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Performance Evaluation of MS Tube Coupler on Axial Load Capacity of Column

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Abstract**:** ***This paper presents the results of an experimental investigation on the axial load behavior of small scale reinforced concrete square columns with tube coupler, where this material represents a relatively new technology, as a solution to overcome the lapping problems. Therefore, a total of 18 columns (550 mm ×150 mm×150 mm size) were tested under compressive axial static loading. All columns had 4-Φ10 mm rebar as main reinforcement and Φ8 mm as transverse reinforcement at 100 mm center to center spacing along the column. The major parameters included in this research were the joining types of main reinforcement, such as solid rebar, lapping of rebar and coupling of rebar. Test results exhibited that the cracking loads and failure loads of column were higher in the column made with coupling of rebar compared to lapping but slightly lower than the solid rebar. In addition, axial deformations and rate of deformation were almost similar in both types of columns using solid rebar and coupler in rebar. So, it can be stated, on the basis of the test results, that uses of tube coupler in rebar rather than lap splice is more expedient to increase the capacity of column.***

Keywords**:** ***tube coupler, lapping, cracking load, failure load, axial deformation***

I. INTRODUCTION

Lap splicing is the traditional method of connecting the steel reinforcing bars in the construction works of concrete structures to transfer load, tension, moment and shear forces. This is largely due to a misconception that lap splicing is a low-cost method of splicing and just requires the overlapping of two parallel bars. However, there is a direct cost for the additional length of rebar required for lap splicing. As per ACI 318R-08, section 12.16.1 [1], the minimum length of lapping for compression splices for bars with fy ≤ 60,000 psi (420 MPa) shall be 0.0005fy db, where, fy = yield strength of steel and db = diameter of rebar and for bars with fy > 60,000 psi (420 MPa) shall be (0.0009 fy−24) db, but not less than 12 in (300 mm). In addition to this, for f′c < 3000 psi (20.7 MPa), the length of lap shall be increased by one-third. This extra length of rebar for lap splice directly increases the cost of materials. Also, there are some hidden costs associated with the process of providing lap splices. The time taken to prepare lap splices, the need for additional transverse reinforcement, the instruments used in forming the lap splice and the cost of rebar placement represent the hidden costs of lap splicing. Lapping of reinforcing bars, although, has long been considered as an effective, economical splicing method, but today's more demanding concrete designs are forcing builders to consider alternatives like mechanical connections. Lap splicing of reinforcing bars often creates congested areas within the formwork that limit working space and hinder proper placement of concrete [2]. When lapping is used in column it caused de-alignment of rebar, because one bar lapped over another. In this way, column may also shift slightly from its position which can be removed by using reinforcement bar coupler. However, lapped joints are not always an appropriate means of connecting reinforcing bars. Because it depends on the bond between concrete and steel to transfer load. For this reason, any degradation in the integrity of the concrete could significantly affect the performance of the joint [3]. On the other hand, reinforcing bar coupler system provides continuity of load path independent of the condition or existence of surrounding concrete that provide greater structural integrity. In freeze-thaw and coastal regions, rebar corrosion can produce concrete delamination and spalling. With reinforcement bar couplers, structural integrity can be maintained even with the loss of the concrete cover because mechanical couplers perform similar to a continuous piece of rebar. Also, 'bar-break' connections i.e. mechanical coupler allow the steel to concrete ratio to be maximized by eliminating unnecessary rebar whilst achieving an ideal balance of steel and concrete and providing greater structural integrity without unnecessarily increasing column dimensions thus promoting more design flexibility, reduced costs and optimum use of floor space.

In the study of Jokūbaitis and Juknevičius, 2010 [4] the appearance of normal cracks was investigated by the analysis of results of the research on tensile reinforcement of reinforced concrete beams which was spliced by threaded couplers. The mechanics of the development of normal cracks caused by different cross-sectional areas and consequently the different tensile stresses in reinforcement and coupler were analyzed in this research by using 12 reinforced concrete beams with reinforcement couplers under the short-term loading. The load on the beams was applied in several steps all the way until their failure.

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The analysis of experimental and numerical results obtained by calculation method showed that the first normal cracks generally appear at the end of the coupler.

