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# Experimental investigation of NSM Carbon Fibre Strand Sheet (CFSS) method for flexural strengthening of the RC beams

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**Abstract**

Carbon Fiber Strand Sheet (CFSS) is a bunch of small diameter CFRP rods/strand of approximate 1mm diameter stitched together leaving a small gap between the strands to allow the adhesive to cover the entire perimeter of each strand which allows greater resistance to debonding at the interface. This CFSS was used as a near surface mounted (NSM) for flexural strengthening of the RC beams with the parameters such as bottom/side NSM reinforcement, amount of CFSS, arrangement of the CFSS and the effect of lap splicing. The results were compared with the external bonding (EB) CFSS reinforcement method and the unstrengthened case. In comparison to the EB cases, further increase in flexural strength between 30-76% was achieved, with 3 of the cases achieving the rupture of the NSM CFSS. In addition, lap splicing of CFSS was confirmed in the NSM system as no failure was observed in the lap spliced area till the ultimate stage. The results also confirmed that the distribution of CFSS among the grooves and addition of side NSM has minimal effect on the strengthening performance.

**Keywords:** NSM, Carbon Fibre Strand Sheet (CFSS), Concrete, Adhesive, Bond, Flexural strengthening

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## Introduction

Use of near surface mounted (NSM) FRP method is considered as a good alternative method for strengthening of the RC structures compared to the external bonding method mainly due to greater bond performance and ease in construction. CFRP bars or strips are more commonly used FRP reinforcements for the NSM method around the world due to ease of availability. However, in Japan CFRP bars/strips are not readily available and the cost are relatively higher compared to the carbon fiber sheet. Thus, strengthening of structures by external bonding carbon fiber sheets are commonly preferred. Among the different kind of sheets, Carbon Fiber Strand Sheet (CFSS)/CFRP, a small diameter CFRP rods/strand of approximate 1 mm in diameter stitched together in a sheet form, is relatively new but widely used material to strengthen the structures requiring the shorter construction period. While strengthening by external bonding is a very good option, premature debonding of the high-strength CFRP materials from the concrete surface restricts its full utilization. Relatively, greater utilization of the CFRP is achieved by using the NSM method due to increase in the adhesion surface area and the confinement provided by the surrounding concrete.

Previously, Shrestha et. al [1] compared several NSM cases with key parameter as type of carbon fiber reinforced materials (fabric, strip, strand sheet) and filling materials (epoxy adhesive, high-strength mortar, polymer cement mortar, epoxy mortar) evaluating the shear bond properties and flexural strengthening performance of the RC beams. Among several cases, the authors found that the combination of CFSS with the epoxy adhesive as a NSM showed better bond and flexural performance resulting in a higher utilization of the CFRP material.

In this paper the results of flexural test of the 12 RC beams strengthened with either EB or NSM CFSS using epoxy adhesive are presented along with the unstrengthed case for comparision. The test variables are chosen as comparison between the EB and NSM reinforcement, bottom and side surface NSM reinforcement, amount of CFSS, arrangement of the CFSS and the effect of lap splicing.

## Experimental program

In total, 13 RC beams with dimension of 200x300x3000mm were prepared. The 28 days mean compressive strength of concrete cylinders (Φ100mmx200mm) was 60.2 N/mm$^2$. As for the strengthening procedure, first the specimens were either disk grinded for the external bonding or grooved for the NSM cases. Then, the CFSS was attached on the concrete surface or inserted inside the groove with an epoxy adhesive. The specimens were cured in uncontrolled environment for at least 7 days before the loading test. The arrangement of the strain gauges, locations of the displacement measurements and the loading arrangements are shown in Fig. 1.

