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Effect of adhesive replacement with cement mortar on NSM strengthened RC Beam

Efecto de la sustitución de adhesivo con mortero de cemento en Viga NSM de Hormigón Reforzado fortalecida

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Abstract

This paper presents the experimental behavior of reinforcement concrete beams strengthened with near surface mounted (NSM) steel bar. Several researchers have used NSM fiber reinforced polymer (FRP) bar or strip for strengthening reinforced concrete beams. Though FRP has a number advantages like high strength, light weight and corrosion resistance it doesn't show any ductile behavior, still highly expensive and not easily available in market. On the other hand, steel bar is less expensive, readily available in the market and shows good ductility. In order to get rapid and economic strengthening solution, strengthening with near surface mounted steel bar may become a potential alternative to retrofit reinforced concrete members. Therefore, the main purpose of this paper to investigate the experimental behavior of reinforced concrete beam strengthened with near surface mounted steel bar. Seven full-size beams (one control beams and six strengthened beams) were tested. Steel bars were used for strengthening. The failure load, mode of failure, deflection, and strain behavior are discussed. The study reveals that the near surface mounted technique with steel bars and cement mortar is the most economical strengthening solution to increase the flexural performance of RC beams.

Keyword: Strengthening, Near surface mounting, Steel bar, Reinforced concrete, Low cost strengthening materials, Cement mortar.

Resumen

En este trabajo se presenta el comportamiento experimental con mortero de cemento en Viga NSM de Hormigón Reforzado fortalecida. Varios investigadores han utilizado barra o tiras de NSM (montaje cercano a la superficie) de FRP (polímero reforzado con fibra) para el fortalecimiento de vigas de hormigón armado. Aunque FRP tiene un número de ventajas como alta resistencia, ligereza y resistencia a la corrosión, no muestra ningún comportamiento dúctil, siendo muy caros y no están fácilmente disponibles en el mercado. Por otro lado, la barra de acero es menos costosa, fácilmente disponible en el mercado y muestra una buena ductilidad. Con el fin de obtener una solución rápida y económica, el fortalecimiento con barra de acero NSM puede llegar a ser una alternativa potencial para adaptar los miembros de hormigón armado. Por lo tanto, el objetivo principal de este trabajo para investigar el comportamiento experimental de las vigas de hormigón armado reforzado con barras de acero NSM. Se ensayaron siete vigas de tamaño completo (una viga de control y seis vigas reforzadas). Barras de acero se utilizaron para el fortalecimiento. La carga de rotura, modo de fallo, deformación, y el comportamiento de tensión se discuten. El estudio revela que la técnica NSM con barras de acero y mortero de cemento es la solución de fortalecimiento más económica para aumentar el rendimiento de flexión de vigas RC.

Palabras Claves: Fortalecimiento, montaje en superficie cercana, barras de acero, hormigón armado, materiales de fortalecimiento de bajo coste, mortero de cemento.

Nomenclature

σ Stress range within tensile reinforcing steel in MPa;
N Number of cycles to failure;
m Inverse slope of $\log\sigma$ - $\log N$
 f_{fu} Ultimate strength of FRP
 ϵ_{st} Strain range in the tension steel
 σ_{max} Maximum stress range
 σ_{min} Minimum stress range
 F_y Steel yielding stress
n Number of CFRP layers
 ϵ_f Strain range in FRP;
 ϵ_{fu} Ultimate strain of FRP

Strengthening of structures is required for numerous reasons like as extension of design life, functional change, mechanical damage and environmental effects, updated design requirements, errors due to design and construction (Cárdenas, Schanack, & Ramos, 2010; Toutanji, Zhao, & Zhang, 2006). It is both environmentally and economically desirable to upgrade structures rather than rebuild them, particularly if rapid, effective and simple strengthening methods are available (Aldana & Serpell, 2012; Islam, Jameel, Jumaat, & Rahman, 2013; Yue-lin, Jong-hwei, Tsong, Chien-hsing, & Yiching, 2005). There are many methods available for strengthening existing deficient structure among which external plate bonding method and near surface mounted technique are the most popular (Bilotta, Ceroni, Nigro, & Pecce, 2015; Hosen, Jumaat, & Islam, 2015; Rahman, Jumaat, Rahman, & Qeshta, 2015).

The bonded steel plates or carbon fiber reinforced polymer (CFRP) plates to soffit of reinforced concrete structures to increase its strength or serviceability has been utilized worldwide since the late 1960s. However, the development of high interfacial shear stresses at the plate ends could cause the premature debonding failure without utilizing its full capacity. More recently, near-surface mounted (NSM) reinforcement has attracted an increasing amount of research as well as practical application because it is less prone to premature debonding (De Lorenzis & Teng, 2007).

Though FRP has a number advantages like high strength, light weight and corrosion resistance, however it is still highly expensive and less available in market. Moreover, FRP expresses less ductile behavior. On the other hand, steel bar is less expensive, readily available in the market and their long-term durability and bond performance has been thoroughly researched (Rahal & Rumaih, 2011). And, it's also shows sufficient ductility. In order to rapid and economic strengthening solution, strengthening with near surface mounted steel bar may become a potential alternative to retrofit reinforced concrete member.

