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Study on Precast Coconut Shell Concrete Beam-Column Junction Using M-Sand under Static Load

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Abstract: Coconut shell (CS) is one of the sustainable alternative aggregates and coconut shell concrete (CSC) was developed a decade earlier. Prefabricated conventional concrete (CC) and CSC using M-sand, and their research are very limited. Capacity and behavior of the joints are important in precast. Hence in this study, precast column-beam behavior of CSC elements was studied. Two different sizes 12 and 16 mm bolts and nuts connection were chosen and used to connect the precast elements. Also, the same sectional details were used and specimens produced for combination with CC using M-sand (CCM). Specimen failure of both monolithic and prefabricated CSC using M-sand (CSCM) elements was typical structural failure and is comparable to that of CCM. Compared to CCM, high deflection was observed on CSCM element. No crack was developed on both CCM and CSCM prefabricated specimen. All elements were able to sustain their maximum potential for strain. Column-beam joint behavior of CSCM monolithic and prefabricated specimen behavior are comparable to that of CCM.

Keywords: Coconut shell concrete, m-sand, precast, beam-column, joint connections

1. Introduction

One of the main constituents of concrete is fine aggregate, which is normally obtained from natural river resources. Due to over exploitation of river sand for construction activities and depletion of natural resources, it is very significant and need of the hour to find an alternate [1]-[6]. Manufactured sand (M-sand) is one of an alternate material for river sand. In recent days, concrete is also produced using coconut shell (CS) as coarse aggregate and the concrete is called coconut shell concrete (CSC) [7]-[10]. Construction is a key industry for many economies as it contributes largely to their gross domestic product (GDP). There is a need for the construction sector to improve its efficiency by adopting an innovated technology such as prefabrication and precast. Therefore, there is a need to do much research in this field, which will aid to enhance the familiarity base for the precast construction [11]. The combination of the precast concrete using CSC and their behaviour are limited at present and hence this study has been taken.

2. Materials and Mix Proportions

As per IS 12269:2013 [12], ordinary Portland cement 53 grade was used in this study. M-sand was obtained from one of the local quarry and this was conforming to zone II as per IS 383: 2016 [13]. To prepare the CS aggregates, from one of the coconut industry raw CS was collected and crushed in to the maximum sizes of 12.5 mm using the coconut shell crusher devised in the University premises. For comparison purpose, crushed stone aggregate (CSA) having the same maximum of sizes of 12.5 mm was used produced the conventional concrete (CC). The properties of the materials used in this study were presented in Table 1.

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Two mixes were considered in this study: one is M-sand used conventional concrete mix designated, as CCM and the other one is M-sand used coconut shell concrete designated as CSCM. Mix proportions adopted for CCM as 1:2.42:3.66:0.60 and for CSCM as 1:1.61.65:0.42 in which the 320 kg/m^3 and 510 kg/m^3 cement contents were used for the respective mixes.

Table 1 - Properties of materials used

Properties	Crushed stone aggregate (CSA)	Coconut shell (CS)	M-sand
Size (mm)	12.50	12.50	4.75
Absorption of water (%)	0.50	24.00	1.96
Specific gravity	2.82	1.05	2.80
Impact value (%)	12.40	8.15	-
Crushing value (%)	20.10	2.58	-
Bulk density (kg/m^3)	1650	650	1860
Thickness (mm)	-	2-7	-
Fineness modulus (sieve)	6.85	6.18	2.89
Flakiness index (%)	12.5	100	-

3. Details of Works

In this section, the design and detailing of monolithic element and precast element connections and the experimental works are discussed.