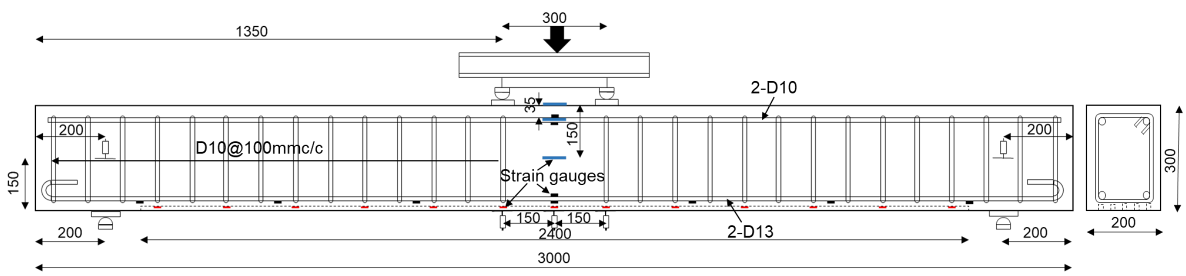
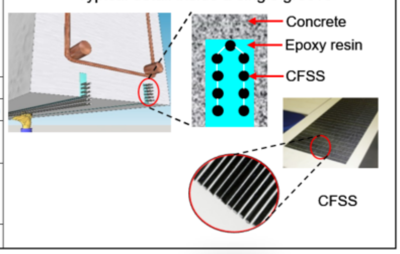



Figure 1: Details of the specimen

The test variables are divided into 4 groups that include, comparison between the EB and NSM strengthening cases, with or without side surface reinforcement in NSM, different CFSS arrangements in NSM, and with or without lap splicing in NSM case. The details of each case is summarized in Table 1.

Table 1: Test cases for the flexural test of the beams

| Case | 1 | 2 | 3 | 4 | 5 | 11 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| Specimen | CTRL. | EB-1 | EB-2 | N-F-1 | N-F-2 | N-F-4 | N-S-1 | N-S-2 |
| Test variable | Unstrengthened | Externallly bonded | | NSM (Distributed) | | | NSM (Side surface addition) | |
| Groove size (no.-widthxdepth) | - | - | - | 5-5x15 | 5-5x25 | 7-5x25+2-8x25 | 5-5x15 | 5-5x25 |
| CFSS distribution (no.-layer x thickness x width) | - | 1-1x0.333x100 | 1-1x0.333x200 | 5-2x0.333x10 | 5-2x0.333x20 | 7-2x0.333x20+ 2-3x0.333x20 | 5-2x0.333x10 | 5-2x0.333x20 |
| EA (kN) | - | 8158.5 | 16317 | 8158.5 | 16317 | 32634 | 8158.5 | 16317 |
| Case | 8 | 9 | 10 | 12 | 13 | Typical detail inside a single groove | | |
| Specimen | N-B-1 | N-B-2 | N-B-4 | N-L-1 | N-L-2 | | | |
| Test variable | NSM (Bundled) | | | NSM (Lap spliced 200mm at center) | | | | |
| Groove size (no.-widthxdepth) | 2-15x15 | 2-25x15 | 2-25x25 | 5-10x15 | 5-10x25 | | | |
| CFSS distribution (no.-layer x thickness x width) | 2-5x0.333x10 | 2-5x0.333x20 | 2-10x0.333x20 | 5-2x0.333x10 | 5-2x0.333x20 | | | |
| EA (kN) | 8158.5 | 16317 | 32634 | 8158.5 | 16317 | | | |




## Results and Discussion

There was a considerable increase in the load carrying capacity of the RC beams after strengthening. The effects of various test variables are discussed as following.

### Effect of strengthening method

The load-deflection relationship for EB and NSM CFSS method of strengthening with different amount of CFSS are shown in Fig. 2. For the EB CFSS method, the increment in ultimate load were about 19% and 75% for EB-1 and EB-2 respectively. At the ultimate stage, the debonding was initiated from the intermediate crack in the constant moment region of the beam which later propagated along the support, causing sudden peeling of the CFSS. In contrast, due to better bond characterstics between the CFSS and the concrete, the ultimate load resistance capacity was considerably increased to 103% and 155% for N-F-1 and N-F-2 respectively. The ultimate failure in those cases were due to the rupture of CFSS and concrete cover separation (CCS) respectively. The typical ultimate failure modes of the RC beams are shown in Fig. 4.