The use of NSM steel bars were started in Europe for strengthening of RC structures since early fifties (Lorenzis, 2002). The earliest reference that could be found in the literature dates back to 1949 (Asplund, 1949) where steel rebar with cement mortar was used to strengthen a concrete slab in the field construction work. More recent applications of NSM stainless steel bars for the strengthening of masonry buildings and arch bridges have also been documented (Garrrity, 2001; Wang, Jin, Cleland, & Zhang, 2009).

Most of experimental study was conducted to investigate the flexural behavior of reinforced concrete beam with NSM-FRP bar (Al-Mahmoud, Castel, François, & Tournier, 2009; Badawi & Soudki, 2009; De Lorenzis, Nanni, & Tegola, 2000; El-Hacha & Gaafar, 2011; El-Hacha & Rizkalla, 2004; Soliman, El-Salakawy, & Benmokrane, 2010) or strip (El-Hacha and Rizkalla, 2004). The test results confirm that NSM FRP rods can be used to significantly increase the flexural capacity of RC elements. Little or so far no experimental investigations was found on the flexure performance of concrete beam with NSM steel bar.

In order to realize the effectiveness of strengthening using NSM steel bar, the structural behavior of RC elements strengthened with NSM steel bar to be fully characterized. Seven medium-size beams (one control beams and six beams strengthened in flexure with NSM steel rods) were tested in this study. The examined variables were adhesive type, the partial replacement of epoxy adhesive with cement mortar, number of NSM groove, amount of reinforcement and its disposition. Performance of the tested beams and modes of failure are presented and discussed in this paper. The test results show that strengthening with NSM steel bar is also effective and economic strengthening technique.

Description of the problem

The strengthening materials like fiber reinforced polymer (FRP) bars and adhesive (epoxy) are very expensive and not available in the global market. However, FRP bars shows very few ductility performance. Alternate rapid and economic strengthening technique is very essential and NSM steel reinforcing approach may fill the necessity suitably.

Experimental Investigation

An experimental program has been arranged to verify the effectiveness of strengthening technique with NSM steel bar. Experimental data on load, deflection, strains and failure mode was obtained. The experimental program consisted of seven RC beams. In this section, a description of material used, the test specimen and its different fabrication stages, the procedure used to strengthen the RC beams; the instrumentations and the test-setup are provided.

Material used and its properties

Concrete

The Ordinary Portland Cement (OPC) was used in casting the beams. The cement was used as a binding materials. The crushed granite (Stone) was used as coarse aggregate and the maximum size of coarse aggregate was 20 mm. It was sieved through 3/16" sieve and air-dried in the concrete laboratory. The natural river sand was used as fine aggregate. Fresh tap water was used for the hydration of the concrete mix during casting and curing of the beam, cubes, prism and cylinders. The concrete mix was designed for 30 MPa strength using DOE method.

Reinforcement

Three types of steel bars were used in this research for preparation of the beam specimen. The measured yield and tensile strength of 12mm bars were 551 MPa and 641 MPa respectively. The flexure reinforcement were bent 90 (ninety) degree at both end to fulfill the anchorage criteria according to BS8110. Ten millimeter diameter bars were used as hanger bars in shear span zone. Six mm diameter bars were used for stirrups. The measured yield and tensile strength of the stirrups were 520 MPa and 572 MPa respectively. Six mm bars were also used for strengthening purpose in NSM strengthening system. Besides six mm bar, eight mm deformed bars were used to strengthened RC beam particularly in NSM groove. The modulus of elasticity of all steel bars was 200 GPa.

Cement mortar and 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 (De Lorenzis & Teng, 2007). However, the very limited data is available on use of cement mortar as groove filler in NSM strengthening technique. It is therefore decided to use cement mortar as groove filler for strengthening RC beam using NSM technique. 50% cement and 50% sand were mixed with water cement ratio of 0.5 to produce cement mortar.

To compare the performance of cement mortar with epoxy adhesive, Sikadur® 30 was used as adhesive for bonding between concrete substrate and strengthening materials. It has two component namely component A and B. The color of the component A was white while the color of B was black. The two components were mixed with a ratio of 3:1 until the uniform colour of grey was achieved. Density would be 1.65 kg/liter at 23°C after mixing. The bond strength on steel is 21 N/mm² according to DIN EN 24624 and on concrete is 4 N/mm². The compressive, tensile and shear strength of this adhesive vary with curing time and temperature that is shown in Table 1.

Table 1: Properties of Sikadur® 30. Source: Self-Elaboration (2015)

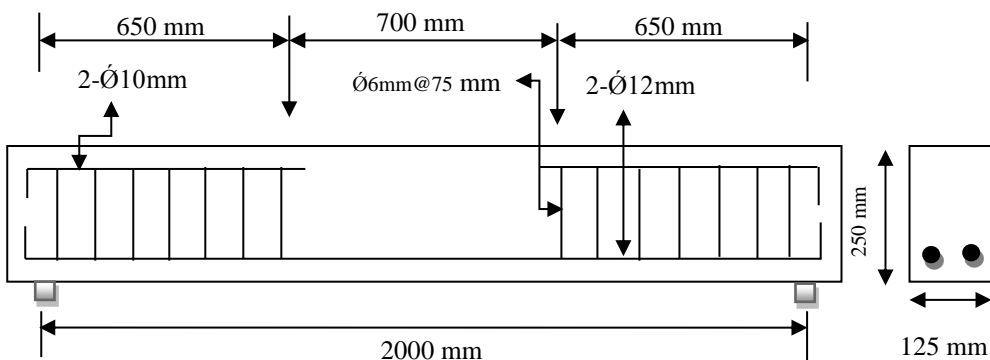
Strength	15 ⁰ c	35 ⁰ c
Compressive strength	70-80 N/mm ²	85-95 N/mm ²
Tensile strength	14-17 N/mm ²	16-19 N/mm ²
Shear strength	24-27 N/mm ²	26-31 N/mm ²

