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A STATE OF THE ART REVIEW ON HOLLOW CORE SLABS

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ABSTRACT

There have been many developments in concrete technologies that have had a major impact on structural systems. This review describes previous research literature relating to hollow-core slabs. Previous studies related to the present research can be categorized according to previous research on weight reduction of slabs studies. The main conclusions obtained from previous research are also included in this paper.

Keywords: reinforced concrete, hollow core, slabs, experimental, finite elements.

INTRODUCTION

Analysis and design of reinforced concrete slabs are interactive areas of research work. At first Reinforced concrete floors or slabs were built on a regular basis at the earliest of the 20th century. Concrete slabs are among the most common types of structural elements. It is a component of the building that normally bounds a space vertically. The slab member may provide the lower support as in (floor) or upper construction as in (roof) in any panel in the building. Slabs are built in a wide change of methods: e.g., pre-cast or compound with a wide change of structural systems as solid, voided, ribbed, and waffle.

Floors and roofs in concrete buildings are often made of prefabricated, hollow core members. These systems are quick to set up and are cost competitive. This will reduce the depth of the structural members to a minimum. The introduction of longitudinal cores reduces the dead load and results in an effective structural systemStanton, J.F., in 1992 [1].

Generally, the situation occurs that structural members have to be renovated because of many issues, or for specific instances. One of the extremely common problems the necessity for openings to be generated in some cases when allocating with reinforced concrete slabs; the essential for openings in slabs becomes encountered in the structural engineering. Post-construction fixing of elevator or escalators, introduction new staircases, heat and ventilation ducts, fire protection of pipelines, additional skylights plumbing , air conditioning, benefits (electricity, telephones and wiring ducts) and architectural aspects are necessary over the flooring slabs. Casadei P., *et al.* in 2003 [2].

Hollow-Core Slabs

A HCS (hollow core slab) is a precast, or a prestressed concrete component having holes that spread during the span of the slab, on condition that decrease weight, thus cost and such a lateral of advantage, can work in electrical or mechanical manages. Mainly operated as surface or else roof deck systems, HCS also have useage as members, partition sections, and bridge deck elements. The span of the HCS reaches equal (18m) without supports. Elements pre-stressed HCS purpose designed for various applications needing floor or roof systems. This method can be preferably used in residential, commercial or car garages projects. Precast, prestressed HCS offer major structural member success through the operation of HSC, but all together demanding little material consumption. Stephen C., in 2013 [3].

The HCS are efficient. Slabs are made using dry casting or extrusion molding systems where the concrete is required very low through a machine. The concrete is compressed around the cores formed with role or pipes. The slab with continuous holes is being as heating/cooling ducts and as channels for electrical wiring. Hollow core slabs minimize the transmission of sound and vibrations between building floors and eliminate floor squeals.[4].

A HCS or voided slab is a precast concrete slab usually used to build floors in structural buildings. The slab was particularly popular in countries where the focus was on the construction of prefabricated concrete houses. The popularity of precast concrete is associated with low-seismic areas and more economical constructions due to rapid assembly construction, low self-weight (less materials), etc.

The precast HCS has longitudinal voids extending the full slab length which makes the slab lighter than a considerable solid slab of equal depth or strength. The lower weight is very important issue because it reduced the costs of transportation and construction costs. Usual precast hollow core concrete slabs are shown in Figure-1.

Figure-1. Typical precast hollow core concrete slabs.

Advantages of hollow core slabs

The main advantages of the slabs system with hollow cores can be summarized as follows Bison in 2007 [5]

- It reduces the total dead load of the building
- It reduces construction cost and time.
- Immediate un-propped working platform.
- Extra-long spans.
- Factory produced to rigorous quality standards

The process of designing HCS

The design method for a HC floor system would naturally contain the subsequent conditions:

- The Over-all organizational arrangement containing the supposed self-weight of the slab and any important floor penetrations.
- All other permanent appointments containing partition loads and possibly changeable loads.
- All designs are placed on the floor containing live loads distributed uniformly and point loads.
- Customized floor support activities containing any special requests for plastic hinge areas.
- Displacements of support caused by Earthquake and rotations.
- Vertical seismic loads.
- Floor diaphragm requests.
- Over any estimated elongations ensuing from inelastic behavior in supporting beams.
- Tolerance issues.
- Any other issues, such as minimum compressive strengths, propping restrictions fire resistance, durability, etc.

