SCOUR AT CYLINDRICAL BRIDGE PIER IN A 180 DEGREE CHANNEL BEND

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The local scour around bridge piers is one of the most common causes of bridge failures. In general, scour phenomenon is extremely complex in nature and consequently in the past many investigators have attempted to develop conservation, analytical, semi-empirical or empirical equations based on the understanding of mechanics of local and general scouring. However most of the researchers have studied the scour at bridge pier located in a straight channel and no study has been conducted when bridge pier is located in a curved channel.

In this paper, scouring are studied both in straight channel and in U-shape channel having a central angle of 180^o. In order to study local scour, a 6cm-diameter pier was located in the straight channel and also in sections 30 and 60 degrees in the bend. This study shows that the minimum amount of scour depth (d_s) at each discharge can be occurred at straight channel when pier is located in the bend, the amount of scour depth increases as compare to that in a straight channel. The location of scour hole in the bend is close to the outer wall of channel and the point bar is close to the inner wall of channel.

Key Words *: Circular pier,local Scour, Bend, Spiral Flow*

1. INTRODUCTION

The importance of local scour around bridge piers has been known for many years.

According to Richardson and Davis (2001), the local scour around bridge piers is one of the most common causes of bridge failures. It is a widespread problem and has the potential for the tragic results.

Eighty-six percent of the 577,000 bridges in the national bridge registry (USA) are built over water ways. More than 26,000 of these bridges have been found to be scoured critical, meaning that the stability of the bridge foundation has been or could be affected by the removal of bed material (Richardson, 2002). Over 1000 bridge failures occurred in the United States during last 30 years. More than 85,000 bridges in the U.S. are vulnerable to scour.

Pier scour is the erosion of the streambed in the vicinity of the pier foundation due to complex vortex system. This system consists of a horseshoe vortex initiated from the down flow at the upstream face of the pier, and wake vortices which shed from sides of the pier due to flow separation (Breusers and Raudkivi, 1991). This complex system digs the scour hole and deepens it.

Flow pattern and mechanism of scouring around a bridge pier has been reported by various investigators. A lot of extensive experiments have been done until now, to study the flow pattern and local scour. Some of these experiments are done by (Raudkivi and Ettema (1983), Chiew and Melville(1987), Dargahi (1987), Breusers and Raudkivi (1991) and Melville and Coleman(2002)). most of these studies have been done in straight channels. There is a few information, to the knowledge of authors, about the scour at bridge pier in a curved channel.

The main feature of a bend flow is the presence of spiral flow and lateral sediment transport across the channel bend is observable. Particles at the surface of the flow in the bend tend to move toward the outer wall while at the bed elevation they tend to move toward the inner wall of channel (Odgaard and Bergs, 1988).

This paper presents the experimental results on scour at a cylindrical pier located at different sections in a 180 degree channel bend. In order to understand the effect of bend on the scour hole, the results are compared with those in a straight channel.

2. EXPERIMENT

Experiments were conducted in a re-circulating channel having the central angle of 180o, radius of channel centerline $r_c = 2.6$ m, width of 0.6 m and height of 0.6 m. Fig.1 shows the schematic plan of the laboratory channel. The bend is connected to straight reaches at the upstream and downstream of the channel. The base and sides of the channel is made of Plexiglas and are supported with metal frames. A sharp crested triangular weir at the downstream of the return channel was used to measure the discharge. Water was supplied from a sump into the entrance basin. Water level in the channel was controlled by a tail gate situated at the end of channel.

A layer of uniform sand with 20 cm thickness, mean diameter of $d_{50} = 1.28$ mm and standard deviation of $\sigma_g = 1.3$ was placed on the bed and covered the total length of channel. The sand bed surface was leveled by a plate which was attached to a carriage. A digital point gauge with ±0.01 mm accuracy was used to measure the water surface level and the topography of the channel bed.

A PVC pipe with 6 cm diameter was used to model the pier. It was located in section 30 and 60 degree from the beginning of the bend and also in the middle of upstream straight channel separately which called position 0 degree at this paper. Therefore, The parameter θ_p which is equal to 0, 30 or 60 degree represents the location of the pier in the channel.

