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# EXPERIMENTAL STUDY ON THE FLEXURAL BEHAVIOUR OF RETROFITTED RC- BEAMS USING NEAR SURFACE MOUNTED TECHNIQUE AND BFRP SHEETS

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## ABSTRACT
Structures are in a phase of faster deterioration due to adverse environmental conditions. Most of the reinforced concrete structures reached their life time and time has come to repair/strengthen them. Various retrofitting techniques have been started in the field of construction and a brief of some of the techniques is mentioned in the study. The awareness among the people regarding retrofitting techniques is quite low. This study primarily deals with the use of Basalt Fiber Reinforced Polymer bars and sheets for strengthening the RC beams. In this work the BFRP bars and sheets are used to enhance the flexural capacity of the RC beams under four-point loading conditions and retrofitted at various pre-loading conditions. The load deflection characteristics are studied for various pre-loading conditions using BFRP bars, sheets and the combinations. The BFRP bars and sheets are introduced into the pre-cracked beam by the use of epoxy adhesive. The study considered the comparison of retrofitted beam of 50% & 70% preloading conditions with the control beam. The enhancement of ultimate load carrying capacity was above 25% in all the cases also the use of bi-directional BFRP sheets increased the capacity by more than 40% and the combinations increased the capacity by more than 50%. Slipping/de-bonding is not observed in the bars but the sheets showed de-bonding with the concrete under ultimate loading conditions.

## INTRODUCTION
Deterioration of a structure means that it has lost its life but not the importance which arise the need to be restored and enhance its life which is done by retrofitting. The main purpose of retrofitting is to enhance the structural capacities of structure that is damaged. Traditional structure retrofitting was performed by the method of bonded steel plates which lead to the several disadvantages such as difficult and time consuming application, and lack of durability. Introduction of new material fibre-reinforced-polymer in the market for aging infrastructure which still getting attention for structural retrofitting lead to improvement of strength and durability of the structures.

Fibre reinforced polymers (FRP) which are also known as “composites” are materials composed of fibre reinforcements and polymer resin. The reinforcements impart strength and stiffness while the resin is an adhesive matrix that bonds the fibres. The resin matrix transfers the applied loads to the reinforcing fibres and protects the fibres from environmental attack. FRP composites are composed of fibre reinforcements and a resin matrix that bonds the fibres. Such composites can also include core materials, fillers, and other additives to provide unique performance attributes. Matrix resin chemistries include unsaturated polyester, viny ester, epoxy, phenolic and polyurethane resins. Unsaturated polyester resins are the most common of the resins utilized in FRP composites. The strength characteristics and mechanical properties of FRP composite’s dependents on the type, amount and orientation of fibre reinforcement which including glass, carbon, aramid, and natural fibres.

Over the time, various types of fibres were introduced like carbon FRP_(CFRP), glass FRP_(GFRP), aramid FRP_(AFRP) with the increase in FRP technology there was introduction of new FRP in market which is basalt fibres. However, basalt-FRP (BFRP) bars are the most recent FRP composite materials developed to enhance the safety and reliability of structural systems compared to GFRP, CFRP, and AFRP composites

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Basalt is a natural, hard, dense, dark brown to black volcanic igneous rock originating at a depth of hundreds of kilometres beneath the earth and resulting the surface as molten magma. And its grey, dark in colour, formed from the molten lava after solidification.

## VARIOUS TECHNIQUES FOR RETROFITTING

In general, two techniques are adopted for strengthening of beam is flexural strengthening or shear strengthening.

1. Strengthening by using externally FRP sheet wrapping on the tension face of RC flexural members.

**Beam after U-wrapping with BFRP fabric for flexural strengthening**

2. Near-Surface-Mounted (NSM) technique which involves cutting grooves into the concrete cover and bonding FRP reinforcing bars inside the grooves through the use of adhesive. This method of strengthening is a promising technology for increasing the flexural and shear capacity of reinforced concrete member.