Yang in (1992) [6] showed that Pre-stressed webs ability to withstand shear failure is calculated using a dedicated design formula. The additional shear stresses that the webs are subjected to due to pre-stressing were taken into account in this method. The suggested procedure for predicting web's shear failure showed a good degree of accuracy when comparing the results from the finite element model and the results obtained from the formula. This formula, by the advised procedure, proved its practicality and can be used to account for different scenarios related to changes in design parameters such as changes in loading cases, types of cross sections, pre-stressing levels, material and finally geometric parameters. The results clearly state that the proposed procedure is more efficient and has a greater potential to predict shear failure in webs than the methods specified in the design codes. This formula was tested on several slab samples to determine its efficiency.

Four test specimens of pre-stressed hollow core slabs were tested by Pajari in (2004) Two of the mentioned slabs have a thickness and a span of 400 mm, 6m respectively, and the other two have 200 mm, 4m respectively. With respect to width, all of the four specimens were 1200 wide. Both of the two sets of specimens were subjected to pure torsion to determine their torsion resistance. For the first set of specimens (400 mm thick slabs), the obtained torsional stiffness was similar to the value that was theoretically calculated. However, the second set (200 mm thick slabs) showed a 30% lower stiffness than what was predicted by the theoretical calculations. The expected torsion resistance came up to be 60% and 70% percent of what was recorded during testing for the 200 mm and 400 mm slabs respectively. Taking into account that the lower typical value of concrete tensile strength was considered in the calculations. The failure mode during tests was similar to what was expected, i.e. 45º cracking with respect to the longitudinal axis of the slab unit located in the top flange. The tested specimen showed substantial ductility after failure to withstand this considerably unexpected failure mode. The tested specimens under this condition didn't collapse but the test had to be stopped due to the extreme rotation.

Hoogenboom in (2005) [8] advised a technique through the use of finite element analysis of HCS flooring, the use of this technique may be crucial in case of relatively large floor openings. The idea of this technique came as a way to create a computer program that is able to perform the analysis and to be used as a assistive design tool. Several formulas are used to determine floor properties in a finite element solution. Formulas that are used to calculate the degree of stress recovery were established by the use of section method of analysis that determines moments and forces in critical parts of the floor. These stresses are then compared to floor material strength at these parts of the floor. This study of hollow-core slab floors reviled that large openings can be possible without the need of additional beams and columns.

Chung, *et al.* (2010) [9] worked on a numerical finite element simulation of in ideal hollow slab shape which is bi-axial with 8900 mm length, 300 mm width, and 250 mm thickness. This simulation was used to check the effectiveness of hollow slabs with different hollow shapes tested which are square, spherical, mushroom and elliptical. LUSAS **[10]** is the name of the finite element program that was used to perform a non-linear analysis on hollow slabs. That is to determine the factors that govern hollow shapes such as shape; corner radius and dimeter to help understand their effect on slabs for example, crack progressions and their area of concentration. Bi-axial hollow shape in longitudinal and transvers directions was represented in a three dimensional model were the basic

ARPN Journal of Engineering and Applied Sciences

design of the model came of an optimized rectangular slab analysis.

Mahdi in 2011 [11] performed a non-linear analysis on a hollow reinforced concrete slabs through a finite element method of plate bending and beam elements. Basically, the study was to divide the HCS into two chief parts, which are hollow pates that represent the top and bottom flanges and stiffening beams which represent the vertical webs between webs. Results from modified computer programs that have the ability to analyze different types of reinforced a pre-stressed hollow slab in addition to finite element solutions were compared against experimental results. That is to prove the ability and potential of computational non-linear models to obtain similar results to experimentally obtained results. The behavior of hollow reinforced and pre-stressed slabs against some changes in the model and material parameters was able through parametric studies when the load-deflection response is obtained. These parameters contained within the influence of concrete strength, pre-stressing tendon amount, existence of holes, hole size, hole shape and failure concrete crushing strain. Generally, the acceptable level of matching between the results obtained from finite element and the investigational work.

