DO IT RIGHT THE FIRST TIME

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ABSTRACT. PRECAST Building Industry in India is rather young and is still trying to get a good foothold. Although we have not yet developed our own guidelines and procedures in this field, sufficient material is available from other international bodies such as the PCI, CPCI etc. It is seen however, that a few Precast building projects are following poor practices, sometimes producing sub-standard quality elements leading to questionable structural performance. A relatively new but promising industry cannot afford to be like this in its infancy. A Case History of a Hollow Core Slab failure is discussed along with recommendations on the needful actions – Training being one of the essential ones.

Keywords: Hollow core slabs, Strand-Bond failure, Voids, Compaction.

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INTRODUCTION

Modern times with their ever-increasing pace of life, have placed huge demands upon the Construction Industry in terms of Speed of Construction. Buildings which took years to build in the past are now expected to be up in months. Precast Concrete Technology has responded to this demand and has fulfilled it fairly well. In India, Precast technology has been used for several decades in Bridges & Infrastructure. It is however new in the field of buildings and is growing every year. New enterpreneurs are entering the trade while more & more Precast manufacturing units are coming up all over the country.

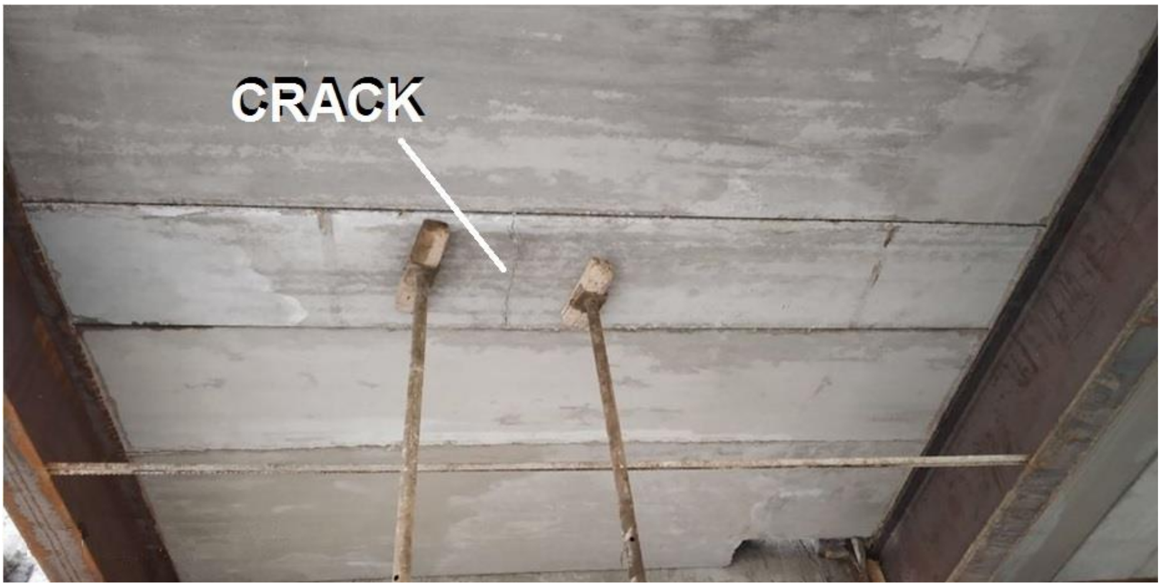
Unfortunately however, the construction culture of some players, is rather poor - not giving Quality its due share of importance. Too often, the demand for speedy deliveries is met by violating practices of “Good concrete” resulting in poor products - endangering lives as well as the reputation of this new technology.

Precast, prestressed Hollow core concrete slab technology was developed in the west decades ago and is well proven abroad. When it came to India, Performance was therefore generally taken for granted. However, a recent case history of a HC slab failure in the NCR highlights the need to look carefully at our practices and attitudes and correct them at the earliest so that the Indian market can look at the Precast technology with confidence and trust. The case is presented below.

THE PROBLEM

The building in question is a recently completed, 12 storey, steel framed structure using 150mm thk. Hollow core slabs, overlain with a structural screed of 75mm.

A week after screeding, an HCS half slab on the 6th floor, 600mm wide & 4m long, developed a major bottom crack at its mid-span. The crack widened quickly and had to be removed by the next day to avoid an accident.