3.1 Design and Details of Elements

Based on the facilities available at the institute, the size of monolithic and precast elements was selected. The following segment presents the cross sectional details and detailing of the both monolithic and precast elements. The cross section of both beam and column remained same for monolithic and precast elements (i.e.) 125 mm × 125 mm. The span of column and beam was 1500 mm and 700 mm, respectively. The beam was positioned such that the centre of the beam coincides with the centre of the column. The beam reinforcement detailing includes: 2 numbers of 10 mm diameter steel bars at both the face of tension and compression and to take care of shear 6 mm diameter stirrups at 30 mm center to center (c/c) spacing at a distance of 240 mm from face of column and at 70 mm c/c spacing for the remaining length was adopted. Similarly, 4 numbers of 12 mm diameter steel bars were provided as longitudinal reinforcement in column and lateral ties of 6 mm diameter steel bar at 60 mm c/c spacing throughout column except in the junction between beam and column for a distance of 210 mm both up and down sides in which spacing was adopted 30 mm c/c as a special confinement as guided in IS 13920: 1993 [14] was provided. For precast element, a corbel was provided at a distance of 812.5 mm from the top of the column to position the beam. The width of the corbel was same as that of cross section of the beam and column, which is 125 mm. the depth of the corbel at the face of the column, was 125 mm and it eventually decreased at the other end to 65 mm. The corbel reinforcement includes: 3 numbers of 10 mm diameter steel bars at both lateral and longitudinal direction. Conversely, these cross sectional and reinforcement detailing are in proportion and equivalent with the similar works by the other researchers [15 and 16]. The cross sectional and detailing of the monolithic and precast specimen was shown in Fig. 1 and 2, respectively. As this was a new attempt and no previous studies were available related to precast technology in CSCM, a basic combination of bolt and nut was used to study their behavior. In this study, 12 mm diameter and 16 mm diameter bolts were used and two numbers were adopted for each specimen. In order to fill the fissure between the bolts and bolt holes, iso-polyster carbon resin was used.

3.2 Experimental Setup

The loading frame of capacity 200 kN self-straining was used for testing. The column was placed vertical in an upright position and beam is in the horizontal direction. The movement of the column was restricted at both the ends using clamps. This condition was adopted because the main objective of this study is to observe the behavior of the beam-column junction. Digital dial gauges having 0.01 mm least count were placed at three various locations on the beam such as one near the corbel (i.e.) 150 mm from the face of the column, one at the midpoint of the beam (350 mm from the face of the column) and other near to the application of load (540 mm from the face of the column) to measure the deformations in the beam. The point of application of load was selected at a distance of 600 mm from the face of the column. A push pull jack with capacity 100 kN was used to apply the load at an increment of 1 kN. During the application of load, the cracks formed were observed using a microscope with an optical magnification of 40× and a sensitivity of 0.01 mm. The electrical resistance strain gauges and demec gauges were used to measure the strain developed both in steel and on the surface. Fig. 3 represents the schematic diagram of the experimental test setup.

