# Bonded Overlay Strengthening of Hollow Core Slab with and without Interface Shearkeys Connection



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# BONDED OVERLAY STRENGTHENING OF HOLLOW CORE SLAB WITH AND WITHOUT INTERFACE SHEARKEYS CONNECTION

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**ABSTRACT**

Precast Prestressed Hollow Core Slabs (PPHCS) are most commonly used as flooring and roofing elements. Usually, a new layer of concrete is placed on the top of hollow core slabs to create a continuous and levelled surface. The common thickness of this bonded overlay will be around 50 mm to 75 mm deep. The provision of Bonded Overlay (BO) will increase the cracking load and flexural strength of hollow core slab after the full composite action is developed. In the present study, the effect of shear keys at the interface of bonded overlay and hollow core slab is studied. The hollow core slab and bonded overlay is expected to have a full composite action until failure without any interface separation. The dimension of hollow core used in this investigation is 600mm wide, 150mm depth and 3500mm length. In total, three full-scale hollow core slabs were tested under shear span (a) to depth (d) ratio of 7.5. The three specimens which include un-strengthened slab denoted as control slab, slab strengthened with bonded overlay without any shear keys at the interface and bonded overlay with shear keys. Bonded overlay specimens without shear keys resulted in interfacial failure and it was able to increase the peak load by 38.4% compared to the control specimen. However, the bonded overlay with shear keys resulted in full composite action till the final failure and it was able to increase the peak load by 59.6% compared to the control specimen. The provision of shear keys at the interface of hollow core slabs and bonded overlay resulted in full composite action.

## 1 Introduction

Precast Prestressed Hollow-Core Slabs (PPHCS) are the precast members which are commonly used as roof and flooring units in residential and commercial buildings, parking structures, short span bridges. PPHCS consist of continuous interior recesses running along its length. These recesses significantly reduce the self-weight of the slab. Good improvement in flexural and shear strength of HCS can be achieved using bonded overlay technique. A thin layer of concrete (bonded overlay) of appropriate thickness can be placed in the compression region to attain desired structural behavior. However, the horizontal shear transfer between concrete interfaces should be sufficient to allow full composite action under flexure loading. Both ACI[1] and PCI[2] code provisions suggest that a minimum roughening amplitude of 6.3 mm is required for attaining full composite action. Previous studies by authors have focused on the FRP strengthening of prestressed hollow core slabs[3-7]. However, a very few investigations in the past have focused on interfacial shear behavior of composite hollow core slabs. Mones and Brena[8] performed push off test on hollow core composite section and the authors concluded that roughened interface develops higher horizontal shear strength and less horizontal slip compared to machine finished specimen. They also noted that the roughening is more effective when the grooves are perpendicular to applied loads. Girhammar and Pajari[9] performed pull off test to determine the interfacial shear strength of different topping materials such as normal and fiber reinforced concrete. The authors concluded that interfacial strength was slightly higher for slabs with fiber reinforced concrete topping. Studies focusing on the flexural behavior of composite hollow core slabs concluded that full composite action is achieved up to ultimate load.

# 2 Research Significance

The placing of bonded overlay on the top PPHCS is a most common technique in the precast buildings. The positive impact of bonded overlay on the strength and serviceability of hollow core slabs will come into the picture once it develops the full composite action with parent concrete. Hence, it is important to understand the complete flexural behaviour of prestressed hollow core slabs strengthened with bonded overlay using with and without shear keys at the interface.

# 3 Experimental Work

## 3.1 General

Three full scale PPHCS were tested under flexure to understand the composite action of the bonded overlay strengthened specimen. To understand the composite action between bonded overlay and hollow core slabs, slab was strengthened with only bonded overlay strengthening and another specimen was strengthened with bonded overlay with interfacial shear keys. All three specimens were tested under shear span depth ratio of 7.5. Figure1 explain the test setup. Details of the test specimens are given in Table 1.

