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Structural Behaviour of Modified Hollow Core Slab: AReview

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ABSTRACT
The aim of this paper is to summarize the review of literature on structural behaviour of modified hollow coreprecast concrete slab. Hollow core slabs (HCS) are used for modular building constructions which helps toreduce the volume of concrete. The voids provided parallel to the length of slabs may leads to early failure.Composite reinforcement methods and other strengthening techniqueswith GFRP strips, steel plates, CFRPlaminates etc. are developed to strengthen the voids of HCS. Experimental and numerical analysis are carriedout to study the effect of various strengthening techniques on HCS. The studies shows that the strengtheningtechniques helps to stabilize the voids and increase the load carrying capacity of hollow core slabs than solidslabs.
Keywords: Hollowcoreslab,Compositereinforcementsystem,GFRPstrips,CFRPlaminates.

I. INTRODUCTION

Hollow core slab (HCS) which is also known as voided slab is a precast slab used for the constructionof multistory building. The presence of voids helps to reduce the weight of the slab, volume of concrete and costof production. The application of modular buildings are increasing day by day, HCS can be used as flooring androofing membersfor residential and commercial buildings.

The traditional reinforced concrete precast solid slabs are heavy and gives remarkable weight to theoverall structure. It also requires considerable time and manpower for the transportation and erection. The HCSislightweight,easyto transportandinstallwhencompared tosolid slabs.

ThevoidspresentinHCSaffectstheflexurala ndshearresistanceperformance.Theincreaseintherati o of hollow to total area will decrease the flexural and shear strength of slab. Therefore, HCS was suggestedfor the construction of simply supported one way slabs where shear was not an important design requirement.The shear failure occurred in the HCS was due to the failure of concrete around the void. Many researchers triedto improvethe performanceofHCSbystabilizingthe voidswith CFRPand GFRPmaterials[2, 10].

The voids present along the length HCS can be utilizes as service ducts for plumbing and electricalworks. They can be used for air conditioning ducts. The implementation of HCS is very effective and efficientforresidentialbuildings, schools,car parksandmulti-storybuildings[4].

II. STREGTHENING TECHNIQUES

Several traditional techniques used for strengthening are reduction of span length, addition of steelmembers, increasing the cross section etc. Various modern external strengthening techniques are developed toimprove the overall behaviour of HCS. These strengthening methods using GFRP, CFRP and steel laminates arediscussedbelow[4].

2.1 CARBONFIBERREINFORCEDPOLYMER(CFRP)

CFRP are extremely strong, light weight and corrosion resistant fiber reinforced polymer. It is usedwhen high strength to weight ratio and stiffness were required. It is widely used for strengthening, repair andservice life extension of RCC members.Different techniques with CFRP sheets are carried out for strengtheningthe HCSbyresearchers[3].

2.1.1 ExternalBonding(EB)usingCFRPlaminates

Shear strengthening in HCSwere carried out using CFRP laminates around the perimeter of thevoids.Thetestedspecimenshadalengthof4575mm, adepthof305mm,andwidthof1216mm.300mmand 450 mm long CFRP sheets and epoxy were used to strengthen the prestressed HCS. Specimens with one layerand two layer of CFRP laminates were tested. Both CFRP sheet and slab void surface were saturated with epoxybeforebonding. Thespecimenswere testedat leastthree daysafterthepreparation[11].
The test results showed considerable increase in shear capacity and some strengthened specimensexhibited more ductility before failure. Increasing CFRP layers improves shear capacity of HCS.Increase in thelength of CFRP laminates improves the shear resistance capacity.It was noted that an arc of 90^0 are enough tostrengthenthecriticalshearregionofeachwebwhichshows32%ofimprovementinshearresistance.Increasingtheprestressing level might not be help to

improve the shear capacity of HCS. It depends on concretepropertyandappliedCFRPmaterial [11].

2.1.2 EBusingCFRPcomposite

CFRP unidirectional fabric with a width of 600 mm and thickness of 0.12 mm were used for the study.Thefabricisplacedbottomsideoftheslab.ThesizeofHCSwas5000mmx990mmx260mm.Thesurfaceof the slab where fabric is attaching were grinded and cleaned using air compressor. The fabric was cut andcleaned with degreaser. Epoxy resin was applied on the marked region of fabric. The CFRP fabric was laid overthe layer of resin on the HCS. Fabric is laid in such a way that 300 mm from both ends of HCS remainedunstrengthen.The testwasconductedat leastoneweekcuring[3].

The failure occurred was sudden and brittle which is produced by shear. A crack extended on the entiredepth, from interior point to the point of application of load.The strengthened slab increased approximately11% of ultimate load carrying capacity than unstrengthen HCS. The results showed that the failure occurred dueto shear and strengthening helped to gain superior flexural capacity. This strengthening did not put forward theimportantmechanical capabilitiesofCFRPmaterial [3].