Rahman*et al.*in2012 [12] tested a full-scale precast pre-stressed hollow-core slabs (PPHC), using various (a/d). In order to determine failure load of slabs, the slabs were loaded until it reached its failure point. About 15 slabs with 5 to 2.5 meters' spans and with 200, 250 and 300 millimeters in depth, they were tested using four-point load test. For a depth greater than 200mm the results were interesting such the failure type of HCS has varied from pure bending to bending-shear mode. Furthermore, the shear strength of (PPHC) slabs has reduced with the increment in depth. Also, during the loading tests, it was noted that a transition from flexure-shear to web shear failure as a function of (a/d) has occurred. The final analysis of the results presented that obtainable ACI318M code formula has miscalculated the flexure-shear strength of the HCS. Finally, depend on the obtained results, a modification for the existing ACI318M code equations was proposed, in order to accurately capture the mode of failure and failure load capacity of the slabs.

Allawi in 2014 [13] experimented the one direction voided slabs to test the structural performance of the voided concrete reinforced slabs. The holes are occupied with styropor as an insulator; it was implanted at the mid region of the slab depth concerning the compression and tension zones. The chief factors were the length and width of the holes, also, the method of applying the styropor. i.e. as isolated ports of styropor separated by concrete ribs. The performance of the voided slabs was calculated based on load-displacement relationships, failure strengths and modes of failure as linked to the slab reference. Additionally, a nonlinear finite element analysis (FEA) was preformed using ANSYS to examine the authority of the suggested numerical ideal and to do a full comparison between the investigational work and the theoretical cases.

The final results showed that the greatest percentage of weight decreasing was 13.7% then it offered the maximum load strength that is almost 96.8% and about 97% of the initial reference slab stiffness. The obtained (FEA) load and ultimate deflection is in accordance with the laboratory ones, the difference between them is less than 10%.

Mansour *et al* in 2015 [14]investigated the bending performance of a precast reinforced concrete floor or slab having steel fibers concrete topping. The characteristic of hooked-end steel fibers of length of 30 mm and a diameter of 0.75 mm were implemented. Since the behavior of slab based on the interaction between the new and old concrete, various kinds of roughness of the surfaces at the interface were used to offer fine bonding between the two layers. Depend on investigational results; the flexural behavior was displayed to be determined by not only on adding the steel fibers to the topping slab but also on the type of surface interface roughness. To study the composite samples, the interface bond slip was also calculated during the experiment. The results presented a fine consistency of roughness in on condition that bonding interface strength. It was shown that roughness of the transverse direction offers the good bonding interface strength. Although the results displayed the interface slip at center, slip was not noticed at either end of the sample.

Foubert*et al*, in 2016 [15] examined the behavior of a flexural strengthened hollow-core slabs. Theses slabs were improved with NSM carbon fiber reinforced polymer strip to increase strength. There were 7 full scale samples which were simply supported subjected to load (monotonic load pattern) up to failure. The variables in this testing were the use of different pre-stressing type of internal reinforcement ratios in addition to three different NSM reinforcement ratios. This investigation type of study looked closely to failure mods, cracking, deflections, load-strain relationship and strengthen capacities. This investigation also included a comparison between the laboratory results and theoretical analysis or estimates that were adopted by relevant standards such as the Canadian and the American standards. The Figure-2 below presents the failure modes of the tested specimens.

