EXPERIMENTAL EVALUATION OF COMPOSITE BEAM USING COLD FORMED SECTIONS UNDER FLEXURE

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Abstract:

Steel structure construction consisting of hot rolled sections which includes I-sections, Channels, angles which are called open sections, or rectangular, square and circular tubes which are called closed sections. For cold formed sections, strengths of section can be increased by increasing the moment of inertia of the cross-section. So, for cold formed section, for a given cross-sectional area, higher moment of inertia can be obtained by making the sections thin-walled or by shifting of neutral axis. Composite beam particularly consists of I beam considering strength properties. This paper deals with experimental study of composite beam using hot rolled sections as well as cold formed sections. Four composite beams were casted with nominal concrete strength of 30 MPa. Experimental set up consisting of two-point load frame with simply supported beam support conditions. Under ultimate loading condition various buckling modes were observed. Buckling modes were identified and recorded. Values of mid span deflection, slip and strain values were recorded for each beam. Experimental flexural strength of beam is compared with Predicted Analytical values.

***Key words**: Hot rolled Section, cold formed section, buckling modes, deflection, slip*

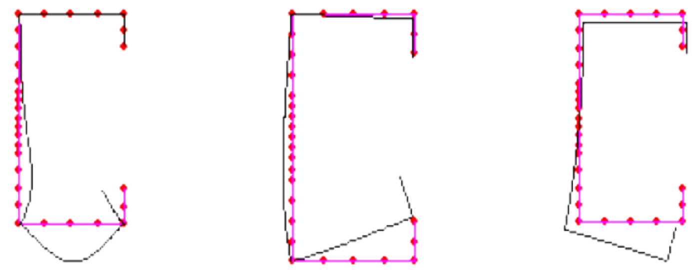
1. INTRODUCTION

Composite construction has important benefits by making steel and concrete behaves as composite unit. Use of light weight cold formed steel sections adds more advantage as compare to hot rolled sections, as sectional properties of cold formed sections can be modified and thus high strength member obtained considering same weight. Use of cold formed sections includes secondary structural members such as purlins and girts, roof and floor deck. Cold formed sections are thin walled, light in weight and cost effective.

The strength of compression member depends upon their slenderness ratio. High strength can be achieved by increasing moment of inertia of cross section and thus making members light weight for same properties. Cold formed sections are subjected to membrane compression or shear, as a result member buckles prematurely Therefore, the buckling of the plate elements of the cross section under compression or shear may take place before the overall buckling of section. Under ultimate load conditions various buckling modes are observed. Buckling modes of hollow sections and C-lipped channel sections are shown in figure-1 and figure-2.

Hollow structural sections are used in various structural applications considering its high torsional resisting capacity. Hollow sections give greater resistance against lateral forces and torsion as compared to I sections. Design of hollow sections are based on yielding; it shows heavy deformation under concentrated load. Hollow sections give excessive deformation due to local buckling. Local buckling of square and rectangular cross sections is shown in figure-1.

Figure-1: Buckling modes of square hollow section and rectangular hollow section



Local Buckling Distortional Buckling Lateral torsional buckling

Figure-2: Buckling modes of C-lipped channel

Local, distortional and lateral-torsional buckling are three different types of buckling which a cold-formed steel member may be subjected. Cold-formed profiles and sheets, due to their slenderness, will experience different buckling modes considering the loadings and support conditions. Some of the buckling phenomena that may occur in CFS(cold formed sections) elements are local buckling, distortional buckling, overall buckling, lateral distortional buckling, flexural torsional buckling etc. When a cold-formed C-profile is subjected to flexural or axial load, it experiences local and distortional buckling along with overall buckling of the beam considering a laterally restrained support condition. Buckling modes of C lipped channel is shown in figure -2.

2. PURPOSE OF STUDY

Under ultimate load conditions cold formed sections are subjected to buckling due to high depth to thickness ratio, sometimes it shows considerable deflection due to shear before reaching to ultimate load. Purpose of this study is to evaluate experimental flexural behavior of cold formed composite beam. Response of cold formed composite beam is also compared with hot rolled composite beam. So, design implementations can be suggested for cold formed sections to reduce buckling.

