ISSN NO: 2770-4491
Date of Publication:30-11-2023

State of the Art Review on Hollow Core Slabs

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Abstract
Numerous advancements in concrete technologies have significantly influenced structural systems. This review provides an overview of the existing body of research literature pertaining to hollow-core slabs. The existing body of literature pertaining to the current research can be classified based on prior investigations conducted on the topic of weight reduction of slabs. This paper incorporates the principal findings derived from prior research.
Keyword: hollow core, slabs, reinforcement concrete, finite elements, experimental

1.Introduction

Analysis and design of reinforced concrete slabs are related fields of study. In the early 20th century, reinforced concrete floors or slabs were prevalent. Concrete slabs are common structural components. Construction elements often enclose a space vertically. In every building panel, the slab element can support a floor or a roof. Slabs can be pre-cast or cast-in-place and created using solid, voided, ribbed, or waffle structural systems. Concrete floor and roof construction often uses prefabricated, hollow core sections. Rapid deployment and affordable price are available with these systems. This reduces structural element depth. Longitudinal cores reduce dead load and improve structural performance. Stanton efficacy. Stanton Typically, structural components must be renovated owing to various issues or unusual circumstances. Creating gaps in reinforced concrete slabs is a common structural engineering problem. Some allocation situations demand such apertures. For post-construction flooring slab modifications and improvements, lifts or escalators, new staircases, heat and ventilation ducts, fire protection for pipelines, skylights, plumbing systems, air conditioning units, and electrical, telephone, and wiring ducts must be installed and maintained. Casadei et al. discuss functional and architectural elements **[2]**. This study examined the latest developments in precast hollow core (HC) slab design, prestressed concrete, fiber-reinforced polymer (FRP) composite reinforcement, and strengthening techniques through a comprehensive literature review

2. Experimental work on hollow core slab

The experimental works carried out on the hollow slab and the researchers' results on hollow concrete slabs are presented

Norman L. Scott 1973 The researcher's load test on the machine-made hollow slab with a composite cover showed that ACI principles may accurately forecast the prestressed components' maximum flexural amplitude. In bending failure, the 31.5-foot slab can withstand 540 pounds per square foot (270 pounds). Service is uninterrupted. This part showed significant shear strength with a 2-inch-thick concrete coating of medium strength. Test findings show the two-linear approach yields conservative estimates of deflection behaviour in the fault band up to 12 vf **[35]**.

Haskell E. Wright and Jr. Ned H. Burns 1974 In an Experimental test, the researcher found that hollow precast concrete panels deflect rapidly after breaking, which causes voltage-induced deflection concerns. Hollow prestressed slabs can handle deflection under service-level loads, according to the research. A study of deviations in the two slabs shows that the double tee controls deviations better than the hollow equivalent. Cracked hollow slabs deflected quickly. Pre-stressed steel is used widely in cracked areas. Low pre-stress lessens cracking hardness, while high pre-stress fracture enhances it. After cracking, portions with more pre-stressed steel are harder. After cracking at the design level loads' general area, where the crack-to-non-cracked hardness ratio was 0.6 to 0.5, the remaining composite components are still hard, according to the researcher. Cracking loses hardness, causing deflection above ACI limits **[39]**.

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I. Rosenthal 1978 The researcher tested the continuous slab system on a hollow concrete slab without a topping. It provides tensile strength between its elements. This method also transfers torque, reducing bending moments, deviations, and cracks. The researcher poured the internal support region and filled the reinforcing steel negative moment. The continuity technique improved the precast hollow slab and stress without pouring the topping layer, according to tests. The slab poured over the inner supports must be strong. No slippage was found, and the slab's negative rebar was securely connected. The slab with continuity can be integrated into the floor structure since it can handle more loads and has fewer variations than the slab supported by basic support **[32].**

helén broo and karin lundgren These two researchers tested a 400mm and 200mm slab for shear and torsion under central and eccentric pressures. In the final analyses, the slab nearest the load and the active support were built using rigid elements, while the remaining slabs were planned for a beam element and the stained rotational crack model mixed the concrete using non-linear mechanical fracture. In particular for centrally loaded samples, finite element studies captured test behaviour, failure mode, crack pattern, and maximum load. The maximum load was overstated for eccentric load samples. The beam element's excessive torsional stiffness overestimated the maximum load. Second, numerous shear-tensile tests showed longitudinal cracks above and below several voids, which contradicted the analyses. Research did not reveal these fissures. When made, sawing may have caused several fissures. The first shear stress fracture was found in one of the 400 mm thick hollow slab's external networks, where one of the interior networks always split first. This is likely due to a manufacturing defect that compressed the internal networks on both sides and the outside networks on one **[8].**

Matti Pajari 2004 The researcher who studied pure torsion on PHSC and its effect on slabs with thicknesses of 200mm and 400mm found that the upper edge is cracking at an angle of 45 degrees with the longitudinal axis of the slab, even though the failure was sudden and the slab units showed ductility afterwards. No one collapsed until excessive rotation ended the test. The study found that the preliminary mathematical approach predicted the same torsional stiffness for a slab 400 mm thick, but for a slab 200 mm thick, the estimated hardness was 30% lower than the measured hardness. The predicted torsional strength for 200mm and 400mm slabs was 60% and 70% of the measured strength using the characteristic value of the least tensile strength of concrete. The upper edge had no longitudinal cracks after sawing the panels into smaller pieces before testing. The estimated and observed hardness were similar for a 200mm slab, but 70% and 100% for a 400mm slab **[29].**

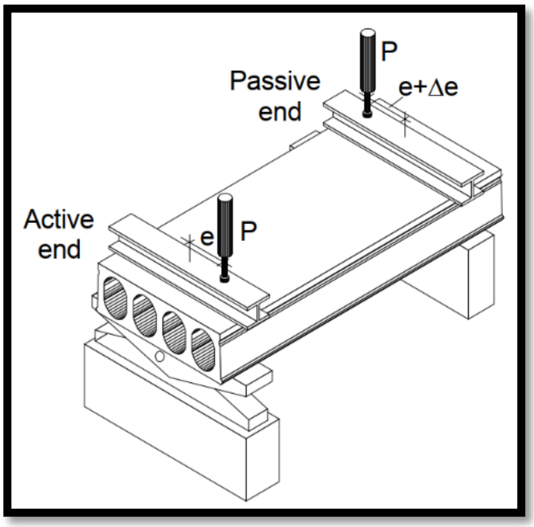

Fig.2 General view on loading arrangements

Abdelhadi Hosny et al 2006 Researchers used CFRP laminates to improve PHCS after investigating negative bending moments. The researchers arranged these slices at the top of the hollow slab portion, so the load destroyed the prestressing threads and concrete in the negative moment area first. The data showed that the

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carbon fibre reinforced slab's breaking moment and negative momentary strength increased by 183%, 225%, and 277% to 574%. The results showed that when cracks form, the failure mechanism must be considered when calculating carbon fiber-reinforced slab nominal moments. The test showed that shear failure occurs if cracks are not halted **[17]**.