2.1.3 NearSurfaceMounting(NSM)usingCFRPlaminates

In NSMstrengthening,groovesarecutin theconcretelayerwhich isfilledwith adhesiveaftercleaning. CFRP laminates are places into the grooves and pressed lightly to spread the adhesives. The remainingportion of grooves filled with adhesives. This techniques have less probability for debonding failure than EBtechnique. The depth of groove was more than 1.5 times width of laminates and width of groove was more thanorequal tothree timesthethicknessoflaminates[ACI 440.2R,7].

The test was conducted under low shear span to depth ratio (3.75) and high shear span to depth ratio(7.5). In low shear span to depth ratio, the post cracking stiffness was found to be stiffer than controlled(unstrengthen) slab. The peak strength due to this strengthening was increased by 49.5%. The specimen wasfailedduetoconversionofflexuralcrackintosuddenflexuralshearcrack.Italsoshowsreductionindisplacementductility

In high shear span to depth ratio (7.5), the specimen showed similar pre-cracking behaviour and aftercracking, it showed stiffer response when compared to control specimen. At higher load levels, ductile flexuralcracksconvertedintoflexuralshearandspecimenfailedduetosuddenflexuralshearcracking.Thestrengtheningincrease the loadcarryingcapacityby68%[7].

2.1.4 CFRPsheets

Studies shows that the CFRP sheets were more efficient than laminates due to its bond characteristics.The ultimate flexural load carrying capacity of slabs were found to increase by 26% withCFRP laminates and49% with CFRP sheets.The test was conducted on 4.7 m x 1.2 m x 0.2m size slabwith 44% void. The HCSwas strengthened using 0.13 mm thick CFRP sheets which was applied at the bottom of slabs fixed by epoxyresin.The slabswere tested inflexureandshear [5].

Theresults showedthattheincreasein crosssectionalareaof sheets improvesthefailureload.However the mode of failure changed from flexural to shear when cross sectional area of sheet increased. Themaximumincreaseinflexuralstrengthwas40%.Shearfailureoccurredwithsuddenshearcompressionfailureinlinear HCS.Thestrengthenedslabgained 10%increaseinshearstrengthandalmost100%increaseinductility[5].

2.2 GLASSFIBERREINFORCEDPOLYMER(GFRP)

Glassfibersarecommonlyusedreinforcingfibersforpolymericmatrix.Glassfibershaveadvantages of low cost, high tensile strength, high chemical resistance and excellent insulation features. But it has lowfatigue resistance, high density and low tensile modulus. When compared with CFRP, GFRP has low cost andlowthermalconductivity.DifferentstrengtheningtechniquesusingGFRPhassummarizedbelow[1].

2.2.1 PrestressedGFRPbars

The specimen of one vent size 4000 mm x 140 mm x 150 mm strengthenedwith 10 mm diameterGFRPbarsaretested.GFRPthreadswere axiallywrappedaround the bars to improvethebondingbetweenbars and concrete. The bars were prestressed at 10, 20, 30 and 40% of their ultimate tensile strength. The GFRP barsweremanufacturedusingpultrusionprocess[1].

The cracks noted in specimens wereoccurred and propagated within flexural zones across the width ofslab. Maximum pretention applied on GFRP bars cannot exceed 30%. 40% pretension bars were crushed whengrips are applied. This is because high tensile stress applied to the bar and ends were subjected to compressivestress during the provision of grips leads to stress exceed the material capacity and crushed. The highest initialcracking load and ultimate load were observed on 20% pretention bars. Also 20% pretention bars has highestelastic and plastic energy absorption. HCS with GFRP bars exhibited flexural failure for prestressing level lowerthan30%[1].

2.2.2 GFRPwraps

100 mm width GFRP strips were used to strengthen the 4100 mm x 1200 mm x 160 mm HCS. Studieswere conducted by varying the number of strips and number of layers provided on each strips.Differentstrengthened specimens were four strips with two layers each (S4G2L), two strips with four layer each (S2G4L),and four stripswithfour layers(S4G4L)[4].

Unstrengthen slab has less ultimate failure load than strengthened slabs. Four strips with four layers(S4G4L) wraps has smallest deformation at same load among other specimens. The initial load cracking ofS4G2L, S4G4L, and S2G4L were increased about 13%, 13% and 6% than controlled slab. The ultimate failureloads were increased by 7%, 19% and 15% than controlled slab. Four strips with four layers each gave betterresults than others. Strengthening process using GFRP wraps reduced the presence of cracks and decreased thewidthofcrack[4].

2.2.3 CompositeReinforcementSystem(CRS)usingGFRP

Recently developed technique to strengthen the voids of HCS was CRS system. Presence of outerflanges provides better interlocking mechanism between CRS and concrete. Different specimens by varying thenumberofCRSandepoxycoatedCRSweretested.Thismethodhelpstoovercomethelimitationsofprestressing,use ofhighqualitydense concrete,hightensilesteel etc. [10].