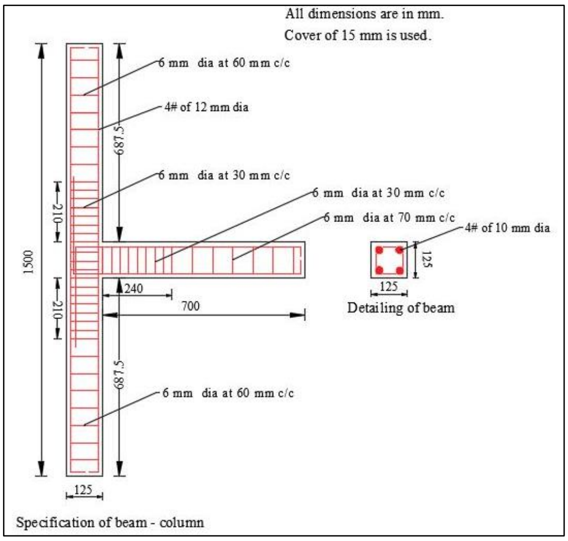

Fig. 1 - Cross sectional and detailing of the monolithic specimen

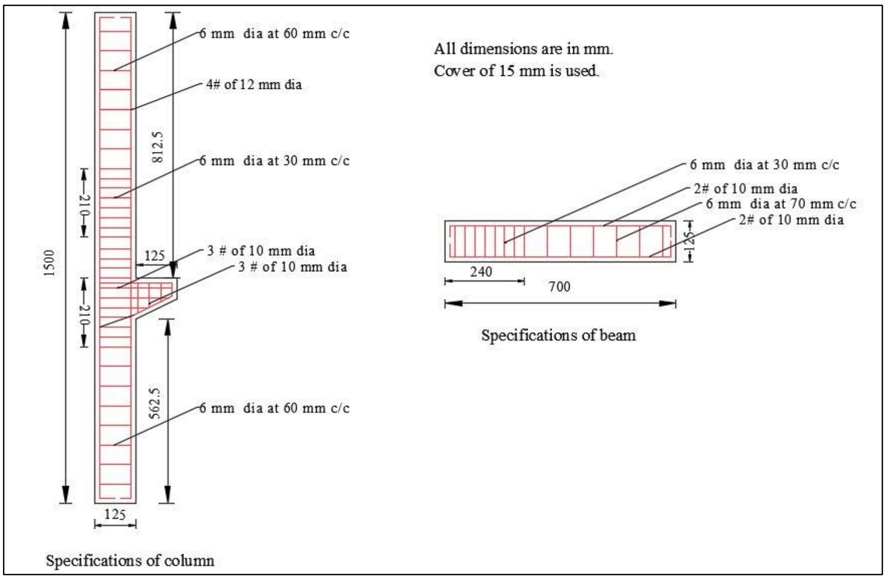

Fig. 2 - Cross sectional and detailing of the precast column and beam specimen

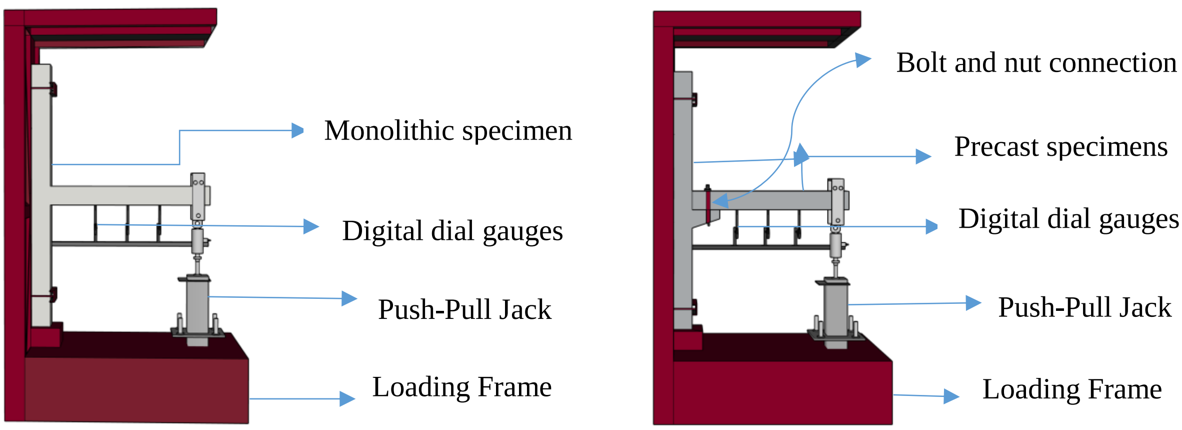

Fig. 3 - Schematic diagram representing the experimental test setup

4. Results and Discussion

The parameters such as ultimate strength of the specimen, deflection behavior and strain in steel and concrete and crack pattern were studied and the results are discussed in this section for both monolithic and precast specimen.

4.1 General Observations

There was typical structural failure observed in both in monolithic and precast elements. Only vertical cracks were formed and no horizontal cracks were found. This indicates that the proper bonding between the steel and concrete matrix exits in both CCM and CSCM. In monolithic specimen at the top of beam, tension cracks were first formed as shown in Fig. 4 in beam–column junction. With the increment in load, the crack, which was formed, developed in both length and width. Also, there were formations of few new cracks as load increased. In precast element, no cracks were formed in both 12 mm and 16 mm diameter bolts used elements. (Fig. 4). In precast specimen, when the initial load was applied, there was a sudden slip of the beam and the same was observed in both the precast elements. This slip was due to the insufficient tightness of the bolts. After the slip, the behavior of both precast specimen was similar till it reaches the maximum load carrying capacity. There was maximum deflection at the ends and lifting of beam was found at the joints as shown in Fig. 4. There were similar kind of behavior in both CCM and CSCM elements. It can be interpreted that the behavior of CSCM specimen was similar to that of CCM.

