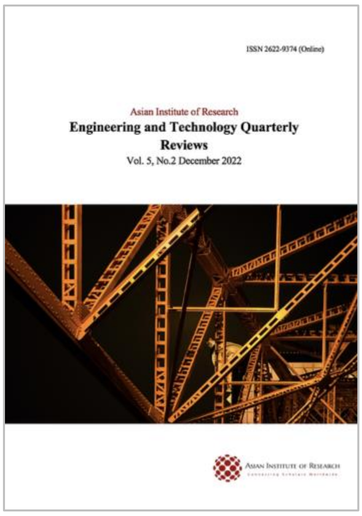

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A Study on the Assessment of Bridge Pier Shape to Minimize Local Scour

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Abstract

Local Government Engineering Department (LGED) intends to construct a bridge over the river Shitalakhya on Kapasia (Lalon Bazar) to Bashgram GC via Panli GC via Horinaraynpur GC via Kushalibaha Hat road in the Kapasia Upazila of Gazipur District. The horizontal lay out of the bridge in UTM projection system at Left Bank (Dhandia Bottola Bazar) is 24°04'26.83''N & 90°37'52.64''E and at Right Bank (Raniganj Bazar) is 24°04'32.26''N & 90°38'03.54''E. Estimated Standard High Water Level is 7.520 mPWD, minimum vertical navigational clearance as per BIWTA is 7.620m and calculated deck height is 2.950m. Thus clear height of the bridge is 15.140 mPWD and crest of the deck level of the bridge at mid point is 18.090 mPWD. The pier scour depth has been calculated as per Manual on hydrologic and hydraulic design of bridges prepared jointly by Bangladesh University of Engineering and Technology (BUET) and Institute of Water Modeling (IWM) in 2008. Seven (7) methods as Breusers [1965], Laursen [1963], Neill [1987], Jain and Fischer [1980], Chitale [1988], Melville [1997] and Richardson & Davis [1995] have been applied for pier scour depth calculation among which Jain and Fischer [1980] method shows the highest scour depth. The present study shows the scour depth for different methods with different effective pier width for non-uniform pier instead of uniform pier.

Keywords: Equivalent Pier Width, Pier Scour, Initial Bed Level, Standard High Water Level (SHWL)

1. Introduction

Scour means the lowering of the river bed level by water erosions such that there is a tendency to expose the foundations of a bridge. Pier scour is the removal of soil particles around the pier and exposer of pile is the product of pier scour. Minimization of local scour around the bridge pier is very important for bridge construction with minimum cost. Non-uniform pier has been considered under this study. Pile dia size 0.7m to 1.5m has been considered for different pier scour calculation formulas with two raw facing and three raw facing pier.

Different studies have been conducted for reducing pier scour by Melville (1997), Melville and Coleman (2000), Al-Shukur and Obeid (2016), Muke and Bhosale (2015), Elsebaie (2013) and others. In the present study, a single cylindrical pier has been considered as a non-uniform pier by using an equivalent pier diameter, b*. It has been calculated by the following formula:

$$b^* = (pm-1) X S + 2 X dp$$

Where, pm is the number of raw, S is the distance between pile and dp is diameter of the pile (Figure 1). The effective equivalent diameter depends on the position of the pile cap and the piles with respect to the initial bed level.