Beam design and preparation

All beam specimens were 2300 mm long, 125 mm wide, and 250 mm deep as shown in Figure 1. These beams were reinforced with two 12 mm diameter steel bars in the tension zone as main reinforcement. Two 10 mm steel bars were used as hanger bars in the shear span and were placed at the top of each beam. Six mm bars were used for shear reinforcement and were symmetrically placed in the shear span. A typical concrete cover of 30 mm was used. Enough shear reinforcement was provided in an amount calculated to ensure that the beams would fail in flexure.

The cement, sand, coarse aggregate and water with proper amount were mixed using laboratory drum mixer. For casting, steel moulds made of steel were used. Before placing the concrete the steel moulds were cleaned and greased. After placing the concrete was compacted by poker vibrator. The beams were cast in three layers, where each layer was compacted using poker vibrator to ensure adequate compaction. During vibration process, each penetration was made at a reasonable distance from each other to avoid the bleeding and segregation of concrete.

Fig. 1: Details of beam specimen. Source: Self-Elaboration (2015)

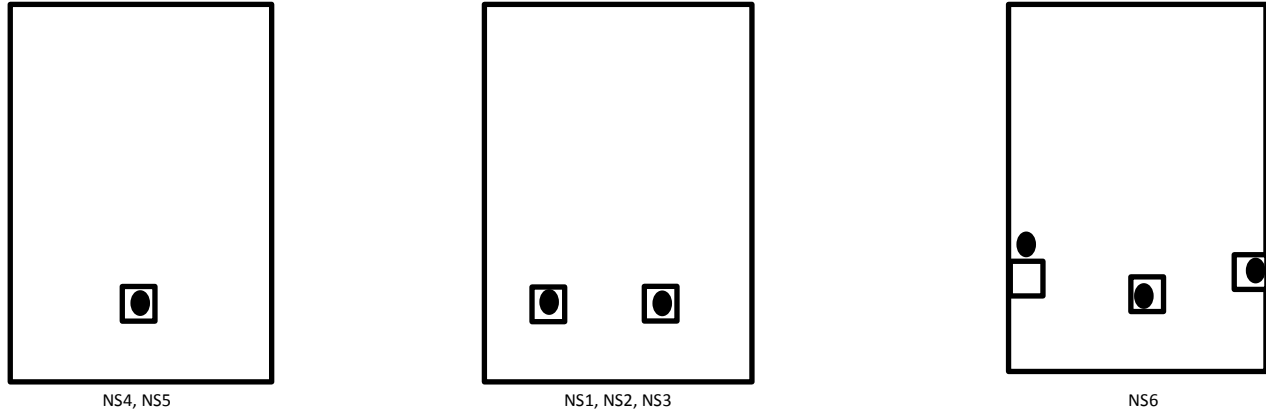


Strengthening of RC beams

Groove Cutting

In NSM technique, grooves are first cut into the concrete cover of an RC element and the FRP reinforcement is bonded therein with an appropriate groove filler. A special concrete saw was used to cut the grooves at the bottom surface of the beam. The groove dimensions were 10 mm wide by 15 mm deep.

Fig.2: Groove position in beam cross section. Source: Self-Elaboration (2015)



After groove cutting and surface preparation, prepared specimen for strengthening is shown in Fig. 3.

Fig.3: Groove cutting in beam cross section. Source: Self-Elaboration (2015)



Placement of steel bar

The properly mixed Sikadur/cement mortar was then spread over NSM groove of concrete surface. The groove was half filled with epoxy/cement mortar and the steel bars were placed and pressed into the center of the groove. Then, the remaining space in the groove was completely filled with epoxy/cement mortar. The epoxy/cement mortar was leveled with a spatula and cured for at least seven days before testing.

Instrumentation and test setup

Linear Variable Differential Transducer (LVDT) with working transverse range of 50 mm was used to measure the deflection of the beam at mid span. The transducer was connected to a portable data logger to record the reading of the deflection of the beam during test. In addition to LVDT, the actuator position of Instron Universal Testing Machine was monitored to measure the deflections at the midspan of all beams particularly to avoid the damage of the LVDT after initiating the failure of the beam. These information are useful to understand the deformability or ductility behavior of both un-strengthened and strengthened beam.

Electrical resistance strain gauges measured the strains in the steel bar and the concrete. The internal tension steel rebars were grinded by mechanical grinder at mid span. After grinding, the surface was cleaned by acetone to remove dust particles. Two 5 mm gauge were then attached to the middle of internal reinforcing bars by fast setting adhesive on top or bottom face two main steel rebars to record the tension strain.

Silicon was applied on the strain gauge as well as necked wire for proper water sealing. Two 30 mm strain gauges were placed at the middle of top face of concrete beam and bottom of the strengthening the steel/FRP plate to measure the concrete compressive and plate tensile strain. The data logger was also connected with the digital controller of the testing machine and strain gauges attached to the beams, for collecting the real-time loading and strains at the top concrete surface and bottom plate surface. The readings are scanned at a time interval of 1(one) second.