The problem was seen in 2 parts :

1. To diagnose & find a possible cause for the sudden failure so that appropriate measures could be taken for future production
2. To examine the soundness of the structure already built and get a reasonable assurance on its safe future performance.

In order to address the 1st part, the damaged slab was tested and analysed (reported below in Appendix 1). To deal with the 2nd part, load tests on some randomly selected HCS panels at the production factory as well as In-situ full-scale load tests at the installation site were carried out. (The findings of these are reported in Appendix 2).

OBSERVATIONS / (DISCUSSION)

(under 4 component heads):

Materials

1. Sand used in the HCS mix was Stone dust with 15% fines under 150 microns size. Fines below 75 microns exceeded 11%. (Some experts believe that fines in this range are highly detrimental to the bond stress developed between strand and the concrete. However, this is a subject of further research).

Production process

2. There was no measure of consistency of the HCS mix (such as a gyratory compactor). (Variations in moisture in the mix can affect the development of the bond strength.)
3. Any part/half slabs were being created on the bed by cutting with a blunt blade between 30 – 60 minutes after casting. (This is the stage when the cement particles are at the peak of hydration reaction resulting in Gel-formation which binds the concrete. For a semi-dry mix it may be best to leave it undisturbed until fully set. Any interventions such as this may disturb the concrete and affect the bond.)
4. Cube strengths at different ages are not indicative of the actual concrete strength. (The cubes for HCS are filled from the semi-dry mix made by the batching plant and prepared with a significant compactive effort – rodding or compaction with a vibratory load. On the other hand, the compaction achieved by the slip forms is quite different & not comparable to what the cubes are subjected to. Moreover, the bed concrete around the strands contains extra water from wetting & bed lubrication nozzles. The extra water content means higher water-cement ratio which reduces strength – not indicated in the cubes).
5. The concrete did not seem well compacted around the strand. Ref. pics. (This seemed to be the most likely cause of the strand bond failure and ultimately the slab failure. If there are frequently occurring pockets of improper compaction, the bond strength developed may be in-adequate. It may just be enough to avoid slippage at the time of cutting but not enough to resist stresses from Imposed loading.)
6. Surface roughness of slabs inadequate to ensure enough ‘keying’. The surface had latance from the slab cutting operation.
7. Curing was inadequate. (The Slab was left on the bed for 22 hrs at ambient room temperature before de-stressing & cutting. At the yard, the slabs were cured by wetting

2 – 3 times/day (after much coaxing reportedly) with a hose. The wetted surface dried up within 20-30 mts. while the lower slabs in the stack did not receive much water. The full potential of strength development was therefore not being achieved.)

Transportation

8. The 20 km road between the factory and the installation site was non-existent in places having large pot-holes. (With such a rough terrain on the way there is a high risk of damage to the slabs. At least on two occasions badly damaged planks were returned to the factory.)

Stacking, Handling & Pre-installation

9. Accidental impact loads occured from dropping of RCC wall formwork, scaffolding elements / gas cylinders / bags of steel nut bolts etc. from hts. as much as 3 - 8 m.(as per site staff).
10. In order to place the HCS slab at its final destination, the crane had to manouvre it through the steel building frame constructed in advance, making it highly prone to accidental hits and shocks. The slab would sometimes get accidentally dropped with a jerk while placement on the steel beams.
11. Surface of slabs was only sprinkled with water just prior to placing topping concrete (as against a desired saturated surface dry condition. Lack of keying& a laitance full surface would prevent a composite behavior of topping with the HCS.)

SPECIFIC OBSERVATIONS ON FAILED SLAB SFH-103:

1. In an effort to remove the failed slab from its installed location, a chisel hammer was used to remove the topping as well as the side concrete. The topping came off easily revealing a clean HCS indicating little bond, consequently with little hope for composite action during future service loads.
2. There were areas of poorly compacted concrete in the bottom zone in 2 out of three slices. SLICE no. 3 revealed a relatively well compacted concrete.
3. Upon testing, the strand-bond strength followed the same pattern as above. The strands in SLICE 1 (the one with most honeycombing) had no bond strength at all. The two strands in SLICE 2 had a low bond strength of 0.6 & 1.0Mpa. Only 2 out of the 3 strands in SLICE 3 had a significant bond friction – mainly because of the rust.
4. The site team reported that the SFH 103 was one of the wrongly stacked pieces, handled (mishandled) by people unfamiliar with the handling rules of precast.