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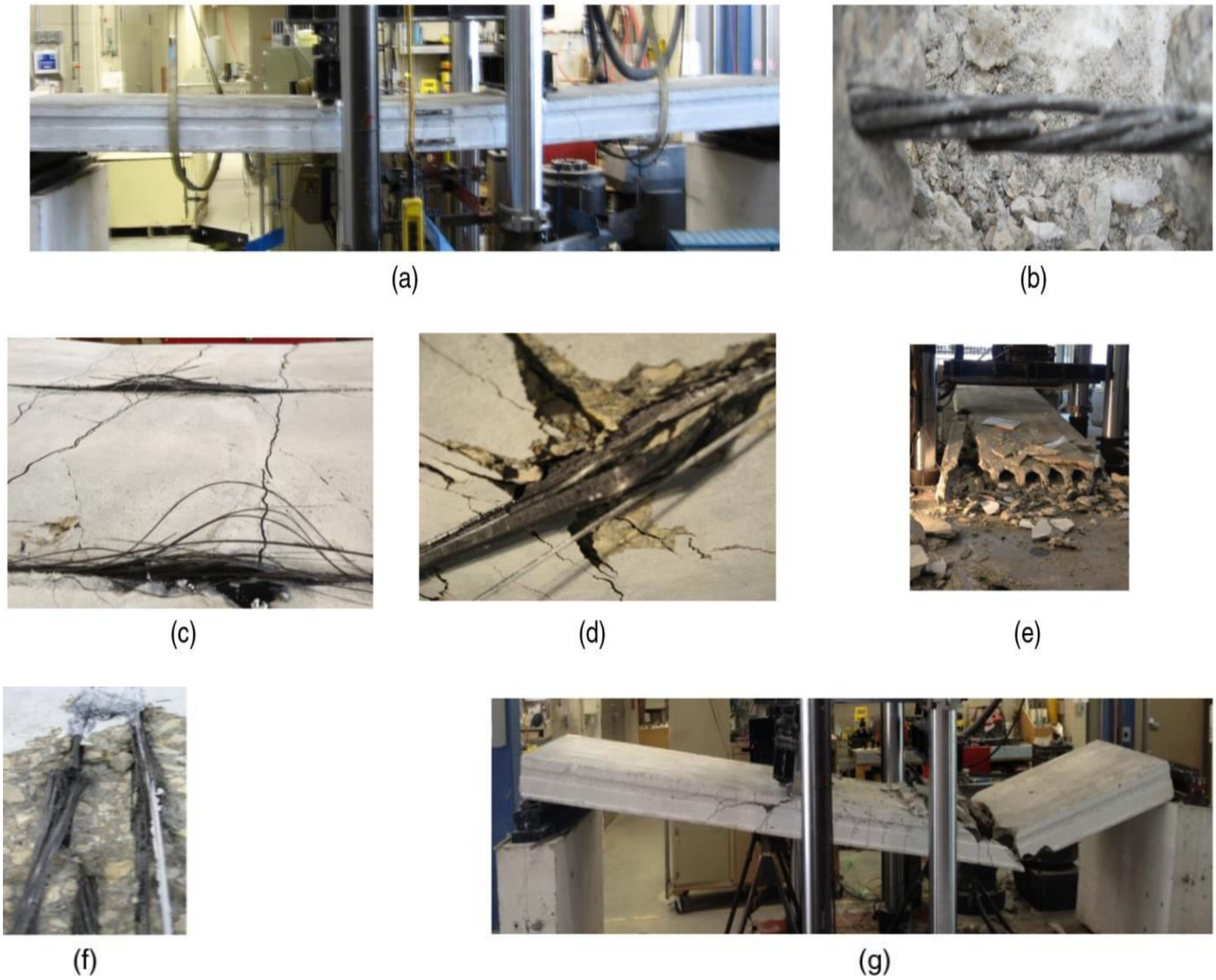

Figuer-2.type of modes of failure for descriptivesamples: (a) Slab I-0 at failure; (b) rupture of strand in Slab I-0; (c) CFRP rupture in Slab I-2; (d) CFRP rupture in Slab I-4; (e) flexure-shear failure of Sample I-8; (f) failure of CFRP strips in Sample I-8; (g) flexure-shear failure of Sample II-4 [15].

The findings of this investigation showed that the capability of pre-stressed hollow-core slabs to resist flexural and shear were efficiently improved through NSM-CFRP strengthening. This research showed that strengthening with NSM laminates enhanced both the deformation ductility and energy absorption of pre-stressed hollow core slabs unlike the non-prestressed concrete slabs.

Ibrahim *et al*, in 2016 [16] presented using an experimental type of research the shear-flexural strength of composite slabs of HCU (hollow core unit) and concrete top cover. Fourteen composite slabs samples were tested in a three-point load type of test. The samples had different apparent roughness and surface condition before designing the concrete top cover. Two dominate types of surface roughness were studied which are smooth and irregular surface. Also, even though the moisture conditions were dry and optimum wet, the behavior of the longitudinal joint between the HCU panels was studied. Values obtained by formulas in the Eurocode 2 and the previous researcher were similar to what was obtained from the experiments.

The results showed that the two factors mentioned previously (surface roughness and longitudinal joint) affect the degree of stiffness and shear-flexural strength. The optimum HCU surface nature found to be achieved are the combination of rough and wet condition which is able to increase the stiffness and shear strength, while the longitudinal joint between HCU panels minimize the slab shear strength. The research found that the horizontal shear is not what governs the strength and response of slabs. The Eurocode 2 does not give an estimate for shear strength, whilst the previous researcher equation was able to provide that.

Abed in 2016 [17] presented a study that includes both numerical research and investigational work regarding the shear strength of concrete slabs with longitudinal hollow cores. The studied specimen had different hollow cores dimensions and were examined under different load conditions by varying the distances of ratios (a/b). The dimensions of the tested specimens were (2.05m) in length, (0.6m) in width and (0.25 m) thickness.