All beams were tested in four-point bending and the tests were conducted with a closed-loop hydraulic Instron Universal Testing Machine. All specimens were simply supported and were subjected to two-point loading. The distance between two supports was 2000 mm and the distance between two loading points of spreader beam was 700. The resulting shear span/depth ratio was 3.0. For the static load test the actuator was loaded and moved down at a low rate so that reading from the data logger and visibility of crack can be done easily. Test matrix are shown in Table 2

Table 2: Test matrix. Source: Self-Elaboration (2015)

Sl. No	Notation	Description	Dimension of strengthening (mm)
1	CB	Control Beam	No strengthening
2	NS1	Beam strengthened with cement mortar and two steel plain bar	Steel bar dia-6 mm Length=1900
3	NS2	Beam strengthened with epoxy adhesive and two steel plain bar	Steel bar-6 mm Length=1900
4	NS3	Beam strengthened with epoxy(end) and cement mortar (middle) and two plain steel bar	Steel bar-6 mm Length=1900mm
5	NS4	Beam strengthened with epoxy and one steel deformed bar	Steel bar--8 mm Length-1900 mm
6	HS5	Damage Beam strengthened with cement mortar and one steel deformed bar	Steel bar-8 mm Length-1900mm
7	HS6	Beam strengthened with cement mortar and three(two side and one bottom) steel deformed bar	Steel bar-8 mm Length=1900 mm

Result and discussion

Experimental behavior of strengthened beams

Load carrying capacity and failure mode

A summary of the flexural behavior of all test beams in terms of first crack load, yield load, flexural loading capacity and failure mode has been given in Table 3. As shown in Table 3, the addition of steel bar and steel plate increases the ultimate moment capacity by 22.5%, 46.8%, 43.75%, 26.46%, 23.26% and 32.8% for NS1, NS2, NS3, NS4, NS5 and HS6 respectively, compared to the control beam. Yield capacity of the beam and first cracking loading also increased after strengthening. It is important to note that the highest improvement achieved in NS2 was 46.8% which is also greater than the performance (39%) of NSM FRP strengthened concrete beam studied by eHassan and Rizkalla (2001) though the cost of FRP bar is 20 times greater than that of steel bar.

Table 3: load and mode, yield load, first cracking load of different beams. Source: Self-Elaboration (2015)

Beam ID	First crack load	First crack load increase over control beam	Bar yield load	Failure load	Failure load increase over Control beam	Mode of failure
CB	12.5	-	72	80		Flexure failure
NS1	20	62.5%	90	98	22.5%	Flexure failure followed by bond failure
NS2	26	112.5%	100	117.44	46.8%	Flexure failure
NS3	22	79.17%	92	115.00	43.75%	Flexure failure
NS4	28	129.17%	100	101.17	26.46%	Flexure failure
NS5	Pre-cracked	-	90	98.00	22.5%	Flexure failure followed by bond failure.
NS6	25	104.17%	100	106.24	32.8%	Debonding failure

The failure modes of all beams are shown in Figure 4. The failure modes of all strengthened beam are found very close to each other i.e. flexure failure. Flexure failure is concrete crushing followed by steel yielding. It is the most commonly reported mode of failure in NSM strengthening system. It is less prone to debonding. However, the failure mode of the most heavily reinforced beam NS6 was premature debonding i.e. the separation of steel bar from concrete side face.

Fig. 4: Failure modes the experimental beams. Source: Self-Elaboration (2015)



Effect of strengthening on damage behavior

The deflection and reduction of deflection due to strengthening hybrid technique at 20 KN, 40KN, 60 KN service loadings are shown in table 4. The deflection of strengthened beams were reduced compared to control beam because the stiffness of strengthened beam increased due to addition of strengthening materials like NSM steel bar.

Table 4: Reduction in Deflection due to NSM strengthening. Source: Self-Elaboration (2015)

Beam No.	Load at 20		Load at 40		Load at 60	
	Deflection	Reduction (%) over CB	Deflection	Reduction (%) over CB	Deflection	Reduction (%) over CB
CB	2.42		5.51		8.48	
NS1	1.48	39%	3.71	33%	5.01	41%
NS2	1.55	36%	3.23	41%	5.26	38%
NS3	1.81	25%	3.69	33%	5.47	35%
NS4	2.61	-	5.48	1%	7.833	8%
NS5	3.86	-60%	5.17	6%	6.81	20%
NS6	1.39	43%	3.12	43%	6.94	18%

The internal reinforcing steel bar strain and reduction of these bar strain due to strengthening at 20 KN, 40KN, 60 KN service loading are shown in Table 5. The bar strain of strengthened beams was reduced significantly. Consequently the bar stress would also be reduced according hook's law. Therefore, the fatigue life of strengthened beam will be increased according S-N curve relation of steel bar (Helagson & Hanson, 1974; Moss, 1982). However, difference in bar strain reduction between hybrid and plate bonding method were not noticed clearly.

