

A Review on Strengthening of RC Beams Using Near Surface Mounted (NSM) Technique

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ABSTRACT: Structures that have been constructed all over the world are subjected to ageing and they deteriorate over time due to corrosion and other distress. Such defects in structures call for strengthening techniques. The technique of near-surface mounted reinforcement (NSM) involves cutting a series of shallow grooves in concrete or masonry surface in required direction. The depth of the groove must be less than the concrete cover in the case of RC structures so that the existing reinforcement is not damaged. The grooves are then partially filled with epoxy mortar into which reinforcements are pressed. The remainder of the groove is then filled with epoxy mortar and the surface is levelled. This method can be used to increase the flexural strength of beams and slabs, or the shear capacity of beams. This paper discusses the influence of various parameters of NSM technique in RC beams and the efficiency of NSM method in flexural and shear strengthening of RC beams.

KEYWORDS: Near surface mounting (NSM), Groove, Filler material, Groove dimension, FRP reinforcement.

I. INTRODUCTION

Structures that have been constructed all over the world are subjected to deterioration with time due to various reasons such as corrosion, environmental effects, lack of maintenance, over stressing due to excessive loading etc. Some other factors that affect the serviceability of the structure are design errors, construction errors, change in codal provisions etc. Concrete experts commonly use the terms structural repair and structural strengthening to describe building renovation activities. Although the two terms sound similar, they refer to slightly different concepts. Structural repair describes the process of reconstructing a facility or its structural elements. This process involves determining the origin of the distress, removing damaged materials and causes of distress, as well as selecting and applying appropriate repair materials that restore the integrity of the structural elements and extend the structure's useful life. Structural strengthening, on the other hand, is an upgrade of a building's structural system designed to improve performance under existing loads or to increase the strength of the existing structural components to carry additional loads.

In Near surface mounted technique FRP reinforcements are inserted into grooves cut into the structural members. The use of NSM reinforcement was developed in Europe for strengthening of RC structures in the early 1950s. In 1948, an RC bridge deck in Sweden needed to be upgraded in its negative moment region due to an excessive settlement of the steel cage during construction. This was accomplished by inserting steel reinforcement bars in grooves made in the concrete surface and filling it with cement mortar. The use of Near-Surface Mounted (NSM) FRP reinforcement is an attractive method for increasing flexural and shear strength of deficient reinforced and prestressed concrete (RC and PC) members as well as strengthening unreinforced masonry walls. Fig. 1 shows Flexural strengthening of RC Girder using Near surface mounted (NSM) technique using CFRP bars.



Fig. 1 Flexural Strengthening of RC Girder
Source:www.aslanfrp.com

II. FLEXURAL AND SHEAR STRENGTHENING OF RC BEAMS USING NSM METHOD

S. B. Singh *et al.* (2014) conducted an experimental investigation on RC beams strengthened in both flexure and shear using near surface mounted CFRP bars. Two-point loading was applied for all the beams. The beams strengthened in flexure (groove are cut at the soffit of the beam) showed an increase in load-carrying capacity by 80% than that of the corresponding control beam. The CFRP reinforcement was subjected to rupture and debonding failure (from the epoxy cover). Fig. 2 shows the load Vs deflection graph for beams strengthened in flexure using NSM CFRP bars where CBUR1 is the control beam and URF2, URF3 are beams strengthened with NSM CFRP bars of size 10 mm and 8 mm respectively [6].

