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# Investigations on RC Beams Retrofitted with UHSCC Overlay under Fatigue Loading

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## Abstract

The present study aims to investigate the use of Ultra High Strength Cementious Composite (UHSCC) overlay strips for strengthening of pre-damaged RC beams. Fatigue loading was conducted in the study, one control beam was tested up to failure. Preloading of 80-90% in terms of number of cycles to failure was applied keeping stress ratio as 0.2 and frequency as 3Hz. Constant amplitude loading spectrum with different maxima minima but keeping stress ratio same was applied to control beam to examine any changes in structural behavior such as deflection and stiffness degradation of beams. The beams used were made of RCC with dimension 1500x100x200mm. The strengthened beams were tested to extract the parameters such as cycles for failure, load, deflection, crack initiation and failure phenomenon. It was observed that the beams retrofitted with UHSCC overlay strips performed efficiently in terms of number cycles to failure in comparison with conventional RCC beams under fatigue loading. Preloaded fatigue beam (FB1) had 17.6% higher load carrying capacity as compared to the control beam. Similarly preloaded fatigue beam (FB2) had 11.7% higher load carrying capacity as compared to the control beam. Acoustic Emission technique is a novel Non-destructive testing method which is used to identify the crack propagation and physical behavior of the beam at selected locations during the onset of loading, which gives a precise idea of the crack initiation and crack propagation under different loading condition.

**Keywords:** Acoustic Emission, Cycles for Failure, Fatigue, Preloading, Strengthening, Ultra High Strength Cementious Composite

## 1. Introduction

Concrete structures have become integral part of any infrastructure development project. It is of no wonder now concrete is the most used man made material. Concrete structures are preferred since they are easy to work, cost of construction is less, good fire resistance and durability properties. Service life of structures reduce with progress time due to various factors, to make the structures serviceable the either the structure has to be fully replaced or retrofitted.

Full replacement of the structure ensures serviceability and safe use but comes with disadvantage of higher cost involved in demolishing, reconstruction which takes a huge toll on men and material along with damage to the environment.

On the other hand retrofitting provides a viable solution to such structures, retrofitting ensures the structure for the service life it is designed for. Several methods of retrofitting are available some of the methods are external cable method, bonding & jacketing method and overlaying method. External cable method is employed for reinforced concrete and masonry structures. Masonry structures have relatively large compressive strength with low tensile strength. Hence, it is most effective in carrying gravity loads. Commonly, induced tensile stress

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exceeds the compressive stresses and reinforcing must be added to provide the necessary strength and ductility. In such cases external steel cables are provided to enhance the performance. Jacketing method is used to increase concrete confinement by transverse reinforcement, especially for circular cross-sectional columns. In overlaying method, the external materials possessing necessary properties for a retrofit material are used in the weaker section of the concrete structures as so as to enhance its load carrying capacity, its durability and as well as in its aesthetics. Most popularly used material in the past five years are the Carbon fiber reinforced polymer [CFRP], Engineering cementitious Composite [ECC] and Ultra High Performance Fibre Reinforced Cementitious Composite [UHPFRCC][1,2]. The weaker section is identified based on its crack width as well as the exposure of concrete surface to extreme environmental conditions. UHSCC overlay was used as the retrofitting material in the study, UHSCC provides maximum strength in minimum thickness, which ensures space is saving in retrofitted structure no hindrance to work space, less weight gain in structure.

## 2. Experimental Program

Tests were conducted on simply supported RC beams strengthened with UHSCC overlay in tension face. The beams were tested under static loading and fatigue loading to evaluate their ultimate load capacity, deflections, and crack behavior on strengthening of pre-damaged RC beam.