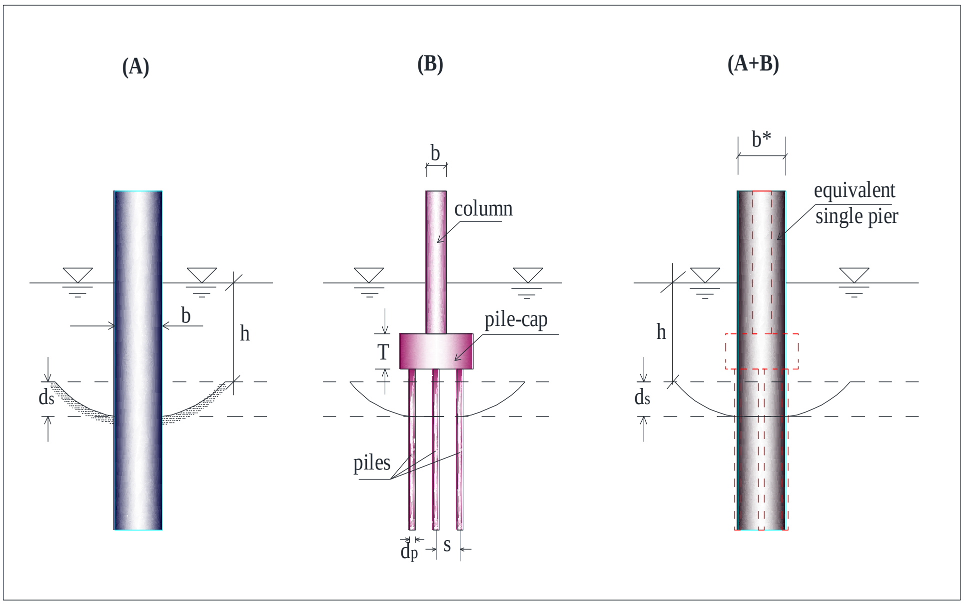

Figure 1: A Non-uniform Pier and Its Equivalent Pier

2. Objectives Of The Study

The objective of the study is to estimate the bridge pier scour for different pier scour calculation methods using equivalent pier diameter process. To know the change of pier scour for different diameter and arrangement of pile is the ultimate result of this study.

3. Literature Review

The methods developed for equivalent single pier by Melville and Coleman (2000), Richardson and Davis (2001), Coleman (2005) and Sheppard (2005) are considered. The basic mechanism causing at piers at the down flow at the upstream face of the pier and formation of vortices at the base. The approach flow velocity is reduced to zero at the upstream side of the pier which results in a pressure increase at the pier face. The associated pressures are highest near surface, where the declaration is greater and decrease downward. Due to this the pressure on the face of the pier also decreases accordingly forming a downward pressure gradient. The pressure gradient forces the flow down the face of the pier. The resulting down flow creates hole in the vicinity of the pier base (Figure 2).

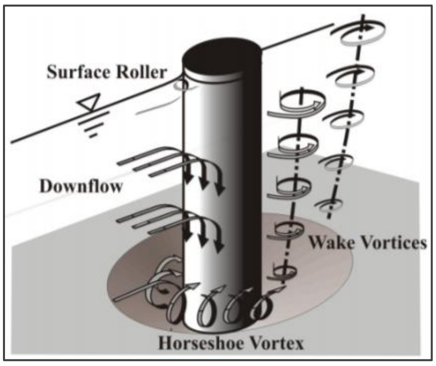

Figure 2: Flow and scour pattern at a circular pier, Melville and Coleman (2000)

Different factors affect the process of scour around bridge piers and the flow pattern. This study focused on the influence of the bridge piers shapes on minimizing the local scour. The shape of pier is one of the important factors that play an important role in the creation and the strength of the vortex system. The system of vortex consists of horseshoe vortex, wake vortex system, trailing vortex system and bow wave vortex (Chiew, 1984). There are two types of piers, uniform (simple) piers and non-uniform piers (complex). Uniform piers are piers having a constant section throughout their depth and non-uniform piers include piers of piled foundations, slab footing and tapered piers (Melville and Coleman, 2000). This study is limited to only non-uniform piers and their effects on the depth of local scour.

Al-Shukur and Obeid (2016) have conducted an experimental study of bridge pier shape to minimize local scour and found that rectangular pier has a maximum exposed area that's why scour depth is much higher than other shape. They concluded that the streamline shape is considered the best shape of piers that reduces the maximum scour depth by 60% as compared with rectangular shape. Another experimental study of local scour around circular bridge pier in sand soil has been conducted by Elsebaie (2013) and found that the depth of scour increases with time, however it was found that the rate of increase of scour depth was decreasing for a longer time interval. Rate of flow does affect the depth of scour, scour depth was more with higher flow rate.