3. TEST SPECIMEN FOR EXPERIMENTAL EVALUATION

Four scaled test specimens of composite beams were casted of span length 1.2 m. The test specimen consisting of cold formed steel sections and hot rolled steel sections with 100 mm thick concrete slab. Two composite beams were casted using hot rolled sections which includes ISMB 175 and ISMC 100. Another two composite beam were casted using cold formed sections which includes C lipped channel and square hollow section. The beam specimens were tested in a loading frame with 500 kN capacity load cell subjected to two-point loading as shown in Fig.3. The deflection of the beam specimens was noted for every 50 kN intervals. The slip at interface of concrete slab and steel beam were recorded. Parameters and sectional properties of test specimen is shown in Table 1 and Table 2.

The detailed geometry of test beams is shown in Figure -5 to Figure -7. The concrete slab and steel beam are connected by means of shear studs. The section size of steel beam includes slenderness ratio of flange and web which falls under compact section criteria specified in Eurocode 4. Load frame set up for experimental program as shown in figure 3. Two beam specimens were casted with 100 mm thick concrete slab. The beam specimens were tested in a loading frame with 500 kN capacity load cell subjected to two-point loading as shown in figure.3 and figure 4. The deflection of the beam specimens was noted down for every 50 kN intervals. The slip at interface of concrete slab and steel beam were recorded. The parameters and sectional properties of test beams are as shown in Table 1 and Table 2.

Table 1: Parameters of test beams

NOTATION	Steel section	Yield Strength (N/mm^2)	concrete grade	Interaction (Full/ Partial)
CB1	ISMB175	250	30	Full
CB2	SHS 150	210	30	Full
CB3	ISMC 100	250	30	Full
CB4	CFS 150	250	30	Full

Table: 2 Sectional properties of steel section

Section	Weight (kg)	Area (cm^2)	Ixx(cm^4)	Iyy (cm^4)
ISMB 175	19.30	24.62	1272	85
SHS (150×150×4)	18.01	22.95	807.62	807.62
2 ISMC 100	18.4	23.4	373.4	201.82
2 CFS 150	16.57	21.12	346.99	195.16