**Beam with NSM groove**

## EXPERIMENTAL PROGRAM AND METHODOLOGY

### a) Overview

1. Thirty rectangular beams were tested in four-point bending. These thirty beams were classified into fifteen group. Two beams were casted for all 15 group and description of all beams types are given in table below

| Beam No. | Number of beam | Specimen | Specification |
|---|---|---|---|
| B1 | B1-A<br>B1-B | C-S-0% | Control beam with steel reinforcement only |
| $B_S$ | $B_S$-A<br>$B_S$-B | S-N-0% | Strengthened beam with NSM technique without any pre-loading |
| B2 | B2-A<br>B2-B | P-N-50% | Preloading RC beam till 50% of ultimate load then strengthened NSM |
| B3 | B3-A<br>B3-B | P-N-70% | Preloading RC beam till 70% of ultimate load then strengthened NSM |
| B4 | B4-A<br>B4-B | P-N-90º | Which failure load is better for retrofit (b4 and b5) then strengthened with 90º inclination bent end on BFRP rod by NSM technique |
| B5 | B5-A<br>B5-B | S-UD-0% | Strengthened beam with U-Wrapping technique without preloading with unidirectional BFRP sheets |
| B6 | B6-A<br>B6-B | S-BD-0% | Strengthened beam with U-Wrapping technique without preloading with bidirectional BFRP sheets |
| B7 | B7-A<br>B7-B | P-UD-50% | Preloading RC beam till 50% of ultimate load then strengthened by U-wrap with unidirectional BFRP sheets |
| B8 | B8-A<br>B8-B | P-BD-50% | Preloading RC beam till 50% of ultimate load then strengthened by U-wrap with bidirectional BFRP sheets |
| B9 | B9-A<br>B9-B | P-UD-70% | Preloading RC beam till 50% of ultimate load then strengthened by U-wrap with unidirectional BFRP sheets |
| B10 | B10-A<br>B10-B | P-BD-70% | Preloading RC beam till 50% of ultimate load then strengthened by U-wrap with bidirectional BFRP sheets |
| B11 | B11-A<br>B11-B | P-UD-N-50% | Combination strengthening of Pre cracked RC beam till 50% of ultimate load using NSM and U-Wrapping with unidirectional BFRP sheets. |
| B12 | B12-A<br>B12-B | P-BD-N-50% | Combination strengthening of Pre cracked RC beam till 50% of ultimate load using NSM and U-Wrapping with bidirectional BFRP sheets. |
| B13 | B13-A<br>B13-B | P-UD-N-70% | Combination strengthening of Pre cracked RC beam till 70% of ultimate load using NSM and U-Wrapping with unidirectional BFRP sheets. |
| B14 | B14-A<br>B14-B | P-BD-N-70% | Combination strengthening of Pre cracked RC beam till 70% of ultimate load using NSM and U-Wrapping with bidirectional BFRP sheets. |

## Mix Proportionof Concrete M-25 Concrete Mix for 1m$^3$ of Concrete

| | |
|---|---|
| Cement | 380 kg |
| Water | 170 Liter |
| Fine aggregate (sand) | 800 kg |
| Coarse aggregate<br>• 20mm nominal size<br>• 12.5mm nominal size | 650kg<br>430Kg |
| Admixture | 1.2% by wt. of cement |
| Water cement ratio | 0.44 |
| Compressive strength<br>• 7 Days<br>• 28 Days | 25.10N/mm$^2$<br>35.32N/mm$^2$ |

