BEHAVIOUR OF RC BEAMS STRENGTHENED WITH NSM STEEL AND CFRP BARS

by

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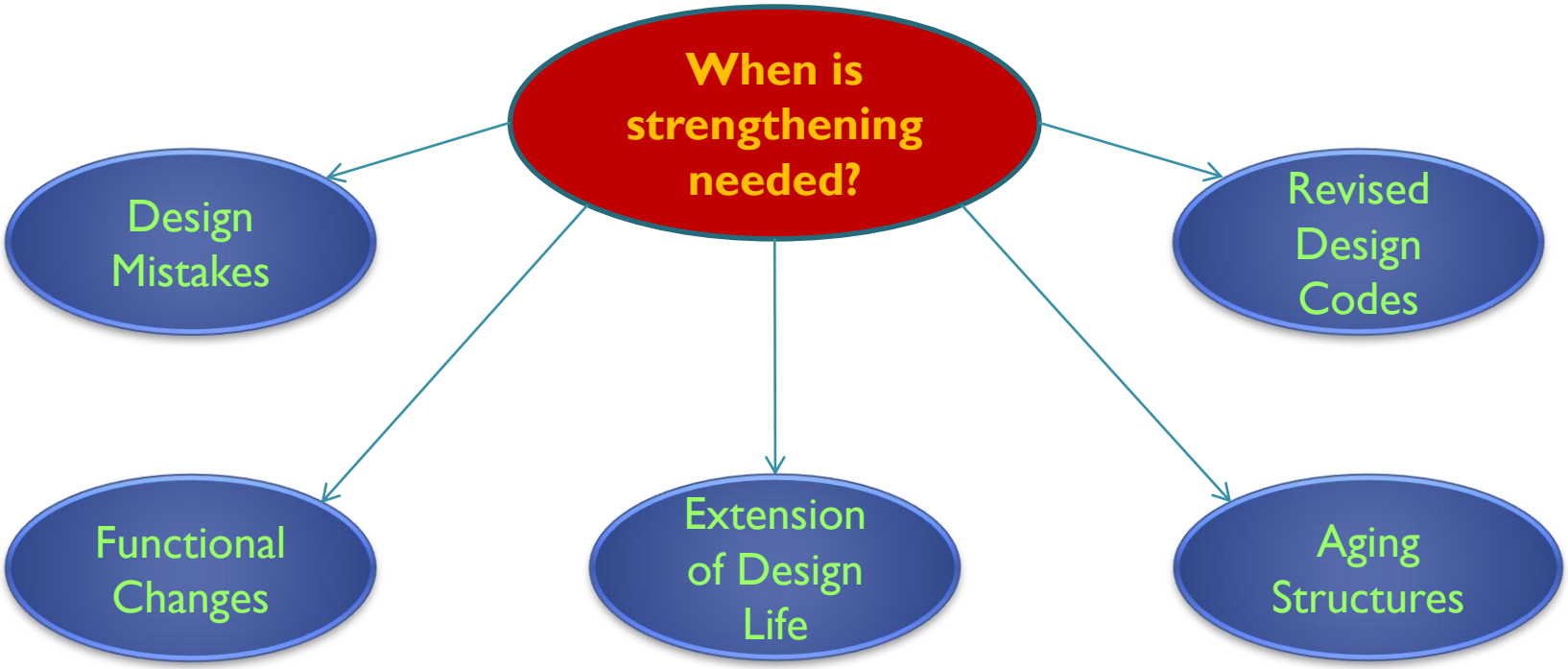
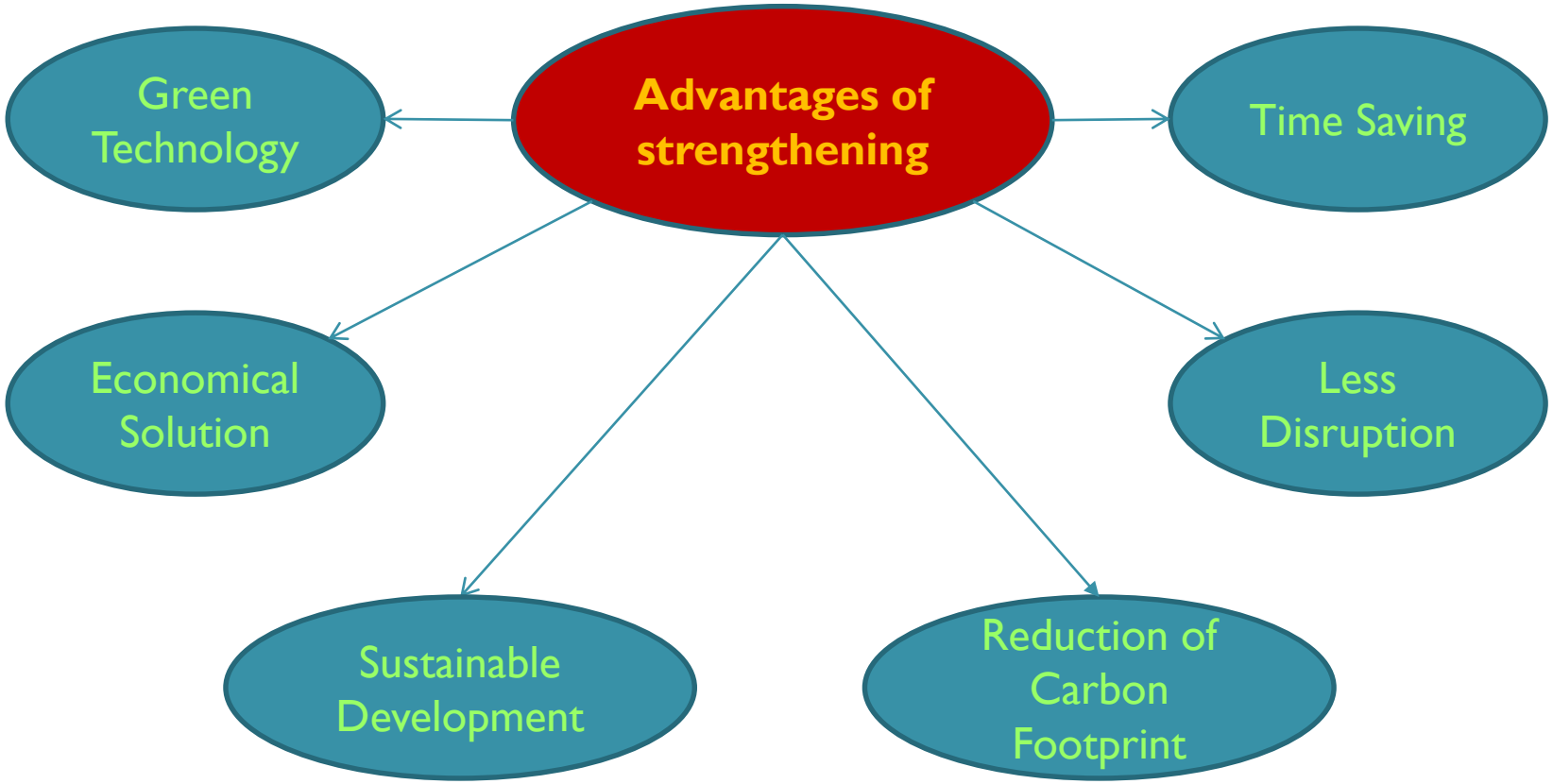
WHY STRENGTHEN?