## 3.2 Material Properties

### 3.2.1 Concrete

All the prestressed precast hollow core slabs were manufactured in the precast plant. The average 28 day cube compressive strength of these slabs was 43 MPa. The unit weight of concrete used was 2400 kg/m3. The concrete used for bonded overlay had an average 28 day compressive strength of 37 MPa. Care was taken to have a more or less similar concrete strength for both the parent slab and the bonded overlay to ensure monolithic behavior.

### 3.2.2 Prestressing strands

Three numbers of seven wire (9.53 mm nominal diameter) low-relaxation strands were used. Coupon tests were conducted and the average ultimate tensile strength and modulus of elasticity was found to be 1860 MPa and 196 GPa respectively. The strands were anchored at one end and stressed from the other end to an effective stress of 980 MPa.

Table 1 - Details of Test Specimens

| S. No | Nomenclature | a/d ratio | Strengthening Details | HCS Concrete Strength (MPa) | BO Concrete Strength (MPa) |
|---|---|---|---|---|---|
| 1 | HCS-150-7.5-C | 7.5 | Control Slab | 43 | - |
| 2 | HCS-150-7.5-BO | | Bonded overlay- No shear key | 43 | 37 |
| 3 | HCS-150-7.5-BO + SK | | Bonded overlay with shear key | 43 | 37 |

## 3.3 Strengthening Procedure

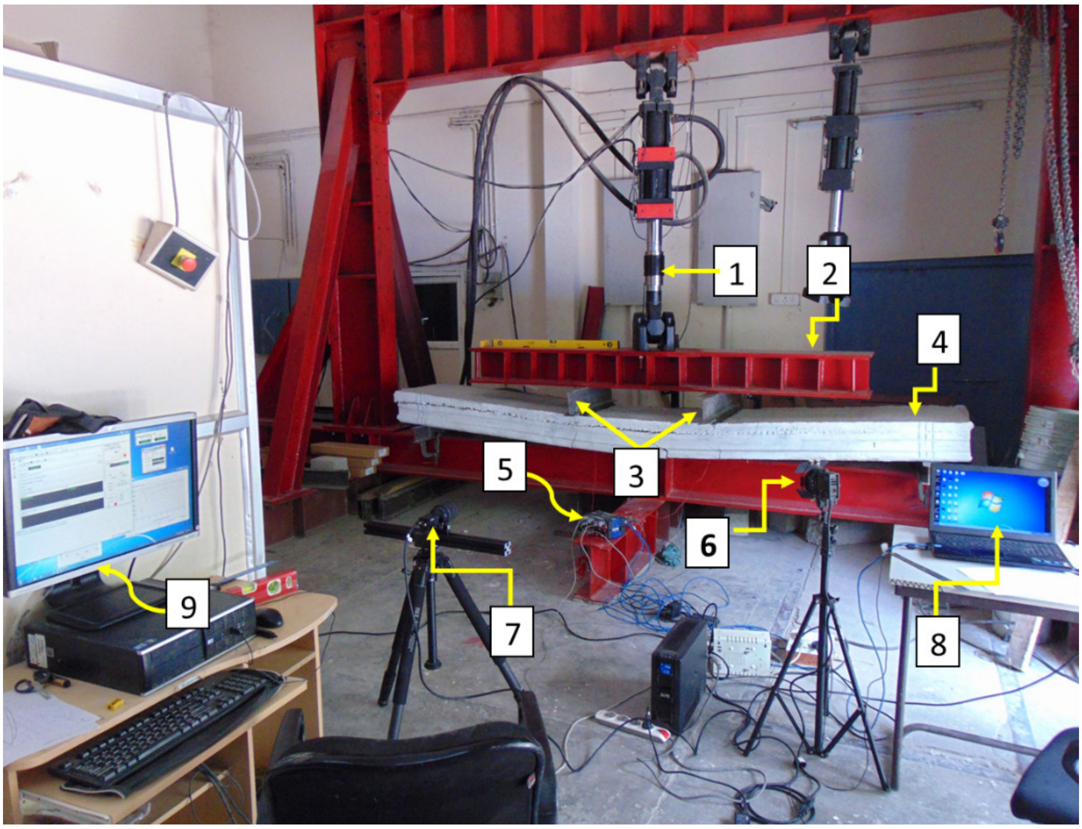
Usually, a new concrete overlay (screed) is placed on top of hollow core slab at the site to create a continuous levelled surface. The thickness of this overlay will be typically about 50 mm. Therefore, to resemble the actual site conditions, 50 mm overlay thickness was placed on the top surface of hollow core slabs. Ensuring proper bond between the overlay and parent concrete surface is very difficult without any shear keys. To ensure proper shear transfer, minimum number of shear keys were provided as per ACI 318 to prevent bond failures and to ensure complete composite action till the ultimate strength. The L- shaped shear keys were placed at 300 mm center to center along the length of hollow core slab. A hole of 8-mm diameter was drilled up to 25 mm depth to place the shear keys. After installation of shear keys, the holes were filled with epoxy resin to ensure bonding of shear keys to the parent slab. Fig. 2 shows the provision of shear keys at the interface of hollow core slab and the bonded overlay. Bonded overlay slabs were tested after proper curing of the overlay for a minimum of 28 days.

