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Influence of Pier Modification Techniques for Reducing Scour around Bridge Piers

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***Abstract*—**Bridge piers often fail all over the world and the whole structure may be endangered due to scouring phenomena. Scouring has been linked to catastrophic failures that lead into the loss of human lives. Various techniques have been employed to extenuate the scouring process in order to assist the bridge designs. Pier modifications plays vital role to control scouring at the vicinity of the pier. This experimental study aims at monitoring the effectiveness of pier modification and temporal development of scour depth around a bridge pier by providing a collar, a cable or openings under the same flow conditions. Provision of a collar around the octagonal pier reduced more scour depth than that for other two configurations. Providing a collar around the octagonal pier found to be the best in reducing scour. The scour depth in front of pier was found to be 19.5% less than that at the octagonal pier without any modifications. Similarly, the scour depth around the octagonal pier having provision of a cable was less than that at pier with provision of openings. The scour depth around an octagonal pier was also compared with a plain circular pier and found to be 9.1% less.

***Keywords*—**Scour, octagonal pier, collar, cable, openings.

I. Introduction

BRIDGES play vital role in the daily life of human being regarding transportation. Most of the time a bridge fails due to scouring process around its piers and abutments [1]. Scour is a natural action caused by flowing water affecting bed and banks of channels. At the upstream of bridge piers, scour is very destructive due to lack of understanding of this process. It is essential for the safe design of a bridge pier to develop an effective method to deal with maximum possible local scour [2]. Thus proper understanding of scouring process and more precisely scour depth is of utmost significance in civil engineering.

Local scour is the primary result of downward flow effect and especially towards upstream face of a pier; actually that downward flow process initiates the formation of horseshoe vortex towards pier base that ultimately increases the scouring process [3] as shown in Fig. 1.

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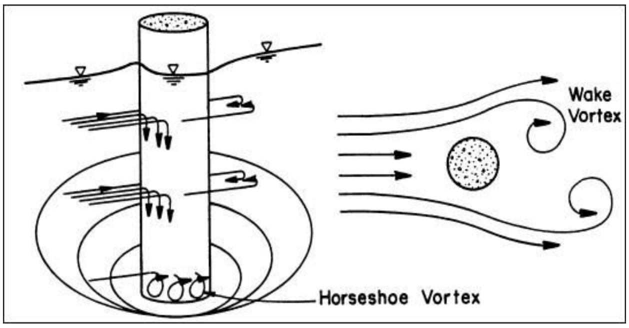

Fig. 1 Demonstration of flow and scour process around pier

A. Literature Review

The vortices system and downward flow are the primary causes of local scour. The pier, acting as a wall in front of approaching water, tries to block that flow thereby the pressure increases and flow velocity reaches to zero. This results in an increase of water level in front of pier. As the flow velocity decreases from surface to the bed, the dynamic pressure on the pier face also reduces downwards. The downward flow creates a hole in front of the base of the pier, rolls up and by interaction with the coming flow forms a complex vortex system. Melville [4] stated that the downward flow, acting as vertical jet, erodes the bed material. He also indicated that downward flow initially scours to form horseshoe vortex which further expands the scour pit.

Nowadays, researchers have exercised many remedial measures to control local scour around bridge piers. Many of them used bed armoring techniques to encounter sediment removal action by applying riprap or hard materials near the base of pier. Zarrati et al. [5] stated that the use of pier collar, along with riprap, greatly minimizes local scour around the piers. They established that two collared piers in line parallel to the flow and having riprap at their base, reduced 50-60% scouring.

A number of other pier modification techniques were also employed to dissipate effect of downward flow thus minimizing horseshoe vortex consequently reducing local scour. The present research is aimed at investigating the erosion around bridge piers by using pier modification techniques. One of the pier modification techniques that often used to minimize pier scour, is the provision of a collar. Fotherby et al. defined collar as a device built around the pier base in order to block the removal of sediments at the pier. Collars of different shapes and varying thickness are practiced around the bridge piers as protective plates against the sediment removal [6], [7].

The thickness of collar could be increased up to certain limit otherwise it would cause high turbulence in the flow resulting in excessive scour [8]. Zarrati et al. [9] studied the effect of width of a collar on the local scour around pier and found that the optimum width of collar is thrice to that of pier in controlling erosion. Thus in present study the width of collar equal to three times to that of pier, was kept for all the experiments. The provision of a collar initiates the scour on the downstream of the pier and forms a wake vortex there. This wake vortex progresses toward upstream to create horseshoe vortex. This horseshoe vortex enhances scouring thereby dissipating the effect of collar [10].