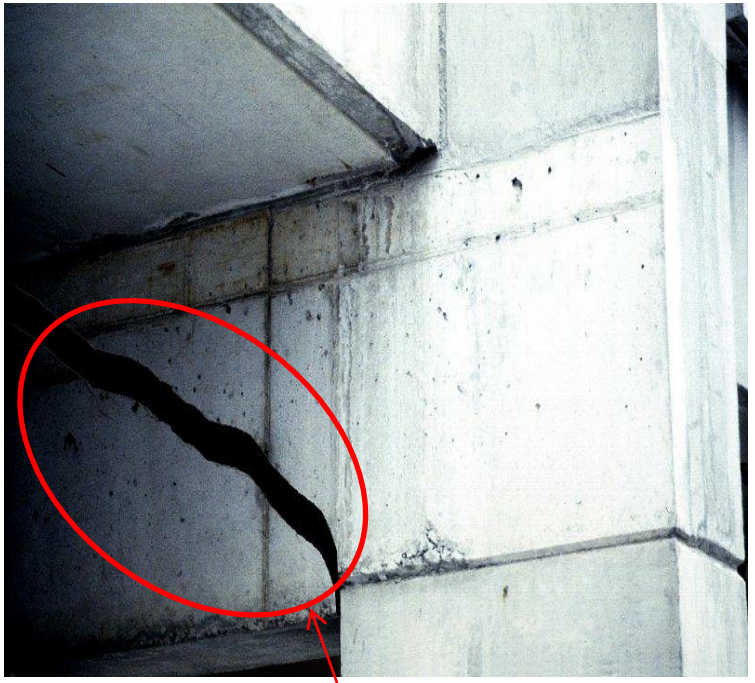


ADVANTAGES OF STRENGTHENING



EXAMPLES OF STRUCTURAL DAMAGE

Flexural failure



Shear failure

POPULAR STRENGTHENING METHODS FOR RC BEAMS

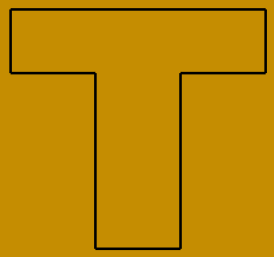
1.) Externally Bonded Reinforcement (EBR)

2.) Near Surface Mounted (NSM)

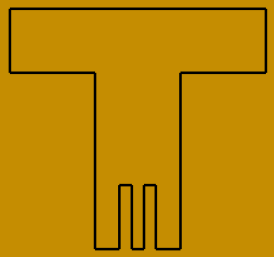
3.) External Prestressing Techniques

EXTERNALLY BONDED REINORCEMENTS (EBR)

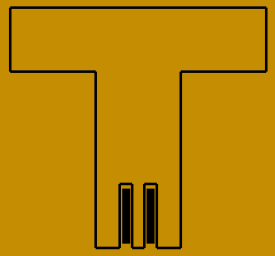
- **Near surface mounting reinforcement (NSM)**