4.2 Strength

Table 2 illustrates the ultimate load carrying capacity of both monolithic and precast elements and also a comparative note on experimental and theoretical load and moment values. With the help of experimental and theoretical values, the capacity ratio was calculated by taking the ratio between them. IS 456: 2000 [17] was used to calculate the theoretical values. In case of monolithic elements, the capacity ratio of CCM and CSCM are found to be 1.90 and 1.63, respectively which show that IS 456: 2000 can also be used for the estimation of CSC strength also. From the strength results, it was observed that the load carrying capacity of precast element connected using with 12 mm bolt was 23% lesser compared to monolithic specimen of CCM and 18% lesser of CSCM. Similarly, the load carrying capacity of precast element connected using with 16 mm bolt was found to be 44% higher than monolithic of CCM and 41% higher of CSCM. From this it can be suggested that the usage of two numbers of 16 mm bolt in precast specimen was sufficient when compared to 12 mm bolts usage for the size and shape and also the detailing of specimen used in this study.

Table 2 - Ultimate capacity comparison of monolithic and precast elements

Experimental Values (load in kN)		Theoretical values (load in kN)		Experimental Values (moment in kNm)		Theoretical values (moment in kNm)		Capacity ratio (Exp / Theo)	
CCM	CSCM	CCM	CSCM	CCM	CSCM	CCM	CSCM	CCM	CSCM
Monolithic elements									
16	13.5	8.42	8.25	9.6	8.1	5.05	4.95	1.90	1.63
Precast elements provided with 12 mm size bolt									
13	11.5	9.39	9.20	7.8	6.9	5.05	4.95	1.38	1.25
Precast elements provided with 16 mm size bolt									
23	19	9.39	9.20	13.8	11.4	5.05	4.95	2.45	2.06

Fig. 4 -Tension cracks at the beam-column junction and lifting of beam in specimen

4.3 Load-Deflection Behavior

The load deflection pattern was found to be similar for both monolithic and precast elements. Fig. 5 show the load versus deflection curve for monolithic elements of CCM and CSCM. Fig. 6 show the load versus deflection curve for precast elements CCM and CSCM connected (a) 12 mm (b) 16 mm size bolts used, respectively. Though the deflection pattern was found to be similar, the deflection of CSCM was found to higher than CCM element in monolithic elements. The porous nature, less stiffness of CS is the reason for the higher deflection. The load deflection was parabolic in nature. The similar pattern was observed in precast element of both the specimen (i.e) specimen with 12 mm bolt and 16 mm bolt. But in case of precast element there was a sudden deflection found during the application of initial load. After this deflection the behavior of element was similar to that of monolithic element.in this case also, the deflection was found to be higher for CSCM element. Over all, the load-deflection curves of both CCM and CSCM are parabolic in which it is initially linear followed by parabolic curve.

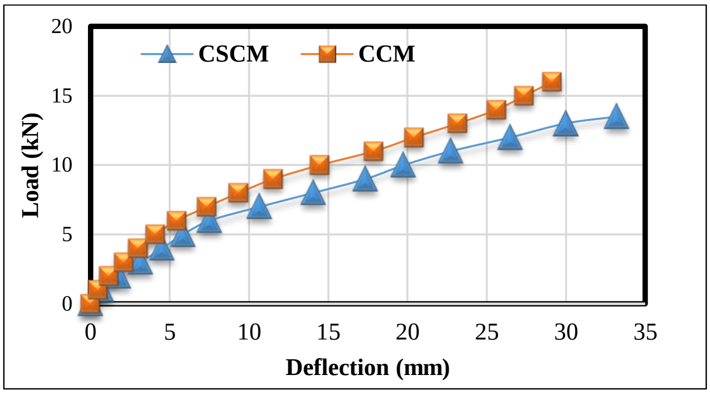

Fig. 5 - Load vs deflection (monolithic)

The limiting value of deflection was not considered as the detailing and specimen cross sections were fixed and the aim was to concentrate on the joint behavior. The factor of safety 1.5 is assumed according to IS 456: 2000 [17] for concrete for calculating the service loads. The corresponding deflections for ultimate and service loads are given in Table 3.