Four different discharges (i.e. 30, 35, 40 and 42 liter/s) were used to study the effect of flow. Depth of flow in all the experiments was constant and equal to 20 cm. Using the Neil's criteria, the corresponding flow intensities (u/u_c) were found to be equal to 0.56, 0.66, 0.75 and 0.79 for straight reach of channel (Neil, 1973). Here u is the velocity at the upstream and uc is the velocity for the initiation of sediment movement. It was observed that for flow intensity of 0.79, sediment particles in the bend just begin to move. This means that this value of flow intensity is the critical value for the sediment.

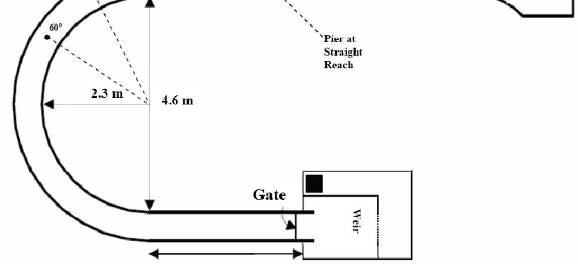


Fig.1 Schematic view of Laboratory channe.

All the experiments were conducted until the equilibrium condition was reached. The preliminary experiments were conducted in order to specify the equilibrium condition. The pier was located at three positions i.e. 0, 30 and 60 degree of the bend and experiments ran separately. It was observed that after 20 hours, the rate of scouring was negligible. After this time, the bed topography around the pier was measured by the point gauge.

3. RESULTS

Results of the bed topography around the pier located at different sections of the channel under various flow conditions are presented here. In this study the effect of discharge or flow intensity on bed topography is investigated. Some specific parameters used in this paper are shown in Fig.2-a and 2-b. Fig. 2-a shows the longitudinal profile of the center line of the channel and shows both scour hole and point bar. Fig.2-b shows the lateral cross section of the scour hole. In this figure; W_h = maximum width of sour hole, L_h = maximum length of scour hole, L_p = maximum length of point bar, φ_u = upstream slope of scour hole, φ_d = downstream slope of scour hole, φ_{ow} = outer wall-slope of scour hole, φ_{iw} = inner wall-slope of scour hole and ds = maximum depth of scour hole. It is to be noted that at the straight channel, the parameters φ_{ow} and φ_{iw} will be equal to φ_w.

(1) Pier at straight channel

Figures (3-a) to (3-d) shows the effect of discharge on bed topography around a pier located in a straight channel $(\theta_p = 0°)$. These Figs. show that the dimensions of scour hole and point bar increased with increasing the discharge. As it is clear, both scour hole and point bar are symmetrical with respect to the center line of the channel.

The dimensions of scour hole and point bar for pier located in the straight channel are given in Table 1. It is evident from this table that the maximum depth of scour hole d_s is increases with increasing the discharge. Also, the length of the scour hole L_h and point bar L_p and width of the scour hole W_h is increased.

It is obvious that φ_u increases while φ_d decreases, despite of φ_w which is constant, so it can be concluded that the slope of lateral-walls of the scour hole are not affected when discharge changes.

Moreover, the values of the parameter φ_u increases by increasing the discharge and at higher values of discharge its value is close to the values of φ_w. While φ_d decreases by increasing the discharge.

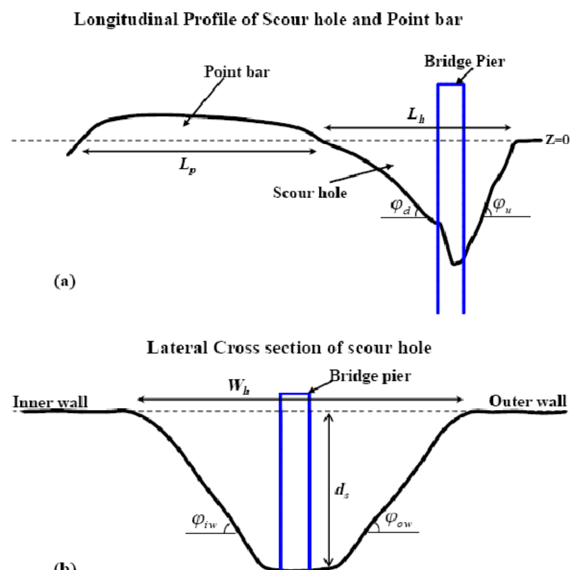


Fig.2 Schematic view of scour hole and point bar, a) Longitudinal profile of scour hole and point bar, b) Lateral cross section of the scour hole.

