LOCAL SCOUR AROUND SPUR-DIKE-LIKE STRUCTURES AND THEIR COUNTERMEASURES USING SACRIFICIAL PILES

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Results of a series of experiments on local scour around spur-dike-like structures are discussed. Flow discharges are varied in the experiments and found to be positively correlated with the volume of the scour hole and the maximum scour depth. Similarity of the growth of maximum scour depth, as well as, the shape of the scour hole is closely comparable to those in the other studies.

Effectiveness of the sacrificial piles as a countermeasure to local scour is tested varying the number of piles and their position. It is observed that the position and orientation of the pile group is very important to get the lowest scour , and hence maximum protection to the spur-dike. Within the limit of the present study, it is found that at the equilibrium state, the depth of maximum scour and the scour volume are reduced by 29% and 26%, respectively, when compared to the spur-dike without sacrificial piles.

Key Words : *Local scour, spur-dike, maximum scour depth, sacrificial pile, countermeasure to local scour*

1. INTRODUCTION

Spur-dike or abutment-like structures are used to divert or guide the flow[1] and provide safety to river banks, and consequently safety to the nearby important hydraulic structures. Local scour associated with this kind of structures is inherent as the shear distributions are modified locally which leads scouring action until equilibrium is established[2]. Most of the studies related to local scour around spur-dike-like (or abutment-like) structures concerned with maximum scour depth[2,3,4,5], whereas, in some studies[6,7] the geometry and shape of the scour holes are also considered. The designers should be aware of the maximum scour depth as well as the geometry of the scour volume to ensure the integrity of the structure and safety against failure. So reduction of local scour around this kind of structures is important from the engineering point of view.

Sacrificial piles as a tool to reduce local scour around bridge piers have long been recognized. Some of these methods include inserting multiple piles or a single sill or sacrificial pile[8,9,10] in front of the pier. The basic idea is to divert the flow around the pier and to reduce the flow intensity and the local scour.

Guided by the sacrificial pile approach in the case of scour reduction around bridge pier, it can be hypothesized that "for the reduction of local scour around spur-dike or abutment like structures, the sacrificial piles may play some positive roles", and some arbitrary arrangements of the sacrificial piles are designed to test their effectiveness in the local scour reduction around spur-dike-like structures.

In the present study, the schematized model of the spur-dike has been selected from an actual example in the Meghna (in front of Meghna Bridge) river in Bangladesh. In the experiments, there was no general movement of bed particles in the upstream straight channel, and the local scour discussed here is classed as the clear water scour. The focused points in the experimental results are summarized as below:

(a) Influence of discharges on the local scours

(b) Precise observation of the time dependent behavior of scour holes

(c) Comparison of the similarity of the local scour hole with the previous experiments

(d) Effectiveness of the sacrificial piles on the reduction of flow velocity and local scour around spur-dikes.

2. EXPERIMENTS

Experiments were conducted in a 10m long, 1m wide and 0.2m deep steel flume, having a longitudinal slope of 0.002 . The test reach was selected in the middle section with 6m length, and the width was reduced to 80cm. Plan form of the approach channel was straight with fixed side bank and mobile sand bed. The thickness of the sand bed was 10cm in all the experiments and the sediment used on the bed had a mean diameter of 1.42mm and a standard deviation $[d_{84}/d_{16}]^{1/2}$=1.28.

The co-ordinate system and dimensions of the model spur-dikes and sacrificial piles are shown in **Fig. 1**. The model of the spur-dike was made of brass, whereas, the wooden sacrificial piles were selected. The length and width of the spur-dike top was 20cm and 10cm respectively. The side slope of the model was 1V:1H, and as the water depth was variable, the width contraction ratio varied slightly ranging from 0.15~0.17. In all the experiments, the model spur-dike was installed at right angle to the flume side wall, whereas, in the experiments with piles, the pile groups were installed at an arbitrary angle of 45° to the side wall. Flow level was always below the spur-dike top, whereas, the piles were always submerged (1.5cm above initial bed).

