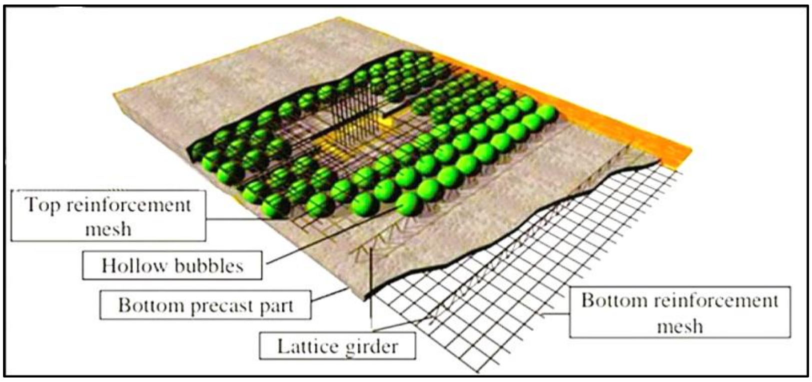


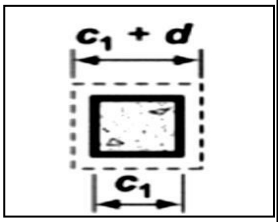
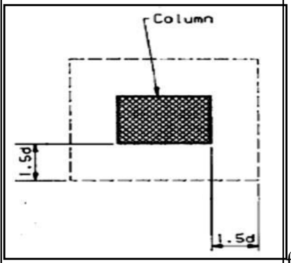
Figure1. Bubbled Slab System [4]

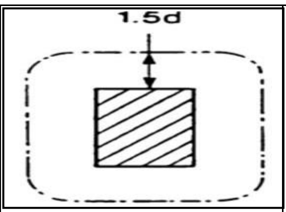
2. Punching Shear

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 connection point's punching shear strength (PSS). Some of these studies and suggestions are shown in Table 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 than 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 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].

Table1. Current Design Methods for Punching Shear [22]

Design Method	PSS (MPa)	Critical Section b0 For Rectangular Columns	Limitations
ACI318-19	$\mathcal{V}c$ 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	$\mathcal{V}c = 0.27k(100\rho t)1/3\ \ f'c\ 1/3, cube$ $k = 4\sqrt{400}/d$ $\rho t \leq 0.03$		The design of shear for concrete strength (fcu) not greater than (40 N/mm2). $(100\rho t)$ 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	$\mathcal{V}c = 0.18k\ (f'c\ 100\rho t)1/3$ $k = 1 + \sqrt{200}/d \leq 2.0$ $\rho t \leq 0.02$		----

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, plastic gaps with a diameter of (40 mm). In this study, steel fibers were 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 ball 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. investigated the punching shear behavior of bubbled slabs using both theoretical and experimental techniques in 2019 [28]. Within their experimental portion, five samples measuring 1000 x 1000 x 90 mm were assessed; two of the samples were solid slabs, and one had bubbles in it. The parametric analysis was carried 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 considered 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 influenced 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 were exposed to real fire flame, and seven specimens were kept without burning as reference specimens. All samples were 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) ℃, 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) ℃, 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 were 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 was 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.

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