EL-Ghorab [11] suggested a technique to provide openings on upstream side of a pier. These openings starting from upstream face of pier continue transversely to lateral sides and straight to the downstream side. In his experiments, he varied discharge, depth, size and vertical spacing of openings. He used opening size equal to 10%, 15% and 20% at vertical spacing of 0.5, 1.0 and 1.5 times the pier width respectively. He found that the opening size equal to 20% with vertical spacing 1.0 times the pier width was the best in decreasing flow pressure thereby reducing the scour.

Dey et al. [12] and Elham and Manouchehr [13] examined the provision of threading or cable around a vertical pier at different angles, i.e., 15°, 30° and 45°. They suggested that the cable wrapped at 15° with a cable-pier ratio of 0.15, was the most effective to countermeasure and weaken the downward flow effect causing horseshoe and wake vortices. The provision of threading around a vertical pier is an economical technique to minimize local scour. Thus, in addition to a collar, other methods could also be adopted to countermeasure local scouring around bridge piers. These procedures include provision of a cable or openings around the pier. The main objective of this experimental investigation is to develop techniques whose application would make bridge piers safer and more strengthened against scouring action by stream flow and flood. These measures are providing protections to bridge piers, in the form of a collar, a cable or openings.

II. Experimental Procedure

A. Pier Alteration

Pier alteration is very essential as this component of bridge is directly affected by the scour action during normal and flood seasons. When the upstream flow collides with the pier, the water moves downward, all around the pier. This flow acts on the bed resulting in the formation of horseshoe and wake vortices. In all the experiments, bridge pier models made of wood were used. The maximum width of both octagonal and circular piers equal to 7 cm was used. All other dimensions of both pier and collar are shown in Fig. 2.