Fig.1 Marked locations of the CFRP strips on Slab

Ashraf Elarabi and A. H. Hosny et al.,2008 They examined PHCS behaviour using CFRP and carbon fiber-reinforced polymer. Nine 4.8 m long, 200 mm thick, 1.2 m broad models were tested. Four monotonic load points were applied till failure. He used 1.2-mm carbon fiber-reinforced plastic strips and 0.38-mm sheets. The cracking load of carbon fiber-reinforced panels increased 13%. More efficient were carbon fiber-reinforced plastic sheets than strips. Finished slat load percentage increased by 26% and slab load percentage by 49%. End anchors for CFRP slats delay slab failure but not bond failure. Due to strong binding, carbon fiber-reinforced plastic panels cracked more, according to the study.Due to CFRP, the disparity was justified **[31]**.

Fig.3 Failure Modes of slabs strengthened with CFRP Sheets .

Sorin-Codruţ Floruţ et al., 2009 They examined how FRP (fiber-reinforced plastics) affects PHCS and bending. Shear stress broke the slab, according to the findings. Reinforcing the slab did not totally increase its bending capabilities, but carbon fiber-reinforced plastic reduced the likelihood of cracks forming and growing. The results also showed that the suggested reinforcement does not introduce CFRP's crucial mechanical capabilities, but if the panels are subjected to uniform loads, as is the case with the design loads, CFRP can achieve its capabilities **[14]**.

Wasif Khudair Majeed et al., 2013 They explored the behavior of concrete Hollow concrete behaviour using ordinary and carbon fiber reinforced concrete. Ferrous fibre spacing ratios Vw and volumetric ratios Vf vary

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between models. This is done to assess the hollow concrete slab's effectiveness after treatment and suitability for usage after partial or complete collapse. The CFRP polymer carbon fiber-reinforced panels had a higher maximum endurance (96.2% - 51.6%) and a lower model deflection value. Iron fibres improve concrete compressive strength by increasing the volumetric ratio of the fibres by (1%–0.5%), while increasing it by 1.5% diminishes concrete compression. When using 1% fibre volume, concrete gains 86.5%, but compressive strength increases 33%. This applies to tensile behaviour. With a change in all volume ratio, ferrous fibres increase, improving unidirectional HCS ductility **[1]**.

When numerous panels with a thickness of 300 m and a width of 600 m failed in shearing or bending, **Tae-Sung Eom and Hye Young Hwang 2015** they looked into the shear behavior of HCS. The test revealed that as voids rose from 20 to 30%, the plate's resistance to shear decreased. However, the plate was unaffected as the effective width of the grid rose, although the hollow member's shape affected its resistance. cutting of tile. The shear strength of the slab is enhanced by the addition of stirrups. It is fastened with a hook with a diameter of less than 10 mm. It is impossible to undervalue the shear strength and deflection of the experimental force **[13]**.

Sameer K.Sarma Pachalla,et al.,2015 investigated an addition low-volume polypropylene fibres at 0.33 (3 kg/m3) to the model with a high a/d of 7.5, the maximum load increased by 19% and ductility increased. The effects of synthetic fibres on HCS were also examined. Peak load increased 10% in 3.75 a/d models. Fibres boost panels' load capacity at low and high a/d. In higher a/d models, flexion-regulated load and fracture load increased. Fibres increase the stress-energy of samples with higher a/d, making them harder **[28]**.

Ali N. Deeb, Mohamed A.Tarkhan, and Esam M. El-Tehewy 2016 The researchers examined how the concentrated load's width changed with the slab's width and how that affected the PHC for shear capacity computation. The finite element model showed that the shear extent increased and the shear capacity decreased by 30%. As the shear range rose from two to four hours, shear ability began to decline. Increased load width increases slab shear capacity, causing abrittle failure. Equation

$$\frac{P_i}{P_{max}} = \text{c} = \frac{0.7}{(\frac{a}{h})^{\frac{2}{3}}}\left(\frac{b_{Li}}{b_s} - 0.87\right) + 1 \leq 1$$

The coefficient C applies to slab thickness, pre-stress level, concrete strength, and ratio. The original nett area allows control of the two factors, intent span, load width, and shorting capacity of the PHC panels **[10]**.

Karam Mahmoud et al.,2016 they examined The effects of apertures and NSM carbon fiber-reinforced polymeric laminates were examined. First, a full-scale prestressed structural model was tested without a hole, second with a hole in pure bending, and third with a reinforced hole. Test results showed that a slit along the flexural extension reduced the slab's final strength, cracking load, and flexural toughness after cracking. However, two NSM-CFRP strips in the slot greatly increased post-cracking toughness. The member's ductility, flexural strength, and bending capacity improved after cutting the hole **[19]**.

Jasim Mahmood Mhalhal 2017 The study used four prestressed hollow slabs and castings with four loading lines and shear gaps of 1.55, 2.35, and 5.5 for effective depth a/d ratios. The slab used is 2000 mm x 1200 mm x 150 mm and has a compressive strength of up to 79.5 MPa. When the a/d ratio increased to 233.3%, slippage of the reinforcing steel in the concrete, flexural, flexural-shear, shear-compression, and the failure that combined tensile and fixation shear failures decreased by 19.6%. The failure load in the sample was 110KN, and when a/d was 5, it was 115KN. The failure mode was bending shear failure at 19º, while in (a/d 2) it was at 16. The highest load was 120 KN at a/d 3.5. The cracking angle was 28º, the maximum load was 135 KN, and the failure mode was shear compression. The agreement stated that diagonal tension caused attachment failure at 1.5, and at 143 KN, the fracture angle increased to 44º. This shows that the slab with more a/d is stiffer than the tiles with a high percentage. Suppose the a/d ratio dropped 70% and sampling failure increased 24.3% **[23]**.

Pradeep Kankeri et al., 2017 Researchers tested a bonded layer on the upper 50–75 mm of concrete to increase fracture load and bending strength. They examined how shear splines affected the overlay-hollow concrete slab surface with diameters of 150, 600, and 3500. The three panels—a control board, a bonded board without cutting keys, and a board with an overlay attached to the cutting keys had an a/d ratio of 7.5. The interfacial failure caused by the bonded slab's (bonded overlay samples') lack of shear keys increased the

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ultimate load by 38.4% compared to the control sample's lack of bonding and shear keys, while the slab's presence increased the end load to 59.6%. Overlapping with shear keys eliminates shear fractures in the interface, the composite section's weak point since the control is fully effective **[18]**.