Table 5: Reduction in Bar Strain due to NSM strengthening. Source: Self-Elaboration (2015)

Beam No.	Load at 20		Load at 40		Load at 60	
	Bar Strain	Reduction (%) over CB	Bar Strain	Reduction (%) over CB	Bar Strain	Reduction (%) over CB
CB	793		1661		2507	
NS1	556	30%	1059	36%	1509	40%
NS3	248	69%	1465	12%	3006	-20%
NS4	406	49%	1528	8%	2418	4%
NS6	-		933	44%	1523	39%

The strain at top of concrete fiber and reduction of these concrete strain due to strengthening at 20 KN, 40KN, 60 KN service loading are shown in table 6. The extreme concrete strain of strengthened beams was reduced significantly.

Table 6: Reduction in Concrete Strain due to NSM strengthening. Source: Self-Elaboration (2015)

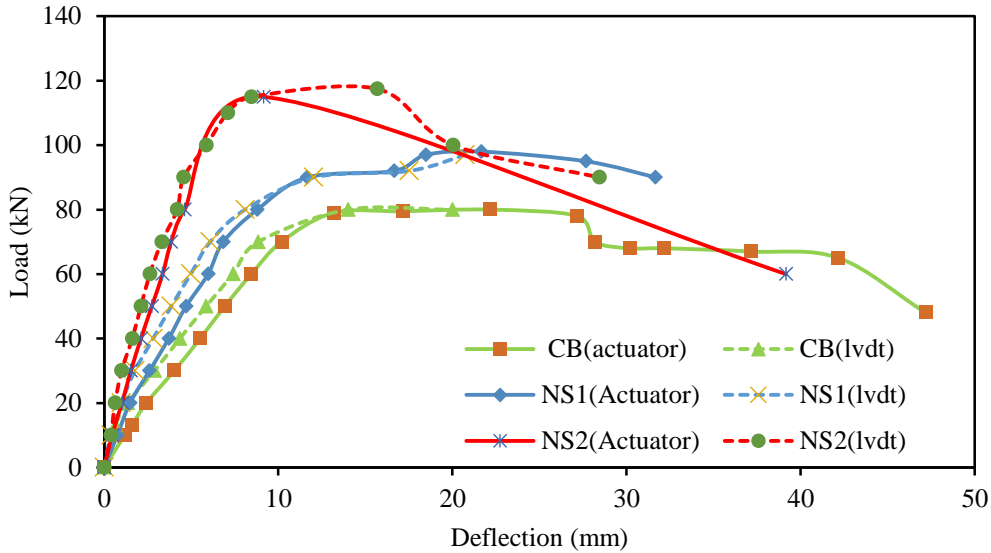
Beam No.	Load at 20		Load at 40		Load at 60	
	Con. Strain	Reduction (%) over CB	Con. Strain	Reduction (%) over CB	Con. Strain	Reduction (%) over CB
CB	252		602		990	
NS1	175	31%	376	38%	510	48%
NS2	126	50%	337	44%	542	45%
NS5	200	21%	383	36%	550	44%
NS6	-		450	25%	697	30%

Parametric study

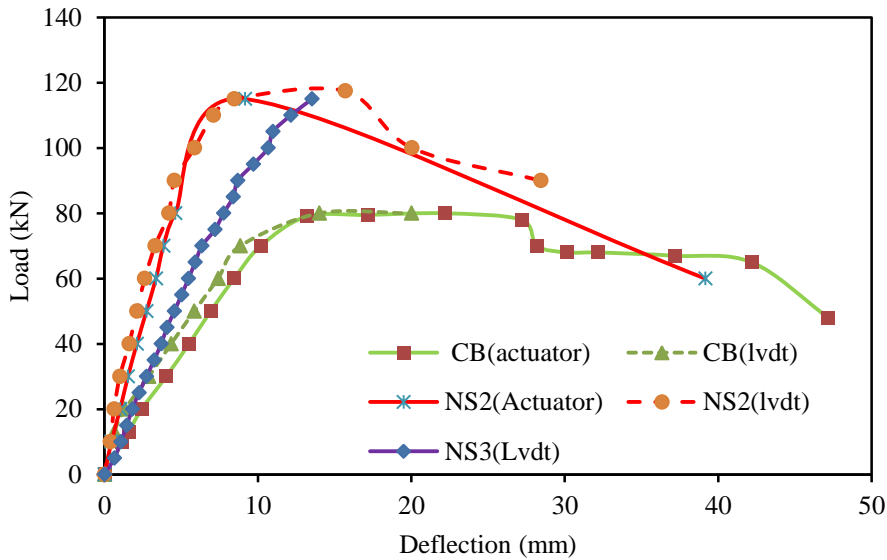
Effect of adhesive type

The effect of adhesive type on the performance of NSM strengthened RC beam is shown in Table 3. Based on experimental data of NS1 and NS2, as the adhesive type changed from cement mortar to epoxy, the failure load also increased from 98 kN to 117.44 kN which is usual behavior because bonding strength of epoxy is significantly higher than that of cement mortar. First crack load also increased from 20 kN to 26 kN due to change of adhesive type. The load deflection behavior of CB, NS1 and NS2 are shown in Fig.5a. The NS2 shows less deflection compared with NS1 owing to higher mechanical properties of adhesive.