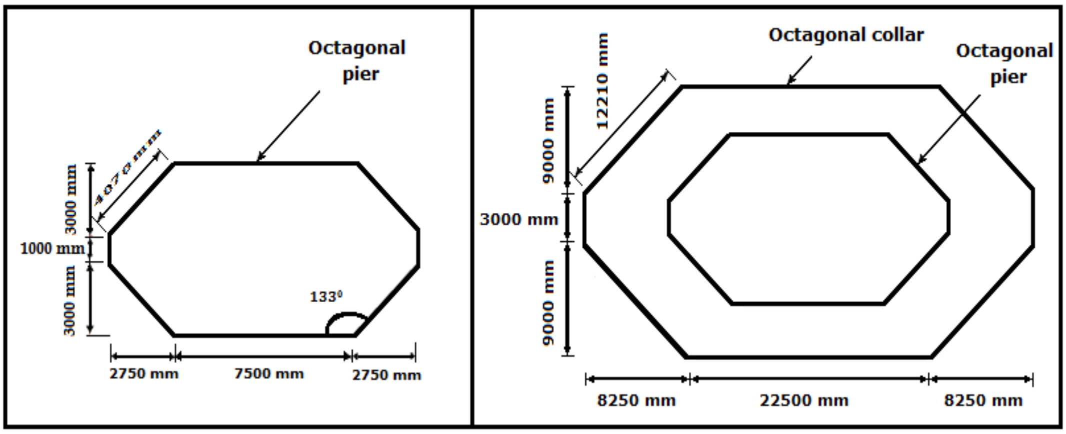

Fig. 2 Detail of pier & collar dimensions

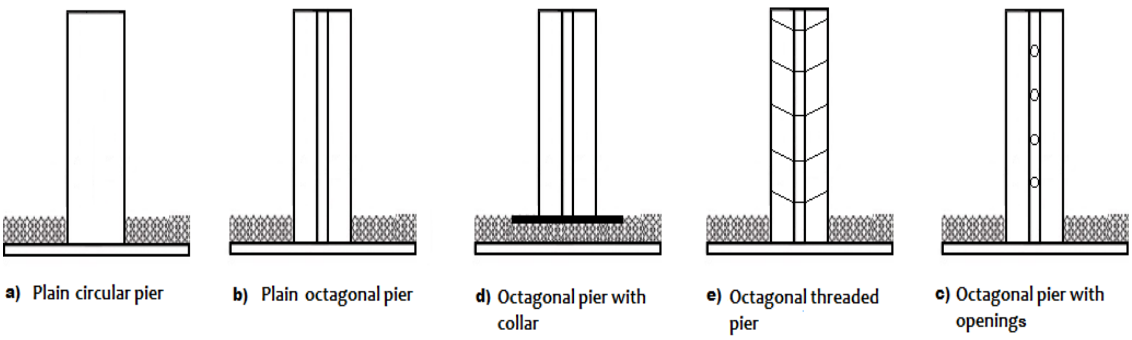

Fig. 3 Details of pier modification

Abdel-Motaleb [14] studied the provision of openings in the pier. In his experiments he used openings, each having a diameter equal to 10% of the pier width. R.J. Garde and U.C. Kothyari [15] carried out experiments on pier models by providing a slot in the direction of flow. He found that the maximum scour depth reduced up to 30%. The upstream to downstream openings provided another path to divert the flow. This reduced the effect of downward flow velocity along the pier causing less scour.

Following are the details of the pier configurations as shown in Fig. 3.

- In the collar-pier experiments, the width of collar equal to thrice to that of pier was used. The shape of the collar around the octagonal pier was also kept octagonal.
- In the cable-pier experiments, the cable of thickness 10.5mm was wrapped around the pier. The vertical spacing between the cable loops was equal to width of the pier.
- In the openings-pier experiments, the diameter and vertical spacing of openings was 20% and 100% of the pier width, respectively.

B. Experimental Set-up and Materials

All the experiments were performed in a smooth rectangular flume (20 m length, 1 m width and 0.75 m depth) equipped with recirculating water facility. The flume is located in the Hydraulics Laboratory of Civil Engineering Department at University of Engineering & Technology, Taxila, Pakistan. The flume base is built of concrete and side walls are made of 0.012 m thick glass sheet. For all experiments same flow conditions was maintained. Figs. 4 (a) and (b) show a sketch of experimental setup.