### 2.1 Specimen Details

For the study totally six beams were taken. The beams were designed for grade of compressive strength of M30 according to the Indian Standards [IS10262:2009 & IS 456:2000]. The final mix proportion arrived at was of 1:1.67:1.86:0.45. The cube compressive strength and split tensile strength of the concrete was 35.93MPa and 2.9 MPa, respectively. The typical geometry and reinforcement of the tested beams are shown in Figure 1. The internal

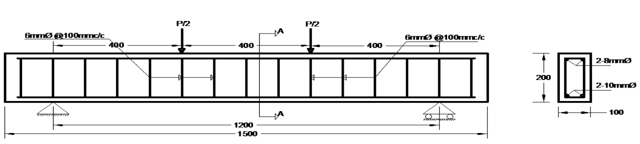


**Figure 1.** Reinforcement Detailing of Control beam.

reinforcement was made of 10mm bars, and the main tensile steel exhibited a yield strength of 415MPa. The dimension of beam measures 1500x100x10mm$^3$.

All the beams were strengthened with a new kind of Ultra High Strength Cementious Composite. The USHCC overlay was fixed to the beam using epoxy. The final mix proportion arrived at was 1:0.25:1.1:0.4:0.23 (Cement: Silica fume: Quartz Sand: Quartz Powder: Water)[3,4]. The cube compressive strength and split tensile strength of the UHSCC strip are 122 MPa and 20.6 MPa. The dimension of the USHCC strip is 1500x100x10mm$^3$. The UHSCC overlay strips were attached to the beams with epoxy adhesive on the tension side by preparing the beam surface with appropriate treatment. Uniform thickness of epoxy adhesive was applied throughout surface of the beam. It was allowed to dry for period of 48 hours. The constituent materials of UHSCC are shown in Figure 2.


**Figure 2.** Materials used in UHSCC.

### 2.2 Testing Procedure

The experimental setup consists of a 500kN capacity servo hydraulic actuator with online data acquisition devices. The control beams were tested under a displacement control testing machine with loading rate maintained at 1 mm/min and the data was recorded using a 50Hz sampling rate as seen in Figure 3. All beams were tested under four point loading, static test was done on three control beams, the average ultimate load carrying capacity was noted. The fatigue loads were applied in a sinusoidal waveform with a frequency of 3 Hz[5]. One beam was tested under fatigue and it was taken as control beam, other two beams were tested under fatigue. The upper limit load in the fatigue test was set to about 90% of the static capacity of the control beam, and the stress ratio was set to 0.2[6].

**Figure 3** **(a)**. Four-point Bending Test Setup of beams. **Figure 3(b)**. Control Beam after Failure.

The fatigue control beam was tested the loads were applied in a sinusoidal waveform with a frequency of 3Hz, the loading spectrum is seen in Figure 4. The upper limit load in the fatigue test was set to about 90% of the static capacity of the control beam, and the stress ratio was set to 0.2, Constant amplitude was applied. The graph between No. of cycles vs. Displacement is seen in Figure 5. The control beam was tested upto failure, the failure of the beam occurred at 25,500 cycles.

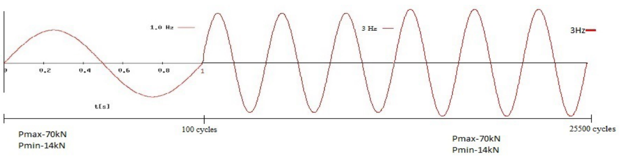


**Figure 4.** Schematic diagram representing spectrum of loading for Control Beam.

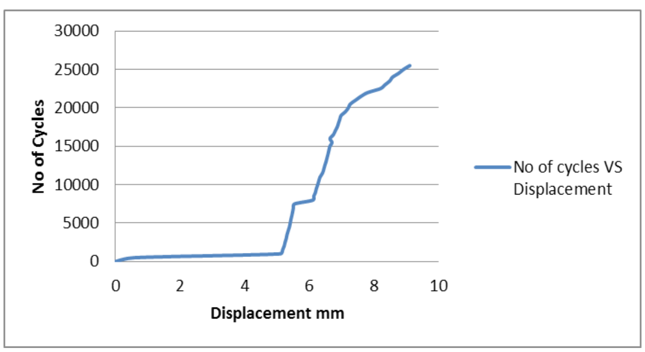


**Figure 5.** No of cycles vs. Displacement for control beam.

The upper limit load in the fatigue test was set to about 90% of the static capacity of the control beam, and the stress ratio was set to 0.2. Stress ratio was kept at 0.2 till completion. Before and after retrofitting loading No of cycles vs. Displacement graph is seen in Figure 6.