Fig. 5: Load-Deflection diagram of CB, NS2 and NS3. Source: Self-Elaboration (2015)



5(a)

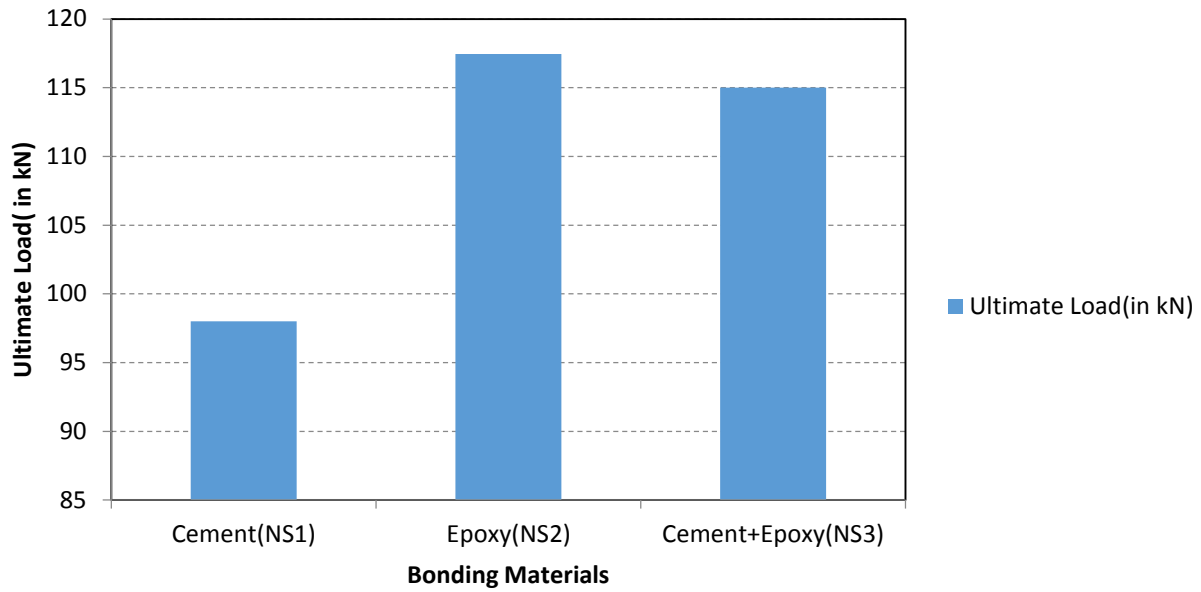


5(b)

Effect of partial epoxy replacement with cement mortar

Cement mortar mechanical properties, durability, and tensile strength lower than of commercially available epoxies (De Lorenzis & Teng, 2007). Results of bond tests and flexural tests (Taljsten, Carolin, & Nordin, 2003) have identified some significant limitations of cement mortar as a groove filler. However, the bond stresses are not equally distributed along the length of NSM bar according to De Lorenzis and Teng (2007). The maximum bond stress is found near end of the NSM bar and it gradually decrease towards the mid span of beam. This characteristic of bond stress variation may attribute the partial replacement of epoxy with cement mortar. Since the bond stress of mid-section of beam is relatively low, the NSM groove at these locations could be filled with cement mortar. However at the other location, particularly at the end, the groove should be filled with epoxy adhesive due to higher bond stress. The stiffness of NS3 is slightly lower than that of NS2, since the deflection of NS3 is higher than NS2 as shown in Fig. 5b. The effect of partial replacement of epoxy with cement mortar is shown in Fig 6. The ultimate load of NS3 (50% epoxy replaced with cement mortar) is almost similar to the ultimate load of NS2 (epoxy is used entirely) but significantly higher than that of NS1 (cement mortar is used entirely).

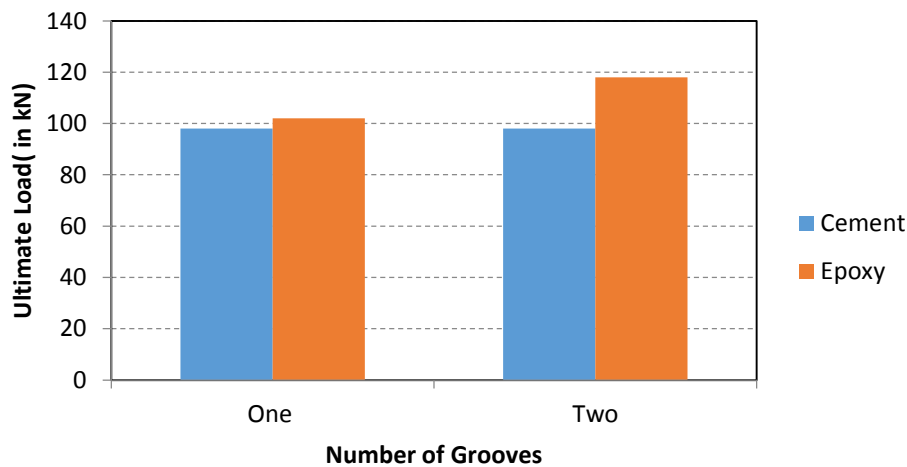
Fig. 6: The effect of partial replacement of epoxy with cement mortar. Source: Self-Elaboration (2015)