4. Methodology

In this method, non-uniform pier has been considered as a single cylindrical pier by using an equivalent pier diameter, b*. This equivalent cylindrical pier is such that, for the same flow and sediment conditions, produces the same scour depth, ds, as the non-uniform pier. The effective equivalent diameter depends on the position of the pile cap and the piles with respect to the initial bed level. In the case of non-uniform pier with pile cap and pile below it (Figure 2), the effective pier diameter needs to be estimated by the following equation depending on the location of the pile cap.

$$b_e = b\left(\frac{h+Y}{h+b^*}\right) + b^*\left(\frac{b^*-Y}{b^*+h}\right)$$

b_e	=	Effective pier width
b_p	=	Pier width
b^*	=	Pile cap width
h	=	Hydraulic depth of flow
Y	=	Distance between the initial bed level and the top of the pile cap

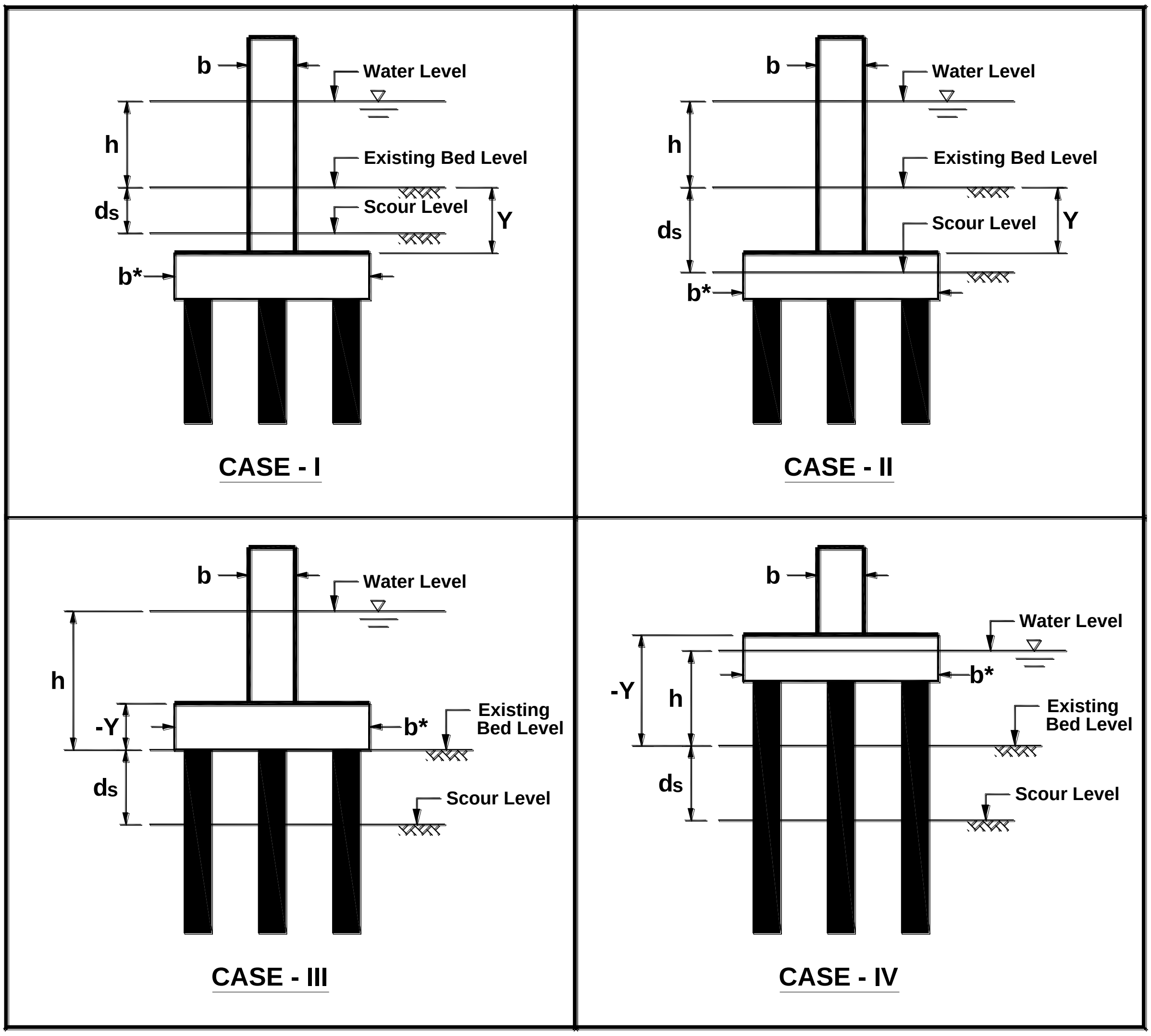

Figure 2: Potential Local Scouring with non-uniform Pier Shapes

In this study, only Case-III has been considered for scour depth calculation. From many available methods for the prediction of the maximum scour depth around piers, only some selected methods are discussed in Table 1.