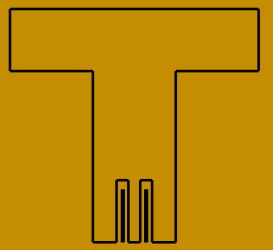
Unstrengthened concrete T-beam



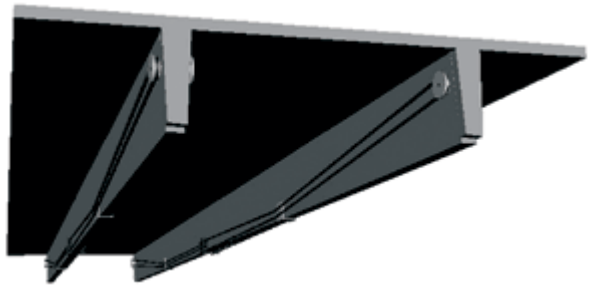
Longitudinal grooves cut into soffit



FRP strips placed in grooves



Grooves filled with epoxy grout

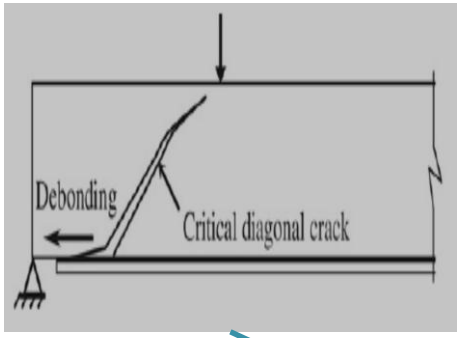


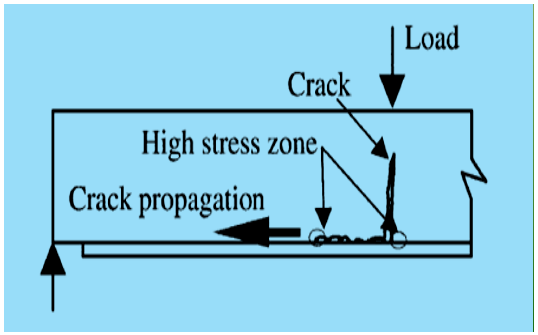
External post-tensioned designs
have been a successful strengthening method
for many years

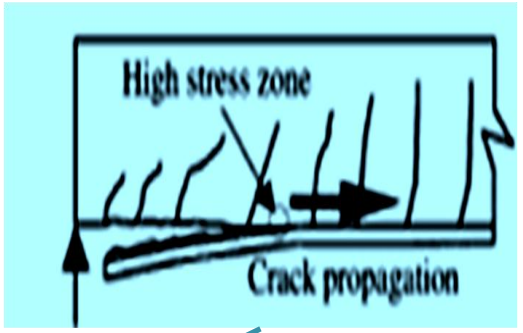
PROBLEMS ASSOCIATED WITH STRENGTHENING

Premature Failures

- **Critical Diagonal Crack Debonding**
- **Crack Induced Debonding**
- **Plate End Debonding/End Peeling**







End Anchorage

Methods of Strengthening

- **Externally bonded reinforcement (EBR)** and the **near surface mounted (NSM)** technique are among the most popular strengthening methods.

Fig.: Externally bonded reinforcement (EBR) Technique

Fig.: Near Surface Mounted (NSM) Technique

Methods of Strengthening

- The EBR technique involves the external bonded steel plates or fiber reinforced polymer (FRP) laminates.
- However, EBR suffers from the high possibility of premature failure. Also, EBR vulnerable to thermal, environmental and mechanical damage.
- **Therefore**, the NSM strengthening technique offers an effective substitute to the EBR technique.
- **The NSM technique** involves cutting a groove in the concrete surface. The groove are partially filled with adhesive. The strips or bars were then pressed into the adhesive. The remains of the groove is then filled with adhesive and the surface levelled.

Existing Works

- The first experimental research on the NSM technique using CFRP strips were conducted by Blaschko & Zilch, 1999.
- The flexural behavior of RC beams strengthened using the NSM technique using FRP were carried out by various researchers. (Al-Mahmoud, Castel, François, & Tourneur, 2009; Badawi & Soudki, 2009; De Lorenzis, Nanni, & La Tegola, 2000; El-Hacha & Gaafar, 2011).

- The authors are now studying the possibility of using steels in the NSM technique. This is because among other things, steel bars are readily available, less expensive, show adequate ductility, had long-term durability and good bond performance (Rahal & Rumaih, 2011).

Proposed Method

- It was also found that RC beams strengthened with NSM technique using FRP bars frequently failed by concrete cover separation or premature failure (El-Hacha & Rizkalla, 2004; Kishi et al. 2005; Al-Mahmoud et al. 2009; Sharaky et al. 2014).

Therefore, in this study the use of U-wrap end anchorages made of CFRP fabrics were investigated to try to overcome this problem.

Experimental Programme

1. Test matrix

- A total of six RC beam specimens were tested.