Effect of number of NSM grooves

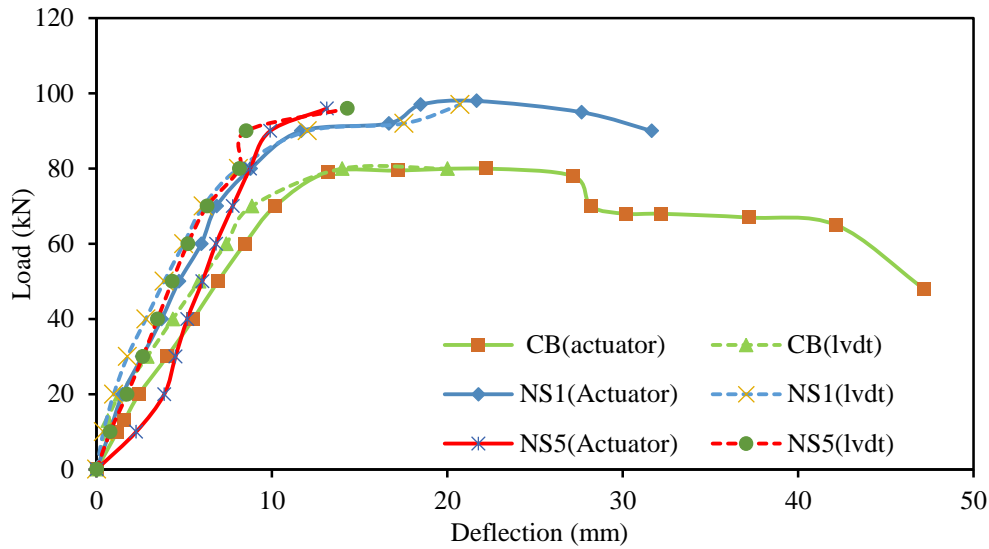
One groove is required for one bar placing into the concrete. Thus, the number of bars is equal to number of grooves. Fig. 7 shows the effect of number of grooves on the performance of NSM strengthening technique. The NS1 and NS5, and NS2 and NS4 specimens were used to investigate the effect of strengthening with cement mortar and epoxy adhesive respectively. The amount of strengthening reinforcement is almost similar (56 mm^2).

Fig. 7: The effect of number of grooves. Source: Self-Elaboration (2015)

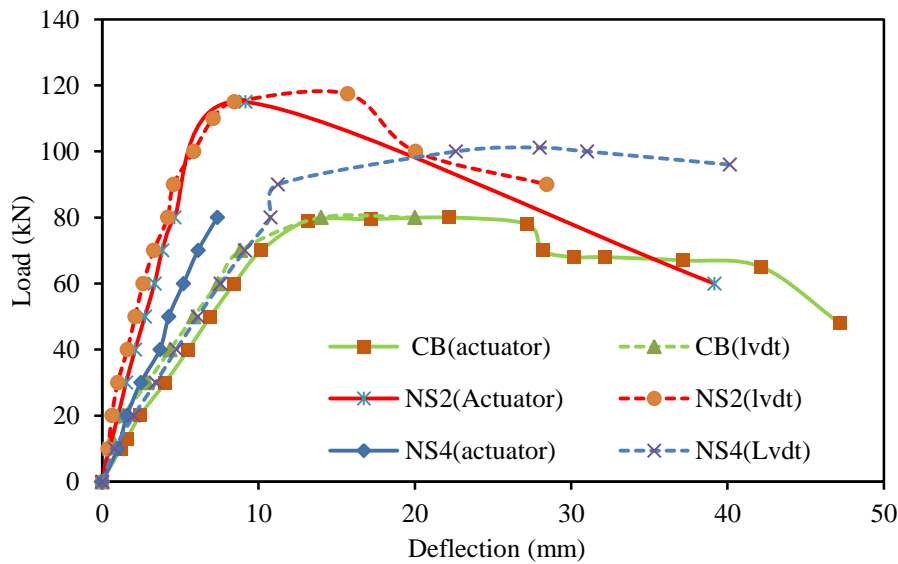


According to Fig. 7, the ultimate load increased with the number of grooves for the case of epoxy strengthened beam due to increasing the volume of adhesive. By contrast of cement mortar, the ultimate load were almost same. Fig. 8 shows the effect of strengthening with cement mortar and epoxy on the load-deflection behavior.

Fig. 8: Load-Deflection diagram of CB, NS2, NS4 and NS5. Source: Self-Elaboration (2015)



8 (a) Strengthening with cement mortar



8 (b) Strengthening with epoxy

Effect of bar number with same size

The amount of reinforcement is the important parameter for flexure strengthening of reinforced concrete beam. Though increase in bar number provides additional reinforcing in concrete beam it decreases both edge clearance and clear spacing of two adjacent grooves. Subsequently the possibility of edge breaking is increased. The beam specimens used in this study might have not enough width to place two 8mm bars according to ACI 440 (2008). For this reason in NS6, three 8 mm bar were placed at different position (one at bottom and two at opposite sides as shown in Fig.2).