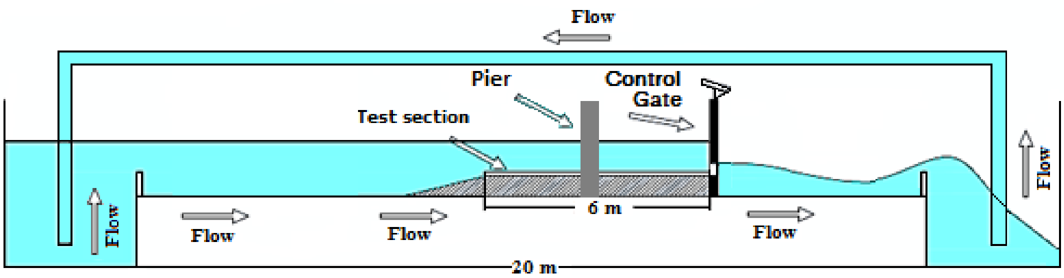

Fig. 4 (a) Cross section of Experimental channel

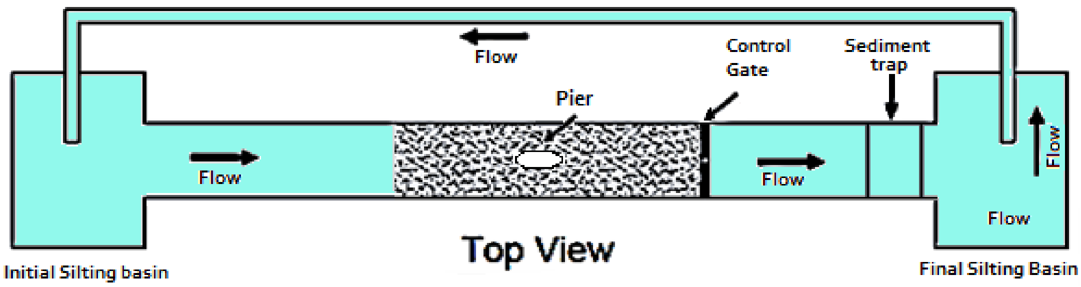

Fig. 4 (b) Top view of Experimental channel

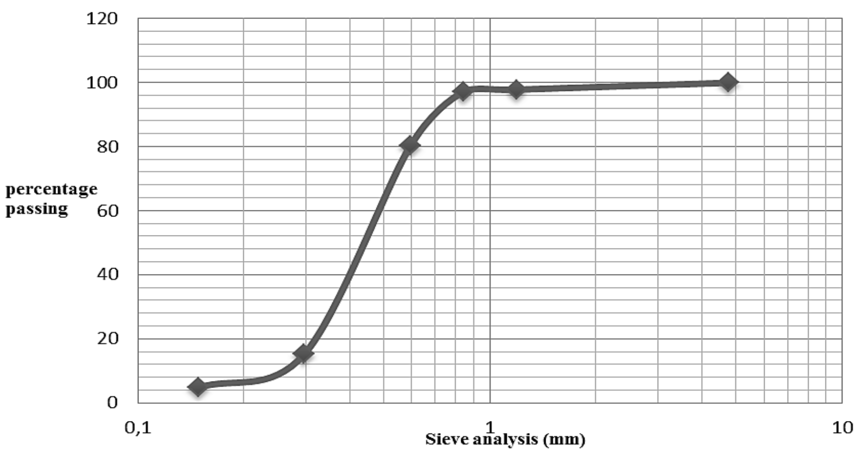

Fig. 5 Gradation curve for fine sand

The flume has a straight entrance with working segment consists of 6 m long and 0.3 m deep layer of non-cohesive uniformly graded fine sand material in which wooden pier is centered. The median sized grain size, i.e., D50 = 0.42 mm is used. The sediment used in the experiments is considered as uniform having specific gravity 2.79 and geometric standard deviation (σg) = (d84/d16) = 1.42; where d16 = diameter for which 16% by mass of sediments are finer; and d84 = diameter for which 84% by mass of sediments are finer. The standard deviation of grain sizes was σg = 1.42 < 1.50 to terminate the impact of non-uniformity of the bed material on scour depth [16]. Particle size analysis of the fine sand is shown in Fig. 5.

The flow to the channel was controlled through a valve located at the upstream end of the channel. The flow depth in the channel was controlled through a tail gate at the downstream end of the channel. The channel was accompanied by a point gauge for vertical measurements and a streamflow velocity meter for measuring velocity.

A rectangular notch was installed at the downstream of the test section for two reasons. First, to measure the flow rate in the channel and second to trap the sediments from entering into the pump that were carried away by the flowing water. For the installation of the pier in the channel a test/working section was created that starts from the point where the flow was uniform. Streamflow was used to measure velocity at different points and hence determine the section with uniform flow. Similarly, due to scouring phenomenon, the scouring depth around vertical pier is measured by means of digital point gauge with an accuracy of ±0.01 mm.

C. Testing Procedure

A series of experiments on five different pier configurations, all under clear-water scour condition, were performed. For each experiment, the initial plane bed level was measured precisely. As the flow continues, the scour progresses at the bed until the equilibrium depth is reached. Same flow depth and discharge was maintained for all the experiments. In order to monitor the eroded profile of scour hole, a meter rod attached with a small flat circular tip was used.

At the end of each experiment, water was drained off from the flume carefully to keep scour pattern unaffected from the draw down flushing. The scour holes and scour pattern profiles around octagonal pier were then accurately measured with the help of depth gauge. Finally, temporal development of scour for all pier configurations was plotted. Fig. 6 shows the description of experimental tests.

D. Test Duration Effect

Several researchers have looked temporal development of scour depth experimentally under both clear water and live bed conditions. Due to clear water conditions, scour depth progresses slowly with time towards the equilibrium state. However, under live bed conditions, the scour depth reaches to equilibrium state rapidly [17]-[19]. The equilibrium scour depth under clear water is 10% more than that under live-bed conditions [20]. Based on their experimental work and findings, several researchers have suggested time duration for scour depth to reach equilibrium state. Kumar et al. [3] halted their experiments, as the scour depth did not vary more than 1 mm over a period of 3 hours. Similarly, Mia and Nago [21] stopped their experiments as the scour depth did not increase by 1 mm over a period of 1hour. They also concluded that major scouring takes place with in the first 3 to 4 hours. Melville and Chiew [18] specified the equilibrium time, when the scour depth did not vary by more than 5% of the pier diameter over a period of 24 hours and developed an equation for calculating the equilibrium time in the clear water condition,

$$\frac{ds}{dse} = \exp\{-0.03 \mid \frac{u}{Uc} \ln \frac{t}{te} \mid^{1/6}\} \quad (1)$$

where 'ds' is the scour depth, 'dse' is the equilibrium scour depth, 'u' represent local velocity, 'Uc' is the critical velocity, 't' is the time and 'te' is the equilibrium time.

