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PUNCHING SHEAR CAPACITY OF REINFORCED LIGHTWEIGHT FOAMED CONCRETE TWO-WAY SLABS USING VARIES SHEAR REINFORCING SYSTEMS

A Thesis Submitted to Council of College of Engineering, University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

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Chapter One

Introduction

1.1 General:

Two-way reinforced concrete slabs are supported by columns without beam, girder, drop panel or column capital on substantive "flat plates" (McCormac, 2001). Such systems are easier to construct than joint systems (beam–slab). They offer high flexibility for arranging rooms which can be enclosed by easily removable non-structural walls and therefore reduce construction cost. The reduced heights of slabs in multi-story buildings also decrease dead loads on the column and foundation (Ying, 2007). These systems are used in buildings that require large spaces, such as car parks, hospitals and shopping malls.

However, the main disadvantage of such slabs is the punching shear failure caused by the combination of shear forces and high bending moments around columns, as shown in Figure (1-1), which increases the exposure of such regions to sudden brittle punching failure. This type of failure does not exhibit external, visible signs, unlike flexural failure which is ductile, as demonstrated in Plate (1-1). Punching collapse occurs around truncated cones above columns, with angles of 25° to 30°, when exceeding the shear–bearing tensile strength of concrete (Alexander et al., 1987), as depicted in Figure (1-2).

Various methods have been adopted to increase punching shear resistance, including (1) appropriate material selection to increase compressive strength and flexural reinforcement ratio and (2) increase thickness (3) the reinforcement of the punching shear zone using vertical and inclined stirrups, bent-up bars, welded wire fabric and hook bars.

Lightweight concrete is used to decrease shear through the reduced dead load of slabs and to reduce the weight of any load-bearing concrete structure elements. The reduced weight of members will decrease the lateral load that will be exerted on the structure during earthquakes (D. Theodorakopoulos, 1980).

Slabs are widely used elements in reinforced concrete structures, and they can be produced using lightweight concrete. Although material production using lightweight concrete incurs high cost, the overall cost is still lower due to the reduction in structural element size, concrete size and reinforcement steel amount(ACI523,1997). Foamed concrete reduces weight by approximately 25% when density is 1800 kN/m^3 (Zaher, A.A, 2010)

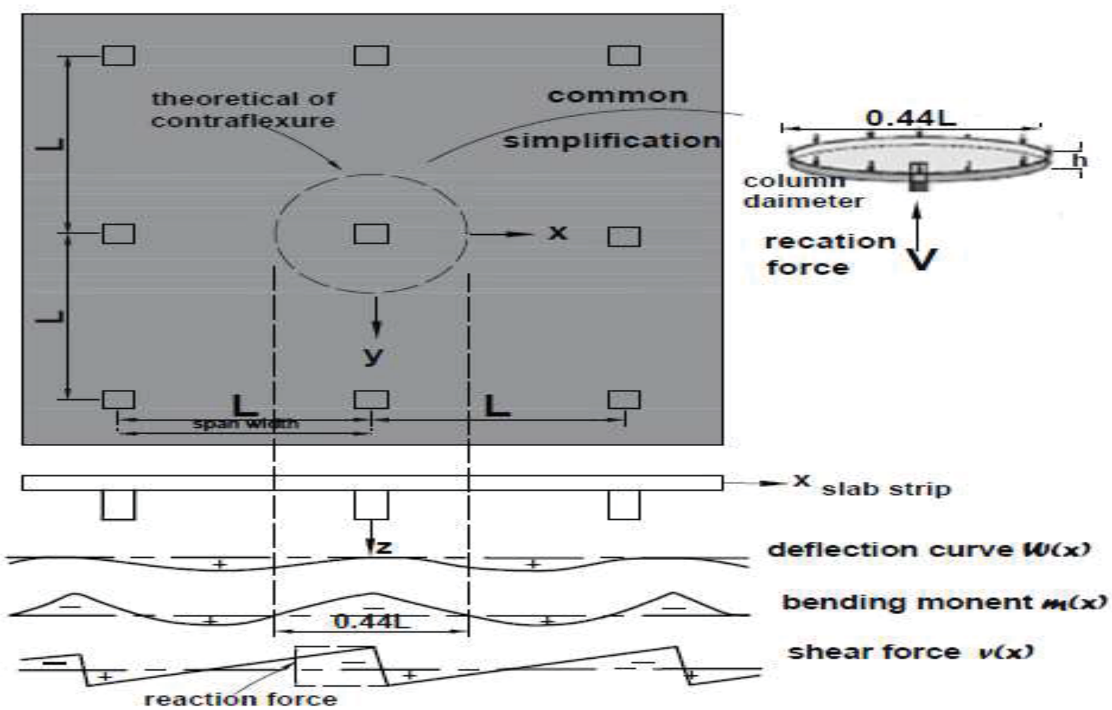
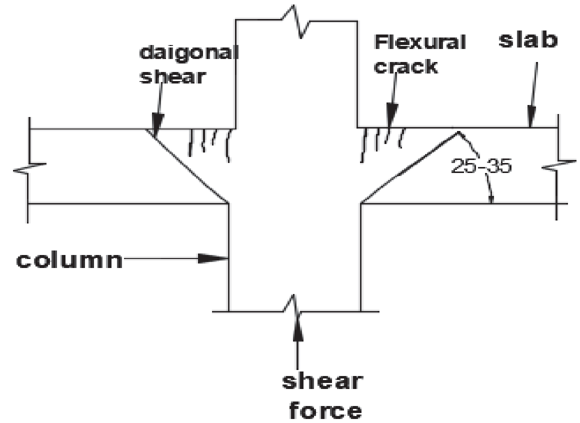