Table 3 - Deflection comparison of monolithic and precast elements

Experimental				Deflection			
Ultimate load (kN)		Service load (kN)		At ultimate (mm)		At service (mm)	
CCM	CSCM	CCM	CSCM	CCM	CSCM	CCM	CSCM
Monolithic elements							
16	13.5	10.67	9.00	29.14	33.24	17.01	17.37
Precast elements provided with 12 mm size bolt							
13	11.5	8.67	7.67	26.55	41.89	21.15	31.12
Precast elements provided with 16 mm size bolt							
23	19	15.33	12.67	35.55	42.85	20.81	27.52

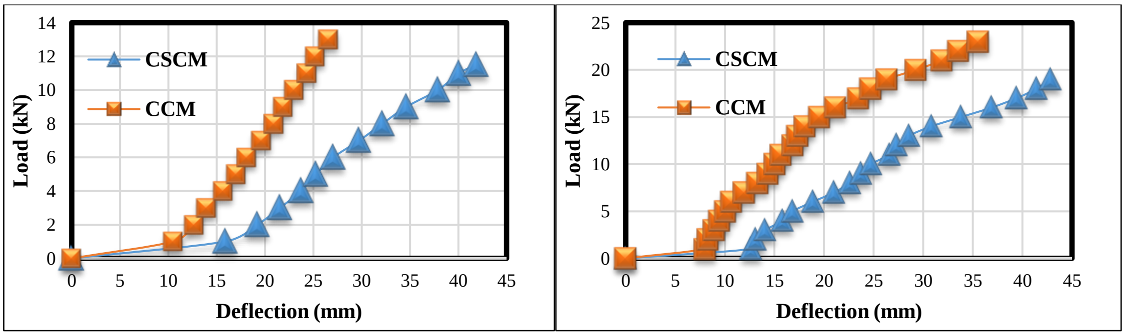

Fig. 6 - Load vs deflection - precast (a) 12 mm bolts, (b) 16 mm bolts used

4.3 Crack Pattern

The formation of cracks and their transmission were measured and marked on all specimens from beginning to end of the test. In the case of CCM and CSCM monolithic specimen, first crack occurred in a place of column-beam junction. First crack occurred at 6.70 kN on CCM monolithic specimen which was about 42% of its ultimate load. Likewise, the first crack was noticed on CSCM specimen was at 5.20 kN which was 38% of its ultimate load. In both cases the cracks formed were further propagated. All the cracks formed have been almost vertical indicated that the behavior of the section of the beam was under flexure. Only the crack occurred at junction propagated crossing midsection of beam and all other cracks propagated less than the midsection of the beam at the ultimate load. There was no more crack, and all the cracks occurred well before half of the beam's span (totally 7 cracks were formed). In the case of CSCM monolithic element, first crack occurred at the junction and totally 5 cracks were occurred. Similar behavior was observed on CSCM compared to CCM element.

No cracks were formed on CCM and CSCM prefabricated specimen. Instead the beam was lifted by 18 mm and 14 mm by the CCM and CSCM elements; respectively in case of beams connected using with 12 mm diameter bolts. In case of beam provided with 16 mm size bolts, these uplift were assessed as 24 mm and 23 mm for CCM and CSCM specimen, respectively. Uplifting of beam and concrete crushing was observed because of constrained in the movement of the beam specimen as shown in Fig. 7. Since only two bolts were provided to connect the beam and column through the corbel and also through the rupture between the bolt and the specimen were filled with iso resin, there were chances of the bolts slipping. This may be the reason why cracks do not form in such cases.

Fig. 7 - Uplift and crushing of CSCM specimen

4.4 Strains

Strains on concrete and steel were measured for each load increment. Strains measured for concrete and steel for both CCM and CSCM monolithic specimen, and precast elements are shown in Figs. 8 and 9, respectively. At the service loads and ultimate and, the corresponding strains are tabulated in Table 4. Steel tension strain at ultimate and service loads of CCM elements are more compared to CSCM elements in all three cases. Surface concrete strain at ultimate and service loads of CCM elements are less compared to CSCM elements in all three cases. It also shows that the characteristics and properties of CCM are typically strong compared to CSCM where CS was used as coarse aggregate instead of CSA. This is due to less stiffness and strength of CS compared to CSA and is obvious. However, it can be stated that the CSCM is capable to succeed its complete strain capacity.