Fig. 9: The effect of bar number on the performance of NSM strengthened beam. Source: Self-Elaboration (2015)

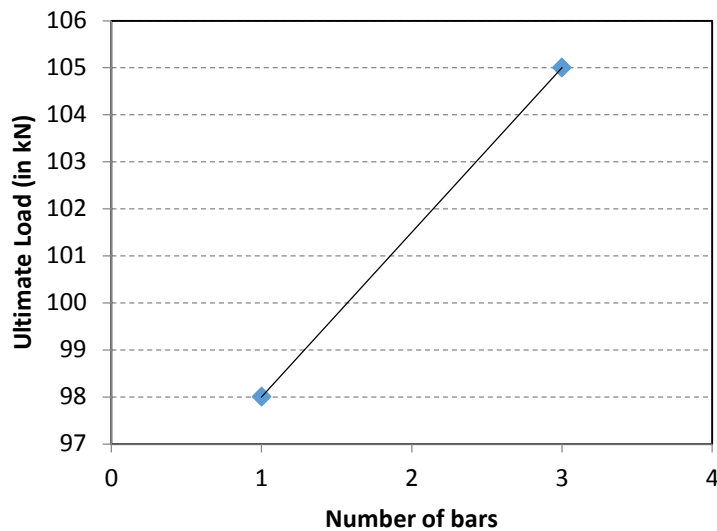
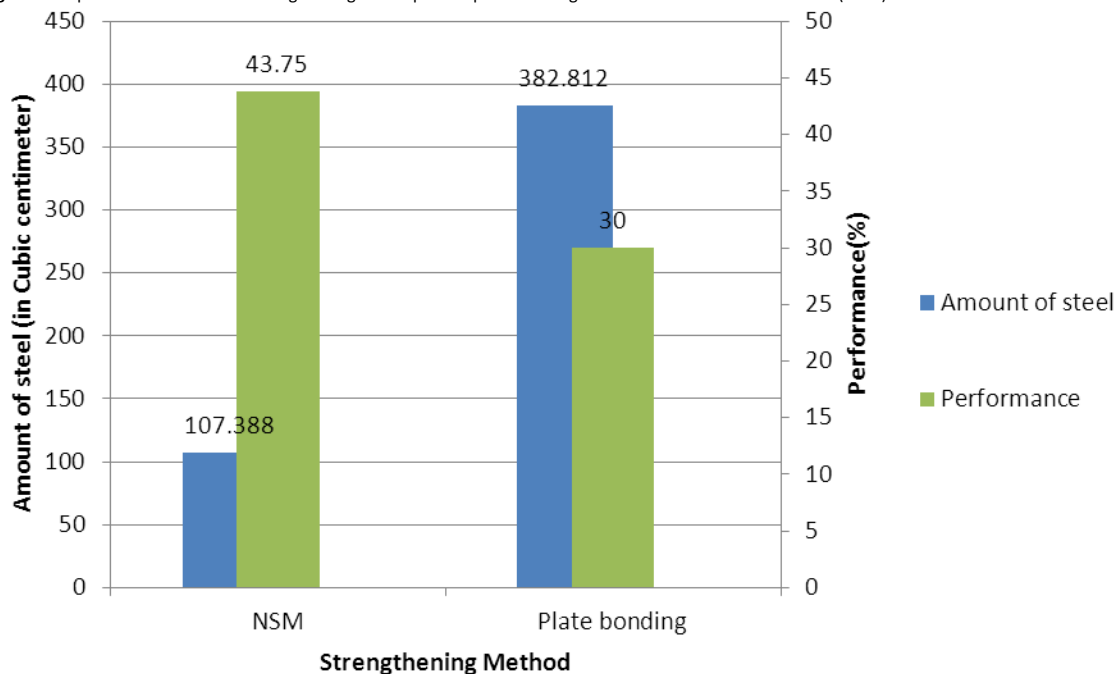


Fig. 9 shows the effect of number of bars on failure behavior of reinforced concrete beam strengthened with NSM steel bar using cement mortar as adhesive. The beam NS5 and NS6 are used to observe this effect.

Comparison with plate bonding method

Compared to the externally bonded FRP reinforcement (Fig. 10), the NSM system has a number of advantages: (a) the amount of site installation work may be reduced, as surface preparation other than grooving is no longer required (e.g., plaster removal is not necessary; irregularities of the concrete surface can be more easily accommodated; removal of the weak laitance layer on the concrete surface is no longer needed); (b) NSM reinforcement is less prone to debonding from the concrete substrate; (c) NSM bars can be more easily anchored into adjacent members to prevent debonding failures.

Fig. 10: Comparison between NSM strengthening technique and plate bonding method. Source: Self-Elaboration (2015)



Conclusion

There is a significant potential for NSM steel bar with cement mortar for use in strengthening of RC beams to cost savings in retrofitting structural elements. Based on the experimental study, the following conclusions can be made.

- 1) Strengthening of RC structures with NSM steel bars is a feasible and economic alternative technique for strengthening structural elements.
- 2) Cement mortar can be used as groove filler of strengthening reinforced concrete elements with steel bars efficiently.
- 3) Partial replacement of epoxy by cement mortar could be possible without significantly affecting flexure performance of reinforced concrete beams strengthened with NSM technique.
- 4) Replacement of 50% epoxy adhesive by cement mortar in middle portion of NSM groove gives almost similar flexure performance compared to the 100% epoxy adhesive.
- 5) Epoxy replacement with cement mortar is most economical alternative for strengthening reinforced concrete beam with NSM strengthening technique.
- 6) Flexural performance of NSM strengthening is quite better than that of corresponding plate method while the requirement of steel for strengthening with NSM technique is significantly lower (one-third) than that of plate bonding method.
- 7) Thorough parametric studies show the effectiveness of NSM technique with low cost materials such as adhesive and steel bars.

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