The initial cracking moment of the beams with reinforcement couplers was smaller than that of the beams without couplers. It was also found that cracking moment is directly proportional to the area of concrete shearing surface at the end of the coupler. The area of such surface, however, depends on the size of reinforcement ribs, distance between them and the diameter of the coupler. Neeladharan et. al, 2017 [5] investigated on the tensile strength of reinforcement with or without three different lengths of the mechanical coupler. The length of the coupler was taken as 3, 5 & 8 times the diameter of the bars. The tests were conducted on 12 mm and 16 mm steel rods. The depth of thread and pitch length was kept constant as 2.0 mm and 1.2 mm. The normal, developed and coupled bars were tested by using Universal Testing Machine (UTM). After testing of developed and coupled bars, the 3d coupler gave good result when compared to 5D and 8D (D=diameter of the bars) coupler and also compared to welded splices and development length of 45D as per IS 456:2000. Therefore, they concluded that mechanical couplers can be used instead of providing development length in the reinforcing bar.

Harinkhede et. al, 2016 [6] carried out a study on the performance of mechanical splices as an alternative to lap splices. In their study, the performance of mild steel couplers and EN8D couplers was analyzed on the basis of ultimate tensile capacity and percentage elongation. They found that mild steel couplers fail in tension test, and obtained result was between 190 and 210 MPa which was not satisfactory as per recommended in IS code 1786-2008. On the other hand, test results of EN8D coupler specimens were found satisfactory; therefore they stated that EN8D material having high carbon content and high strength can be used for making couplers. Swami et. al, 2016 [7] verifies the strength of different couplers and also an economic viability study was carried out. The materials used in this experimental work were mechanical threaded couplers and HYSD rebars (Fe=500). Fe 500 steel bars of diameters 12, 16, 25, 32 mm were used for the study. For comparison purpose, an incremental tensile load test was carried out on welded splices and coupler splices or mechanical splice. A cost has been computed based on saving of steel in lapping which indicates couplers are an effective and an economic replacement of lap splice. This study showed that couplers are not only provided strength to the joints but they are also an economic means of connections of two bars.

However, it is observed in the above studies that coupling of rebar was tested in many researches to know the cracking behaviour of beams under tensile loads and tensile load capacity of the coupling rebar only but the performance under compressive force in the column, which is a compression member, was found limited. Therefore, in this study, threaded coupler was used to investigate the difference of compressive force of column made with lap splice and coupler. Threaded tube coupler is the simplest type of coupler and the use of reinforcement couplers significantly reduce the consumption of both construction time and reinforcing steel. It also increases the overall reliability of reinforcement splices. The reinforcement couplers not only provide strength to the joints but they are also an economic means of connections of two bars [8, 9]. This study aims to compare the cracking load, ultimate load and axial deformation of columns reinforced with solid rebars, lap splicing and mechanical splicing by tube couplers and also to know the better type of joint among lap splice and mechanical splice for compression reinforcement of column.

II. EXPERIMENTAL PROGRAM

A. Constituents Materials

Concrete is the artificial stone like material produced from the mixture of various ingredients-water, aggregate, binding materials, and any additives. In our country, two types of coarse aggregates: stone and brick aggregate are commonly being used in the construction works. Among these two coarse aggregates, brick aggregate is comparatively cheap and easily available and good quality bricks give good strength of concrete. Therefore, it is a popular coarse aggregate in our country. However, in this study, brick aggregate having the maximum size of 19 mm and fineness modulus of 7.2 was used as coarse aggregate. Locally available Sylhet sand with fineness modulus of 2.51 was used as fine aggregate and Portland composite cement was utilized as a binding material for concreter mix. Water plays an important role in the concrete mix and the most important chemical process which is responsible for hardening of concrete paste is hydration process that occurs in the presence of required amount of water so, clean tap water was utilized. Water-cement ratio was kept constant as 0.45 and concrete mix ratio of 1:2:4 (cement: fine aggregate: coarse aggregate) was adopted to obtain 22 MPa concrete strength for conducting this experimental study. In addition, 420 grade (420 MPa) MS rebar and also MS tube coupler prepared from MS rebar was used for the preparation of column specimens.