Fig.4 Installation of Shear Keys

Fig.5 Hollow Core Slabs with Bonded Overlay

F. el-khouly et al.,2017 evaluated three types of hollow concrete tiles (4100mm x 1200mm x 1600mm), a control slab without holes, and a 250 x 250 mm slab with holes to measure bending resistance. The final slab's hole in the midst of a third of the span was intentionally placed to test the hollow concrete's strength. The researcher collapsed the table with four points. Having a hole in the middle of the span reduces the slab's bending resistance, stiffness, and collapse load by 23.5% and 11.4%, respectively. The collapse was identical to the 11.4% elastic collapse of the control slabs (slabs without apertures). The centre gap in the big shear zone affects a hollow concrete slab since it collapsed due to only concrete and no steel. 21% collapse load lowered, 6% first failure. The centre hole was ductile like the control board, therefore it did not alter failure mode **[21]**.

Fig.6 hollow core slab content holes

Labeeb S. Al-Yassri et al.,2017 They tested NSM ordinary strength concrete to see how hybrid reinforcement affected hollow core slabs. FRP and steel bars inside the slab enhanced ductility compared to CFRP-reinforced HCS. CFRP bars do not alter the hollow core slab's shear strength, but they raise it by 4.5% when paired with steel bars. CFRP reinforcement lowers slab hardness after cracking, increasing deflection at the same load **[3]**.
N. Brazzale et al.,2017 investigated the addition steel fibres to HCS concrete increased shear capacity and bearing capacity of the load maintained after failure by 20%. As steel fibre rises, slab residual strength increases. Using 13.33% kg/m3 steel fibres increased ultimate capacity by 20% and residual strength by 50%. Increasing steel fibres to 26.67kg/m3 enhanced ultimate capacity by 25% and residual power by 90% **[6]**.
Amr Alaa Abdelaal 2017 He investigated using GFRP and carbon fiber-reinforced plastic sheets to increase PHCS shear capacity. Test sheets were 1219 mm wide, 4,500 mm long, and 305 mm thick. The study found that shear capacity increased by 58% over PHCS-specific controls. The prestressing force did not effect PHCS strengthening. Strengthening PHCS sheets with a full 180º arc width from GFRP sheets or limiting the arc width to 120º has no impact on shear capacity, as long as the essential shear area is covered. Wet fixing increased model shear by 13% and 58% over shear reinforcement. PHC sheets reinforced with two layers of 450 mm CFRP sheets had a reed strength of 31%–38%, whereas those reinforced with two layers of GFRP sheets had 36%–58% **[4]**.

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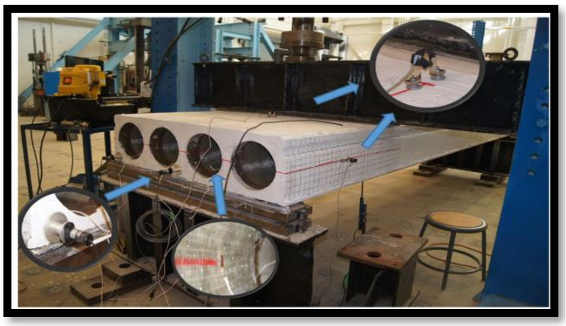

Fig.7 Overall experimental setup at loaded end

Khaled mohamed heizaet al.,2018 Researchers examined the behaviour of the concrete topping layer over the slab. First sample was controls without a cover, second had plain concrete and a top layer, and third had steel anchors joining plain concrete to the upper surface. Four had two fibrous concrete-coated samples. The team Fifth, ferrocement topping, has two samples. Samples were tested under steady-line load until failure. The results showed that the higher concrete layer on top of the HCS slab enhances bending by increasing fracture moment resistance from 6% to 31% and failure moment from 11% to 41%. Since PPHC steel anchors prevented sliding between the slab and the concrete cover, they improved slab performance by reducing deformation and increasing rigidity. Anchors reduced the deviation at the same weight from 72 mm to 31 mm at 150 KN. It raised the breaking moment and final moment of failure capacity by 10% and 27% for full extension anchors compared to RC models without anchors. Fiber-layered concrete without internal reinforcing has better ultimate and cracking strengths, less distortion, and higher hardness. In addition, glass and steel fibre fracture torque and moment of failure capabilities improved by 12%, 26%, 19%, and 33%, respectively, compared to control samples. A thin ferro-cement topping will reduce slab thickness and load, increasing torque capability. Breaking moment capability was increased by 6% and crushing torque capacity by 33% **[25]**.

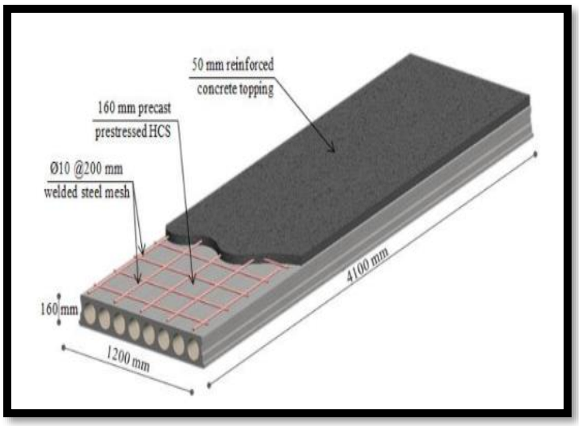

Fig.8 Use concrete topping

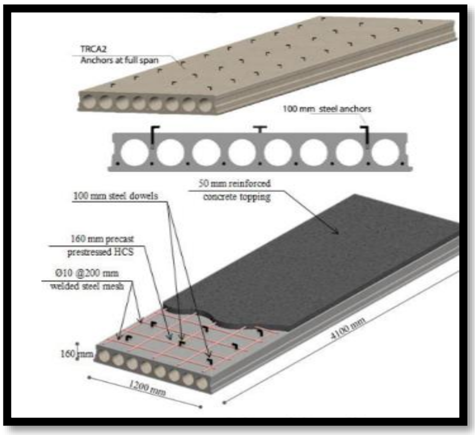

Fig.9 steel anchors with reinforcement

Sadi Ibrahim Haruna1 et al.,2018 studied the use a topping layer was used to study the PHCS slab's horizontal shear behaviour. Two models—120 cm and 55 cm—were used. A board tested to prevent slab-topping layer sliding was also used. The concrete composite system, which was cast in place and placed over the finished surface of the machine made of precast concrete hollow units, did not have enough shear strength at the interface to develop its overall flexural capacity without intentional roughening. When the top layer and

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slab slip, load capacity drops and composite behaviour is lost. This behaviour affects bending only when the composite behaviour is present. The prestressing threads at the hollow tile ends slipped when the external force was applied. This slippage ranged from 2 to 3 mm to 21 mm, and it may worsen during load tests **[16]**.