The effective span of the beam was kept at 1200mm. The fatigue load was applied in a sinusoidal waveform with a frequency of 3Hz. The beam was intentionally preloaded such that the beam undergo minimum of 12mm displacement which is equivalent to 92% of

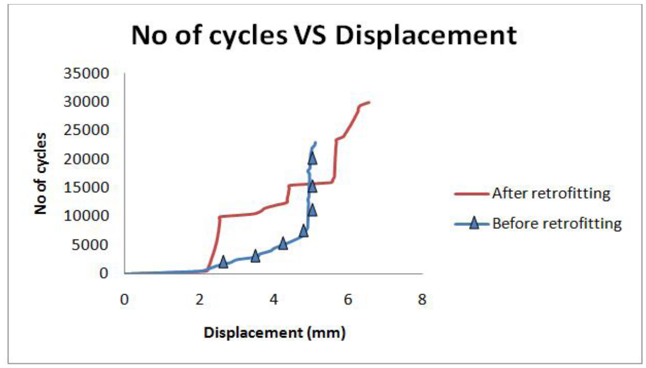


**Figure 6.** No of cycles vs. Displacement for FB1 beam.

ultimate load of control beam, this simulation was done by applying low impact loading condition to observe the behavior of beam under sudden applied load. The upper limit load in the fatigue test was set to about 90% of the static capacity of the control beam, and the stress ratio was set to 0.2 for retrofitted beam till completion of the test. Before and after retrofitting loading No of cycles vs. Displacement graph is seen in Figure 7.

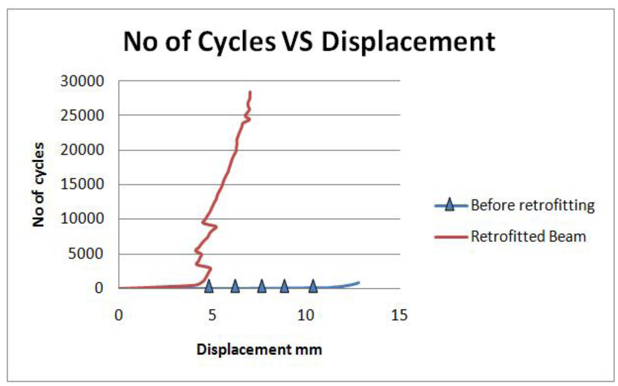


**Figure 7.** No of cycles Vs Displacement for FB2 beam.

The strengthened pre-damaged RC beams were tested and the beams performed better in terms of cycles to failure compared to control beam, the strengthened pre-loaded RC beams no. of cycles exceeded no. of cycles of failure of control beam. If the test had been continued upto failure of the strengthened pre-damaged beams would be expected to take more cycles. The deflection of retrofitted beam would have been much more than the control beam, which will be useful for prediction for ductility of the beam if the test was continued upto failure.

Acoustic emission technique was used to monitoring the crack growth in plain concrete beams under four point loading. Crack growth is continuously monitored using four acoustic sensors. The term Counts N, refers to the number of pulses emitted by the measurement circuitry if the signal amplitude is greater than the threshold in this study threshold was set as 40 dB, four channel system was adopted[7,8]. The beam with acoustic sensor is seen in Figure 8. Acoustic emission study on the beam gave an idea about the crack propagation it was observed that maximum counts occurred in the zone around channel 2 which implies maximum cracks occurred around channel 2. The location of AE sensor plays major role in capturing the behavior of concrete in terms of crack initiation and propagation. This aspect is to be taken care with the prior knowledge of beam behavior under different loading conditions in order to fix the AE sensor and to minimize number of sensors.