Total nine experiments were conducted having different initial arrangements. The initial hydraulic and other boundary conditions are summarized in **Table. 1.** During the experiments, the time dependent behavior of local scour was observed. Each time, the depth of scour hole was recorded manually at five locations of the interface between spur-dike and sand bed. From the measured data, the temporal behavior of scour holes were depicted. Time to time vortex formation and flow visualization were observed using color injection near the upstream nose of the spur-dike. Initially,

Table 1 Experimental Conditions

Run No.	Q (l/s)	h_0 (cm)	Fr	U_*/U_{*c}	Run time (min.)	No. of piles
1	2.41	1.55	0.50	0.68	40	-
2	5.05	2.38	0.55	0.84	60	-
3	6.19	2.69	0.56	0.88	60	-
3a	6.19	2.69	0.56	0.88	240	-
4	7.48	3.02	0.57	0.93	110	-
5	6.19	2.69	0.56	0.88	240	10: P1~p10
6	6.19	2.69	0.56	0.88	240	3: P8~p10
7	6.19	2.69	0.56	0.88	240	5: P1~p5
8	6.19	2.69	0.56	0.88	Fixed bed	-
9	6.19	2.69	0.56	0.88	Fixed bed	5: P1~p5

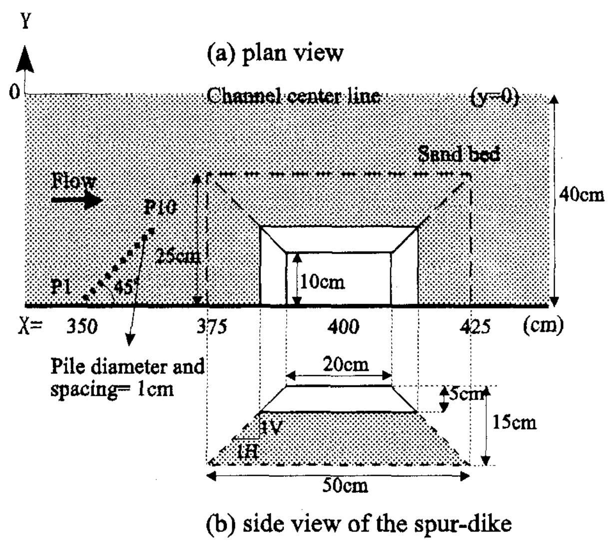

Fig. 1 Experimental arrangements and dimensions of model spur-dike and sacrificial piles.

the equilibrium state was guessed to be after 60 minutes observing the scour behavior of Run3, but from the result of the same discharge flow for 240 minutes in Run3a, it was clear that both the scour depth and volume was changing very slowly, and equilibrium state was considered after 240 minutes. Flow was stopped after 110 minutes in the case of Run4, as the upstream bed form entered the measured section. At the equilibrium state the detailed bed level data were recorded by a computer aided laser sensor (Model: Keyence LB300) which was movable both in lateral and longitudinal direction. The spatial interval of the measurement

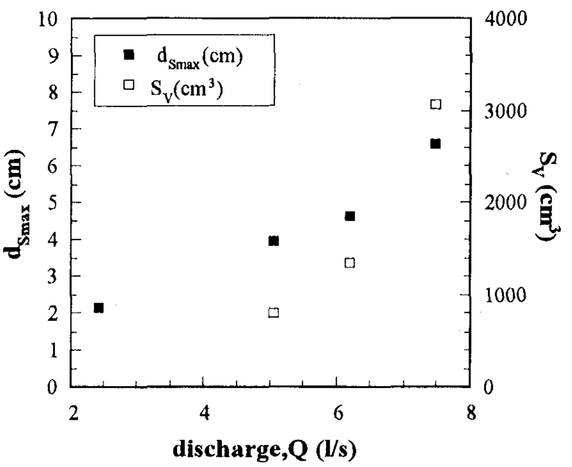

Fig. 2 Local scour as a function of discharge.