B. Details of Column

This study was carried out by 550 mm x 150 mm x 150 mm size column specimens. Three different types of columns were prepared in this test. One type of column specimen was made with continuous solid bar which was considered as control specimens. The second type of column was cast with lapping at middle of the bar and another type of column was provided with tube coupler at discontinuous end at the middle of the bar length. The reinforcement detailing of the specimens are presented in figure 1. Providing 25 mm concrete cover at both end and side of the column the total length of the bar was kept at 550 mm. All column specimens were made with 10 mm diameter as a main bar and 8 mm diameter as a tie bar with a spacing of 100 mm centre to centre.

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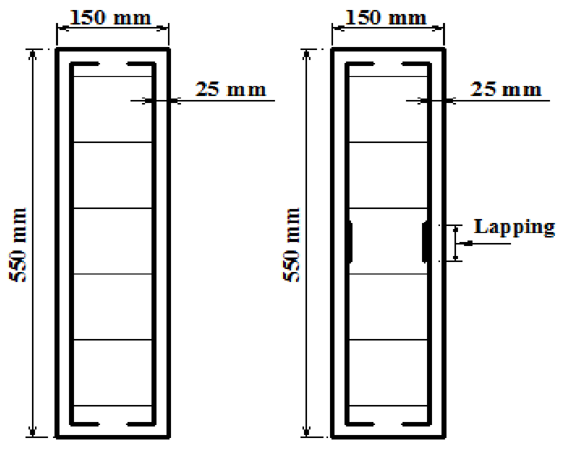
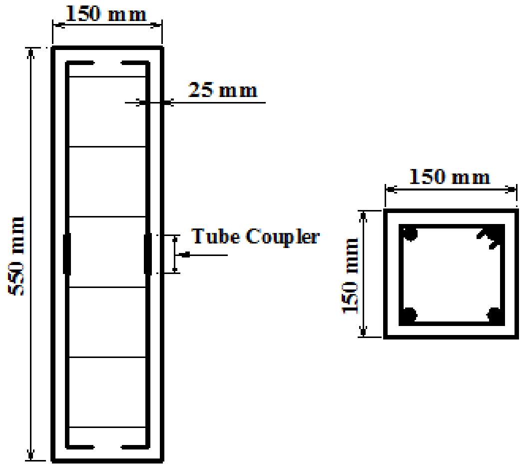


(a) Column with solid bar (b) Column with lapping



(c) Column with tube coupler (d) Cross section

Fig. 1: Details of column specimens

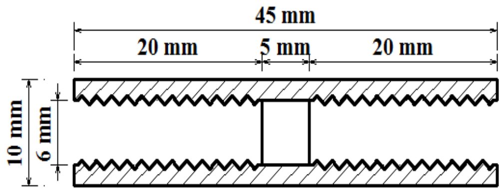
In the actual field, we found that lapping is provided at discontinuous end to take the column up to the desired length. Lapping should be provided within middle one-third height of column so, in this test, lapping was provided at the middle of the bar length. In addition, MS tube coupler was used to join the discontinuous end of bars to make tube coupler columns. The tube was such that both ends of the bars were attached with it by the thread portion i.e. inner diameter of the tube was equal to outer diameter of the bar.

C. Details of Tube Coupler

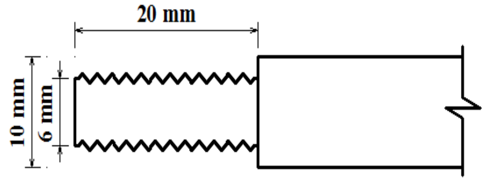
The tube coupler was made from MS bar and had the same properties of main rebar. So the structural arrangement of tube and rebar were same. Yield strength of MS rebar and tube coupler was 420 MPa. Inner diameter of the tube was provided with 6 mm whereas the outer diameter was 10 mm which was same as rebar, so that the total combination was formed as a solid bars. Inner portion of the tube and outer part of the rebar was threaded, thus, it was easy to coupling the rebar with the tube. The length and thickness of the tube were 45 mm and 2 mm respectively. The length of thread portion in the rebar was 20 mm. The figure 2 and 3 show the used MS tube coupler and threaded rebar and details of these respectively.