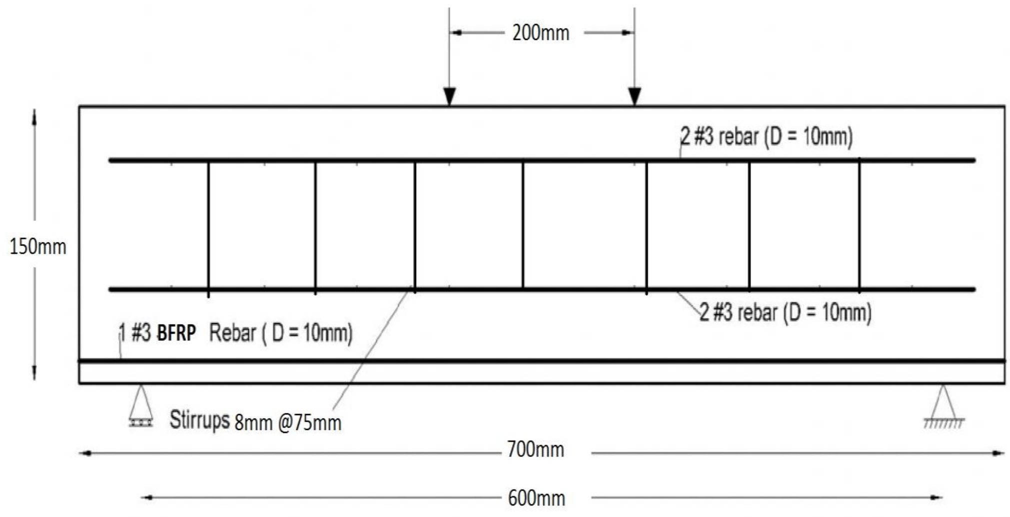
**b) Materials**

**Basalt fibre reinforced polymer bars and sheets**

BFRP spirally wound deformed bar with nominal diameter of 10mm was used for NSM reinforcement . The ultimate tensile capacity of the BFRP bar is 1000MPa, tensile modulus of elasticity of 50GPa and elongation min value is 2.5%. The epoxy used for NSM technique. This epoxy has tensile strength of 35 Mpa, bond strength of 14MPa U-wrapping was performed using 300 GSM (Grams per Square Meter) BFRP unidirectional and plain fabric by wet-layup procedure Ultimate tensile strength in the primary fibre direction >1500MPa, elongation at break 2.2%, tensile modulus of elasticity 26.1GPa.

**c) Beam dimension and reinforcement**

The beam length is 700mm and the span between the supports is 600mm. The beams were loaded under four-point bending with two concentrated loads following ASTM standards. The spacing between two concentrated loads is 200mm. The cross section of the beam is a square with a depth of 150mm. All beams were reinforced with four #3 steel bars with a nominal diameter of 10mm. Of four longitudinal bars, two bars were used as compression reinforcement and two bars were used as tension reinforcement. #3 with nominal diameter of 10mm, stirrups were used to resist the shear reinforcement and spaced at 75mm.

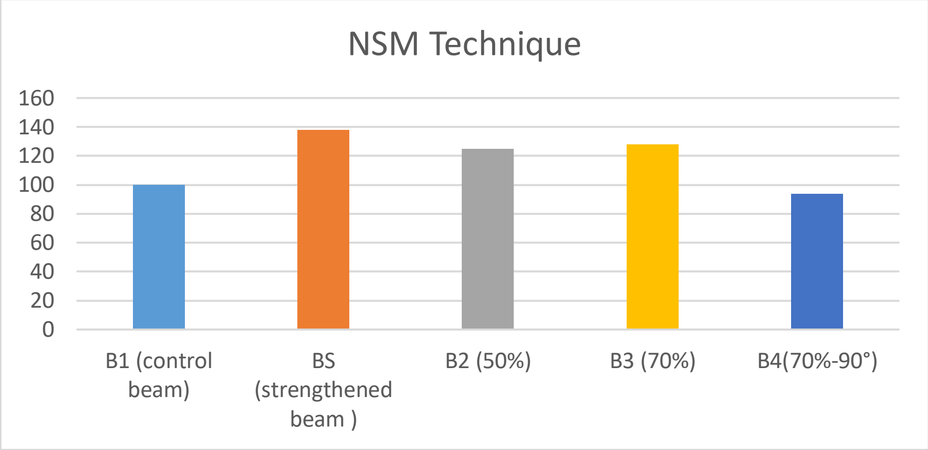



**Longitudinal section of the beamwith BFRP by NSM Technique**

## RESULT AND DISCUSSION

**NSM Technique**

| Beam No. | Ultimate load (KN) | w.r.t control beam | w.r.t to strengthened beam |
|---|---|---|---|
| B1 (control beam) | 100 | - | - |
| $B_S$ (strengthened beam) | 138 | - | - |
| B2 (50%) | 124.75 | 24.75% | 9.60% |
| B3 (70%) | 128 | 28% | 7.25% |
| B4(70%-90°) | 93.6 | -6.90% | -32.17% |