Table 1. Scour parameters for pier in straight channel

Experiment Code	Q (l/s)	L_h (m)	L_p (m)	φ_u (Deg.)	φ_d (Deg.)	W_h (m)	φ_w (Deg.)	d_s (m)
ST1-30	30	0.18	0.135	29	24	0.175	34	0.03990
ST1-35	35	0.30	0.29	34.5	23	0.275	34	0.07325
ST1-40	40	0.40	0.58	35.5	19	0.325	34	0.09939
ST1-42	42	0.53	0.74	36	14	0.375	34	0.10633

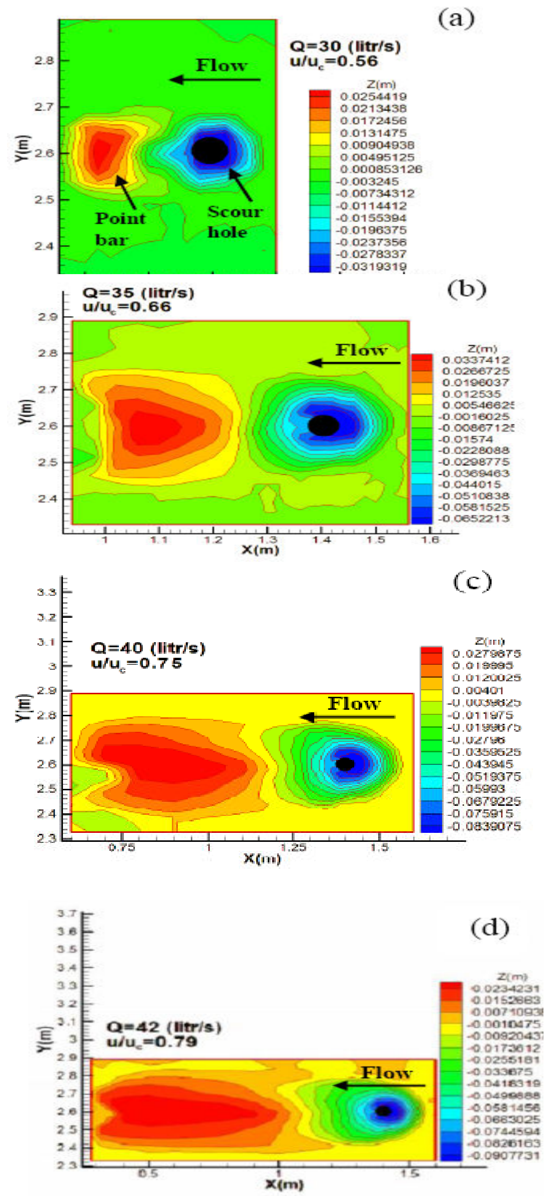


Fig.3 Bed topography around the pier located in straight channel (θp =0°)

a) Q=30 lit/s b) Q=35 lit/s
c) Q=35 lit/s d) Q=42 lit/s

(2) Pier at section 30 degree of the bend

When the pier is located at section 30 degree of the bend $(\theta_p = 30°)$, it causes a significant changes the topography of bed. These changes are shown in Fig. (4-a) to (4-d). As it is evident from these figures the dimensions of the scour hole and point bar, specifically maximum scour depth, increase with increasing the discharge. The rate of increasing is significant at higher discharges. Also the scour hole is found to be close to the outer wall of channel. Moreover, the point bar tend to occur nearer to the inner wall of channel. The reason for this is the effect of spiral flow on scouring process. At the upstream face of the pier, spiral flow and horseshoe vortex merge and forms a complex flow which digs the bed and deepens the outer part of the scour hole (near the outer wall of channel) more. But at the downstream of the pier, spiral flow is stronger so flow carries the scoured bed material toward the inner wall of channel. At higher values of discharge, the point bar is much more close to the inner wall of channel.