Figure (1-1): Beutel 2003 Plan view of typical flat slab. Section of slab strip with internal forces. and common simplification by punching models considering a circular slab cutout with diameter0.44L (adapted from Beute,2003)

Plate(1-1): Piper‘s Row Car Park, Wolverhampton, UK



Figure(1-2): Flexural and shear cracks in the flat slab near the vicinity of column (Moe,1961)

1.2 Punching Shear Reinforcement System

1.2.1 Lattice Shear Reinforcement System:

The lattice system has developed in recent years by having different shapes. A lattice is a combination of inclined webs with an angle and longitudinal bars welded at the top and bottom, similar to a truss (Park et al., 2007),as shown in Plate (1-2).

Main advantage of lattice system

- ✓ More effective in preventing cracks because it acts similarly to truss construction
- ✓ Uses precast and site-cast slabs
- ✓ Requires minimum space.

1.2.2 Band Shear Reinforcement System

A band is a folded plate made of steel strips with a hole; it increases the anchor between concrete and steel plates. A band can be used in thin slabs (Pilakoutas and Li, 2003), as shown in Plate (1-3). The other advantages of band shear are presented as follows:

- ✓ It is easy to construct and install.

- ✓ It does not reduce the effective depth of flexural reinforcement, and its usage requires minimum cover.
- ✓ It can be combined with another reinforcement system.

1.2.3 Stud Shear Reinforcement System:

The stud shear system is effective for carrying load capacity. Shear studs consist of steel bars with varying diameters and double heads welded into them, as shown in Plate (1-4). The main advantage of studs as below:

- ✓ easy and quick installation
- ✓ No caging is necessary because stirrup reinforcement
- ✓ can be added after placing longitudinal upper or lower reinforcement.

Plate (1- 2): Lattice system

Plate(1-3): Band system

Plate(1-4): Stud system

1.3 Light Weight Foamed Concrete

Foamed concrete is a lightweight concrete type with cementitious material and foam (van Deijk, 1991); it contains minute particles with a strong structure. The voids formed by adding a foaming agent to cementitious paste reduce concrete weight (Nambiar and Ramamurthy, 2006).

Current trends in civil engineering tend towards high and sustainable buildings. Many researchers have developed lightweight concrete and have improved concrete properties to meet general requirements. Foamed concrete meets many requirements in terms of sustainability, economy and durability (Jones and McCarthy, 2005).

The density of structural lightweight concrete ranges from 1350 kg/m^3 to 1950 kg/m^3 with a compressive strength of 17 MPa (ACI-213R, 2012). Foamed concrete has a density range of approximately 400 kg/m^3 to 1900 kg/m^3 (ACI 523, 1997).

Foamed concrete achieves concrete sustainability via decreased weight, minimal consumption of coarse aggregates and usage of secondary or recycled materials (Jones and McCarthy, 2006). The air content in foamed concrete mix is 35% of the total volume. The production of cellular concrete is important due to the presence of air bubbles in cement paste, which can be used to control mix density (L. De Rose, 1999).

1.3.1Advantage of Light Weight Foamed Concrete

The foamed concrete used in the construction industry offers many benefits and advantages, such as the following:

a. Lightweight concrete can offer economic benefits because it reduces the dead load of structures, concrete volume and steel reinforcement amount.

b. Lightweight concrete is mostly used in thermal insulation. The thermal insulation property of foamed concrete depends on its density. High-insulation properties have low density.

c. Lightweight concrete is much easier to pump as compared to conventional concrete, pumpable vertically and horizontally. Large volumes of lightweight concrete are easier to transport and accommodate. Moreover, it has ease of production, fast completion, and can be produced from the components that are available in any region (Fouad 2006).

d. It has an easy application as compared to other materials such as steel and timber, in addition to being economical, cost saving and cost reduction.

e. Innovative characteristics throughout, such as durability, workability, freeze-thaw resistance, reduced permeability, seismic resistance, shock absorption, low to ultra-low plastic density (this can be designed to be anywhere between 200-1600 kg/m3), flowing, self-levelling, self-compacting, rheology, and very low ‘settlement’ compared to conventional granular fills (Fouad 2006).

f. In addition, it has controlled strength, excellent thermal insulating capacity (0.10-0.65 W/mK), and it is also non-combustible, with good fire resistance and re-excavatable, if necessary (Jones & Giannakou 2004).