Table 1: List of formulae considered for pier scour depth prediction.

Reference	Equation	Notes
Breusers [1965]	$\frac{d_s}{b_p} = 1.4$	For tidal flow
Laursen [1963]	At the threshold condition: $d_s / b_p = 1.34(h / b_p)^{0.5}$	applicable for clear-water scouring
Neill [1987]	At the threshold condition: $d_s / b_p = K_s$	K_s =1.5 for round nose and circular pier and =2.0 for rectangular piers
Jain and Fischer [1980]	At the threshold condition: $d_s / b_p = 1.86(h / b_p)^{0.5}$	applicable for clear-water scouring condition

Chitale [1988]	At the threshold condition: $d_s / b_p = 2.5$	applicable for clear-water scouring condition
Melville [1997]	At the threshold condition: $b_p/h<0.7$: $d_s / b_p = 2.4$ $0.7<b_p/h<5$: $d_s / b_p = 2(h / b_p)^{0.5}$ $b_p/h>5$: $d_s / b_p = 4.5(h / b_p)$	the shape correction factors for square nosed and sharp nosed are 1.1 and 0.9, respectively
Richardson and Davis [1995] (HEC-18)	At the threshold condition: $d_s / b_p = 2 * K_s K_\theta K_3 K_4 (h / b_p)^{0.35} * Fr^{\wedge 0.43}$	the shape correction factors for square nosed and sharp nosed are 1.1 and 0.9, respectively. Applicable for tidal and clear water

5. Selection of Study Area

Local Government Engineering Department (LGED) intends to construct a bridge over the river Shitalakhya on Kapasia (Lalon Bazar) to Bashgram GC via Panli GC via Horinaraynpur GC via Kushalibaha Hat road in the Kapasia Upazila of Gazipur District. Kapasia Upazila has an area 356.98 sq km is located between 24°02' and 24°16' north latitudes and between 90°30' and 90°42' east longitudes. It is bounded by Gaffargaon and Pakundia Upazila on the north, Kaliganj, Shibpur and Polash Upazilas on the south, Monorhardi Upazila on the east and Sreepur Upazila on the west. Main rivers are Old Brahmaputra, Shitalakhya and Banar; Buri Beel, Machha Beel and Nail Beel are notable water bodies.

The Shitalakhya river originates from old Brahmaputra river located at Labutola Union of Monohordi Upazila under Narshingdi District and meets with Dhaleswari river located at Kalagachiya Union of Bandar Upazila under Narayanganj District. At present time this river carries low discharge. Movement of different types of vessels are existed almost all the year round and all most no erosion is existed. Famous River Port Narayanganj is situated in the shore of this river. Bangladesh Inland Water Transport Authority (BIWTA) has been declared its Class III Navigational Route for this river.