Gustavo J. Parra-Montesinos et al, 2018 They studied prestressed concrete slab casting shear strength with deformed steel fibres randomly placed in hollow slabs. Extruded panels had a 3–3.5 shear depth-to-effective depth ratio. One fibre had a 30 mm length, 0.55 mm diameter, and 1100 MPa tensile strength, while the other had a 60 mm length, 0.9 mm diameter, 2300 MPa tensile strength, and double hooks on both ends. The shear-effective depth ratio was 2 and 3. First-type fibre fractures at 0.38% (290 N/m3). whereas the second type of fibre has (0.3, 0.38%, 0.47%), or (230, 290, 360 N/m3) fracture volume. For slipform slabs, the first type has densities of 320 and 385 N/m3 and fibre size fractures of 0.42% and 0.5%, while the second type has densities of 230 and 290 N/m3 and fibre volume fractions of 0.3% and 0.38%. Fiber-free panels broke at 0.93 and 0.87 times the web fracture shear stress, the study found. Extruded panels with second-type fibres failed at shear resistances of 0.94 and 1.29 times the web breaking strength calculated with a rise in shear resistance, but their inclusion gradually decreases strength beyond the peak. Because slip slabs behave by sliding a strand along a flexure fracture, external prestressing increases bending strength and causes shear failure. The sliding-method slabs, which did not shear, had maximum shear forces of 1.04 Vwc and 0.8 to 0.21 Vwc. The panels with second-type fibres, for which transmission lengths were exactly estimated, had a higher shear strength differential. First-type slab extensions that failed to shear 320 n/m3 and had a 50-db transmission length can be strengthened. Type 1 and type 2 fibre boards must have Vcw shear strength for transmission lengths of 50 db **[38]**.

V.M. Mitasov et al.,2019 The researchers evaluated how pre-organized cracks affect crack formation and hollow slab deformation under short-term strain. They used the panels without prestressing, poured the first panel conventionally, and poured the second with cracks. Slit width shortened and deviation decreased due to reduced deformation susceptibility. The notch is 0.4 mm wide in ordinary panels and 0.1 mm in panels with prepared slots. The conventional panel's central deviation exceeds 15% of the slotted panel **[24]**.

Min-Kook Park et al. 2019 The researchers examined PHCS shear tests at typical thicknesses. Studies have shown that panels thicker than 315 mm have patterns that are sensitive to shear failure. However, the researchers examined the fish. Studies have shown that panels thicker than 315 mm have patterns that are sensitive to shear failure. The power of the web is not underestimated due to its size. Web cutting yielded unconservative results for PHCS members with thicknesses less than 315 mm as well. Analysis of the PHCS web shear database found that model aci318-08, which limits the web shear capacity of PHCS members below 315 mm, can increase uncertainty about the shear capacities of thicker members without enhancing shear **[30]**.

Yousif Nassif Sabr 2016 The researcher used lightweight pre-row hollow concrete made from recycled crushed clay bricks and iron powder waste to optimise the mixture. The 28-day cylinder had 1910 kg/m3 density and 42.3 MPa strength. Twelve 1200 mm by 450 mm panels with 200–325 mm thicknesses were evaluated, or three variants. The hole was 75 mm broad. Cutting one hollow in half, two hollows in half, and adding shear reinforcement raised the ultimate load by 127.89%—32.73%). Early fracture load ranged from 16.4%-90.24% and was maximum at 22.86%–6.1%. For the first slit load (10.26% to 53.66%), increasing HCS thickness raised ultimate load by 15.58% to 87.07% and decreased maximum deflection by 16.6% to 6.52%. Shear strengthening, the best shear resistance, reduces two hollow lengths to one. Shear failure becomes bending shear, one hollow is shortened, and two hollow lengths increase the final stress. Overall weight rises. Shortening one hollow, two hollows, and shear reinforcement moved the load from the support to the centre span, increasing compression and tensile stress. Because hollows are shorter, increasing thickness reduces compressive, tensile, and slab shear stress by 20.1% to 58.7% **[33]**.

A S Vasilyev 2019 He examined how the cross-sectional form affects direct stress and cracking moments from the slab's extension's middle bending moment. After filling the spaces in the second and fourth samples of the i-beam section with concrete, the HCS slabs' crack propagation is later than the i-beam slabs'. I-shaped slabs deflect more during breaking, making them less hard than regular slabs. All reinforced materials had an average fracture load bending of 8.68%. An average difference of 7.8% was observed in reinforcing stress during cracking between sections of typical width. Slab cross-section affects calculation information for the second group of ultimate loading circumstances **[37]**.

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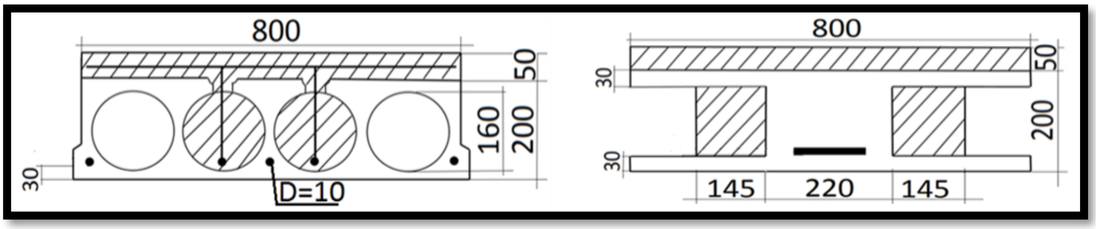

Fig.10 cross-section of hollow core slab with filling the spaces in the samples

Sameer Kumar Sarma Pachalla et al.,2019 They examined FRP's effects on flexural and shear behaviour. The study first tested FRP reinforcement with external bonding and near-surface mounting (NSM). The second and final strategies include strengthening reinforcement ratios and lengthening shear to depth ratio. The data show that strengthening FRP increases strength more efficiently. final slab failure and change patterns. PPHCS supports 14%–36% more bending stresses. To avoid brittle shear failure, choose a fixed brittle stiffening ratio at the NSM surface. Sheet flexural to flexural-shear failure seemed intriguing. Possibly EB GFRP. Despite having a larger board cut, NSM GFRP bars outperform EB reinforcement at all a/d ratios. Sample a/d 7.5 showed that EB GFRP reinforcement increased bending capacity by 17.5% without impacting energy dissipation. The failure mode changed from bending to flexural shear when the EB GFRP was elevated, even though the final load increased by 27% and the displacement dropped. NSM is more fracture-resistant than EB yet has 47% higher peak strength. Additionally, NSM has a better ideal connection than EB. On the a/d 5.4 sample, a modest amount of FRP strengthening caused it to prematurely rupture and did not boost final capacity, but it did improve post-cracking toughness. When FRP was strengthened by a large amount alone, it enhanced final capacity by 27% and fracture hardness. As dominant flexion failure has given place to dominant shear behaviour, low NSM is now more efficient than high EB strengthening **[27]**.