1.3.2 Disadvantage of Light Weight Foamed Concrete

When the utilisation of foamed concrete is proposed, determining its disadvantages compared with conventional concrete and considering all design criteria are necessary, particularly in terms of the:

a. Compressive and flexural strength will degrade typically as a function of density.

b. Unless purpose designed equipment is used mixing, may be the problem, in terms of the tendency of foam to float at the surface of the mix and thus its effectiveness, is diminished. In the case of an open mixer, the issue readily addressed is injecting foam into rather than onto the mix, or it is not a problem in the case when the foam is introduced into a flowing product line (Westendaus 2009).

c. The disadvantage of lightweight concrete is that it does not increase compressive strength within a low density range. However, lightweight concrete poses an advantage in the application of foamed concrete. Foamed concrete and NC are typically used in various applications. Each concrete type has different performance characteristics (ECOSMARTE, 2009).

1.3.1 Application of Lightweight Concrete and Foamed Concrete

One example of using LWA concrete in slabs for high-rise buildings is the Lake Point Tower in Chicago (built in 1968). This building consists of 71 stories with a density of 1730 kg/m^3 and a 7-day compressive strength of 22 MPa (ACI-213R, 2012), as shown in Plate (1-5).

- The Australian Circular Tower has 50 stories with LWA for slabs, columns and beams. The density of concrete is 1792 kg/m^3 with a compressive strength of 34 MPa . The tower saved 13% of construction cost (ACI-213R, 2012), as illustrated in Plate (1-6).
- The main non-structural uses of foamed concrete are precast ceiling panels, as shown in Plate (1-7), partition wall filling and fixed settlement. Track (1988) minimised asphalt settlement by using fine compressible soil (ACI-213R, 2012), as shown in Plate (1-8). The maintenance of damaged concrete is illustrated in Plate (1-9).
- Foamed concrete is used to make load-bearing and non-load bearing masonry blocks, as shown in Plate (1-10). The benefits of these blocks are their low weight, large size, reduced cost for housing units and usage in high-rise buildings , such as in the building of an Engineering School in Brescia, Italy. These blocks can be used in thermally insulating, sound-insulating and load-bearing external walls (Abd, 2010).
- Foamed concrete is used to insulate roofs and floors. In the City of Visitors in Karbala, Iraq, foamed concrete is utilised in the thermal insulation of ceilings. Foamed concrete is used in the roof as a levelling layer to prevent the accumulation of dirt. When foamed concrete is used as a levelling layer, two layers with a felt thickness of 4 mm are placed above it,

followed by a geotextile layer, cork with a thickness of 5 mm, river dust and shtiker, as shown in Plate (1-11). The applications of foamed concrete in Iraq are limited to rehabilitation, maintenance and the use of secondary slabs. Foamed concrete was used in the secondary ceiling of the Conference Palace (Al-Shammary) and in the Sports AL-Ascan Club in Baghdad, as shown in Plate (1-12).

Plate (1-5): Lake Point Tower in Chicago

Plate (1-6): Australian circular tower

Plate(1-7): Panel Foamed concrete

Plate (1-8): Fix settlement soil by Foamed concrete

Plate (1-9) :maintenance of damaged concrete

Plate(1-10): block foam concrete

Plate (1-11): Foamed concrete for using isolation thermal in city of visitors in Karbala (Anadolu Construction Company)

Plate (1-12): Foamed concrete for using roof in Sports AL-Ascan Club in Baghdad(Anadolu Construction Company)

1.4 Scope of the Study

This work sets the following goals:

1. Two types of concrete, namely, lightweight-foamed concrete LWFC and normal concrete NC, are used in this study. The mechanical properties of foamed concrete with and without fibres and foamed concrete with and without aggregates are studied. The range of physical properties which can be considered useful is governed by the requirements of structural strength. Materials with compressive strengths (i.e. below 17 MPa) are generally inadequate for lightweight structural uses and tend to be fragile. Compressive strengths above 25 MPa are necessary for normal structural applications.
2. The punching shear capacities of LWFC and NC slabs are compared.
3. Two-way slab specimens are produced, and their punching shear capacity is evaluated
4. The effects of concrete type and compressive strength are determined.
5. Three types of punching shear systems on the aforementioned samples are studied, namely (stud ,band,and lattice).