**Figure 8.** Acoustic Sensors placed on beam.

The inference from the acoustic emission study shows that maximum counts occurs in zone 2, indicating maximum cracks occurred around channel 2 as seen in Figure 9 & Figure10. The cumulative counts graph compares the counts of all sensors, show that channel 2 had maximum number of hits as seen in Figure 11.

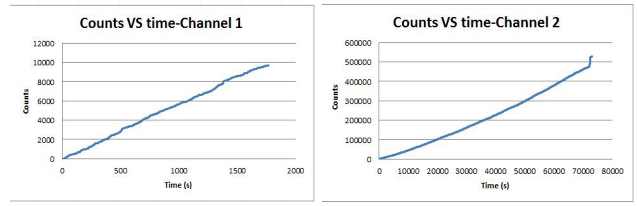


**Figure 9.** Counts vs. Time for channel 1, 2.

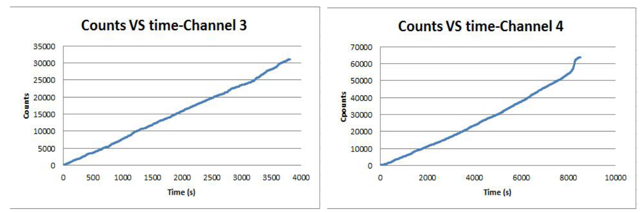


**Figure 10.** Counts vs. Time for channel 3, 4.

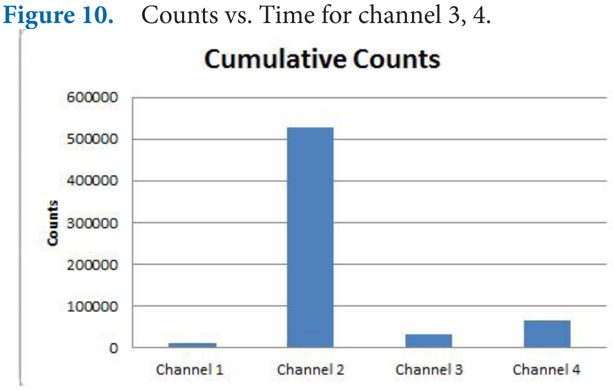


**Figure 11.** Cumulative Counts of all Channels.

## 3. Results and Discussion

The experimental results are summarized in Table 1, including load carrying capacity, number of cycles.

The following results are inferred from the study.

1. The ultimate load carrying capacity of strengthened fatigue tested beams are higher in range of 11-17%.

**Table 1.** Summary of loading conditions and test results.

| Specimen | Load carrying capacity (kN) | Upper load Pmax (kN) | Stress ratio sr | Frequency (Hz) | Fatigue life Nf (cycles) | Note |
|---|---|---|---|---|---|---|
| CB1 | 69.8 | - | - | - | - | Static test |
| CB2 | 80 | - | - | - | - | Static test |
| CB3 | 85 | - | - | - | - | Static test |
| FBC | - | 70 | 0.2 | 3 | 25500 | Fatigue test |
| FB1 | - | 70 | 0.2 | 3 | 30000 | Fatigue test |
| FB2 | - | 70 | 0.2 | 3 | 28500 | Fatigue test |

2. The ultimate load carrying capacity of strengthened fatigue tested beam FB1 is 17.6% higher as compared to the control beam.
3. The ultimate load carrying capacity of strengthened fatigue tested beam FB2 is 11.7% higher as compared to the control beam.
4. Deflection corresponding to the ultimate load for cyclic tested beams is less than that of the control beam since the experiment was not continued till failure of experiment. If the test would have been continued till failure. The deflection of retrofitted beam would have been much more than the control beam, which will be useful for prediction for ductility of the beam.
5. Cumulative count of sensor positioned on top of the beam was higher compared to other channels indicating more events have occurred around that channel.

## Conclusion

Significant increase in performance of strengthened of pre-damage RC beams using UHSCC overlay is a good method of retrofitting that could be put to use extensively owing to its slender dimension and good performance characteristics.

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