Beam ID	NSM strengthening materials			End anchorage with CFRP fabrics
	Type	***Diameter (mm)***	***Number of bars***	
CB	unstrengthened			
NS10	Steel bars	8	2	-
NS12		10		
NC12	CFRP bars	12		
NS10U	Steel bars	10		3 layers
NS12U		12		3 layers

Experimental Programme

2. Specimen configuration

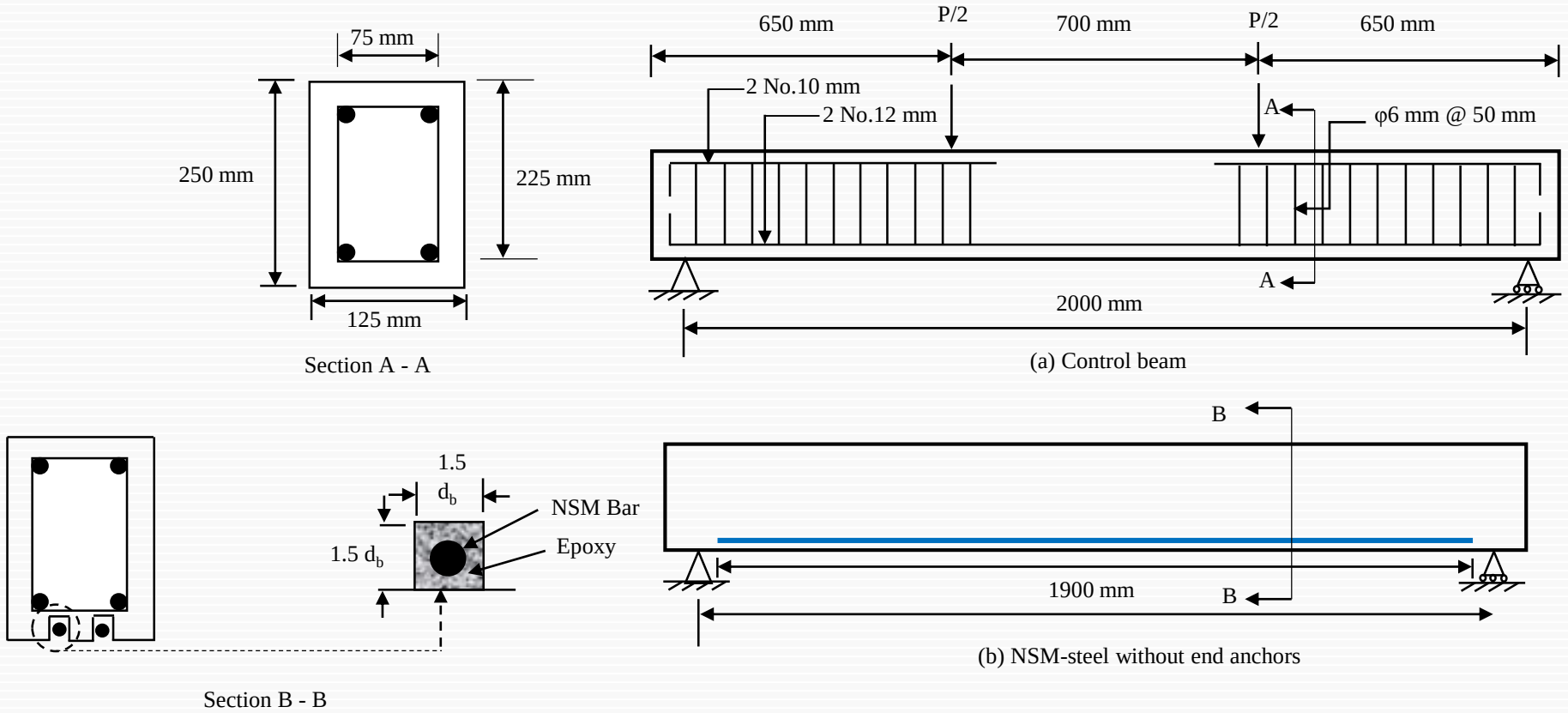


Fig.: Specimen design details

Experimental Programme

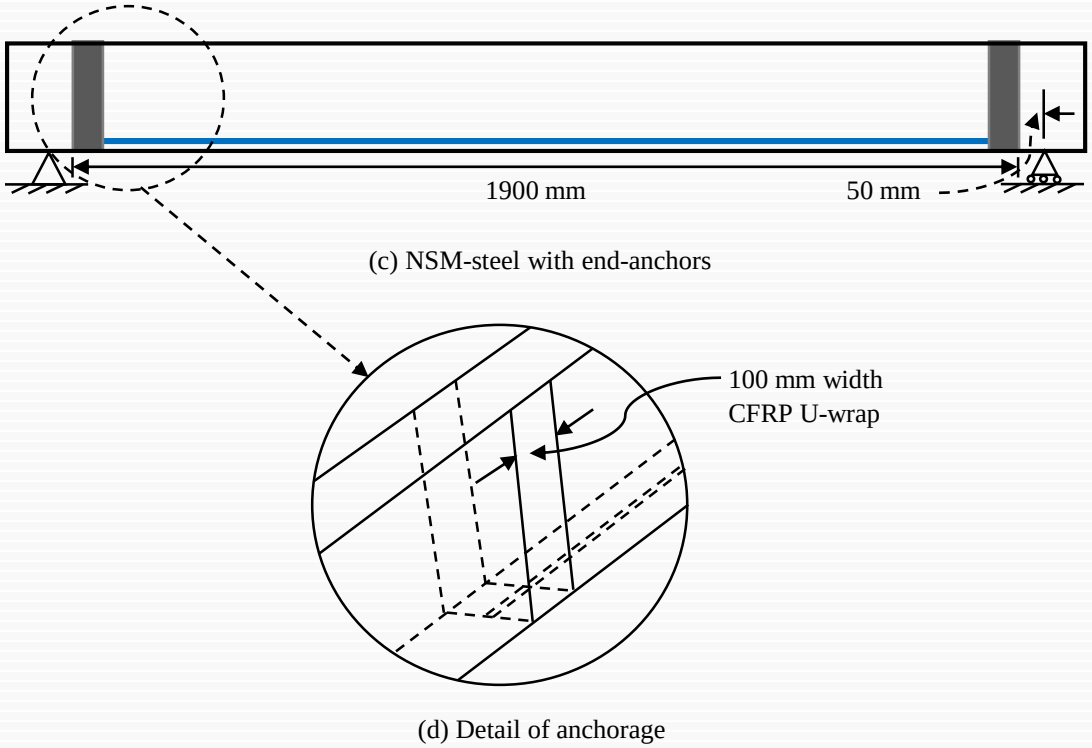


Fig.: specimen with end anchorage details

Experimental Programme

3. Strengthening Procedure

Fig. Cutting of the groove and cleaning the groove by air jet

Fig. Insert the bar and fill up the groove after insert the bar

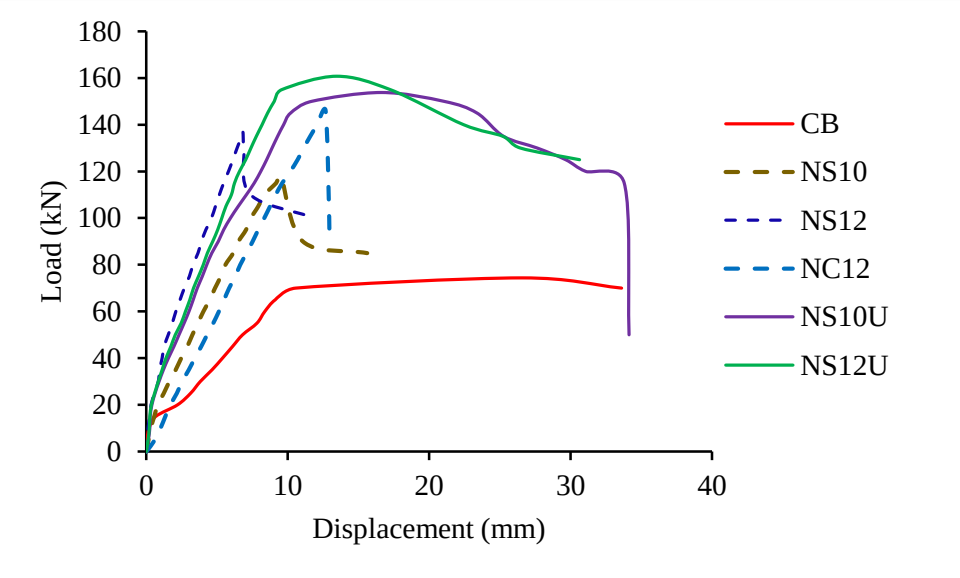
Experimental Programme

4. Instrumentation and test set-up

Fig. Instrumentation and loading set-up.

Experimental Results (1/3)