Fig. 6 Description of Experiments

In the current study, a long time experiment was performed for 50 hours according to the Melville and Chiew [18] criteria. The results suggested that, depth of scour increases with time and there is a good relation between experimental results and (1) for the equilibrium time. It was observed that 90% of the equilibrium scour depth was achieved in the initial 3 to 4 hours. Since the peak flood flow may not last long enough to develop equilibrium scour depth, the duration for further experiments was maintained as 8 hours.

III. Results and Discussion

In the current study, experiments were conducted to determine the effectiveness of pier modification on scouring action. In order to minimize scour around pier, different pier configurations were used. Initially to examine the response of pier geometry on scour dynamics, two pier shapes, i.e., circular and octagonal, were studied under same flow conditions. After getting much satisfactory results from octagonal shaped pier, both in terms of overall spatial distribution and temporal development of scour, as shown in Fig. 7, further experiments were performed on octagonal pier.

Temporal evolution of scour was analyzed specifically at the upstream of the pier for all the experiments. From the experimental results, maximum scour depth was observed for plain octagonal pier. The erosive action of downward flow caused horseshow vortex resulting in maximum scour of octagonal pier as it was unprotected and without any modifications.

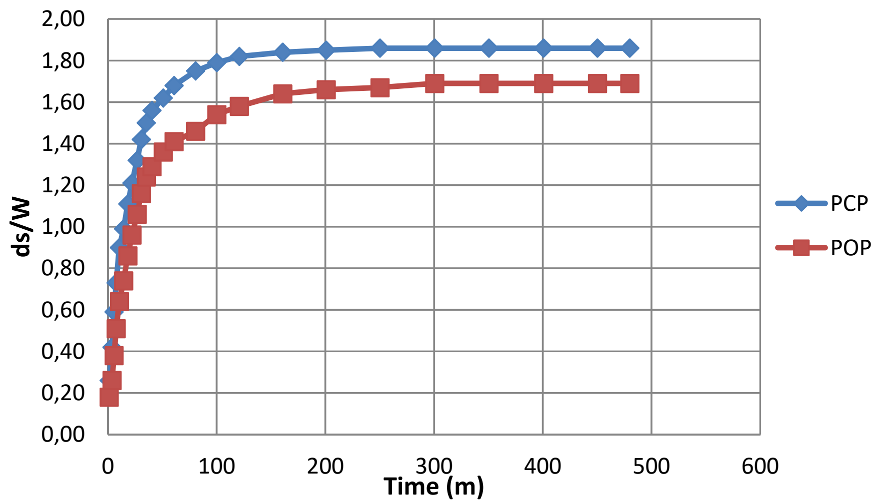

Fig. 7 Temporal evolution of scour at the upstream of pier

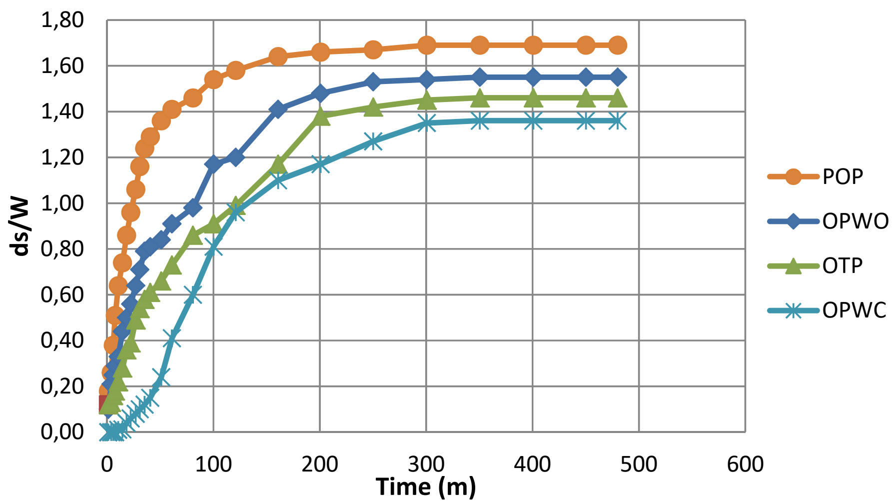

Fig. 8 Temporal evolution of scour at the upstream of pier

Three pier configurations were then applied individually, under the same flow conditions. For the octagonal pier with collar, the maximum scour depth was found to be less than that in the following two cases, i.e., octagonal threaded pier and octagonal pier with openings. The reduction in scour depth occurred due to provision of collar causing obstruction to downward flow and resulting in horseshoe vortex. For collared pier, the initial scour was delayed as compared to other cases. The flow is shifted to downstream of pier forming wake vortex there resulting in small scour pits. These pits expand and progress towards upstream and initiate scour depth there. Due to this delayed process, the equilibrium stage of scouring takes more time.