(a) MS tube (b) Threaded rebar

Fig. 2: MS tube coupler and threaded rebar



(a) Long section of tube coupler



(b) Details of threaded rebar

Fig. 3: MS tube coupler and threaded bar details

D. Details of Lapping

Lapping is provided in the column when the length of rebar is not meant the total length of the column. Actually, it is not possible to provide solid rebar whole through the length of the column. For conducting the research the lapping was provided at middle length of the rebar with a lapping length of 55 mm. Overlapped portion was tied with wire, so both parts of the bar remained in position. Lapping was provided in the four rebars at the same height with configuring the same dimension. A photo view of lap spliced rebar and details of lapping are shown in figure 4.

Fig. 4: Lapping of rebar

E. Test Procedure

A total of six column specimens with solid rebar, six specimens with lap splices and six specimens with tube coupler were tested. Half of the total specimens were tested at days of curing and remaining half were tested at 28 days of curing. For each type of columns three samples were tested and the average of the test value was taken.

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All test specimens were subjected to direct compression load and no another load (that is lateral or moment) was subjected. Failure of the column was accompanied by an increment of load that was successively added. The successive load increment was 10 kN and the load at which crushing in column occurred was taken as failure load of column. For each load increment respective deflection was taken from dial gauge. All the short column specimens were tested with Universal Testing Machine as shown in figure 5. The load was applied until complete failure took place. Axial deformations of the columns were noted down at an equal interval with the help of a dial gauge. Then ultimate load and corresponding deformation were noted down. The load carried by the column was considered to be the original load carrying capacity of the column. Deformation caused by the direct compression force for this column was found from the dial gauge. Column used for this test was considered as short column as its length was less than 10 times of the least dimension.

Fig. 5: Test setup of column specimen.

III. RESULTS AND DISCUSSION

A. Axial Load

Table 1 shows the cracking load and failure load of the tested column specimens for different types of columns at 7 days and 28 days of curing. Cracking load was measured at that time when first hair crack was visible in column face and failure load was measured when column was crushed under applied axial load. Columns using lap slices and tube coupler; identified as CL and CC respectively, had notably lower load carrying capacities than the control columns made with solid rebar; identified as CS. Cracking loads of columns using lap splices were 63-70% and 64-66% at 7 days and 28 days respectively lower than that of solid rebar. On the other hand, these values were 83-94% and 83-89% for columns made with tube coupler. In addition, failure loads of columns were also lower for both lap splice and tube coupler than control columns. Although the cracking loads and failure loads of columns for lap splice and tube coupler were lower than that

Of solid rebar, columns using tube coupler gave better results compared to lap splice. Cracking loads of columns using coupling of rebar at 7 days and 28 days were 14-26% and 16-25% respectively higher than the columns using lapping of rebar. Also, the coupling of rebar gave higher value of failure loads compared to the lapping of rebar, from 5-6% and 7-16% at 7 days and 28 days respectively.

B. Axial Deformation

Axial load–deformation curves of 18 column specimens at 7 days and 28 days of curing are presented in figures from 6 to 11. It is clear from the figures that the axial deformation of CS and CC are almost same until the failure of columns occurred but CL shows greater deformation at lower axial load compared to others. Although, in some columns, CL exhibited lower deformation, the average failure load and also average ultimate deformation at failure load of CC were lower than CL but higher than that of CS at both 7 days and 28 days.