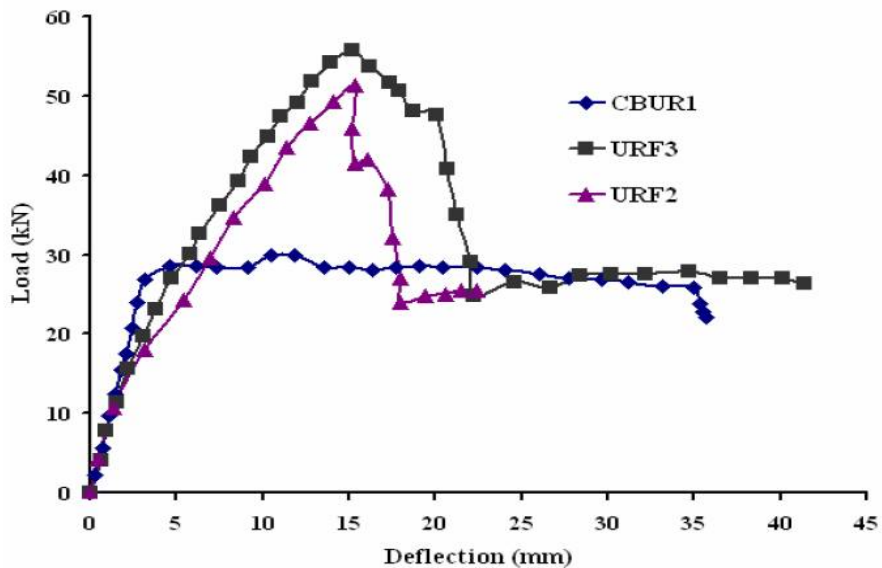


Fig. 2 Load vs deflection curve
Source: S. B. Singh et al (2014) [6]

In the case of beams strengthened in shear using NSM CFRP bars, three patterns were used i.e. vertical, inclined and mixed strengthening patterns (grooves are cut at the side of the beam). The beams strengthened in vertical, inclined and mixed pattern showed an increase in load carrying capacity by 26%, 20% and 49% respectively. This shows that mixed pattern is more effective when compared to other to patterns. Fig. 3 shows the failure pattern of beam strengthened in shear using mixed pattern.



Fig. 3 Failure pattern of beam strengthened in shear using mixed pattern.
Source: S. B. Singh et al (2014) [6]

III. FACTORS AFFECTING THE EFFICIENCY OF NSM METHOD

III.AFRP reinforcement

The tensile strength and elastic modulus of CFRP are much higher [1] than those of GFRP, so for the same tensile capacity; a CFRP bar has a smaller cross-sectional area than a GFRP bar and requires a smaller groove. This in turn leads to easier installation, with less risks of interfering with the internal steel reinforcement, and with savings in the groove-filling material. FRP bars can be manufactured in a virtually endless variety of shapes. NSM FRP reinforcement may be round; square, rectangular and oval bars, as well as strips. Different cross-sectional shapes have different advantages, and offer different choices for practical applications. FRP bars are also manufactured with a variety of surface textures, which strongly affect their bond behaviour as NSM reinforcement. Their surface can be smooth, sand-blasted, sand-coated, or roughened with a peel-ply surface treatment.

W.K.K.G. Kalupahana *et al.* (2013) conducted bond test on CFRP bars. It was observed that as cross-sectional area/perimeter ratio increases, effectiveness of utilising the full tensile capacity reduces. Full tensile capacity of CFRP bars was achieved only by the rectangular bars, with the lowest cross-sectional area/perimeter ratio. Therefore, rectangular bars seem to be the most efficient shape. The specimens containing rectangular bars are not likely to develop high stresses in the concrete cover leading to concrete cover separation failure (CCSF), unlike circular or square bars. Fig. 4 shows the variation of ultimate load/tensile strength (%) with bond length, for different bar shapes [2].