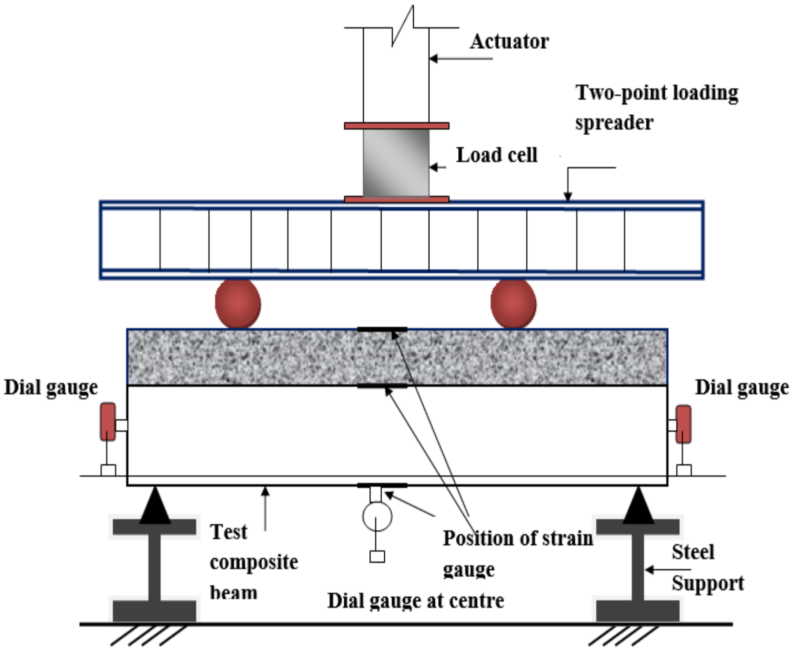


Figure -3: Load frame set up diagram

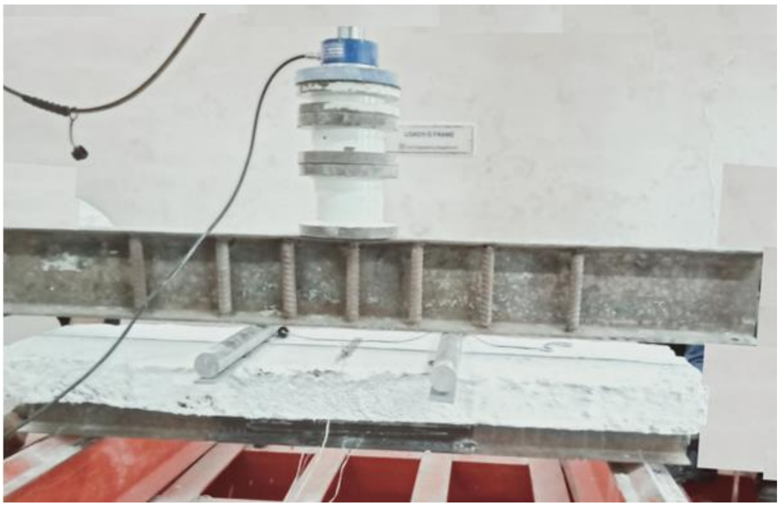


Figure-4: Load frame set up at test lab

3.1 Composite beam 1(CB1) (ISMB 175)

The composite beam-1 specimen consisting of ISMB 175 with full interaction between concrete slab and steel beam. A distribution spandrel beam with two-point loading placed at one third of distance from the supports as shown in figure 3 and figure 4. The load was applied at a uniform rate from a 50-ton capacity load cell. Linear Variable Differential Transducer was attached at mid span as well as at interface as shown in figure 3. Composite beam shows limiting mid span deflection and slip. It shows very less buckling under ultimate load condition and the same rebounds after releasing load.

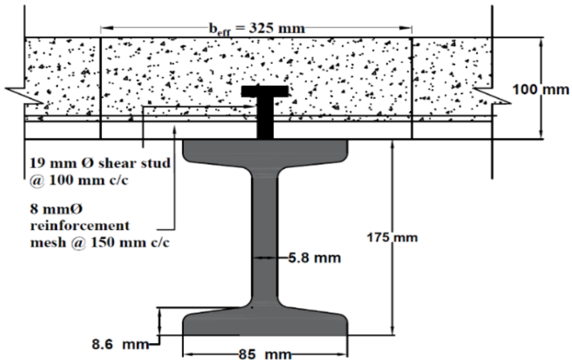


Figure-5: Composite beam 1(CB1) (ISMB 175)

3.2 Composite beam 2(CB2) (SHS 150)

The composite beam-2 consisting of SHS 150 with full interaction between concrete slab and steel beam. Composite beam 2 shows excessive deflection and slip as well as it buckling at support.

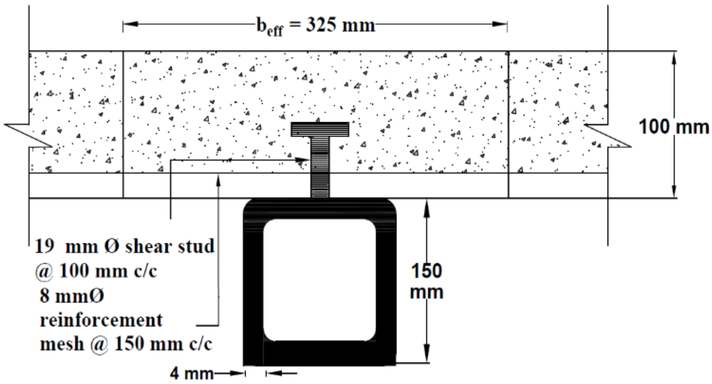


Figure-6: Composite beam 2 (CB2) (SHS 150)

3.3 Composite beam 3 (2 ISMC 100)

The composite beam-3 specimen consisting of 2 ISMC channel with a spacing of 50 mm with full interaction between concrete slab and steel beam. Hot rolled channel shows limiting mid span deflection and slip under ultimate load condition which rebounds after releasing load**.**

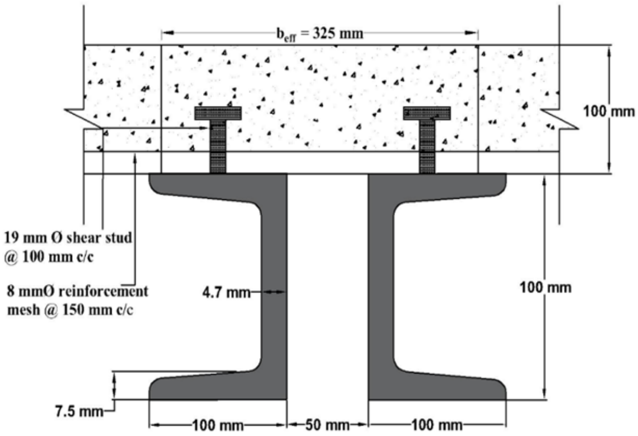


Figure-7: Composite beam 3(CB3) (2ISMC 100)