(a) Installation of Shear Keys (b) Hollow Core Slabs with Bonded Overlay

Figure 1: Strengthening of PPHCS with bonded overlay

## 3.4 Test Setup and Instrumentation

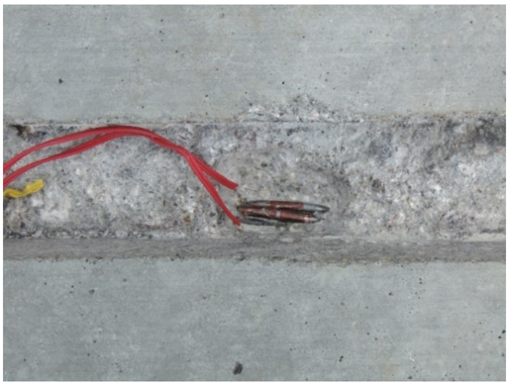
Two Linear Variable Displacement Transducers (LVDT) of 100 mm stroke were placed to measure the deflection at the mid-span. Two additional LVDT's of 50 mm stroke were placed at one-third of the span to measure the deflection as shown in Figure 3 (a). Two strain gauges (Pl-60) of 60 mm gauge length were placed at the top and bottom of the concrete slab to measure the concrete surface strain variation during the testing. Four strain gauges (UFLA-5) of 5 mm gauge length were installed on prestressing strands at mid-span and at one-third of the span as shown in Figure 1(b).




1) MTS 250 kN 2) spreader beam 3) Point Loadings 4) Hollow core slab 5) DAQ
6) DIC light source 7) DIC camera 8) DIC system 9) MTS System

Figure 2: Test setup of Hollow Core Slabs

(a) Placing of LVDT's



(b) Strain gauge on strands

Figure 3: Instrumentation Details

**Table 2: Test Results of HCS**

| Specimen ID | First Crack Load (kN) | Displ. at cracking Load (mm) | Peak Load (kN) | Change in PL (%) | Peak Displ. (mm) | Strain Energy (kN.mm) | Stiffness at Cracking (kN/mm) | Failure Mechanism |
|---|---|---|---|---|---|---|---|---|
| 7.5-C | 25 | 4.17 | 50.7 | -- | 44.6 | 3440 | 6.0 | Crushing of Concrete |
| 7.5-C+BO | 40 | 4.21 | 59.2 | **38.3** | 13.4 | 3866 | 9.50 | Interfacial Shear Failure |
| 7.5-C+BO+SK | 49.1 | 3.69 | 80.9 | **59.6** | 56.7 | 6880 | 13.3 | Flexure-Shear Failure |

# 4 Experimental Results

The experimental results observed were presented in Table 2. The overall behavior of individual specimens are described in the sections below.