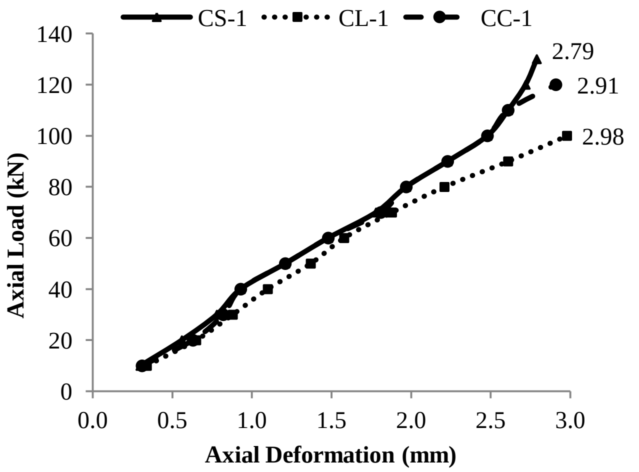

Fig. 6: Load-deformation curve at 7 days

7 days test results					28 days test results				
Column ID	Cracking load, kN	Average cracking load, kN	Failure load, kN	Average failure load, kN	Column ID	Cracking load, kN	Average cracking load, kN	Failure load, kN	Average failure load, kN
CS-1	88	91.00	126	125.33	CS-4	98	98.67	138	137.33
CS-2	92		128		CS-5	97		132	
CS-3	93		122		CS-6	101		142	

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CL-1	62	61.33	95	95.00	CL-4	65	64.33	108	107.00
CL-2	58		92		CL-5	62		101	
CL-3	64		98		CL-6	66		112	
CC-1	83	80.67	114	110.00	CC-4	81	84.00	118	121.33
CC-2	82		112		CC-5	86		122	
CC-3	77		104		CC-6	85		124	

Note: CS, CL and CC indicate the columns made with solid rebar, lap splice and coupler respectively.