3.4 Composite beam 4 (2 Cold formed section (CFS 150))

The composite beam-4 specimen consisting of 2 cold formed lipped channels with spacing of 50 mm with full interaction between concrete slab and steel beam. Sectional properties of cold formed section are checked as specified in Eurocode EN 1993 1-3. CFS 150 shows considerable buckling at support.

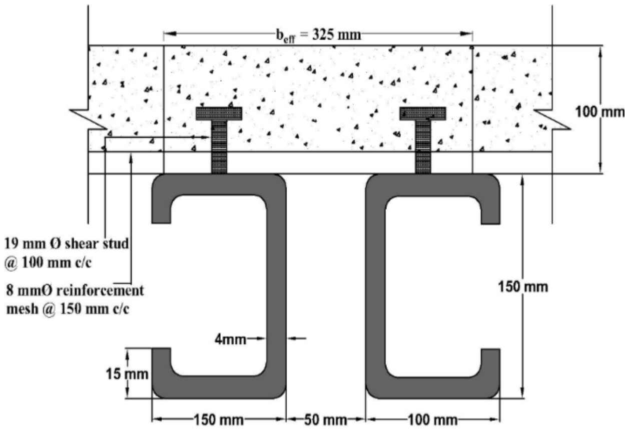


Figure-8: Composite beam 4(CB4) (2CFS 150)

4. EXPERIMENTAL RESULTS

For all test specimen values of mid span deflection, slip and strain values are recorded. The buckling modes for cold formed sections were identified and recorded. The deflection and slip values were recorded at each 50 kN load increment. Recorded test values are shown in Table:3 (CB1), Table :4 (CB2), Table:5 (CB3) and Table:6 (CB4). Cold formed composite beams shows considerable deflection and slip at interface as compare to hot rolled composite beam.

Table 3: Mid span deflection and Slip (CB1)

Load (kN)	Mid span deflection (mm)	Slip (mm)
0	0	0
50	2	1
100	3	1.5
150	3.5	2
200	4.5	2.25
250	5	2.5
300	6	3

Table 4: Mid span deflection and Slip (CB2)

Load (kN)	Mid span deflection (mm)	Slip (mm)
0	0	0
50	2	1
100	4	2.5
150	7	3
200	11	4
218	14	5

Table 5: Mid span deflection and Slip(CB3)

Load (kN)	Central Deflection (mm)	Slip (mm)
0	0	0
50	0.5	0.5
100	1	1
150	2	1.5
200	4	2
250	5	2.7
300	6	3.5

Table 6: Mid span deflection and Slip (CB4)

Load (kN)	Central Deflection (mm)	Slip (mm)
0	0	0
50	2	1
100	4	2
150	8	3
200	9	5
222	12	7

