

Structural Behaviour of Modified Hollow Core Slab: A Review

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Abstract

The aim of this paper is to summarize the review of literature on structural behaviour of modified hollow core precast concrete slab. Hollow core slabs (HCS) are used for modular building constructions which helps to reduce the volume of concrete. The voids provided parallel to the length of slabs may leads to early failure. Composite reinforcement methods and other strengthening techniques with GFRP strips, steel plates, CFRP laminates etc. are developed to strengthen the voids of HCS. Experimental and numerical analysis are carried out to study the effect of various strengthening techniques on HCS. The studies shows that the strengthening techniques helps to stabilize the voids and increase the load carrying capacity of hollow core slabs than solid slabs.

Keywords: Hollow core slab, Composite reinforcement system, GFRP strips, CFRP laminates.

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I. INTRODUCTION

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

The traditional reinforced concrete precast solid slabs are heavy and gives remarkable weight to the overall structure. It also requires considerable time and manpower for the transportation and erection. The HCS is light weight, easy to transport and install when compared to solid slabs.

The voids present in HCS affects the flexural and shear resistance performance. The increase in the ratio of hollow to total area will decrease the flexural and shear strength of slab. Therefore, HCS was suggested for 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 tried to improve the performance of HCS by stabilizing the voids with CFRP and GFRP materials [2, 10].

The voids present along the length HCS can be utilizes as service ducts for plumbing and electrical works. They can be used for air conditioning ducts. The implementation of HCS is very effective and efficient for residential buildings, schools, car parks and multi-story buildings [4].

II. STRENGTHENING TECHNIQUES

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

2.1 CARBON FIBER REINFORCED POLYMER (CFRP)

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

2.1.1 External Bonding (EB) using CFRP laminates

Shear strengthening in HCS were carried out using CFRP laminates around the perimeter of the voids. The tested specimens had a length of 4575 mm, a depth of 305 mm, and width of 1216 mm. 300 mm and

450 mm long CFRP sheets and epoxy were used to strengthen the prestressed HCS. Specimens with one layer and two layer of CFRP laminates were tested. Both CFRP sheet and slab void surface were saturated with epoxy before bonding. The specimens were tested at least three days after the preparation [11].

The test results showed considerable increase in shear capacity and some strengthened specimens exhibited more ductility before failure. Increasing CFRP layers improves shear capacity of HCS. Increase in the length of CFRP laminates improves the shear resistance capacity. It was noted that an arc of 90° are enough to strengthen the critical shear region of each web which shows 32% of improvement in shear resistance. Increasing the prestressing level might not be help to improve the shear capacity of HCS. It depends on concrete property and applied CFRP material [11].

2.1.2 EB using CFRP composite

CFRP unidirectional fabric with a width of 600 mm and thickness of 0.12 mm were used for the study. The fabric is placed bottom side of the slab. The size of HCS was 5000 mm x 990 mm x 260 mm. The surface of the slab where fabric is attaching were grinded and cleaned using air compressor. The fabric was cut and cleaned with degreaser. Epoxy resin was applied on the marked region of fabric. The CFRP fabric was laid over the layer of resin on the HCS. Fabric is laid in such a way that 300 mm from both ends of HCS remained unstrengthened. The test was conducted at least one week curing [3].

The failure occurred was sudden and brittle which is produced by shear. A crack extended on the entire depth, from interior point to the point of application of load. The strengthened slab increased approximately 11% of ultimate load carrying capacity than unstrengthened HCS. The results showed that the failure occurred due to shear and strengthening helped to gain superior flexural capacity. This strengthening did not put forward the important mechanical capabilities of CFRP material [3].

2.1.3 NearSurface Mounting (NSM) using CFRP laminates

In NSM strengthening, grooves are cut in the concrete layer which is filled with adhesive after cleaning. CFRP laminates are placed into the grooves and pressed lightly to spread the adhesives. The remaining portion of grooves filled with adhesives. This technique has less probability for debonding failure than EB technique. The depth of groove was more than 1.5 times width of laminates and width of groove was more than or equal to three times the thickness of laminates [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 (unstrengthened) slab. The peak strength due to this strengthening was increased by 49.5%. The specimen was failed due to conversion of flexural crack into sudden flexural shear crack. It also shows reduction in displacement ductility

In high shear span to depth ratio (7.5), the specimen showed similar pre-cracking behaviour and after cracking, it showed stiffer response when compared to control specimen. At higher load levels, ductile flexural cracks converted into flexural shear and specimen failed due to sudden flexural shear cracking. The strengthening increase the load carrying capacity by 68% [7].

2.1.4 CFRP sheets

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% with CFRP laminates and 49% with CFRP sheets. The test was conducted on 4.7 m x 1.2 m x 0.2 m size slab with 44% void. The HCS was strengthened using 0.13 mm thick CFRP sheets which was applied at the bottom of slabs fixed by epoxy resin. The slabs were tested in flexure and shear [5].

The results showed that the increase in cross sectional area of sheets improves the failure load. However the mode of failure changed from flexural to shear when cross sectional area of sheet increased. The maximum increase in flexural strength was 40%. Shear failure occurred with sudden shear compression failure in HCS. The strengthened slab gained 10% increase in shear strength and almost 100% increase in ductility [5].