Table 4 - Strain comparison of monolithic and precast elements

Steel tension strain at ultimate load		Steel tension strain at service load		Surface concrete strain at ultimate load		Surface concrete strain at service load	
CCM	**CSCM**	**CCM**	**CSCM**	**CCM**	**CSCM**	**CCM**	**CSCM**
Monolithic elements							
3535	3346	1777	1601	1709	2714	716	1256
Precast elements provided with 12 mm size bolt							
1592	1484	1040	811	767	1359	335	733
Precast elements provided with 16 mm size bolt							
2056	1968	1365	1318	1702	1723	781	1158

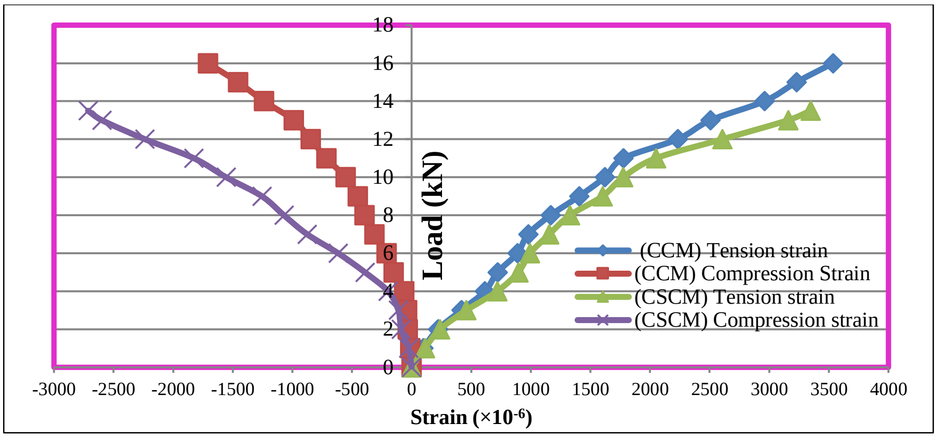

Fig. 8 - Load Vs Strain monolithic elements

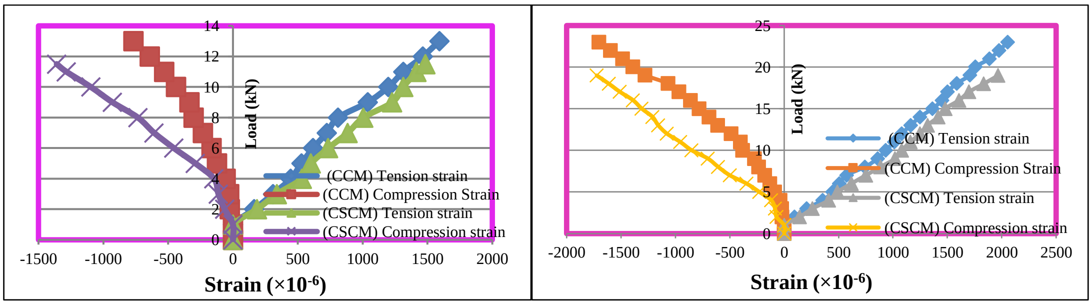

Fig. 9 - Load Vs Strain - Precast (a) 12 mm bolts; (b) 16 mm bolts used

5. Conclusions

Typical structural behavior has been observed in both monolithic and prefabricated elements of both CCM and CSCM. There is no possibility of bond failure between the CSCM and reinforcement, since no horizontal cracks have been found. For prefabricated elements connected with 12 mm and 16 mm bolts, no crack was formed. The precast beam element above the corbel was initially lifted and occurred in all precast beam elements because the tightness provided to the bolts was not adequate and therefore the specimen was initially slipped. For the sectional details used in this research, 2 numbers of 12 mm bolts provided are in sufficient and 2 numbers of 16 mm bolts are sufficient. The strength of both monolithic and precast elements can be estimated using IS 456: 2000. Due to the porous nature, less stiffness and low density of CS, the deflection of CSCM element was high compared to CCM element. All the cracks formed in the maximum flexural zone (i.e) well before half the span of the beam, which shows that the behavior of CSCM is similar to that of CCM element. However, more focus is to be given in the future to avoid the slippage happened between the bolts and the elements. CSCM elements used in this study were able to achieve their full strain capacity. Column – beam joint behaviour of CSCM monolithic and precast specimen behaviour is comparable to CCM. However, further research must be carried out to overcome the deficiency currently faced in this study.

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