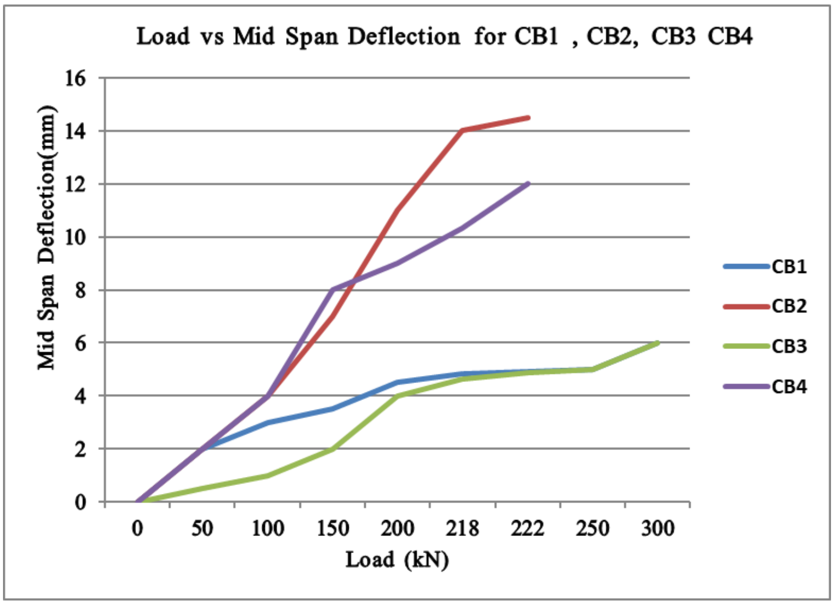


Figure-9: Mid span deflection (CB1 -CB4)

Figure-9 shows values of mid span deflection for CB1(Hot rolled ISMB 175), CB2 (Cold formed SHS 150), CB3 (Hot rolled ISMC 100) and CB4 (Cold formed lipped channel CFS 150). Cold formed composite beam recorded very high deflection.

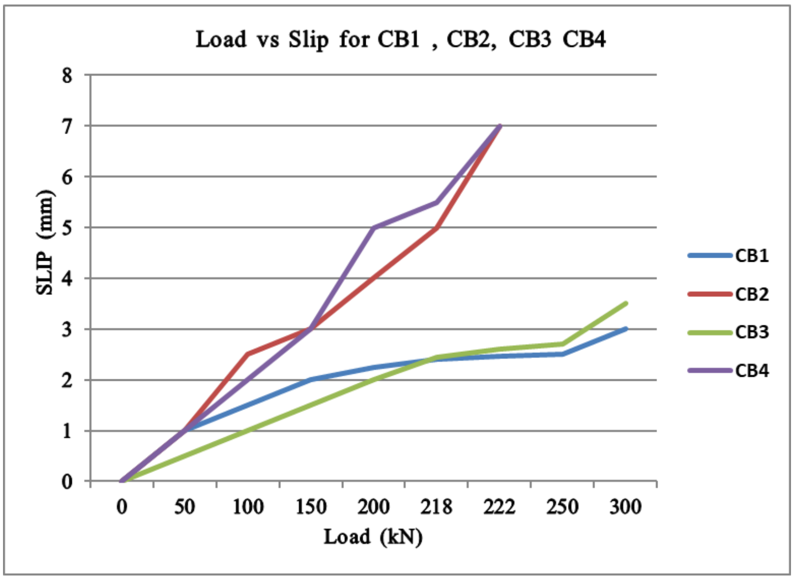


Figure-10: Slip (CB1 -CB4)

Figure-10 shows values of slip at interface for CB1 (Hot rolled ISMB 175), CB2 (Cold formed SHS 150), CB3 (Hot rolled ISMC 100) and CB4 (Cold formed lipped channel CFS 150). cold formed composite beam shows higher values of slip as compare to hot rolled composite beam.

5. DISCUSSION AND FINDINGS

Analytical flexural strength of CB1 (Hot rolled ISMB 175) matches with experimental flexural strength. It shows little buckling of flange at support as shown in figure 11. Minor cracks are also observed under ultimate load conditions as shown in figure 12.

CB2 (Cold formed SHS 150) buckles at support without reaching ultimate load conditions due to thinner web in spite of sectional properties criteria for the same section checked using EN 1993 1-1: Eurocode 3. The square hollow section satisfied criteria of compact section as specified in EN 1993 1-1: Eurocode 3. Still, Section shows considerable buckling and deflection at support as shown in figure 13. Buckling mode of CB2 exactly matches with mode shown in figure 1 for square hollow section.

Table 7: Analytical and Experimental strength of beam

Composite beam	Predicted Analytical strength	Experimental Strength	Remarks
CB1 (Hot rolled ISMB 175)	300 kN	310 kN	Buckling of flange and cracks in slab observed at 330 kN
CB2 (Cold formed SHS 150)	250 kN	220 kN	Considerable Buckling of web observed at 220 kN
CB3 (2 ISMC 100)	250 kN	300 kN	Little buckling of flange observed at 250 kN
CB4 (2 CFS 150)	220 kN	180 kN	Considerable distortional buckling of observed at 180 kN

Figure-11: Little buckling of flange at support (CB1)