It can be showing that for load-deflection result with each enlarges of load until the final load which failed with it.Both the cracking load failure load was recorded during in addition to noting the spread of the cracks and the associated deflection at the center of the slab under two-line loading. Results obtained from testing showed a 21% to 33% reduction in the ultimate strength of solids and 13% to 48.5% reduction in deflection in the center of the slabs relative to the increase in the shear span ratio from 2 to 2.5 and 3 respectively. In addition, a reduction in the ultimate strength by (5, 49%, 15.75 and 20.6%) was found due to the existence of the circular hollow cores with a dimeter of (75,100 and 150 mm). Finally, the load of HCS was reduced by nearly 31% to 45%, at the same time an increase in the deflection by 24.8% and 6.85 was noticed respectively.

Prakashan*et al,* in 2017 [18] carried out an investigational work on four various HCS along with the solid one as a reference case. The load-deflection curves have been gained with the ultimate load and the deflection were recorded at the first concrete crack. The efficiency of the conventional bending capacity formula in calculating the strength of HCS was estimated. The obtained results from the investigational work were also used to do a proportional study of the samples considered. The research determined that the suggested formula for calculating the bending strength can be used for HCS too and they have better responses than the solid one both in terms of serviceabilityand load-deflection response. Figure-3 shows the samples fabricated for the laboratory study.

Figure-3. Slabssamplesmade-up for the laboratory work [18].

Wariyatno*et al*, in 2017 [19] carried out an experimental test on samples involve a solid slab such as a reference and a HCS type 1 (use PVC pipe to create the cavities) and a HCS type 2 (using Styrofoam to create the cavities). The slab thickness was 12 cm; the result showed that HCS type 1 and 2 can decrease the weight of the slab by about (24% and 25%) as related to the solid slab. The flexural strength of HCS type 2 is larger than the HCS type 1; so that, it is less than the reference slab with totally differences in steel diameter. The value of the flexural stiffness of the solid slab is greater than HCS type 1 and 2. A crack that occurs in the solid slab is distinguished as flexural crack, although the cracks which occur in the HCS type 1 and 2 are shear cracks.

Abdul Al-Aziz[20] tested 7 HCS under two monotonic line loads. The specimens dimension was of length (1.1m), width of (0.6m) and depth of (0.12m). The laboratory findings demonstrate that the reduction in shear span to effective thickness ratio for solid slab with (LWA) cause a larger in flexural failure strength by about (29.06%) and enlargement in slab deflection at failure load by about (17.79%).Using (LWA) in pouring hollow slabs with square core with constant (a/d=1.9) (weight reduction about 36.64%) gives lesser the cracking and failure loads by about (14.29%) and (27.70%) respectively

The use of (LWA) in concrete pouring HCS with circular cores (a/d=2.9) (weight reduction by about 32.92%) shows reduced cracking and failure loads of about (21.43%) and (4.69%) then the same specimen (weight reduction of about 13.64%) with normal weight aggregate. The analysis results shows good correspond with the laboratory test findings with average variation of (7.56%) in ultimate or failure strength and (7.26%) in ultimate deflection.

CONCLUSIONS

The main conclusion is as follows:

a) Feasibility to use HC one-way slab as a roofing member for buildings. It was proved also that these slabs efficient after rehabilitation using carbon fiber (CFRP) srips.

b) by eliminating bubbles at the center of the slab at distance 2D and 3D the failure load increased by about (14.72 and 8.76%), respectively for slabs with (D/t = 0.6) compared to slabs with bubbles at all slab area, and for slabs with (D/t = 0.7) the ultimate load increased by (30.85 and 27.65%), for bubbles at distance 2D and 3D, respectively.

c) The NSM-CFRP strengthening method majorly supports the bending and shear load capacity of prestressed HCS. The increase in failure flexural capacity was minimized in slabs that failed by shear before reaching their full bending capacity. Unlike nonprestressed concrete, the addition of NSM laminates maximized both the energy and absorption of the HCS.

d) The conventional bending strength formula can be used for HCS as they give good behavior than the solid slabs. This is obvious in the load - deflection behavior.

e) The greatest percentage of decreasing in the cross sectional area is extending between 29%-35% for styropor block slabs.

f) The reduction in shear span to depth ratio for (LWA) solid slab cause larger flexural failure strength by about (29.06%) and ultimate deflections by about (17.79%).

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