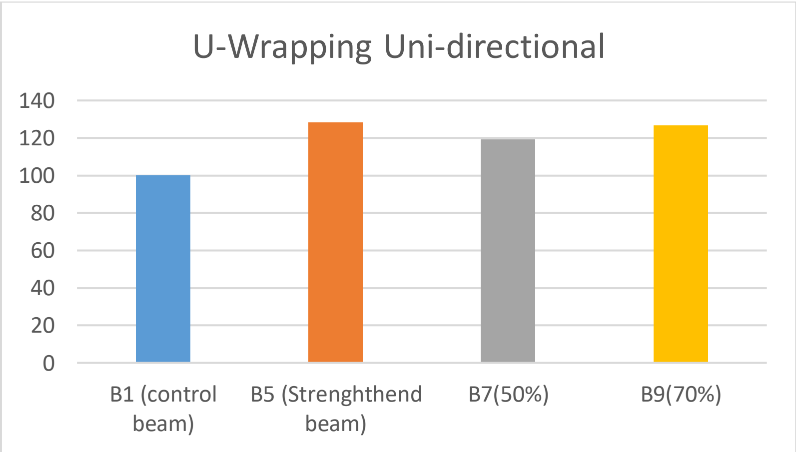



**Comparison of ultimate load w.r.t control and strengthened beam**

**U-wrapping Technique**

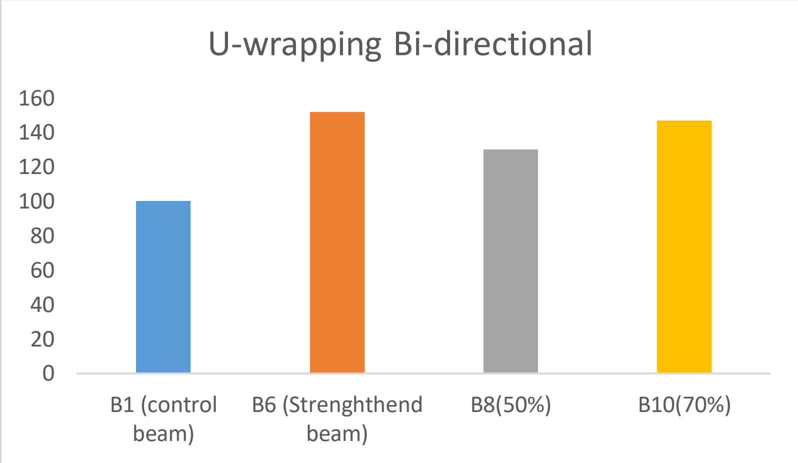
**(a) Comparison of ultimate load w.r.t control and strengthened beam by Uni-directional wrapping**

| Uni-directional wrapping | ultimate load (KN) | % w.r.t control beam | % w.r.t strengthened beam |
|---|---|---|---|
| B1 (control beam) | 100 | - | - |
| B5 (Strengthened beam) | 128.2 | 28.20% | - |
| B7(50%) | 119.28 | 19.28% | -6.96% |
| B9(70%) | 126.82 | 26.82% | -1.08 |




**a) Comparison of ultimate load w.r.t control and strengthened beam by Bi-directional wrapping**

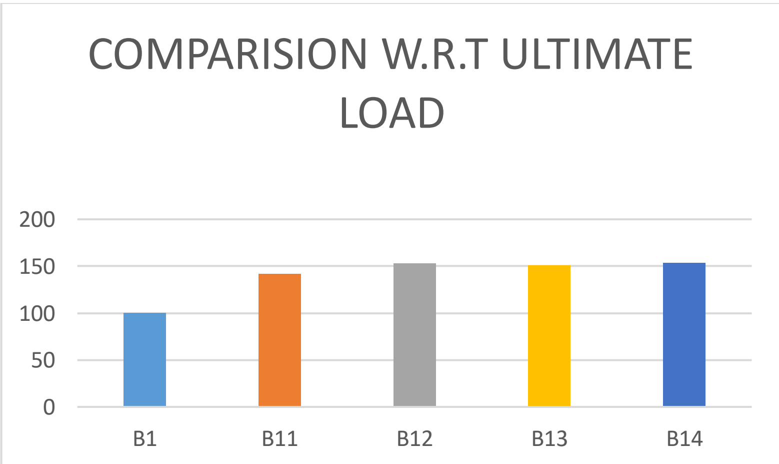
| Bi-directional wrapping | ultimate load(KN) | % w.r.t control beam | % w.r.t strengthened beam |
|---|---|---|---|
| B1 (control beam) | 100 | - | - |
| B6 (Strengthened beam) | 151.9 | 51.90% | - |
| B8(50%) | 130.16 | 30.16% | -14.31% |
| B10(70%) | 146.91 | 46.91% | -2.63% |