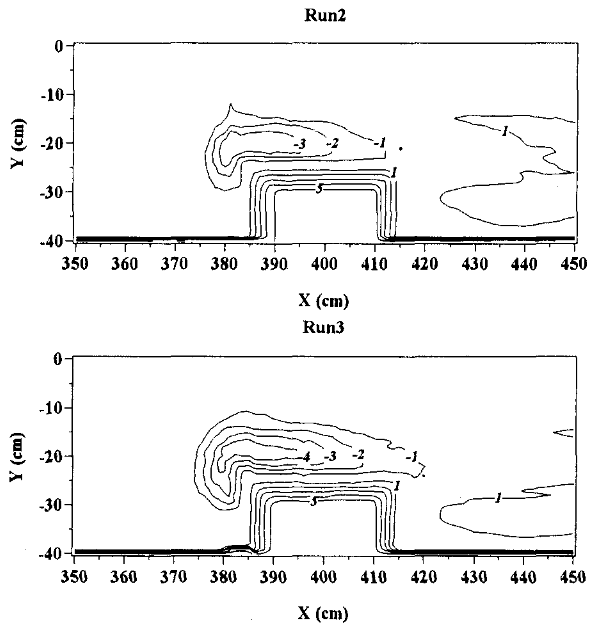

Fig. 3 Contour type plots for Run2 and 3 after 60 minutes (Contour intervals are 1cm, 0 is initial bed level, positive contour value are for deposition).

points were 1～10cm along X direction and 0.5～1cm along Y direction. Using the collected data, the bed contours were plotted and analyzed. For Run1～4, the behavior of local scour due to the discharge variation was observed, whereas, for Run5～7, the effect of piles on the local scour was observed having fixed discharge and run time (as Run3a). During Run5～6, the pile model was installed starting from the at X=350cm. Ten piles p1～p10 were used in Run5, whereas, for Run6, only three piles p8～p10 were used. In the case of Run7, the starting position of the piles were shifted to X=355cm and five piles p1～p5 were used. From the results of the three different arrangements of piles in front of the spur-dike, the best possible position was examined. In Run8 and 9, sand bed around the spur-dike was made fixed with cementing material and flow velocities were measured using a propeller with 3mm diameter.

3. RESULTS AND DISCUSSIONS

(1) Outline of the experimental results

Three basic different kinds of experiments were conducted. Under the first category, experiments consisted with a model of spur-dike having discharge variation, and the corresponding runs were Run1, 2, 3, and 4. In the experiments under the second category, the discharge and run time were fixed, but the location and number of piles at upstream were variable, consisted with Run5, 6 and 7. Under the third category, velocity measurements were performed , and the corresponding runs were Run8 (without pile) and 9 (with 5 piles).

In all the experiments, it was observed that the occurrence of the initial scour was very fast and about 50% of the maximum scour depth at equilibrium states occurred within the first 2 to 5 minutes, but it slowed down gradually with time. At the beginning, the scour observed at slightly downstream of the upstream corner (nose) of the spur-dike, but the maximum scour position moved gradually in the vicinity of the nose, and at the equilibrium state it was observed near the upstream nose. Discharges had direct effect on both the maximum scour depth (d_{smax}) and scour volume (S_v)) at the equilibrium state. The results can be observed from the plotting of d_{smax} and S_v in the final stages as a function of discharge in **Fig. 2**. The value of both the parameters increased with discharge and seemed to be positively correlated.

There was no sediment transport except around the spur-dike, and the scoured volume of local scour hole and the volume of the sand deposition downstream was in good balance with some little discrepancy. The position of the upstream edge of the scour holes moved upstream, as discharged increased. But for the both cases, the maximum scour depth was located in the vicinity of the spur-dike nose.

The results of the local scour in Run5, 6 and 7 were compared with the results of Run3a. It was found that the effect of piles may have some positive effects to reduce local scour around spur-dike-like structures, if they are placed and oriented properly. Flow velocity distribution in the vicinity of spur-dike were compared for Run8 and 9. The detailed results and their comparison would be explored in the final sub section .

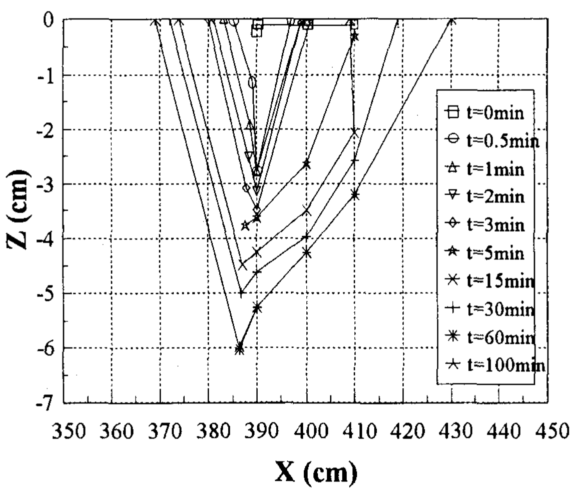

Fig. 4 Development of scour hole with time (Run4).