Table 1: Cracking load and failure load of columns

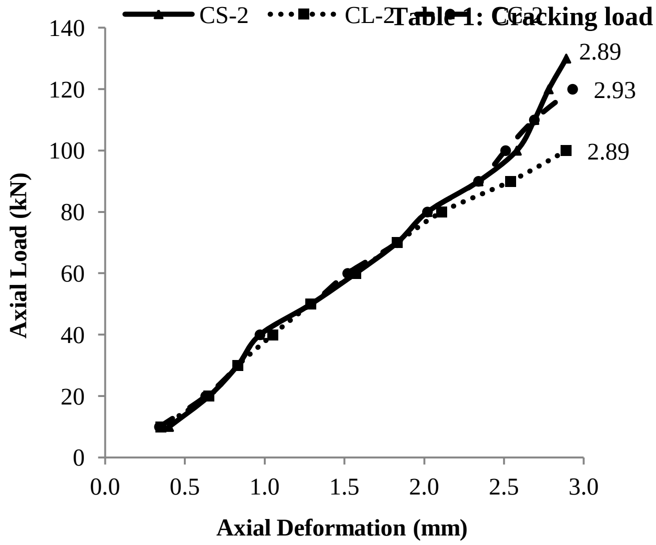

Fig. 7: Load- deformation curve at 7 days

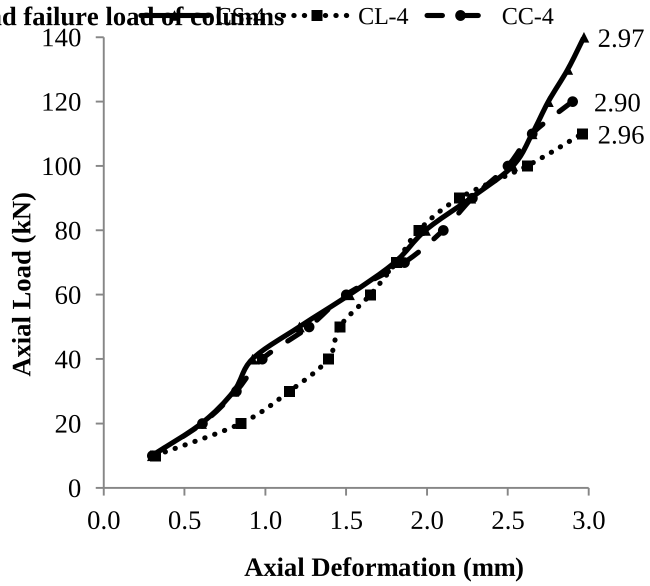

Fig. 9: Load- deformation curve at 28 days

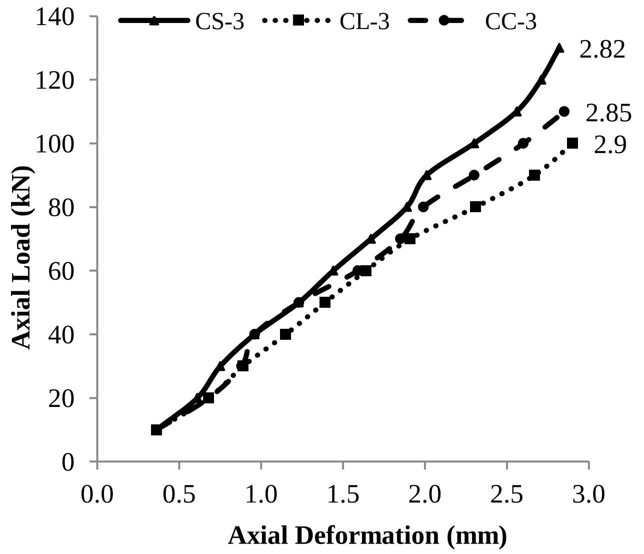

Fig. 8: Load- deformation curve at 7 days

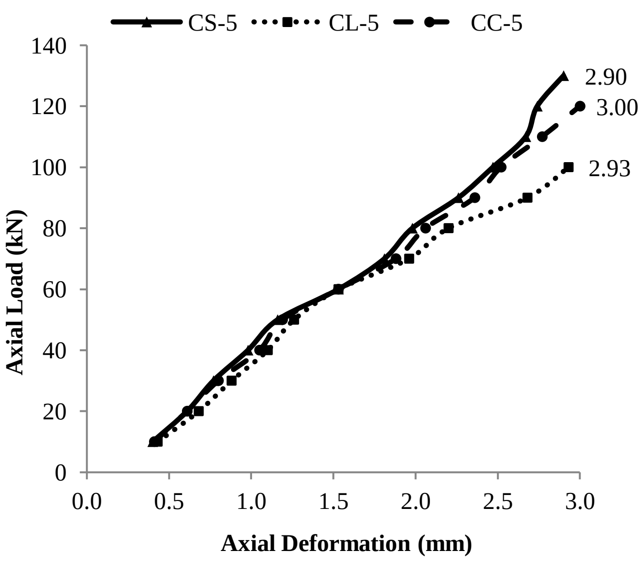

Fig. 10: Load- deformation curve at 28 days

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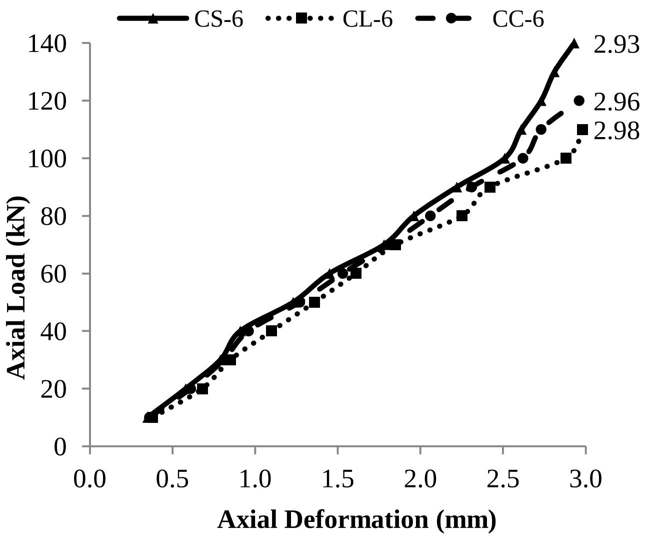

Fig. 11: Load-deformation curve at 28 days

IV. CONCLUSION

It can be concluded, based on the analysis of the experimental results of the studied columns under axial compressive load and within the range of the tested columns, that the incorporation of MS tube coupler replacing lap splice had a significant effect on the columns cracking load and failure load. It improved the column cracking loads and failure loads on average by more than 19% and 14% respectively from the respective loads of lap spliced columns at both 7-days and 28-days of curing period respectively. It had also a great influence on all axial deformation aspects. The columns made with solid rebar and coupling of rebar gave a very close value of deformations for all tested column specimens and columns using coupler showed greater ultimate deformations compared to lap slice. However, both types of rebar joining method gave lower value of axial loads and corresponding axial deformations in comparison with solid rebar. So,

It can be concluded that the use of tube coupler to join the rebars in compression member, like column is more effective to carry greater axial load than lap splicing.

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