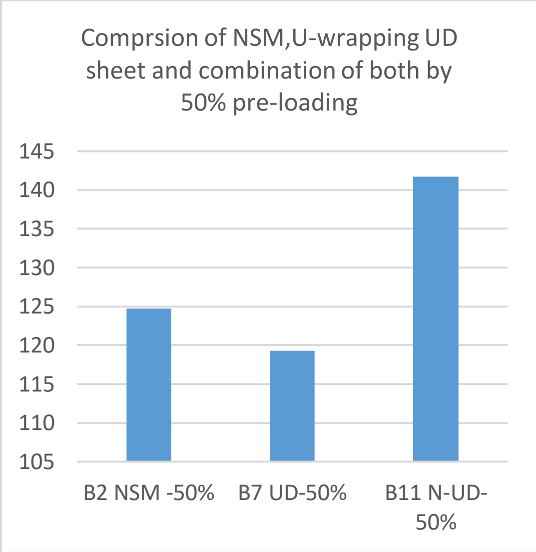

- Beams strengthened with NSM and U-wrap Strengthening

**Comparison of ultimate load w.r.t control by combination of NSM and U-wrapping wrapping**

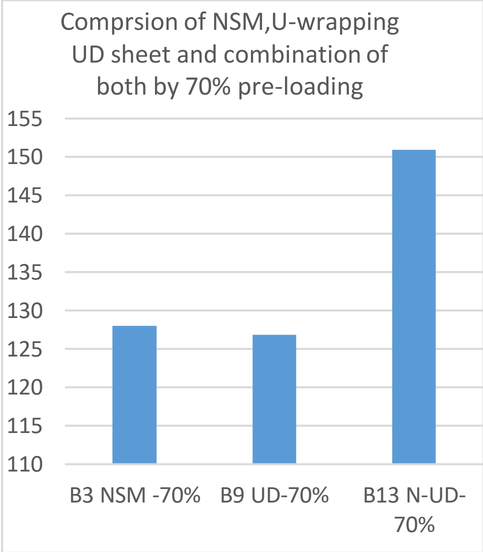
| Beam No. | **Ultimate load (KN)** | **w.r.t to control beam** |
|---|---|---|
| B1 (control beam) | 100 | - |
| B11(P-UD-N-50%) | 141.74 | 41.74 |
| B12 (P-BD-N-50%) | 152.79 | 52.79 |
| B13 (P-UD-N-70%) | 150.90 | 50.90 |
| B14(P-BD-N-70%) | 153.49 | 53.49 |




**Comparison of NSM, U-wrapping UD sheet and combination of both by 50% pre-loading(a) and Comparison of NSM, U-wrapping UD sheet and combination of both by 70% pre-loading(b)**

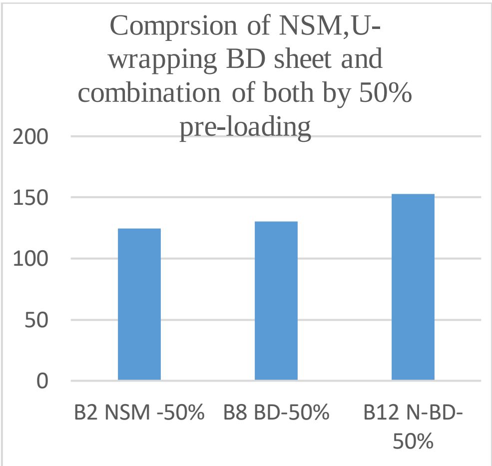



(a)

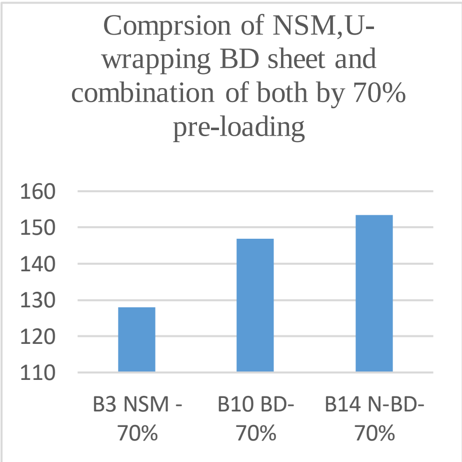



(b)