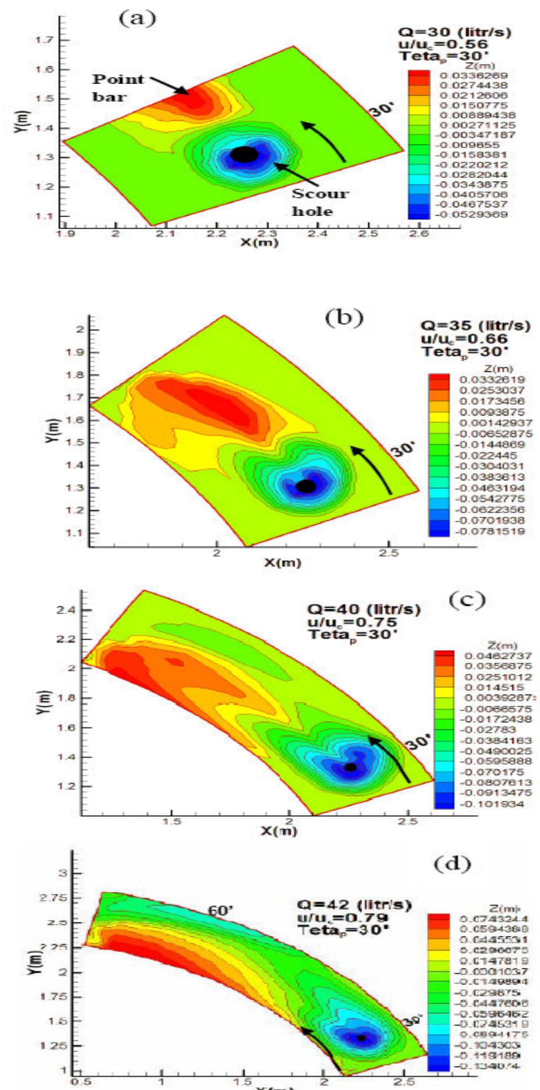


Fig.4 Bed topography around the pier located at section 30 degree of the bend (θp =30°)

a) Q=30 lit/s b) Q=35 lit/s
c) Q=35 lit/s d) Q=42 lit/s

Table 2. Scour parameters for pier at section 30o of the bend

Experiment code	Q (l/s)	L_h (m)	L_p (m)	φ_u (Deg.)	φ_d (Deg.)	W_h (m)	φ_{ow} (Deg.)	φ_{iw} (Deg.)	d_s (m)
C30-30	30	0.26	0.20	30	22.5	0.225	26.5	33	0.05912
C30-35	35	0.38	0.49	31	17	0.325	32	35	0.08611
C30-40	40	0.72	0.99	28	13	0.460	26	33	0.11252
C30-42	42	1.45	1.11	27.5	7.5	0.535	28.5	33.5	0.14896

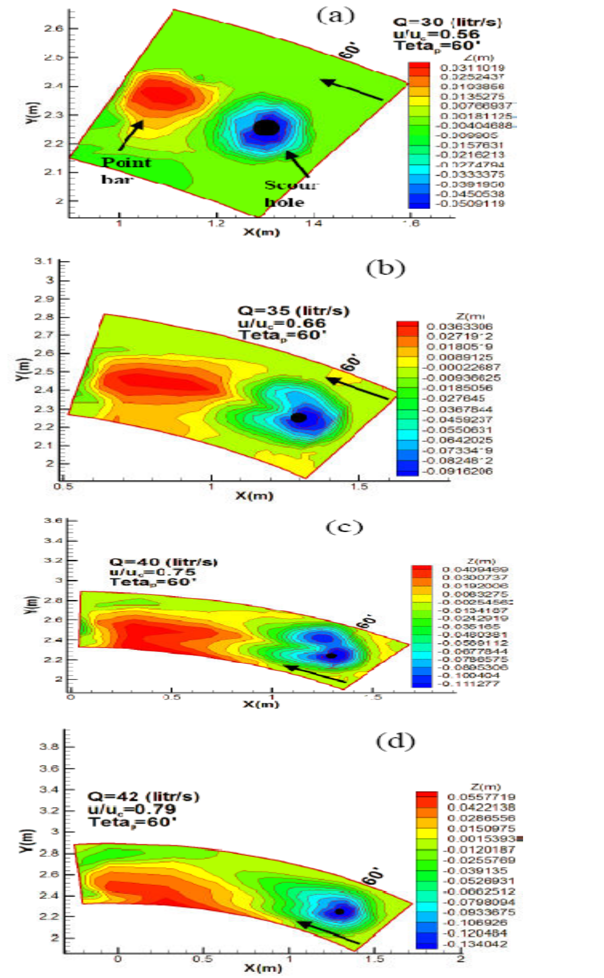
According to Table 2, it is clear that φ_d <, φ_u for all discharges, because the scour in the downstream wall of the scour hole is more. Also we can say that φ_{iw}, is approximately constant and is the same as the wall-slope of scour hole at the straight channel φ_w, which means that the inner wall of the scour hole is not susceptible to be affected by spiral flow in the bend. But the value of φ_{ow} is always less than φ_{iw}, because of the presence of complex flow in the bend.