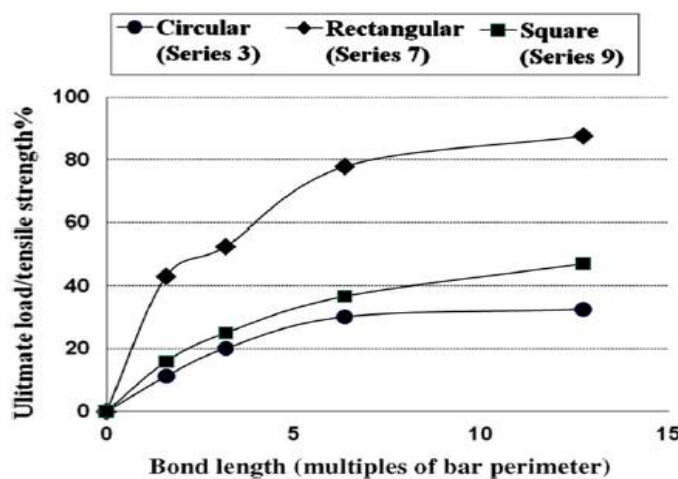


Fig. 4 Ultimate load/tensile strength (%) vs. bond length, for different bar shapes
Source: W.K.K.G. Kalupahana *et al.* (2013) [2]

III.BGroove filler

The groove filler is the medium which transfer stresses between FRP bar and concrete. In terms of structural behaviour, its most relevant mechanical properties that should be considered while selecting a filler material are the tensile and shear strengths. The tensile strength is especially important when the embedded bars have a deformed surface, which

produces high circumferential tensile stresses in the cover formed by the groove filler (simply referred to as “the cover” or “the epoxy cover” hereafter) as a result of the bond action. In addition, the shear strength is important when the bond capacity of the NSM reinforcement is controlled by cohesive shear failure of the groove filler.

The most common and best performing groove filler is a two-component epoxy. The use of cement paste or mortar in place of epoxy as a groove filler has recently been explored in an attempt to lower the material cost, reduce the hazard to workers, minimize the environmental impact, allow effective bonding to wet substrates, and achieve better resistance to high temperatures and improved thermal compatibility with the concrete substrate. However, cement mortar has inferior mechanical properties and durability, with a tensile strength an order of magnitude smaller than that of common epoxies.

Md. MoshirRahman *et al.* (2015) conducted a study on effect of groove filler material (cement mortar and epoxy) on Steel NSM method. The purpose of the study was to find the most economical strengthening solution to increase the flexural performance of RC beams. In his study he used two types of filler material; 1) Cement mortar of 1:1 ratio 2) Sikadur® 30 epoxy. The result showed an increase in failure load from 98 kN in the case of beam strengthened with cement mortar to 117.44 kN in the case of beam strengthened with epoxy i.e. 19.8% increase in load carrying capacity. This is the usual behavior because bonding strength of epoxy is significantly higher than that of cement mortar. Thus it can be concluded the most efficient filler material is epoxy adhesive [3].

III.CGroove dimension and position

Fig. 5 shows several configurations of NSM FRP reinforcement, where d_b is the nominal diameter of a round bar, and t_f and h_f are the thickness/width and the height of an FRP strip or rectangular bar respectively. The groove width b_g , the groove depth h_g , the net distance between two adjacent grooves a_g , and the net distance between a groove and the beam edge a_e are all relevant construction parameters, which can influence the bond performance and hence the structural behaviour.