2.2 GLASS FIBER REINFORCED POLYMER (GFRP)

Glass fibers are commonly used reinforcing fibers for polymeric matrix. Glass fibers have advantages of low cost, high tensile strength, high chemical resistance and excellent insulation features. But it has low fatigue resistance, high density and low tensile modulus. When compared with CFRP, GFRP has low cost and low thermal conductivity. Different strengthening techniques using GFRP has summarized below [1].

2.2.1 Prestressed GFRP bars

The specimen of one vent size 4000 mm x 140 mm x 150 mm strengthened with 10 mm diameter GFRP bars are tested. GFRP threads were axially wrapped around the bars to improve the bonding between bars

and concrete. The bars were prestressed at 10, 20, 30 and 40% of their ultimate tensile strength. The GFRP bars were manufactured using pultrusion process [1].

The cracks noted in specimens were occurred and propagated within flexural zones across the width of slab. Maximum pretension applied on GFRP bars cannot exceed 30%. 40% pretension bars were crushed when grips are applied. This is because high tensile stress applied to the bar and ends were subjected to compressive stress during the provision of grips leads to stress exceed the material capacity and crushed. The highest initial cracking load and ultimate load were observed on 20% pretension bars. Also 20% pretension bars has highest elastic and plastic energy absorption. HCS with GFRP bars exhibited flexural failure for prestressing level lower than 30% [1].

2.2.2 GFRP wraps

100 mm width GFRP strips were used to strengthen the 4100 mm x 1200 mm x 160 mm HCS. Studies were conducted by varying the number of strips and number of layers provided on each strips. Different strengthened specimens were four strips with two layers each (S4G2L), two strips with four layer each (S2G4L), and four strips with four 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 of S4G2L, S4G4L, and S2G4L were increased about 13%, 13% and 6% than controlled slab. The ultimate failure loads were increased by 7%, 19% and 15% than controlled slab. Four strips with four layers each gave better results than others. Strengthening process using GFRP wraps reduced the presence of cracks and decreased the width of crack [4].

2.2.3 Composite Reinforcement System (CRS) using GFRP

Recently developed technique to strengthen the voids of HCS was CRS system. Presence of outer flanges provides better interlocking mechanism between CRS and concrete. Different specimens by varying the number of CRS and epoxy coated CRS were tested. This method helps to overcome the limitations of prestressing, use of high quality dense concrete, high tensile steel etc. [10].

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

As per CRS contribution, slabs with two CRS was more effective than slabs with 3 CRS. The addition of coarse aggregate with epoxy coating CRS has better distribution of stress and crack propagation due to composite action and good interlocking between CRS and concrete. This proved that the performance can be improved or the CRS number can be reduced by coating the CRS with epoxy matrix [10].

2.3 STEEL PLATES

HCS were strengthened using steel plates. Various specimens with varying width, depth and strips were observed for understanding its behavioural pattern. Different strengthened specimens were 2 mm thick four strips of 100 mm width (S4ST2), 3 mm thick four strips of 100 mm width (S4ST3), 2 mm thick two strips of 200 mm width (S2ST2), and 3 mm thick two strips of 200 mm width (S2ST3) analyzed [4].

The results said that S4ST3 has smallest deflection at the same load when compared to other specimens. When compared to controlled specimen, the initial cracking load for slabs S4ST2, S4ST3, S2ST2 and S2ST3 were increased about 48%, 59%, 41% and 48%. The ultimate failure load increased about 48%, 59%, 41% and 48%. S4ST3 has better load carrying capacity than other specimens. Strengthening with steel plates increases the flexural capacity of the slabs [4].

2.4 BONDED OVERLAY (BO) USING CONCRETE LAYER

In this method, a layer of concrete laid above the HCS. A 50 mm thick BO was placed on 2-3 mm roughened top surface of HCS. The surface should be cleaned before placing BO. To ensure the composite action, shear keys should be provided between BO and surface of HCS. The holes are drilled to insert the shear keys. After inserting the shear keys the holes were filled with epoxy resin. Minimum number of shear keys have to be provided to avoid the 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 strength increased higher than shear strength and failure mode changed to shear dominant [7].

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

2.5 HYBRID STRENGTHENING (BO + NSM/EB)

In this method, bonded overlay technique was adopted with NSM or EB method to create hybrid strengthening. The experimental results of BO + EB with 7.5 shear span to depth ratio showed an initial flexural crack in constant moment zone. At higher loads, due to local debonding of laminate, sudden drop in load was observed. It was failed in flexural shear mode. The experimental results of BO + EB with 3.75 shear span to depth ratio showed linear behaviour until first crack and multiple load drops were found due to debonding of CFRP laminates. The BO + NSM has similar failure progression as that of BO + EB. It was failed in shear tension mode [7].

The studies explained that the simultaneous increase in BO thickness and reinforcement ratio leads to improvement in peak load by more than 100% without compromise in ductility [7].

III. CONCLUSION

Various strengthening techniques are developed by the researchers for improving the structural performance of HCS. Some of the modern strengthening methods are discussed in this paper. The review shows that vast studies are required to find out the most effective methods.

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

CRRP fabric technique increase the load carrying capacity but it was not much favorable technique because of less utilize the mechanical properties of CFRP material. HCS strengthened with CRS sheets shows a transition in failure mode from flexural to shear on increase of number of CFRP sheet layers.

Strengthening with steel plate was more effective than GFRP wraps. Steel strips increases the flexural capacity more than that of GFRP layers. Among all strengthening techniques CRS was the latest technology which shows good improvement in load carrying capacity. Future studies are required to find the better CRS shape, cross section and number of CRS for the better strengthening technique.

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