TABLE I
SUMMARY OF EXPERIMENTS

Sr. No.	Pier Shape	Cable	Opening	Collar	Scour Depth
1)	Circular	-	-	-	13.02 cm
2)	Octagonal	-	-	-	11.83 cm
3)	Octagonal	Y	-	-	10.22 cm
4)	Octagonal	-	Y	-	10.85 cm
5)	Octagonal	-	-	Y	9.52 cm

Comparing scour depth around threaded pier to that around pier with openings, the former was observed to be more effective than the later. The threads of cable obstructed the downward flow more effectively than the openings in the pier, as shown in Fig. 8. Comparison of scour depth of plain circular pier (PCP), plain octagonal pier (POP), octagonal pier with opening (OPWO), octagonal pier with collar (OPWC) and octagonal threaded pier (OTP) were made as shown in Fig. 9.

IV. CONCLUSION

This experimental study aimed at assessing the capability of various pier modifications to minimize erosive power of flow acting on the stream bed around bridge pier. The main objective of this research is to reduce maximum scour depth using a collar, a cable or openings provided in the pier under clear water flow over the mobile sand bed. It was concluded,

- Under same conditions the maximum scour depth around octagonal and circular pier was monitored and found to be 9.1% less around the former pier.
- The provision of a collar around the octagonal pier decreased erosion depth more than that for the other two configurations, i.e., pier with cables and pier with openings. For the collared pier, the scour depth was 6.8% and 12.3% less than that for the pier with cable and the pier with openings respectively.
- In all experiments of collared pier, as scouring action is delayed, the equilibrium scour time was longer than that for pier with cable or openings.

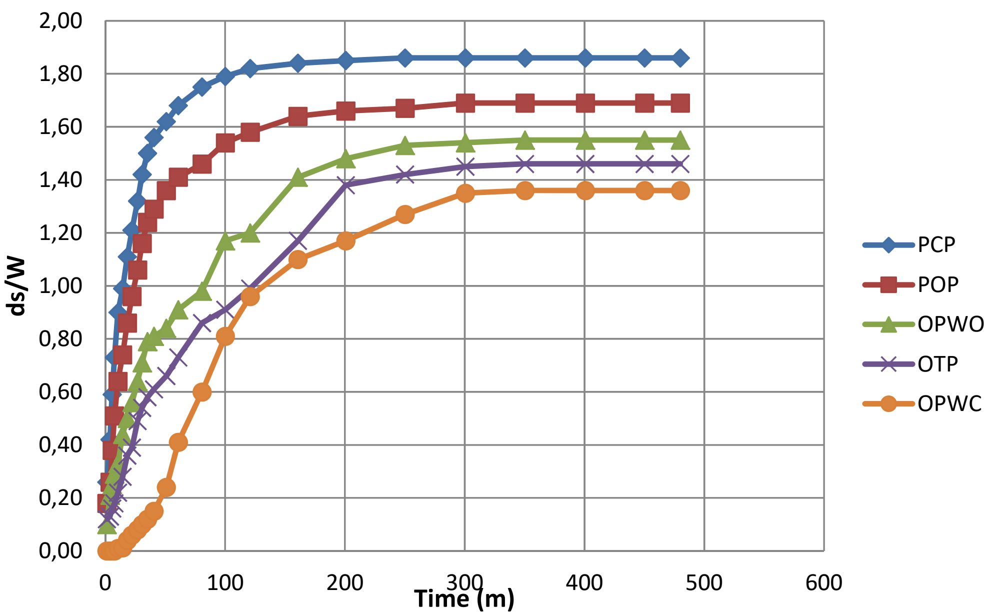

Fig. 9 Temporal evolution of scour at the upstream of pier

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