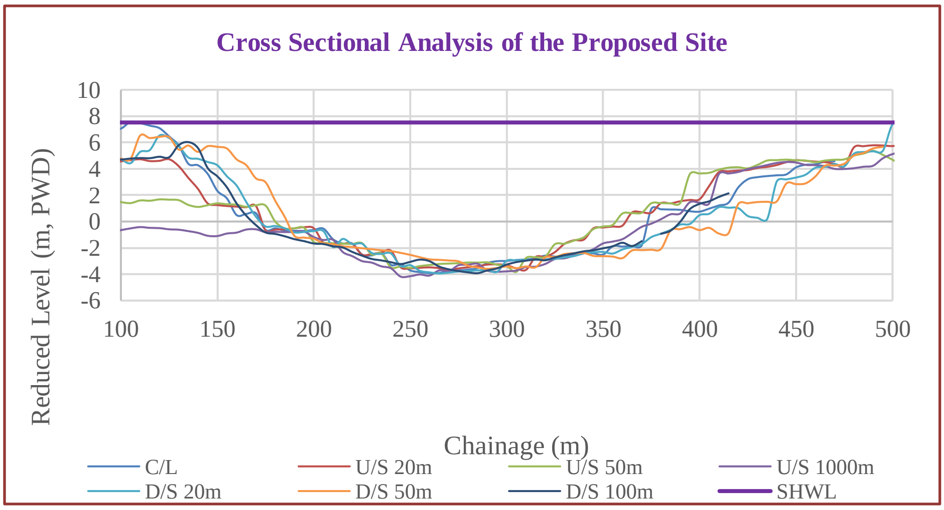

Figure 3: Cross-Sectional Analysis at Proposed Project Site

Kapasia Upazila has moderate level of road transportation facilities. It has RHD regional highway as well as LGED road network. This Upazila is located within North-Central Hydrological Region of Bangladesh. The mean annual rainfall of the study area is about 2582 mm. The bridge site is located in the Agro-ecological Zone 28 i.e. Madhupur Tract. This is a region of complex relief and soils developed over the Madhupur Clay. The soil type at Kapasia

Upazila near the study site is Deep Red-Brown Terrace Soils which is mainly occur on level to rolling relief on the Madhupur Tract. The bridge site is located in zone-II of the earthquake zones which is a zone of medium seismic risk with a basic seismic co-efficient of 0.05.

Figure 4: Location of Project Area

6. Results

Scour depth under before said seven methodologies have been calculated for different effective pier width with respect to different pile diameter. The outcome of the findings are presented in Table 2 as integrated outcome and Figure 5 and Figure 6 for 3 flow facing row and 2 flow facing row respectively.

Table 2: Summary of Scour Depth for Channel Pier

Pile Dia (m)	Flow Facing Pile Row Number		Effective Pier Width, b_e (m)	Scour Depth from Initial Bed Level (m) [IBL = -3.00 mPWD]						
				Breusers [1965]	Laursen [1963]	Neill [1987]	Jain and Fischer [1980]	Chitale [1988]	Melville [1997]	Richardson and Davis (HEC-18)
1.50	3		8.245	11.542	12.656	12.367	17.567	20.611	17.001	12.971
1.50	2		4.927	6.898	9.784	7.391	13.581	12.318	10.643	12.101
1.20	3		6.243	8.740	11.013	9.364	15.287	15.607	13.485	12.493
1.20	2		3.855	5.397	8.654	5.782	12.013	9.637	8.327	11.706
1.00	3		5.029	7.040	9.884	7.543	13.720	12.572	10.862	12.134
1.00	2		3.233	4.526	7.925	4.849	11.000	8.082	6.982	11.431
0.90	3		4.467	6.254	9.316	6.701	12.931	11.168	9.649	11.942
0.90	2		2.955	4.136	7.577	4.432	10.517	7.387	6.382	11.293
0.80	3		3.942	5.519	8.751	5.913	12.147	9.855	8.515	11.742
0.80	2		2.702	3.782	7.245	4.053	10.057	6.754	5.836	11.158
0.70	3		3.458	4.841	8.197	5.187	11.377	8.645	7.469	11.536
0.70	2		2.477	3.467	6.937	3.715	9.628	6.192	5.349	11.027