### Effect of side NSM

Fig. 3 shows the comparison between the only bottom surface NSM (N-F-1, N-F-2) to the addition of side surface NSM (N-S-1, N-S-2). The results confirmed that addition of CFSS on the sides of the RC beams showed similar strengthening effect and the failure modes compared to the conventional bottom surface NSM only. However, it is worth mentioning that CCS failure in N-S-2 was instantaneously followed by the rupture of the CFSSs on the sides surfaces which could be due to sudden redistribution of additional tensile stresses to the side reinforcements. Further, despite the similar CCS failure mode, the ultimate load for N-S-2 was slightly higher than the N-F-2 which could be due to shallower groove depth allowing greater area of concrete between the steel reinforcements and the groove to resist the generated radial tensile stresses by the steel thus delaying the CCS failure in the RC beam.

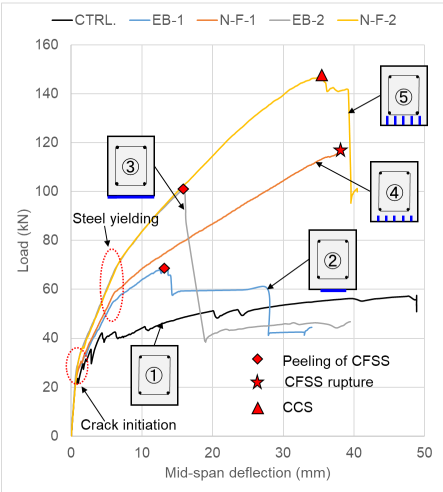



Figure 2: Comparison between EB and NSM strengthening method

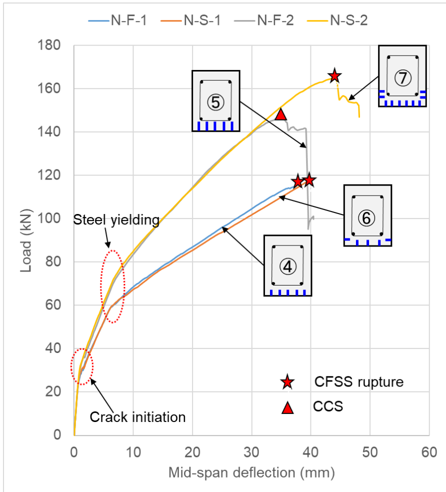



Figure 3: Effect of side NSM

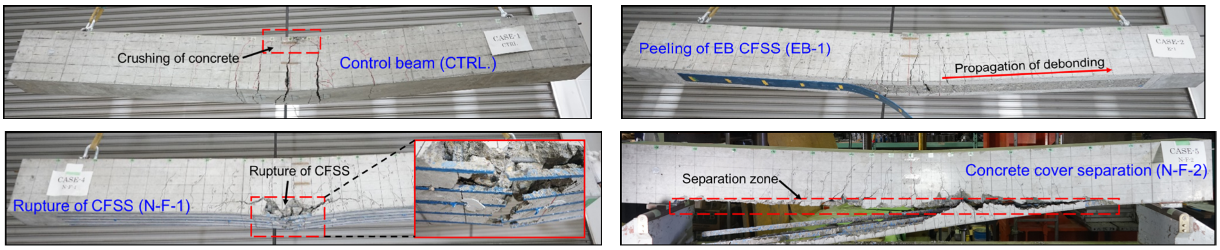



Figure 4: Typical failure modes of the RC beams

**Effect of CFSS arrangement**

Fig. 5 shows the effect of CFSS distribution along the surface of RC beams. The results do not indicate any remarkable difference between distribution of CFSS in many narrow grooves or bundling-up in fewer grooves. While distributing the CFSS in number of smaller grooves increases the overall bonding area for the CFSS to the concrete, the overlapping of stress zones around the closely spaced grooves may have cancelled out its benefit resulting in insignificant effect. However, such similar behavior could be beneficial from the construction point of view as forming a fewer grooves might be faster and economical compared to the other case. From the results, it can be noted that with the increase in the amount of CFSS, the strengthening effect was increased, however, that increment was not proportional to the amount of CFSS as the ultimate failure was restricted by the failure in concrete region. Due to this, the material utilization of the CFSS was reduced from around 90% to 44%.