(3) Pier at section 60 degree of the bend

Scour around the pier at section 60 degree of the bend $(\theta_p = 60°)$ is similar to that of the pier at section 30 degree of the bend. As it is shown in Fig.5 it is clear that the point bar is closer to the inner wall and scour hole closer to the outer wall as compare to the pier located at section 30 degree of the bend (see Fig.4). The reason for this phenomenon is the effect of spiral flow. As it is studied by Rozovskii (1957) the strength of spiral flow is more considerable at the middle parts of first half of 180 degree bend, so the location of point bar and scour hole at section $\theta_p = 30°$ is more expected to be near the walls. He found that the strength of spiral flow from section 0 to 60 degree of the bend increases, while after this section it is decreasing gradually

Other features of scouring at this section such as increase in dimensions of scour hole and point bar are similar to pier located at section 30 degree of the bend.

Table 3 shows dimensions of scour hole for four different discharges when pier is located at section 60 degree of the bend. According to this table it is clear that all the dimensions of scour hole increases due to increase of the discharge. It is also clear that the amount of φ_d is much smaller than φ_u. Meanwhile because of spiral flow effects, φ_{iw} is always bigger than or near to φ_{ow}. At section 60 degree of the bend, the amount of φ_{iw} is near to the amount of scour hole wall slope at straight channel φ_w, and near to pier located at section 30 degree of the bend. This means that spiral flow doesn't have influences on the inner wall slope of scour hole.



F**Fig.5** Bed topography around the pier located at section 60 degree of the bend (θp =60°)

a) Q=30 lit/s b) Q=35 lit/s

c) Q=35 lit/s d) Q=42 lit/s

Table 3. Scour parameters for pier at section 60° of the bend

Experiment code	Q (L/S)	Lh (m)	Lp (m)	φ_u (Deg.)	φ_d (Deg.)	Wh (m)	φ_{ow} (Deg.)	φ_{iw} (Deg.)	ds (m)
C60-30	30	0.28	0.22	28	21	0.250	30.5	31.5	0.05677
C60-35	35	0.50	0.55	28	18	0.400	30	33.5	0.10076
C60-40	40	0.77	0.93	32	12	0.490	28.5	33	0.12215
C60-42	42	1.14	0.94	29.5	10	0.550	30	32	0.14760

(4) Effect of location of pier on the scour parameters

At this part of paper, specific focus takes place on the parameters of scour hole (L_h, W_h, L_p and d_s) and point bar for different discharges.

a) Length of scour hole for pier at different locations

Fig. 6 shows the influence of location of the pier and discharge on the length of scour hole L_h.

This Fig. shows that the length of scour hole L_h increase as the pier is located further downstream in the bend (i.e. increasing θ_p increases L_h), except for discharge 42 liter/s.

This Fig. also shows that the rate of increasing in the length of scour hole is less at lowest amount of discharge and by increasing the discharge, the rate of increasing the length of scour hole increases.

At discharges 30, 35 and 40 liter/s, the maximum length of scour hole occurs for pier at section 60 degree of the bend.

The maximum length of scour hole at discharge 42 liter/s occurs for pier at section 30 degree of the bend. For this discharge the length of scour hole decreases when pier is located at section 60 degree. At this flow condition, the movements of sediment particles are observed at about section 30 degree of the bend which inters the scour hole of the pier at section 60 degree. As a consequence, the amount of scour decreases.

b) Width of scour hole for pier at different locations

As it is evident from Fig.7, scour holes at the bend of the channel is wider than those of straight channel.