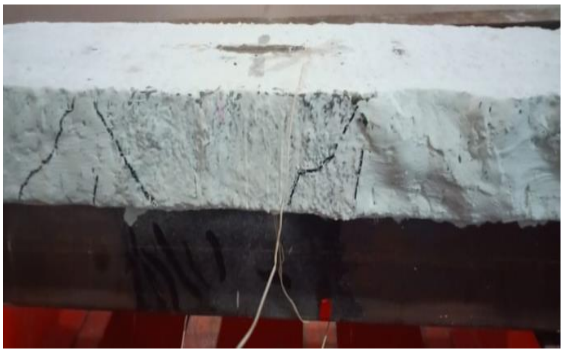


Figure-12: Minor cracks developed in slab(CB1)

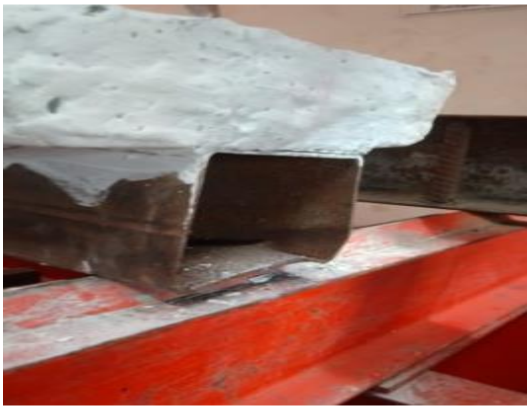


Figure-13: Buckling of hollow section support (CB2)

Figure -14: little Buckling of ISMC at at support (CB3)

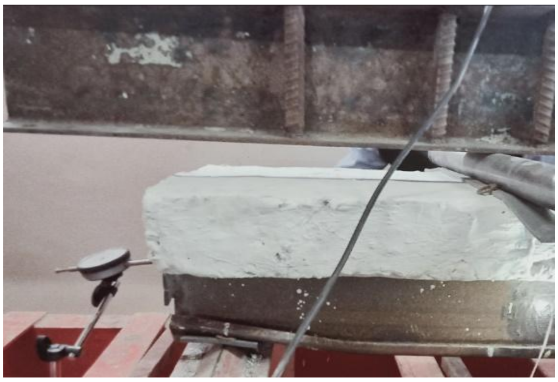


Figure-15: Distortional buckling of CFS 150 at support (CB4)

CB3 (ISMC 100) shows very little buckling at support as shown in figure 14. Very fine cracks were observed at ultimate load conditions, which disappears after releasing load.

CB4 (CFS 150) shows excessive buckling at support as shown in figure 15. Section undergoes very high deflection under ultimate load condition. Permeant deformation observed after releasing load. The buckling mode of CFS 150 matches with distortional buckling as shown in figure 2.

6. CONCLUSION

1. Use of cold formed section decreases over all weight of structure as well as it can be built according to the strength requirement, but It is also important to look over its limitations. Cold formed sections limitations and its enhancement of structural applications needs to be focused.
2. Structural hollow sections give greater moment of resistance against torsion but the same is subjected to considerable buckling at support. CB2 (Cold formed SHS 150) satisfied criteria of limiting depth to thickness Ratio of hollow Square Section as per EN 1993-1-1 (2005). (Eurocode :3) but shows considerable web buckling at support. The provision of depth to thickness ratio limits prescribed in EN 1993-1-1 (2005). (Eurocode :3) needs to be revised.
   CB2 (Cold formed SHS 150) shows buckling of web at support only as shown in figure 13, so a stiffening plate can be provided at support (at beam to column Junction). As a result, total shear acting at support will be distributed between connecting plate and web of hollow square section and eliminating web buckling
3. Observed deflection is more in CB4 (Cold formed CFS 150) as compare to CB3 (Hot rolled ISMC 100). CB2 undergoes distortional buckling under two-point loading condition as shown in Figure 15.Cold formed composite beam undergoes higher deflection as well as deformation near support. Web buckles under ultimate load at support, so bearing stiffeners needs to be provided to prevent buckling.
4. Hot rolled composite beam CB1 (ISMB 500) and CB3 (2 ISMC 100) shows very less deflection and slip as compare to cold formed composite beam. Analytical results of design strength match with experimental testing results for CB1(ISMB 500) and CB3 (2 ISMC 100) as shown in Table 7.

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