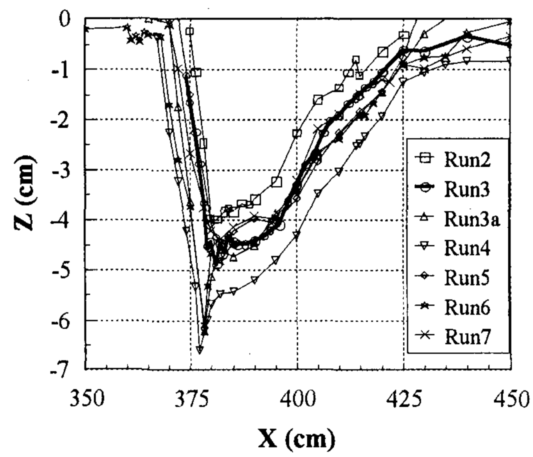

Fig. 6 Longitudinal profiles of the scour holes at the final state.

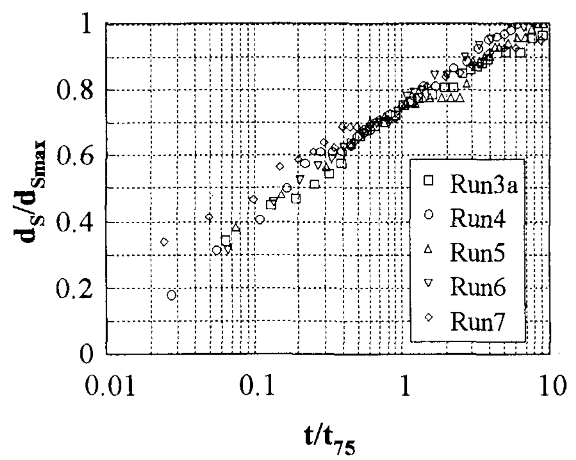

Fig. 5 Temporal similarity of the development of maximum scour depth.

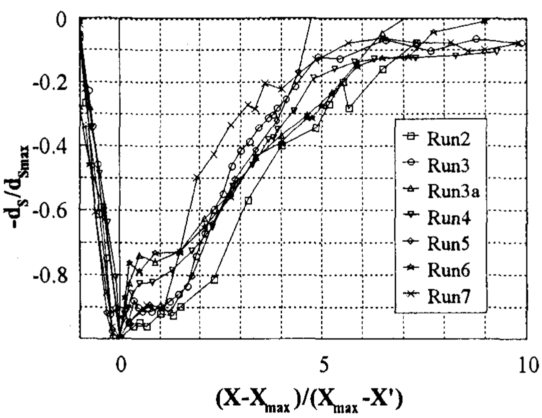

Fig. 7 Spatial similarity of local scour at the final state.

(2) Development phase of local scours

The initial position of the scour hole was near X=390cm along the longitudinal direction at the interface between spur-dike and sand bed. The scoured material was deposited just downstream of the hole. Deposited materials were transported towards downstream, and at the same time scouring continued, thus gradually scour hole was expanded. A typical example of the above features can be observed from the results of Run4 in **Fig. 4**.

Initially, a very steep slopped local scour was developed having the longitudinal side slope approximately equal to the angle of repose (30^0) of the sand used on the channel bed. Upstream part of the scour hole maintained almost the same slope as it was initially, but the downstream part became gradually flat and at the final stage the slope of the downstream part was about 6^0, 1/5 of the slope of the upstream part.

The temporal similarity of the development of maximum scour was tested and plotted in **Fig. 5**. Here, d_s is the instantaneous depth of local scour, d_{smax} is it's final value, t_{75} is the time required for 75% *of the final value* of the maximum scour depth. The development of maximum scour depth are identical, and closely comparable with the previous experimets[6)] using groin-like structures. It is also clear that the time required for the last 25% of the scour depth is about 10 times the time required for the first 75% of it. So, the scouring processes become slow as tending towards the equilibrium state.