**Effect of lap splicing**

Fig. 6 shows the comparison between the continuous and the lap spliced NSM CFSS cases. Despite lap splicing all the 5 sets of CFSS at the maximum moment zone creating the worst case senario, the ulitmate moment resisting capacity of the RC beams were almost unaffected when compared to the continuous CFSS reinforcement cases. In both N-L-1 and N-L-2 cases, ultimate failure was due to the CCS at the end region of the beam without any separation/failure at the lap spliced zone which indicates that the simple lapping of the CFSS with the lapping length of 200mm was sufficient to transfer the stresses across the CFSS.

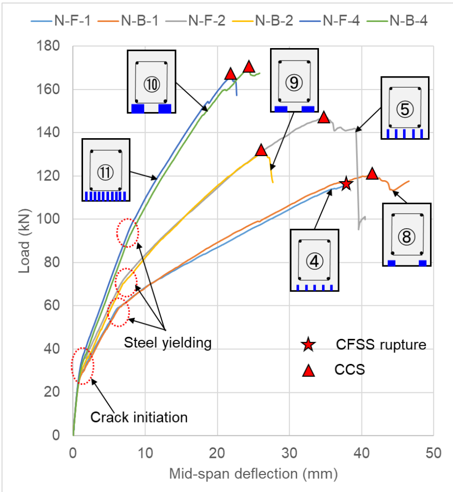



Figure 5: Effect of CFSS arrangement

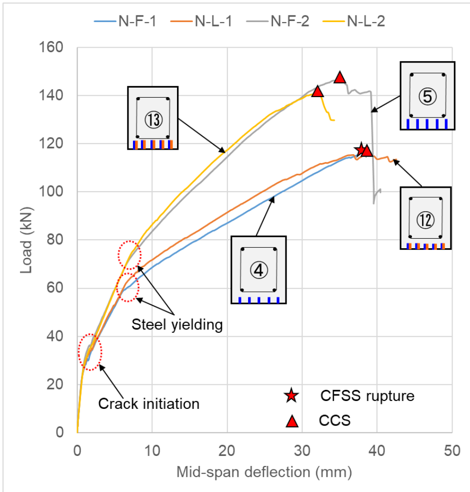



Figure 6: Effect of lap splice

## Conclusions

The use of NSM CFSS reinforcement to strengthen the RC beams in flexure was confirmed and the key findings are listed below.

1. Strengthening by NSM method is more advantageous compared to the EB method using the same type and amount of CFSS reinforcement. Ultimate flexural strength increased about 30-76% depending on the amount of CFSS.
2. With the same amount of CFSS but with different arrangements in the groove showed insignificant effect on the flexural strength. In addition, it was confirmed that addition of NSM CFSS reinforcement on the side surface of the beams is possible without affecting the ultimate flexural performance. These result leads to the flexibility in design and construction with the NSM CFSS.
3. The lap splice length of 200 mm in NSM CFSS was sufficient to develop the equivalent strengthing effect in the RC beams without the splice.

## Reference

[1] Shrestha, J., Seki, M., and Komori, A., 2018, "Evaluation of the modified Near Surface Mounted (NSM) CFRP Reinforcements for the Strengthening of the Concrete Structures," The 8th International Conference of Asian Concrete Fedaration, Fuzhou, China, pp. 1145-1154.