CRS could reduce the propagation of crack and make the crack path longerby changing the directionof cracks. It also delayed the yielding of bottom steel bars. The load carrying capacity and initial stiffness wereincreased by 112% and 24% when compared to solid slab. The increase in number of CRS increased the loadcarrying capacity. CRS helped to maintain the properties of initial stiffness even though bottom bars reached theyield strength [10].

As per CRS contribution, slabs with two CRS was more effective than slabs with 3 CRS. The additionof coarse aggregate with epoxy coating CRS has better distribution of stress and crack propagation due tocomposite action and good interlocking between CRS and concrete. This proved that the performance can beimproved or theCRSnumbercanbereducedbycoatingtheCRSwith epoxymatrix[10].

2.3 STEELPLATES

HCS were strengthened using steel plates.Various specimens with varying width,depth and stripswere observed for understanding its behavioural pattern. Different strengthened specimenswere 2 mm thickfour strips of 100 mm width (S4ST2), 3 mm thick four strips of 100 mm width (S4ST3),2 mm thick two stripsof200 mmwidth(S2ST2),and 3 mmthicktwostripsof200 mm width(S2ST3)analyzed[4].

TheresultssaidthatS4ST3hassmallestdeflectionatthe sameloadwhencomparedtootherspecimens. When compared to controlled specimen, the initial cracking load for slabs S4ST2, S4ST3,S2ST2andS2ST3wereincreasedabout48%,59%,41%and48%.Theultimatefailureloadincreasedabout48%,59%, 41% and 48%. S4ST3 has better load carrying capacity than other specimens. Strengthening with steelplatesincreasestheflexural capacityofthe slabs[4].

2.4 BONDEDOVERLAY(BO)USINGCONCRETELAYER

In this method, a layer of concrete laid above the HCS. A 50 mm thick BO was placed on 2-3 mmroughened top surface of HCS. The surface should be cleaned before placing BO. To ensure the compositeaction, shear keys should be provided between BO and surface of HCS. The holes are drilled to insert the shearkeys. After inserting the shear keys the holes were filled with epoxy resin. Minimum number of shear keys haveto be providedto avoidthe bond failure due to shrinkage cracking[7].

The test was conducted under low shear span to depth ratio (3.75) and high shear span to depth ratio(7.5). In low shear span to depth ratio, load displacement behaviour was found to be stiffer than control slab.There was increase in cracking load due to the increase of section modulus on BO specimen. BO gained 60%increase in bending strength when compared to controlled slab. In this strengthening technique, bending strengthincreased higher thanshearstrengthand failuremodechangedto sheardominant[7].

In shear span to depth ratio, BO has different inclination angle compared to control slab. The presenceof shear keys at the interface helped to achieve full composite action between BO and HCS. This techniqueincreased 88.8% strength without much change in its failure displacement. The slab was finally failed in flexuralshearmode [7].

2.5 HYBRIDSTRENGTHENING(BO+NSM/EB)

In this method, bonded overlay technique

was adopted with NSM or EB method to create hybridstrengthening. The experimental results of BO + EB with 7.5 shear span to depth ratio showed an initial flexuralcrack in constant moment zone. At higher loads, due to local debonding of laminate, sudden drop in load wasobserved. It was failed in flexural shear mode. The experimental results of BO + EB with 3.75 shear span todepth ratio showed linear behaviour until first crack and multiple load drops were found due to debonding ofCFRP laminates. The BO + NSM has similar failure progression as that of BO + EB. It was failed in sheartension mode [7].
The studies explained that the simultaneous increase in BO thickness and reinforcement ratio leads toimprovementinpeakload bymore than100%withoutcompromiseinductility[7].

III. CONCLUSION

Variousstrengtheningtechniquesaredevelopedbytheresearchersforimprovingthestructuralperformance of HCS. Some of the modern strengthening methods are discussed in this paper. The review showsthatvaststudiesare requiredto findoutthemosteffectivemethods.

FRP were commonly used material for strengthening of HCS. CFRP was widely used in the form ofsheets, laminates, and wraps with different reinforcing methods due its great advantages. NSM and EB havealmost similar behavioural pattern in low and high shear span to depth ratio. Among these hybrid strengtheningwas found more efficient at higher shear span to depth ratio than lower ratio. Remarkable increase in peakstrength and post cracking stiffness can be achieved by selecting suitable BO thickness and FRP reinforcementratio for hybridstrengthening.

CRRP fabric technique increase the load carrying capacity but it was not much favorable techniquebecause of less utilize the mechanical properties of CFRP material. HCS strengthened with CRS sheets shows atransitionin failuremode fromflexuraltoshearonincreaseof number ofCFRPsheetlayers.

Strengthening with steel plate was more effective than GFRP wraps. Steel strips increases the flexuralcapacity more than that of GFRP layers. Among all strengthening techniques CRS was the latest technologywhich shows good improvement in load carrying capacity. Future studies are required to find the better CRSshape, crosssectionandnumber ofCRSforthe better strengtheningtechnique.

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