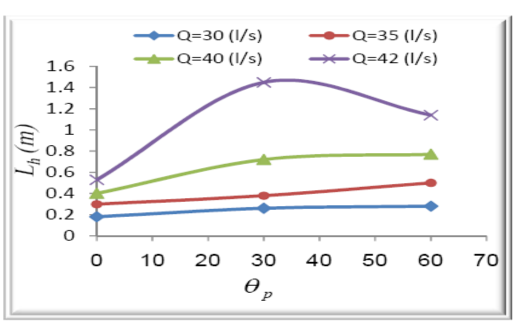


Fig.6 Length of scour hole at different locations and discharges

c) Length of point bar for pier at different locations

The trend of variations of the point bar-length L_p is approximately similar to trend of variations of L_h and Wh which were described above. Fig.8 shows this similarity.

As it is evident from this Fig., at discharge 30 liter/s the amounts of point bar-length do not significantly change for pier at different sections of the channel, nevertheless we can see the highest amount for pier at section 60 degree of the bend. With increasing in the amount of discharge, difference between straight channel and bend sections become more considerable, insofar as in discharges 40 and 42 liter/s we can see a considerable peak in the chart for pier at section 30 degree of the channel. This Figure shows that at lower amounts of discharges (i.e. 30 and 35 liter/s), the maximum length of point bar occurs when pier is located at section 60 degree of the bend while at higher discharges (i.e. 40 and 42 liter/s) it is found for pier at section 30 degree of the bend.

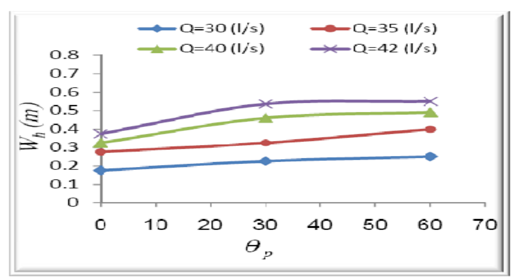


Fig.7 Width of scour hole at different locations and discharges

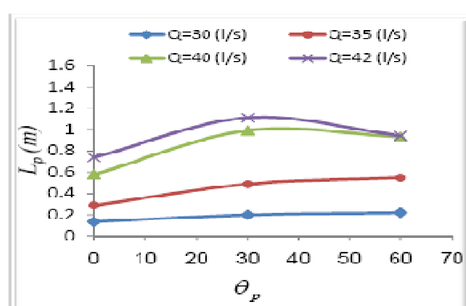


Fig.8 Length of point bar at different locations and discharges

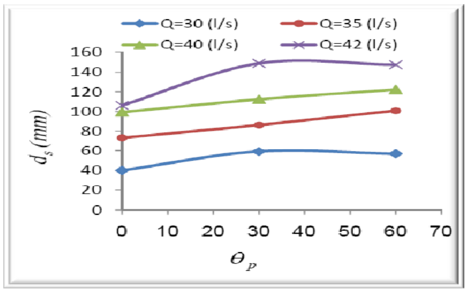


Fig.9 Maximum depth of scour hole at different locations and discharges

d) Maximum depth of scour for pier at different locations

Fig.9 shows the variations of Maximum depth of scour hole due to changes of discharge and pier location in the channel. The trend of variations of depth of scour is almost same as that of length of scour hole. According to Figure 9, the minimum amount of scour depth for each discharge occurs for pier at straight channel $(\theta_p = 0°)$. The maximum values of scour depth, almost for all the discharges, occur when pier is located at section 60 degree of the bend.

4. Summary of results

This paper investigates the effects of channel bend on scour hole geometry and point bar. Following conclusions are drawn from this experimental study:
At all locations of pier, the amount of scour depth increases with increasing in the amount of discharge. Also other parameters such as width of scour hole, length of scour hole, and length of point bar have similar trend.
When pier is located at the channel bend, the sour hole occurs nearer to the outer wall of channel while the point bar occurs nearer to the inner wall of channel.
The rate of increasing the length and width of scour hole and length of point bar at lower discharges due to increase of θ_p (i.e. from straight channel to sections 30 and 60 degree of bend) is low and will increase with increasing in amount of discharge.
The minimum amount of scour depth (d_s) at each discharge can be occurred at straight channel. When pier is located in the bend, the amount of scour depth increases as compare to that in a straight channel.
The maximum amount of scour depth for each discharge occurs for pier at section 60 degree of the bend.

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