DIAGNOSIS OF FAILURE / CONCLUSIONS

The performance of HCS depends heavily on the embedded pre-stressed steel strands. These strands enhance the load carrying capacity of concrete by precompression & bear the tensile forces - by virtue of their bond with concrete.
In the case under study, the HCS plank suffered a midspan bottom crack across full width – indicative of a sudden flexural failure.

A Lab testing programme on the failed slab (Ref. Appendix A) revealed that the **concrete quality in SFH 103 was quite variable, with honeycombing & loose, poorly compacted concrete** in some areas, resulting in a poor strand bond. All the 3 strands at one end of the slab were debonded. Both the strands in the slice near midspan had a low bond strength of less than 1 Mpa. Only in the third slice, it took a significant force to push 2 of the 3 strands out of the concrete.

Under the mere self weight and that of the structural topping, the bottom concrete in the plank did not receive any help from the strands to carry tension (bond failure). The concrete cracked at the point of maximum Bending Moment failing the slab in flexure. Amongst the many factors, Lack of compaction seemed to be the most critical cause for bond failure.

RECOMMENDATIONS:

For a good effective bond between strand and HCS concrete:

1. Consult slip-former machine supplier & rectify machine related causes of un-compacted concrete. This is an Imperative.
2. Optimize the mix design – not only for a target cube strength but also for a target bond strength. A device like a Gyratory compactor is required for this.
3. Avoid as much as possible – use of extra water at the slip-former.
4. Ensure clean, dust-free & oil-free strands at the time of casting
5. Cuts – longitudinal or transverse to be made only after slab is fully set and has developed requisite strength (Precautionary measure).
6. Curing at yard to be more complete by covering with polythene sheets for at least a week. (Longer the better)
7. Handling at all stages only by certified personnel
8. Packing foam / appropriate material to be used during transit to avoid shocks.
9. Protect from overloading due to accidental impacts

For a complete bond between the HCS and the structural overlay:

10. Provide some extra paste on the top surface during slip forming to enable better keying.

11. Surface to be pressure washed a few hours before placing overlay to wash away any settled dust / laitance from cutting & bringing it to SSD condition before overlay casting. A mere single sprinkling is not enough.
12. A thin coat of a PMC (Polymer modified cement slurry) (applied as per correct procedure) can enhance the bond

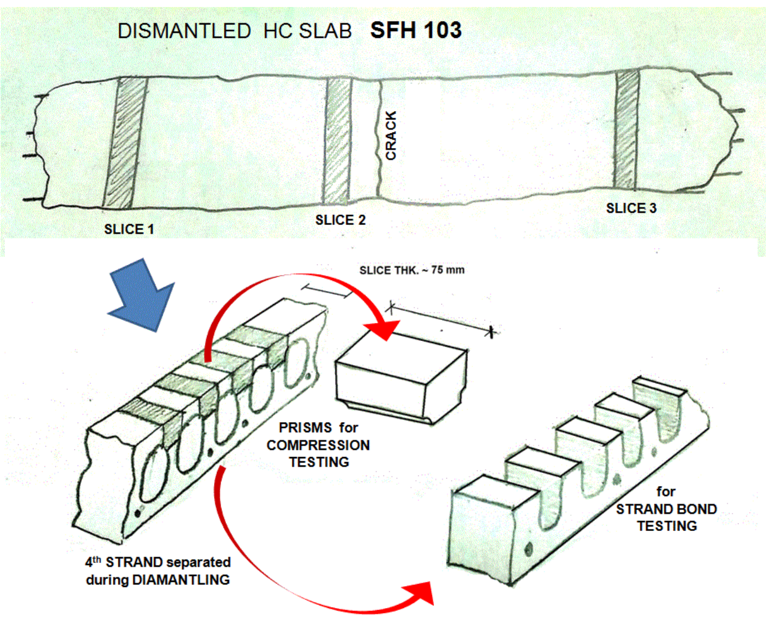
For avoiding damage from handling etc.