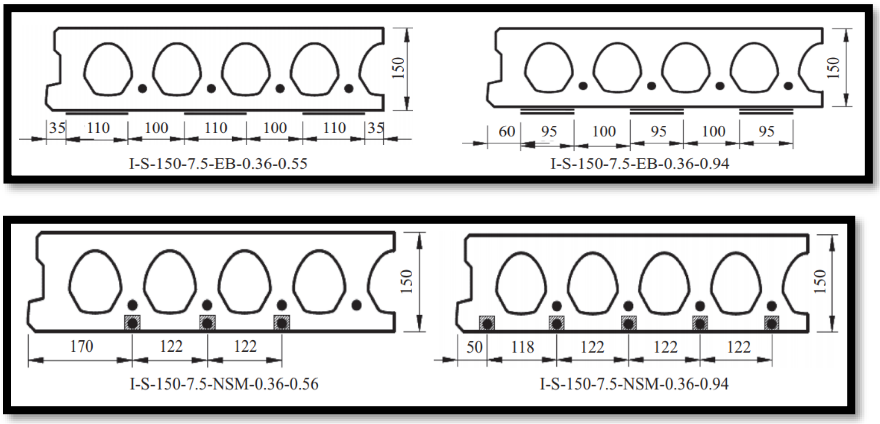

Fig.11 cross section of high flexure to shear ratio specimens

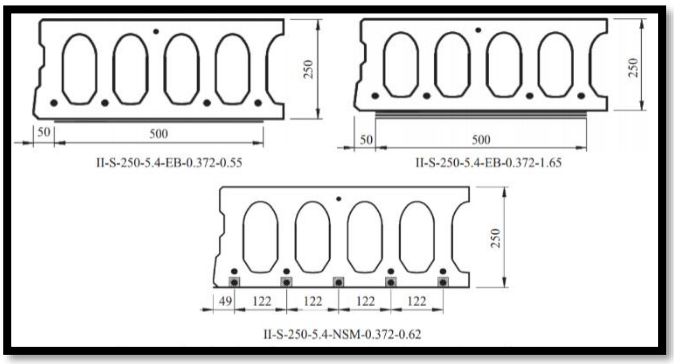

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Fig.12 cross section of moderate flexure to shear ratio specimens

R. Apostolska et al., 2020 They tested in situ casting of RC beams and HCS slabs for seismic performance. Researchers used local building practises to produce the original models, whereas upgraded samples were designed with additional reinforcement T12 B500 B in the second and fifth slots of the HCS. The results showed that upgraded seismic resistance models outperformed baseline models in main earthquake strength and resistance. Although the two samples' failure mechanisms are identical, the reinforcement suggests a larger end resistance. Upgraded model ultimate resistance has not improved. The earthquake protection improvement performs better against vertical than horizontal stresses. It might be argued that the revised VS and Hs models perform seismically better **[9]**.

Gregory Lee Pinheiro et al.,2020 They examined standard extrusion and packing methods. The investigation demonstrated that the slab with perforations filled with a higher compressive-strengthening substance worked better. Slabs that collapsed due to shear strength are stronger than those that collapsed due to joint bending with strand slide or torsion. Strand slide caused several samples to bend and fail. The crack between the concrete used to fill the gaps and the voids suggests slippage or material separation caused the four-hole-filled slab to lose some resistance.Quantifying structural parts' capacitance resistance was successful **[22]**.

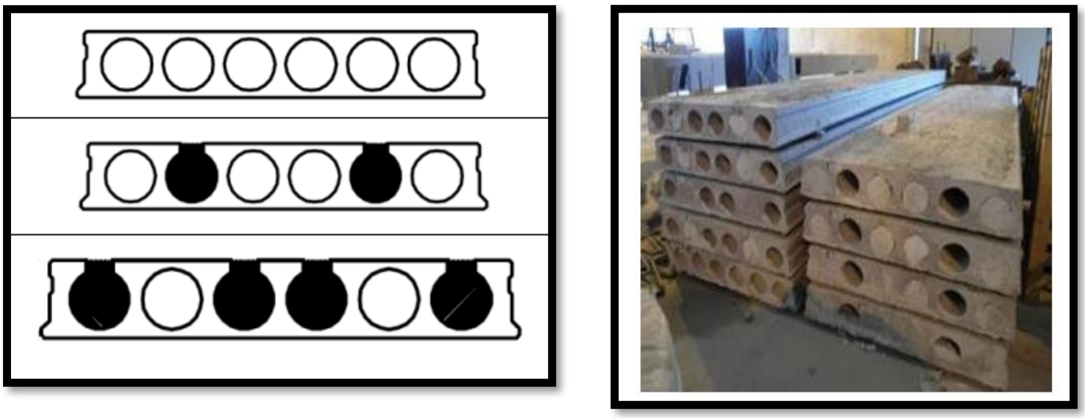

Fig.13 slab with perforations filled with a higher compressive -strengthening

Hang T. N. Nguyen and Kang Hai Tan 2020 They studied bent steel fibres at high temperatures to determine how they affected hollow core precast concrete (PCHC) fire resistance. Researchers used two PCHC plates at high temperature and a fiber-free control sample to improve PCHC performance. At 40 kg/m3, the steel fibres had 0.51% volumetric content, or nothing. Both load resistance and high temperature improved for the PCHC. Crimped steel fibres can avoid shear failure and boost fire-resistant ductility and hardness in PCHC extruded panels. Only PCHC panels show brittleness during web cutting **[26]**.

Fig.14 hooked Steel fiber used

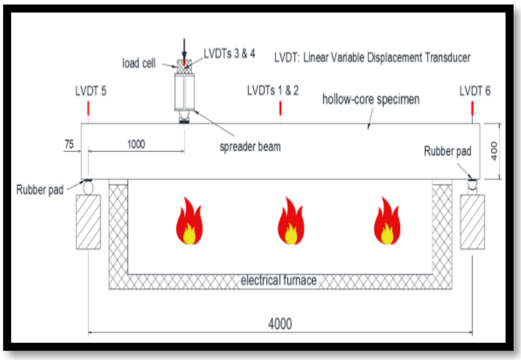

Fig.15 Load cell and LVDT arrangements

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Yahyia M. Hameed and Murtada A. Ismael 2021 Researchers studied hollow core concrete bidirectional behaviour using self-compacting concrete slabs with a cross-section of 70 mm x 450 mm x 450 mm. They were divided into two groups with differing hollow numbers and diameters. Expanding the hollow core's diameter from 15 mm to 23 mm and 30 mm reduced the initial fracture load by 7.5%, 9.65%, and 14.5% compared to steel plates. When hollow cores are raised from 3 to 4 and 5, the first fracture load decreases from 14.5% to 18% and 23.7%, respectively. The maximum load drops from 15.9% to 20.2% and 24%. Increasing the hollow core's number from 3 to 4 or 5 reduces its final deflection by 8% to 9.7% to 13.8%. Increasing the hollow core's diameter from 15mm to 23mm and 30mm reduces the final load by 4.7% to 10.1% and 15.8% and its load deflection by 3.2% to 5.8% and 8%. When the hollow core diameter increases from 15 to 23 and 30 mm, the slab becomes less hard than a solid slab. As the hollow cores expand from 3 to 4 and 5, the slab becomes less hard than a solid slab **[15]**.