**Comparison of NSM, U-wrapping BD sheet and combination of both by 50% pre-loading(c) and Comparison of NSM, U-wrapping BD sheet and combination of both by 70% pre-loading (d)**



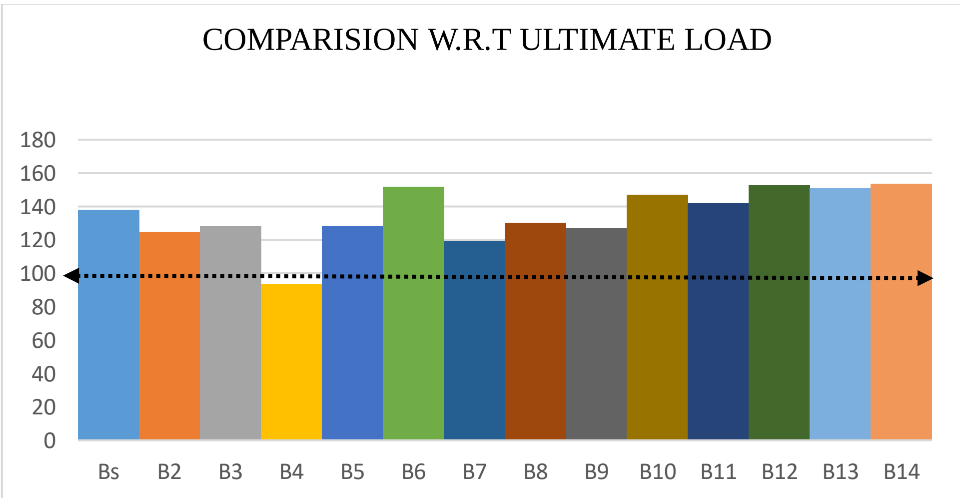

**c)**




**(d)**

**Comparison of ultimate loads of all types of strengthened beams**

The ultimate load carrying capacity of all the specimen with different techniques and at different pre-loading conditions



## DISCUSSION

1. The investigation carried on the strengthened RC beam (without pre-loading) using NSM technique showed a significant increase of 38% in load carrying capacity of the beam when compared with control beam. Hence this enhancement of load carrying capacity has shown the effectiveness of this technique.
2. The retrofitted beams using BFRP bars and NSM technique, pre-loaded at 50% and 70% showed an increase of 24.75 % and 28% in ultimate load carrying capacity compared to controlled beam. Hence, proving this technique as a promising method of retrofitting
3. The gain in strength of beams retrofitted using BFRP bars and NSM technique was more in case of beam pre-loaded up to 70 % when compared with beam pre-loaded up to 50% of the ultimate load. But no significant change was observed (<10%) under preloading conditions.
4. No de-bonding of sheets was observed while testing of strengthened beam till failure but de-bonding was predominant in retrofitted beams. This strange behaviour was due to non-bonding nature of sheets at cracks.

## CONCLUSION

1. Both uni-directional and bi-directional wrapping of preloaded beam significantly improved the ultimate load carrying capacity by 26.82% and 46.91% w.r.t control beam.
2. In both uni-directional and bi-directional U-wrapping 70% pre-loading conditions retrofitting proved more promising.
3. No tearing was observed in case of Bidirectional BFRP sheets as compared to uni-directional sheets which can be justified that the longitudinal fibre of BFRP sheets on the beam improved the performance of the pre-cracked beam by keeping intact already formed cracks and by providing addition longitudinal support under flexure as on the other hand the transverse fibre of Bidirectional wrapping prevents the beam under shear failure condition.
4. Beams which were strengthened with NSM and u wrapping showed the increase in ultimate load capacity and was more than 50% w.r.t control beam in all the cases. So the combination is useful to retrofit the structure which are to be used for entirely different loading condition or else it shall prove uneconomical to retrofit structure to get back to its original strength .
5. Even with the effect of de-bonding of sheets, U-wrapping proved significant improvement in strength in both uni and bi-directional sheets.

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