## 4.1 Control Specimen (7.5-C)

The load-displacement response of the control specimen is illustrated in Figure 4. The first flexural crack was observed at mid-span in the constant moment zone when the load reached to 25 kN. Cracking was also reflected through the change in the slope of the load-displacement curve. With the further increase in the applied load, strands significantly contributed to the load resisting mechanism. Specimen attained a peak load of 50.7 kN, and a corresponding displacement of 44.6 mm. The load resistance was slowly declining with the further increase in load level and the slab failed by crushing of concrete in compression at a displacement of 93 mm.

## 4.2 HCS with Bonded Overlay (7.5-HCS+BO)

HCS+BO was strengthened specimen, which is having concrete bonded overlay of 50mm in the compression region. This slab has also tested at same shear span to depth ratio of 7.5 to find the effectiveness of the overlay. From concrete bonded overlay, it was observed that the ultimate load of the strengthened specimen was 59.2 kN with the deflection of 13.4 mm and ultimate deflection measured was 85 mm. Failure progression was as follows; First crack observed at the bottom over the constant moment zone; sudden horizontal separation between bonded overlay and hollow core slab; the yielding of strands; finally crushing of concrete at compression region.

## 4.3 HCS with Bonded Overlay and Shear Keys (7.5-HCS+BO+SK)

HCS+BO+SK was strengthened specimen which is having a thin layer concrete bonded overlay with shear keys at the interface to prevent horizontal shear failure. This slab has also tested at same shear span to depth ratio of 7.5 to find the effectiveness under flexure. From concrete bonded overlay, an increase in the cracking moment and post cracking stiffness was observed whereas from the shear keys it was observed that it was very effective in preventing the horizontal shear failure. The ultimate load of strengthened specimen was 80.9 kN with the deflection of 56.7 mm. Failure progression was similar to that of control specimen (flexure-shear mode).