Susana Hernandez Brito et al.,2022 Researchers studied the samples tested under tension were a natural withdrawal of the support or parallel loads regardless of load direction. Lateral joints were investigated to strengthen the slab against lateral loads. Before the peak load, it reached productive stresses or was close to yield, when plaster tension and division caused sample failure. The parallel-stressed samples deformed significantly or not. Because it was made at low levels, plaster and panels did not break after yielding. The eccentric deviation in the load path between the end and side joints with identical features did not change under pushing or pulling forces normal or parallel to the supporting beam.
The welding force and reaction caused premature torsional bending of the rod at the bending region. Communication capacity should improve greatly with decentralization **[7]**.

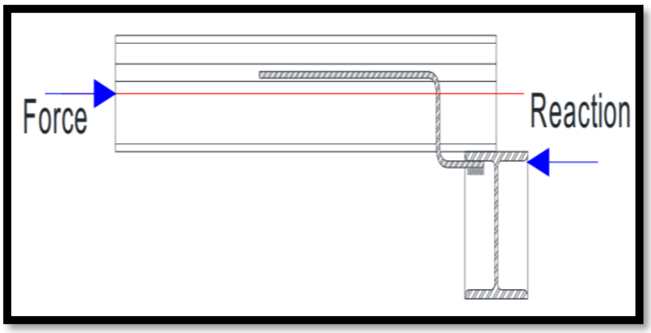

Fig.15 Eccentricity of the load application in relation to the reaction.

Fig.16 Mode of failure for end-bearing specimens tested under axial pulling

Luis Alberto Montoya Coronado et al.,2022 they tested iron-based shape memory alloys, the PHCS flooring' stifling bending moment zone above the supports has pre-stress. FE-SMA improved in the absence of service, which is caused by HCS-SF and delays cracking. generating active HCS-SF bending zone continuity. Because it requires mounting and heating the bars without a hydraulic jack and is easier to execute on the ground, normal steel is harder to work with than the experiment material. SLS (service limit state) was shown to have the model. On FE-SMA, rebar deformations and cracks were smaller. In conclusion, active continuity enhances structural floor behaviour. FE-SMA strain distribution along rebar is also affected by in situ concrete casting and precast concrete contact **[11]**.
Thomas Thienpont et al.,2023 They researcher compared the load-displacement behaviour for axially constrained and unconstrained hollow slabs, as well as fracture patterns and failure behaviour, and studied the compressive membrane's action on hollow precast concrete core slabs on real scale to improve load-bearing capacity in the event of an accident. Despite the slab's huge gaps, the compressive membrane boosted the hollow slabs' load-bearing capability at heavy impact. The panels' failure mode ranges from ductile bending in an unrestrained setup to sudden web shear failure in strong axial and rotational restrictions. Thus, lateral and rotational restrictions considerably affect capacity change **[36]**.

ISSN NO: 2770-4491
Date of Publication:30-11-2023

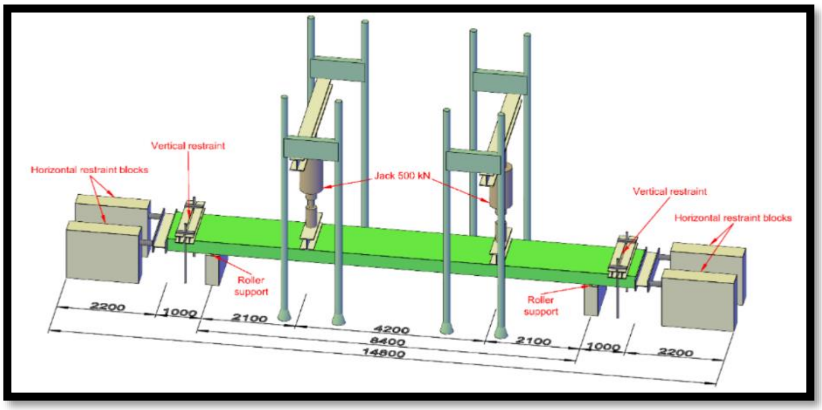

Fig.17 Restrained four-point bending test : Schematic overview

3. Analytical Work on hollow core slab

This section contains earlier research that used finite element theories and analytical analysis to examine the behavior of precast/prestress hollow core slabs.

Asst.Prof.Abdul Ridha Saleh and Muaid Adnan Abid Shahatha 2014 They investigated the analysis and construction of hollow slabs using Visual Basic, examining the effects of optimal weight, cost, and live load. Taking into account the section's submission to all constraints, the optimal weight sections have an average of 50% voids, where the voids are exhausted and the greatest distance from the width and height. The analysis found a 41% ratio of void size to the lowest-cost sections. A 5 centimetre concrete layer over the topping slab can enhance space length by 16% to 20% for 15 cm to 22 cm thickness. It was also shown that deflection limits space length by 60%. For distances under five metres, consider a width under 1.2 metres to reduce weight. The ideal cost of HCS yielded an average of 41% voids, where the width is less than the thickness by a few distances. By increasing length and live load, we increase slab surface and thickness and decrease voids. The variance reduces table span length by at least 60% in hollow foundation slab areas. As shown in table1, topping lengthens span **[35]**.

Taple (1)

Hollow Core Slab Thickness (cm)	**Span Length Increasing**
15 - 22	16% - 20%
25 - 32	8% - 14%
40 - 50	3% - 8%

Wit derkowski and mateusz surma 2015 They studied examined structural surface interactions with precast hollow concrete slabs. The interface of composite floors made of hollow slabs covered by a structural layer is not strengthened since these features affect longitudinal shear strength. They eliminated transverse reinforcement in their experiment, leaving the slab-concrete interface weak. When they compared their results to those of other research institutes, they noticed a decline in bearing capacity. Since production and surface preparation affect interface capacity, they should be done before pouring the top layer. Computational results showed that composite concrete structures without facade reinforcement may have variable façade shear capacities for each standard. The longitudinal joint's friction did not affect shear capacity, therefore it could be neglected in estimations **[12]**.