1.5 Objectives of the Study

The objectives of this research are to investigate the punching shear behaviour of LWFC slabs subjected to punching loads and to compare their results with those of normal-weight concrete. An experimental work with the following aims is conducted:

- ✓ Producing LWFC that is suitable for structural applications and sustainable LWFC members that are environmentally friendly and have improved properties
- ✓ Investigating the use of LWFC in two-way reinforced concrete slabs with a structural.
- ✓ Investigating the use of LWA with foamed concrete.
- ✓ Optimising the resistance of punching shears using different reinforcing systems

1.6 Thesis Layout

The thesis is offered in five chapters:

- ❖ **chapter one**.: The definition of punching shear failure and foamed concrete .the importance of the research problem chosen for the present study, scope, and objective
- ❖ **Chapter Two:** Presents a review of the previous studies.
- ❖ **Chapter Three;** Consists of experimental program related to materials and casting trail mixes, details of the two-way slab, casting specimen and method of testing
- ❖ **Chapter Four:** This chapter consists two part: part one for results and discussion of trail mixes, part two included results and discussion behavior of two-way slabs as a structural.
- ❖ **Chapter Five:** conclusion drawn from the experimental work and recommendations for future works.

Punching Shear Capacity of Reinforced Lightweight Foamed Concrete Two-Way Slabs Using Varies Shear Reinforcing Systems

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Abstract

This study optimizes the properties of lightweight foamed concrete (LWFC) and investigates the punching shear capacities of two-way slabs using different punching shear reinforcement systems.

In the part of optimizing and improving LWFC properties comprise on utilizing different types of lightweight coarse aggregate (LECA) and Porcelinate as coarse aggregates and fly ash (FA) as fine aggregate (replacement for sand), were utilized and silica fume was added to optimize LWFC properties. Moreover, steel fibers with different aspect ratio were used. The investigated properties were fresh-state properties (i.e. fresh density and workability) and hardened properties (i.e. compressive strength, splitting tensile strength, flexural strength, modulus of elasticity and dry density). For comparison, four different mixes were used to complete the second part of the study, three mixes of LWFC with optimum properties and NWC as reference mix.

In the second part of the study, the effects of different systems for punching shear reinforcement, namely, band, stud and lattice, on the punching shear capacity of two-way slabs were evaluated. Fourteen two-way slabs, which were simply supported along the four edges and had dimensions of 1000 mm × 1000 mm × 90 mm, were tested under a concentrated load on a central stub column. The specimens were divided into four groups according to concrete type: Group 1 comprised lightweight foamed concrete LWFC , Group 2 consisted of lightweight foamed concrete with lightweight aggregate (LWFC+LWA), Group 3 included

high strength foamed lightweight concrete with fly ash (LWFC+FA), and Group 4 was composed of reference concrete, i.e. normal concrete (NC). Each group included four slabs, depending on the shear reinforcement system (without reinforcement, with stud, with band and with lattice). The main characteristics studied were deflection at the center slab, crack pattern, ultimate load capacity, stiffness, ductility, failure angle, punching stress and punching strain in the tension and the compression zone. Results were compared with reference codes (ACI318M-14, BS8110 and EC2).

The results of the trial mixes for LWFC when materials (e.g. steel fiber, aggregate and FA) were added exhibited improved properties of LWFC in terms of compressive and tensile strengths. These results meet structural requirements and reduce weight by approximately 25%. The ultimate load of NC is higher than that of foamed concrete by 5%. However, the ultimate loads of foamed concrete slabs with shear reinforcement are greater than those of slabs without shear reinforcement. The increase in ultimate load for (LWFC) is approximately 16% to 43%, that for (LWFC+LWA) is approximately 13% to 40%, that for (LWFC+FA) is approximately 19% to 31% and that for (NC) is approximately 55% . The deflection in LWFC is higher 25.6% than that in NC. Nevertheless, the deflections in slabs with shear reinforcements are lower than that in the slab without shear reinforcement. The slabs with punching shear reinforcements are stiffer than the slab without shear reinforcement approximately (9%-67%). The results achieve optimum resistance for punching shear failure by using lattice and stud reinforcement systems. The band system has lower stiffness and resistance than the other systems by 18%. The addition of aggregates to foamed concrete improves the structural behavior of foamed concrete slabs. The ACI318-14 code gives higher estimates of punching strength than the experimental results. The EC2 code provides estimates that are close to the test results. The prediction results of the BS8110 code underestimate the experimental results.