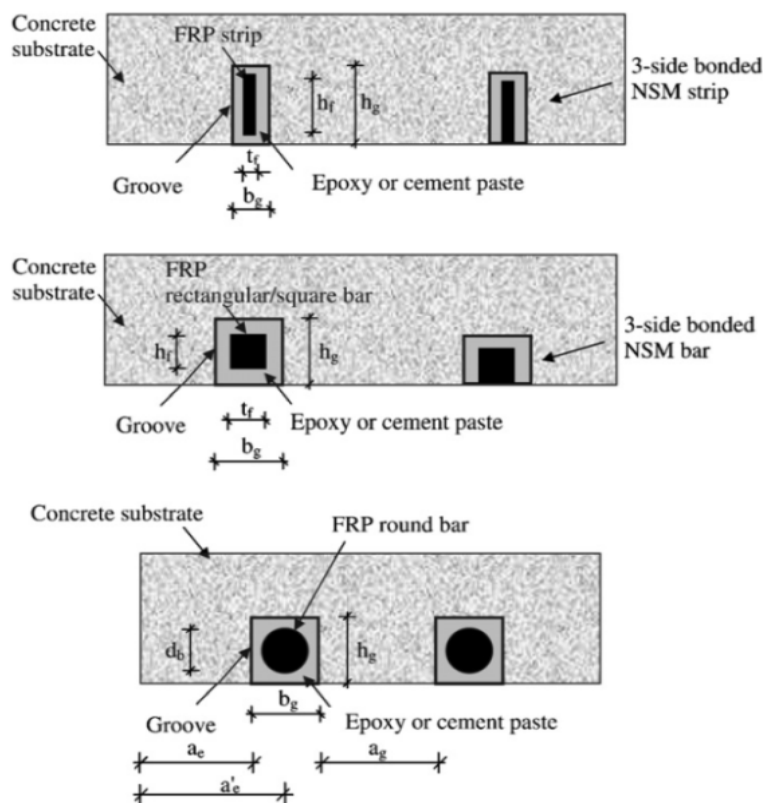


Fig. 5 Different NSM systems and nomenclature

Source: L. De Lorenzis (2007) ^[4]

For NSM systems, the following recommendations are been provided for grove dimensions as per ACI 440.2R-08 (Page 39):

1. Minimum dimension of the grooves should be taken at least 1.5 times the diameter of the FRP bar.
2. When a rectangular bar with large aspect ratio is used, a minimum groove size of $3.0a_b \times 1.5b_b$ is suggested, where a_b is the smallest bar dimension.
3. The minimum clear groove spacing for NSM FRP bars should be greater than twice the depth of the NSM groove to avoid overlapping of the tensile stresses around the NSM bars.

4. A clear edge distance of four times the depth of the NSM groove should be provided to minimize the edge effects that could accelerate debonding failure.

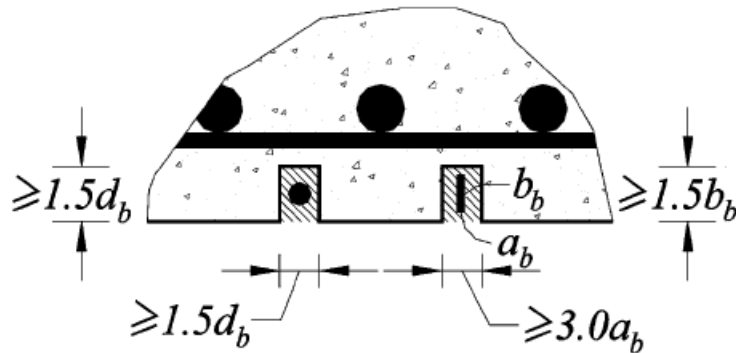


Fig. 6 Groove position for NSM Reinforcement
Source: ACI 440.2R-08 (2015)^[5]

IV. CONCLUSION

The NSM method can be used in for strengthening of RC beams both in flexure and shear. The beam strengthened in flexure showed an increase in load carrying capacity by 80 % and beams that were strengthened in shear showed an increase in load carrying capacity by 49 % [6]. This shows that NSM method is more effective in strengthening of RC beams in flexure than compared with its performance in shear. The various parameters that affect the strength of NSM technique is FRP reinforcement, Groove Filler material, Groove dimension and position etc. CFRP bars are available in various shapes such as round, strips etc. Among all the shapes, strips are more effective compared to round bars [2]. Different groove filler material generally used are cement mortar and epoxy adhesive. Epoxy adhesive showed 20% [3] increase in bond strength than cement mortar which shows that the most efficient filler material is epoxy adhesive for NSM method. Thus it can be concluded that NSM technique can be applied in RC beam for strengthening and factors that should be considered while using this method are FRP reinforcement, Groove Filler material, Groove dimension and position etc.

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