	
2 Row Facing Pile (Gorib Saha Bridge, Magura)	3 Row Facing Pile (Tikkar Char Bridge, Cumilla)

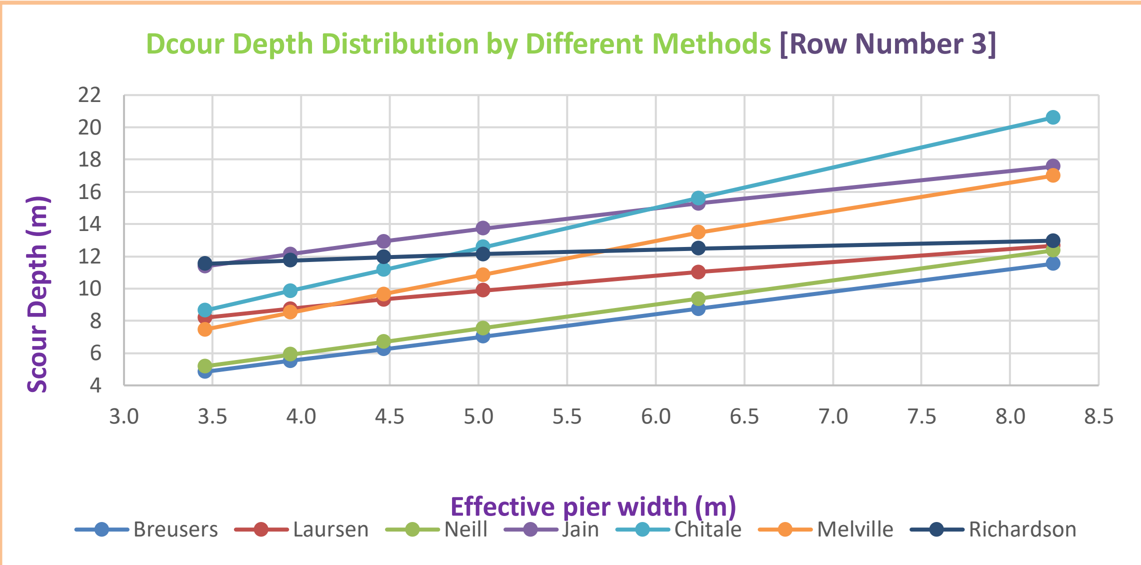

Figure 5: Scour depth for different effective pier width under 3 flow facing row

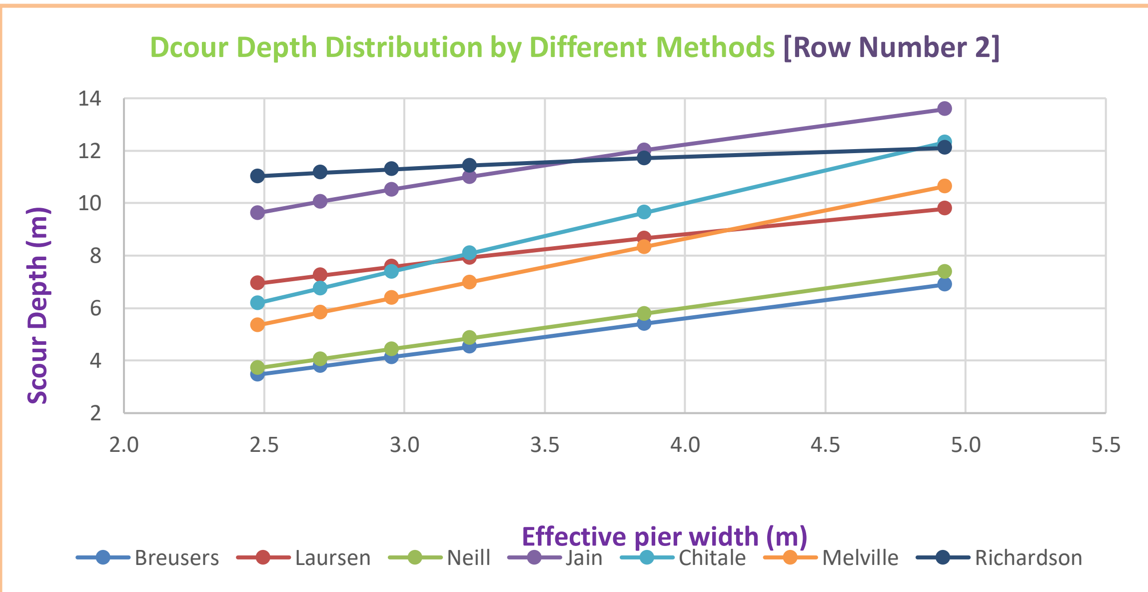

Figure 6: Scour depth for different effective pier width under 2 flow facing row

From Table 2 and Figure 5 and Figure 6, it is reveals that scour depth is 128% higher compare with 0.70m to 1.50m pile diameter for 3 flow facing row under the Method of Melville (1997). On the other hand for 2 flow facing row under the Method of Melville (1997), scour depth is 99% higher compare with 0.70m to 1.50m pile diameter. Arrangements of piles also affect the pile scouring. Existing bed level with respect to pile cap, structural arrangement of pile position and bed material characteristics affect the pier scour.

7. Conclusion

From scour depth calculation under different effective pier width, it is concluded that scour depth depends on the structural arrangement of bridge pier for the same discharge and same velocity in the proposed bridge river channel.

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