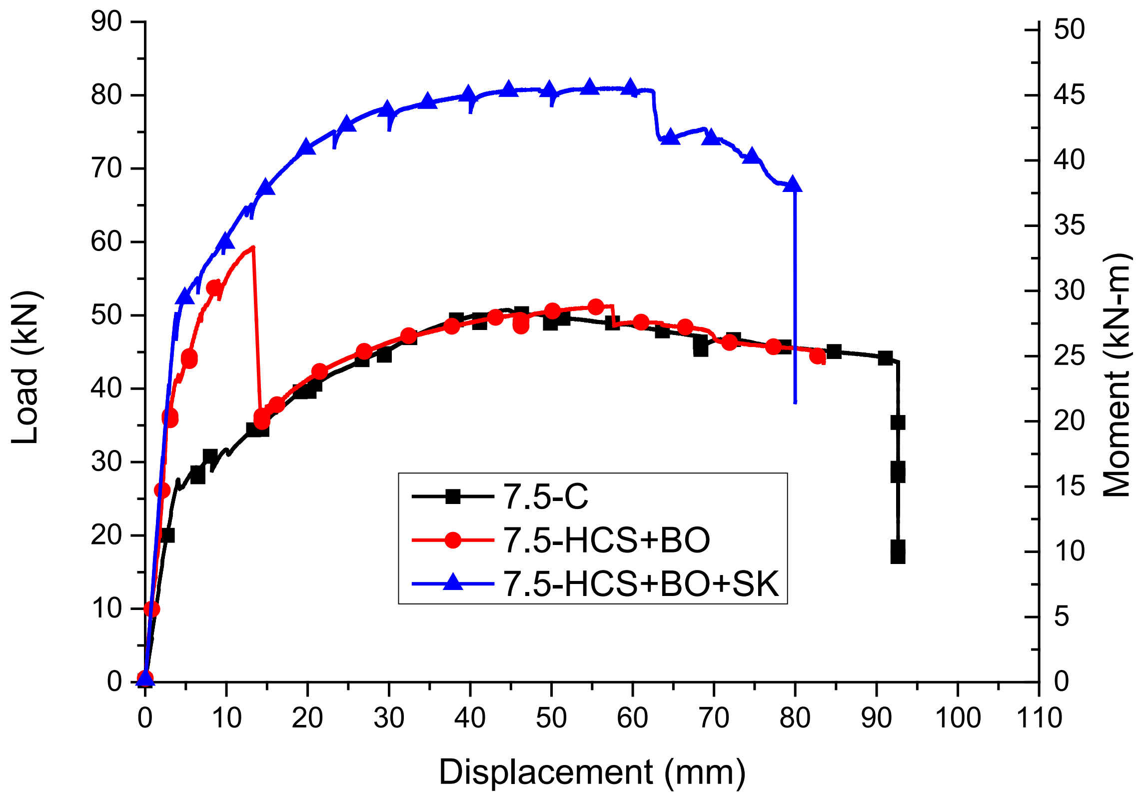



Figure 4: Load - displacement behavior of HCS with and without BO strengthening

## 4.4 Comparison

Figure 4 shows the comparison of load-displacement of all tested slabs. The hollow core slab strengthened with bonded overlay without any shear keys was able to increase the load by 38.3% after an interfacial shear failure. A sudden drop in the load was observed after which the strengthened slab behaved like a control specimen. The slab strengthened with bonded overlay and shear keys at the interface was able to increase the load by 59.6% without compromising the post-cracking stiffness behavior. The table 3 summarizes the calculations for cracking moment, failure load for the control and strengthened slabs. Moment capacities are calculated by developing moment-curvature for the cross sections. Shear capacity (Ps) predictions are calculated based on ACI 318-05 specifications. Finally, the predicted response are compared with experimental test results and a good correlation was observed between them.

**Table 3 - Comparison between the predicted and the experimental results**

| S. No | Specimens | Analytical results | | | | | Experimental results | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $P_{cr}$ (kN) | $P_{fc}$ (kN) | $P_s$ (kN) | $P_u$ (kN) | Predicted failure mode | $P_{cr}$ (kN) | $P_u$ (kN) | Failure mode |
| 1 | 7.5-C | 20.6 | 45.0 | 80.0 | 45.0 | Flexure | 25.0 | 50.8 | Flexure Failure |
| 2 | 7.5-HCS+BO | 48.0 | 78.0 | 123.0 | 78.0 | Flexure | 40.0 | 59.2 | Interfacial shear |
| 3 | 7.5-HCS+BO+SK | 48.0 | 78.0 | 123.0 | 78.0 | Flexure | 49.0 | 80.9 | Flexure-Shear |

(*Note: $P_{cr}$=Load at first crack; $P_{fc}$= Flexure load capacity of the specimen; $P_s$=Shear load capacity of the specimen; $P_u$=Ultimate load of the specimen governing failure.)

# 5 Conclusions

Three full-scale prestressed hollow core slabs were tested to investigate the composite action between the hollow core slabs and the bonded overlay. The main conclusion drawn from this study are as follows:

- The hollow core slab strengthened with only bonded overlay without any shear keys at interface increase the strength by 38.3%.The specimen had a failure at the interface due to propagation of shear crack through them.
- The bonded overlay strengthened specimen with interfacial shear keys increased the peak load by 59.6% and full composite action was achieved. The interfacial shear failure of HCS were prevented and the specimens finally failed in a flexure-shear mode.
- Shear keys are effective to resist the interfacial horizontal shear force. As a result, they helped the specimen in preventing the propagation of shear crack at the interface which was considered as the weak link of the composite section.
- The analytical predictions calculated as per ACI code to predict the capacity of the hollow core slab with and without overlay had a good correlation when compared to the experimental results.

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