(3) Final state of scour holes

The final state geometry of the scour holes along longitudinal direction was shown in **Fig. 6**. The upstream and downstream part of the scour holes from maximum scoured point had different shape. The upstream was very steep and short, whereas, the downstream was relatively mild and longer. The

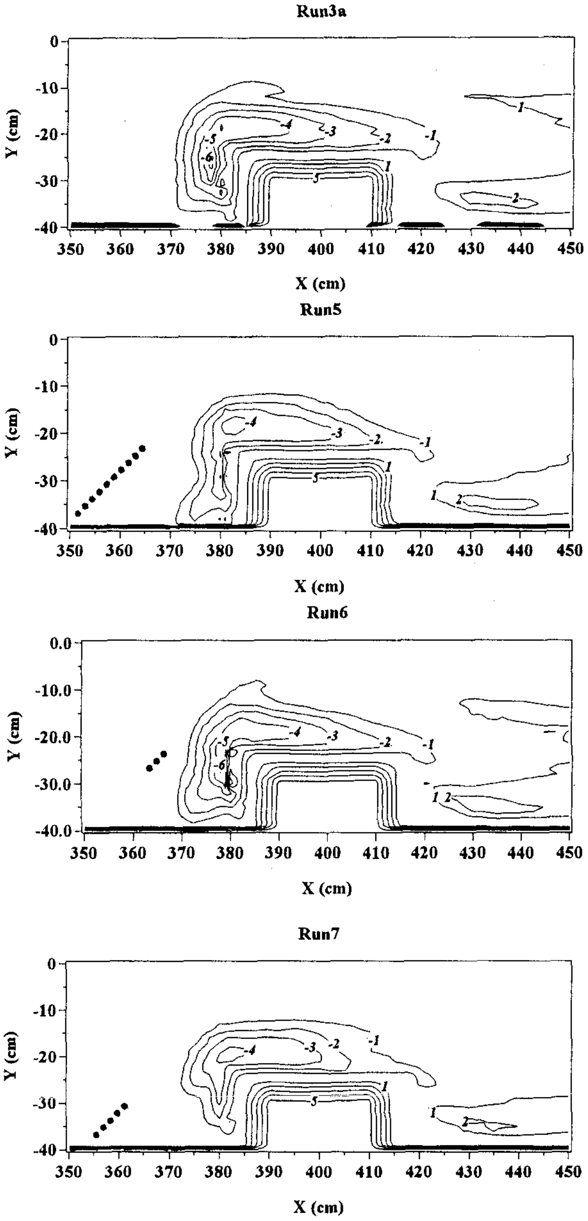

Fig. 8 Comparison of bed elevation contour for the experiments with and without sacrificial piles (Contour intervals are1cm; 0 is initial bed level and positive contour value is deposition).

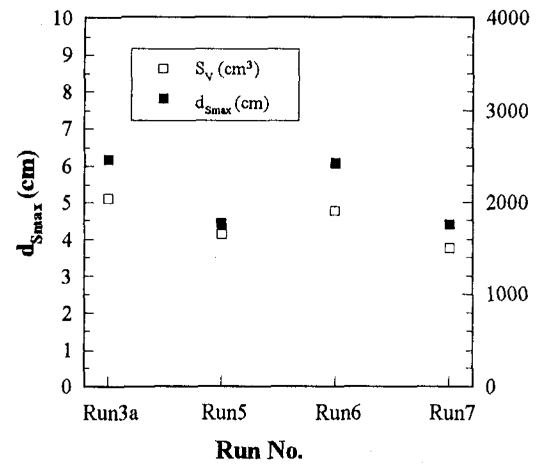

Fig. 9 Local scour reduction using sacrificial piles.

spatial similarity of the scour holes for the upstream and downstream part was tested in **Fig. 7**. In this figure, X_{max} and X' are the X co-ordinates of the maximum scour and upstream edge of scour holes, respectively. It can be seen that the upstream part had similarity, but downstream part had no similarity. The similarity behavior of the upstream part was identical to the results of the experiments[6] with groin-like structures.

(4) Effectiveness of the sacrificial piles to scour-depth restriction and flow velocity retardation

The basic objective of the experiments with sacrificial piles was to test their effectiveness to reduce local scour, and hence provide countermeasure against failure. Results of the experiments with piles (Run5, 6 and 7) were compared to the results of Run3a, where piles were not used, but the discharge and run time were same. It was found that local scour could be reduced by the use of pile groups, but their position and orientation was very important to optimize the benefit. The scour depth around the piles were negligible (15 to 25%) as compared with the scour depth around spur-dike. The bed elevation contours of the final stage of Run3a, 5, 6 and 7 are shown in **Fig. 8**. From these contours, it is clear that local scour was restricted for Run5 (10 piles) and 7 (5 piles), whereas, for Run6 (3 piles), there was no significant reduction.