ISSN NO: 2770-4491
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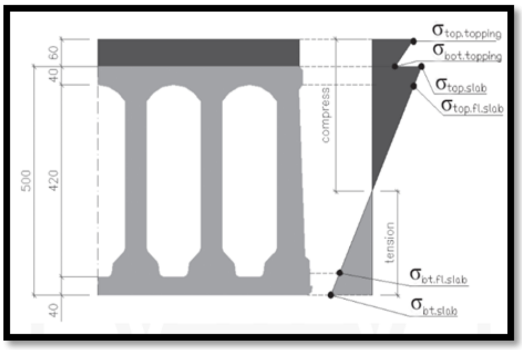

Fig.18 Concrete stress distribution on the height of the composite cross-section

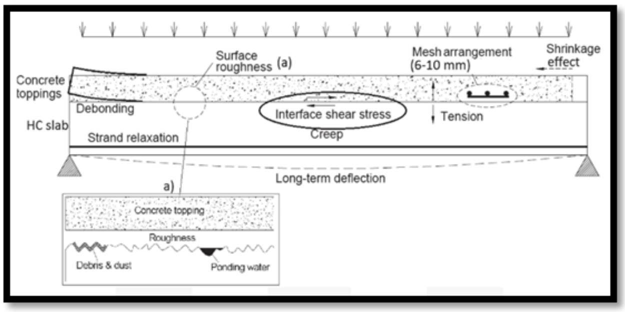

Fig.19 Factors influencing the composite action of the Hollow core slab with topping

D. l. araújo and g.d.c. pinto 2020 they investigated the fire resistance test of hollow concrete slabs indirectly, this method can tolerate 90 minutes. this method can tolerate 90 minutes of temperature. The 16 cm-thick slabs with rectangular gaps have slower heat transfer than the slab with circular voids of 20 cm thickness. Despite having the largest distance between the bottom face of the voids and the slab bottom face for hollow slabs, this delay did not lower the upper region's ultimate temperature after 140 minutes of fire exposure. The 20-cm slab should last 80–90 minutes when the Msd/Mrd ratio is 0.6, 90–100 minutes at 0.49, and 120 minutes at 0.4–0.49 for 500 degrees Celsius. The table underestimates the fire resistance of hollow faces with Msd/Mrd values of 0.49 and below. The slab was 16 cm thick and the prestressing reinforcement's temperature was higher than projected after 60 minutes of fire exposure. A 20 cm reinforcement thickness and lower reinforcing temperature match published predictions. Conclusion: A 16-cm slab can endure a 60-minute typical fire with a Msd/Mrd ratio over 0.6 without collapsing. The data overestimates the shallow hollow slab's fire resistance since the simplified design technique for 500 °C achieves a Msd/Mrd ratio of 0.6 in 35 minutes of standard fire exposure. The slab's bending strength was 29% of its final bending moment at ambient temperature after 60 minutes of fire exposure. Since it must be used to build HCS panels, the simplified design technique with a temperature of 500 degrees Celsius, which is coupled to the researcher's thermal model temperature exposure profile, has more accurate fire resistance estimations **[5]**.

Muhammed Maleknia et al.,2021 The researchers tested slab bending strength utilising CFRP and GFRP fibres at various distances from the support point using th e finite element approach. They also examined how FRP sheet length affected the final bearing capacity of carbon fibre and reinforced plastic HCS panels. The researcher found that carbon fiber-reinforced plastic fibres should be 1.5 and one-tenth of the support face, or one-fifth of GFRP fibres. GFRP Since the researchers found that longer FRP panels do not affect the test panels' final capacity, installing the fibres at the prescribed spacing saves time and money **[20]**.

4. Conclusion

The following is the major:
a) It is feasible to employ HC one-way slabs as construction roofing members. Additionally, the effectiveness of these slabs following rehabilitation with carbon fibre (CFRP) strips was demonstrated.
c) The prestressed HCS's bending and shear load capacities are primarily supported by the NSM-CFRP strengthening technique. Slabs that collapsed by shear before reaching their maximum bending capacity had a reduced rise in failure flexural capacity. In contrast to nonprestressed concrete, the energy and absorption of the HCS were maximised by the use of NSM laminates.
d) Because HCS behave better than solid slabs, the standard bending strength formula can be applied to them. The behaviour of load deflection makes this clear.

References

[1]Abdullah, J. A., & Salih, O. A. (2013). *ISSN : 1813-162X Tikrit Journal of Engineering Sciences available online at : http://www.tj-es.com Behavior and Design of Partially-Encased Composite Beam-Columns* 36–24 ,(6)*20* .ةصلاخلا.

[2]Al-Shaarbaf, I. A., Al-Azzawi, A. A., & Abdulsattar, R. (2018). A state of the art review on hollow core slabs. *ARPN Journal of Engineering and Applied Sciences*, *13*(9), 3240–3245.

[3]Al-Yassri, L. S., Ali, A. Y., & AL-Khafaji, M. M. (2017). Experimental investigation for the behavior of hollow core concrete slab reinforced with hybrid reinforcement. *Al-Qadisiyah Journal for …*, *10*(2), 214–225. http://qu.edu.iq/journaleng/index.php/JQES/article/view/287

[4]Alaa Abdelaal, A. (2017). *Scholarship at UWindsor Scholarship at UWindsor Shear Strengthening of Prestressed Hollow Core Slabs using Shear Strengthening of Prestressed Hollow Core Slabs using Externally Bonded Glass Fibre Reinforced Polymer Sheets Externally Bonded Glass Fibre Rei*. https://scholar.uwindsor.ca/etd

[5]ARAÚJO, D. L., & PINTO, G. D. C. (2020). Fire behavior of shallow prestressed hollow core slabs from computational modeling. *Revista IBRACON de Estruturas e Materiais*, *13*(2), 398–432. https://doi.org/10.1590/s1983-41952020000200011

[6]Brazzale, N., Kennett, D. I., & Marshall, J. B. (2017). *Benefits of Top Strand and Steel Fibres in the Design and Manufacture of Hollow-core Precast Floor Slabs . 1998*.

[7]Brito, S. H., Mahmoud, K., & El-Salakawy, E. F. (2022). Behavior of Reinforcing Bar Connection of Hollow-Core Slabs to Steel Beams under In-Plane Forces. *CivilEng*, *3*(4), 831–849. https://doi.org/10.3390/civileng3040048

[8]BROO, H., & LUNDGREN, K. (2002). *Finite element analyses of hollow core units subjected to shear and torsion*. *December*, 1–70.

[9]Connections, S. B. (2020). *Slabs-Rc Beam Connections*.

[10]Deeb, A. N., Tarkhan, M. A., & El-Tehewy, E. M. (2016). Shear capacity of pre-stressed hollow core slabs under concentrated load. *International Journal of Engineering Sciences & Research*, *5*(1), 855–863.