13. Avoid a tedious journey in-the-air for the HCS panel between the site-stack and its final resting place.
14. Use only trained crane operators & other erection personnel with appropriate communication tools including sign language.
15. Before taking up a job, a construction & erection sequence be reviewed as well as a risk evaluation conducted at various stages by competent personnel and necessary modifications made.

APPENDIX – A
LAB TESTING ON FAILED HC SLAB

Test Specimens

The HCS slab was removed from its 6th floor location after cutting away the structural topping & the surrounding concrete.
Three slices 75 – 80mm wide were cut from the slab – 2 near each end and 1 near midspan. 4 Specimens in the form of rectangular prisms were extracted from each slice. The bottom portion was retained for strand bond testing.



OBSERVATIONS

1. The topping screed was removed with fair ease revealing a nearly clean top surface of the HC Slab, indicating that there was little bond between the structural topping and the HCS.
2. Voids were noticed around strands in several locations.
3. In 2 out of 3 strands of SLICE 1, the strands were FINGER-PUSH LOOSE, while the 3rd was pushed with negligible load.
4. The compression test on the prisms gave a fairly narrow range of strengths – between 24 – 27 MPa.

APPENDIX – B
TESTING AT STOCKYARD

The codal procedure for conducting a load test is a time consuming procedure & was considered unviable for testing 300 slabs. A quick test was therefore devised by checking deflections & rebound after maintaining the full load for 30 mts. only. After another slab failed during testing merely at half the load, it was felt that each of the 300 slabs be tested before putting them to use.
A three stage regime was undertaken at the factory stockyard:

1. Shortlisting slabs on the basis of **visual examination** including a peek into the cores with help of a borehole inspection camera. Slabs with more than 20% of webs indicating honeycombing or lack of compaction were rejected.
2. **Load Testing** the shortlisted slabs with a quick equivalent single load placement in the centre, measuring instantaneous deflection and rebound upon removal. The HC slabs were considered satisfactory if they could sustain the full load for 30 minutes and rebound back 73%.
3. **Strand slippage criterion** The slab was considered PASSED if :
   - the strand slippage was below 2 mm on any of the ends.
   - the slippage was up to 3mm on any one out of 4 strands or 2 out of 8 strands
   - the increase in slippage was less than 0.5mm after the load test

As a result of carrying out this strict selection process on the basis of clearly defined objective criterion, 37 HC slabs were rejected while the rest were cleared for erection. The machine manufacturer's engineers were called in who opened up the whole machinery, corrected the necessary settings to produce further HC slabs whose quality was clearly improved.

In order to take care of the slabs already installed & screeded, In-situ Load tests as per the codal procedure were conducted on two randomly selected full panels on 5th & service floor using sand bags. Deflections were noted after 24 hrs of removal of load. The measured rebounds were 87% & 93% - both safely above the threshold.

CONCLUDING REMARKS & RECOMMENDATIONS

1. Quality measurement at the manufacturing facility is the first imperative. Every job offers an opportunity to collect data on Quality vis-à-vis practices. An HCS manufacturing facility should at least have the following equipment for testing & monitoring along with clearly defined Quality checks:

    a. A device like a gyratory compactor to help mix design as well as for conducting routine consistency checks.
    b. A concrete cutter to cut specimens from HCS slabs for testing.
    c. An arrangement to test strand Bond strength
    d. Compression testing equipment
    e. A load cell for periodic calibration of pre-stressing equipment

    A minimal testing regime of the finished product (say – load testing one random panel from each bed) should be propagated at every manufacturing facility.

2. We in India, are in a technology assimilation stage. Due to differences in work cultures, people skills, climate as well as materials, certain aspects of production & end-use need indigenous R&D to develop confidence in borrowed practices. Examples include:

    a. A study of effect of fines on strand bond strength,
    b. Surface treatments to ensure a target shear strength at the HCS-Topping interface.
    c. Determination of Optimum moisture content in the concrete mix to maximise density and strength.

    Manufacturing units therefore should be equipped for some minimal in-house R&D.

3. Regular internal audits should be conducted on every job by experts who understand structural implications of each aspect of production. Irregularities and violations should be recorded scrupulously for the purpose of learning as well as timely correction in the production process. The collected data should be suitably documented and used in Quality management as well as regular training – of all stakeholders.

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