Again, it can be observed from **Fig. 9** that the local scour depth and volume was reduced in Run5 and 7, as compared with Run3a, whereas, in the case of Run6, there was no significant change on the final results. Under the present study limit, the maximum reduction of local scour was achieved in Run7. The maximum scour depth and volume were reduced by 29% and 26%, respectively, when compared to the spur-dike without sacrificial piles.

More specifically, the effect of sacrificial piles to flow retardation as well as scour restriction can be seen in **Fig. 10**. In this figure, the longitudinal distributions of near bed flow velocity in Run8 (without piles) and Run9 (with 5 piles) are plotted together with the distribution of scour holes in Run3a (without piles) and Run7 (with 5 piles). It can be seen that the maximum flow velocity at the interface between spur-dike and sand bed (Y=-25cm) was occurred at X=390cm in both the Run8 and 9, and then the velocity decreased due to flow separation along the downstream direction. But the

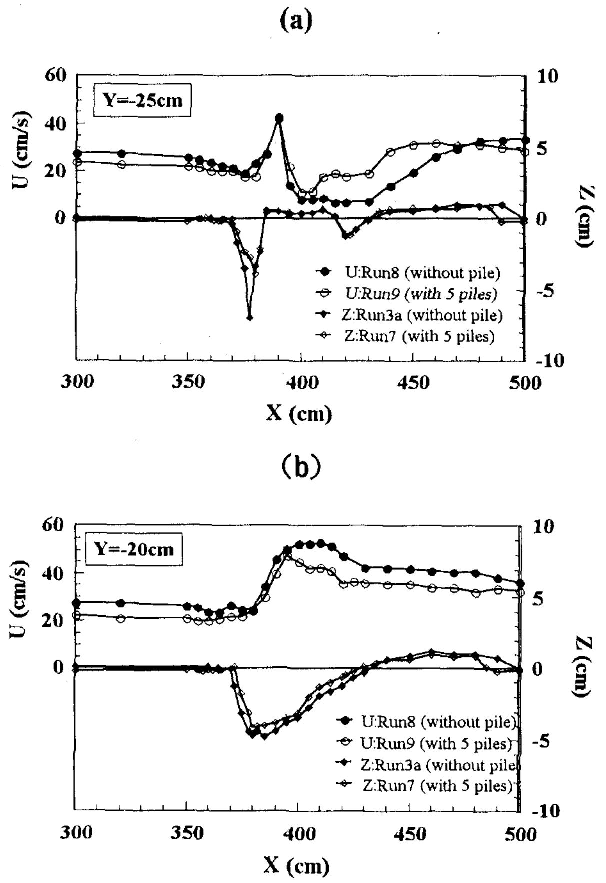

Fig. 10 Longitudinal distribution of near bed flow velocity (Run8 and 9) and scour holes (Run3a and Run7); (a) Y=-25cm (b) Y=-20cm

velocity in Run9 exceeded the velocity in Run8 in the downstream direction (after X>390cm), whereas, reverse situation is occurred within the same reach at Y=-20cm. This indicates that due to the flow redistribution by sacrificial piles, weaker flow separation was achieved, resulting the reduced magnitude of flow velocity at Y=-20cm, and consequently, the scour hole was restricted. Therefore, sacrificial piles played positive role to flow velocity retardation and scour-depth restrictions around the spur-dike-like structures, when properly oriented.

4. CONCLUSIONS AND FUTURE WORK

From the present study the following conclusions can be drawn:

(a) The depth and volume of local scour around spur-dike like structure can be correlated with the flow discharges.

(b) Temporal and spatial similarity of the scour profiles are identical to the previous experiments.

(c) Sacrificial piles can divert the flow and reduce the flow velocity near spur-dike.

(d) Local scour can be reduced using sacrificial piles, if they are placed and oriented properly, however, optimum position, orientation and spacing of piles are yet to be decided from the present study and expected to study near future.

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