[11]Del Río-Bonnín, S., Montoya-Coronado, L. A., Ribas, C. R., Ruiz-Pinilla, J. G., & Cladera., A. (2022). Using iron-based shape memory alloy rebars as hogging prestress for continuity of Hollow-Core Slabs. *Fib Symposium*, *September*, 795–802.

[12]Derkowski, W., & Surma, M. (2015). Composite Action of Precast Hollow Core Slabs With Structural Topping. *Technical Transactions*, *3-B*, 15–29. https://doi.org/10.4467/2353737XCT.15.159.4334

[13]Eom, T.-S., Hwang, I.-H., & Park, T.-W. (2015). Evaluation of Shear Strength of Non-prestressed Reinforced Concrete Hollow-Core Slabs. *Journal of Korean Society of Hazard Mitigation*, *15*(6), 43–54. https://doi.org/10.9798/kosham.2015.15.6.43

[14]FLORUŢ, S. C., NAGY-GYÖRGY, T., STOIAN, V., & DIACONU, D. (2009). Strengthening of hollow core precast slabs using FRP composite materials – procedure , testing and rating. *Proceedings of the 11th WSEAS International Conference on Sustainability in Science Engineering*, *May 2014*, 496–501.

[15]Hameed, Y. M., & Ismael, M. A. (2021). Structural Behavior of Hollow-core Reinforced Self-compacting Concrete Two-way Slabs. *IOP Conference Series: Materials Science and Engineering*, *1076*(1), 012120. https://doi.org/10.1088/1757-899x/1076/1/012120

[16]Haruna, S. I., Gora, A. M., & Malami, S. I. (2018). *Geometric Impact on the Behaviour of Composite Precast Prestressed Concrete Hollow Core Slab*. *4*(1), 1–11.

[17]Hosny, A., Sayed-Ahmed, E. Y., Abdelrahman, A. A., & Alhlaby, N. A. (2006). Strengthening precast-prestressed hollow core slabs to resist negative moments using carbon fibre reinforced polymer strips: An

[18]Kankeri, P., Chellapandian, M., & Prakash, S. S. (2017). Bonded Overlay Strengthening of Hollow Core Slab with and without Interface Shearkeys Connection. *3rd International Symposium on Connections between Steel and Concrete (Germany)*, *September 27th-29th*.

[19]Mahmoud, K., Foubert, S., & El-Salakawy, E. (2016). Strengthening of

[20]Maleknia, M., Biklaryan, M., & Radmehr, M. (2021). *Effect of FRP Sheets Length on the Ultimate*

Loading Capacity of CFRP and GFRP Strengthened Hollow-Core Slabs by the Finite Element Method. *12*(13), 5042–5052.
[21]Meleka, N. N., Tayel, M. A., & Heiza, K. M. (2017). Behavior of Precast Prestressed Hollow Core Slabs With Openings: Experimental Study. *ERJ. Engineering Research Journal*, *40*(4), 325–329. https://doi.org/10.21608/erjm.2017.66358
[22]Menezes, F., Filho, D. A., & Ferreira, M. D. A. (2020). *V.1 n.1*.
[23]Mhalhal, J. M. (2017). Prestressed Precast Hollow-Core Slabs with Different Shear Span to Effective Depth Ratio. *Wasit Journal of Engineering Sciences*, *5*(2), 1–11. https://doi.org/10.31185/ejuow.vol5.iss2.53
[24]Mitasov, V. M., Statsenko, N. V., Sametov, F. K., & Kurbonov, A. M. (2019). Crack Strength of Hollow Core Slabs: Experimental Research. *The Russian Automobile and Highway Industry Journal*, *16*(3), 366–377. https://doi.org/10.26518/2071-7296-2019-3-366-377
[25]Nabil, A., & Mohamed Heiza, K. (2018). Pphc Slabs Strenthened With Different Types of Concrete Toppings. *Fifteenth International Conference on Structural and Geotechnical Engineering*, *December 2018*, 1–14. https://www.researchgate.net/publication/333247829
[26]Nguyen, H. T. N., & Tan, K. H. (2020). *Effect of steel fibers on fire endurance of extruded hollow-core slabs*. 353–362. https://doi.org/10.14264/8a10a18
[27]Pachalla, S. K. S., Dhara, J. S., & Prakash, S. S. (2019). Experimental study on flexural behavior of NSM and external bonded FRP strengthened pretensioned precast hollow core slabs. *Journal of Structural Engineering*, *46*(2), 1–14.
[28]Pachalla, S. K. S., & Prakash, S. S. (2015). Behaviour of Synthetic Fibre Reinforced Prestressed Hollowcore Slabs under Flexure-Shear. *2nd R.N. Raikar International Conference and Banthia- Basheer International Symposium on Advances in Science and Technology of Concrete*, *June 2016*, 1–6.
[29]Pajari, M. (2004). Pure torsion tests on single hollow core slabs. *VTT Building and Transport*.
[30]Park, M. K., Lee, D. H., Han, S. J., & Kim, K. S. (2019). Web-Shear
[31]Ref: Proceedings of the 8. (2008). *September*, 17–20.
[32]Rosenthal, I. (1978). Full Scale Test of Continuous Prestressed Hollow-Core Slab. *PCI Journal*, *23*(3), 74–81. https://doi.org/10.15554/pcij.05011978.74.81
[33]Sabr, Y. N., & Jarallah, H. K. (2016). *لا ذ ني أ و ت وا لا ع لم د ر ج تا *" اللّّ لاُ ذ ني آ م ن وا م ن ك م و*. *March 2019*.
[34]Saleh, A. R., & Abid Shahatha, M. A. (2014). Optimal Design of Prestressed Concrete Hollow Core Slab Panels. *Kufa Journal of Engineering*, *5*(1), 33–50. https://doi.org/10.30572/2018/kje/511241
[35]Scott, N. L. (1973). Performance of Precast Prestressed Hollow Core Slab With Composite Concrete Topping. *J Prestressed Concr Inst*, *18*(2), 64–77. https://doi.org/10.15554/pcij.03011973.64.77
[36]Thienpont, T., Van Coile, R., De Corte, W., & Caspeele, R. (2023). Capacity and failure modes of restrained hollow core slabs taking into account compressive membrane action. *Structural Concrete*, *June*. https://doi.org/10.1002/suco.202201015
[37]Vasilyev, A. S. (2019). Research of stressed-state stiffened hollow strengthened concrete slabs in cracked condition. *IOP Conference Series: Materials Science and Engineering*, *687*(3). https://doi.org/10.1088/1757-899X/687/3/033019
[38]Wicaksana, A., & Rachman, T. (2018). 済無No Title No Title No Title. *Angewandte Chemie International Edition*, *6(11), 951–952.*, *3*(1), 10–27. https://medium.com/@arifwicaksanaa/pengertian-use-case-a7e576e1b6bf
[39]Wright, H. E., & Burns, N. H. (1974). Deflection of Double Tees and