1. Load-deflection curve



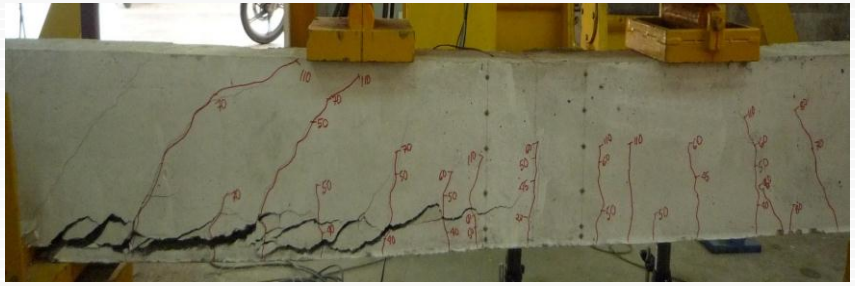
- First cracking loads of the strengthened beams increased by 33%, 69%, 59%, 71% and 100% compared with the Control Beam.
- NS10, NS12 and NC 12 had their ultimate loads increased by 58%, 84% and 96% compared to the Control Beam respectively.
- NS10U and NS12U had their ultimate loads increased by 107% and 116% compared to the Control Beam respectively.

Experimental Results

2. Mode of Failure

(a) CB

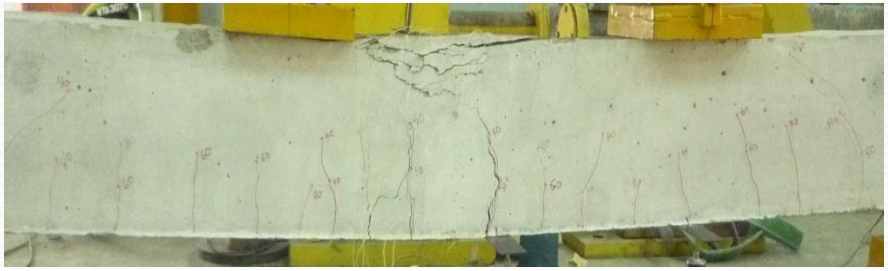
(b) NS10



(c) NS12

(d) NC12

(e) NS10U



(f) NS12U

Experimental Results

- Strengthened beams without end anchors failed by separation of the concrete cover.
- Brittle mode due to the establishment of shear cracks at the curtailment of the NSM bars.
- Strengthened beams with NSM steel bars and with end anchors failed in flexure.
- Ductile failure mode due to U-wrap end-anchored reduced the risk of the formation of shear cracks at the end of the NSM bars.

Summary and Conclusions

- Strengthened beams enhanced the first cracking and ultimate loads, and reduce the displacements.
- Beams with NSM-steel and without end anchors had their first cracking and ultimate loads increased up to 69% and 84% respectively.
- Beam with NSM-CFRP and without end anchors had the first cracking and ultimate load up to 59% and 96% respectively.

Summary and Conclusions

- Beams with NSM steel together with end anchors had their first cracking and ultimate loads increased up to 100% and 116% respectively.
- Beams with NSM and without end anchor failed by concrete cover separation and shows brittle behavior.
- Beams with NSM together with end anchor failed by flexure.

Thank you