(May 2024). DETERMINATION OF LOCAL SCOUR DEPTH FOR DIFFERENT SHAPE OF BRIDGE PIERS
International Journal of Economic Perspectives,*18*(05) 55-67
ISSN: 1307-1637 UGC CARE GROUP II
Retrieved from https://ijeponline.com/index.php/journal

DETERMINATION OF LOCAL SCOUR DEPTH FOR DIFFERENT SHAPE OF BRIDGE PIERS

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ABSTRACT

Scour is the process or effect of erosion caused by flooding water, which excavates & transports debris from stream bed, banks, and adjacent structures such as bridge piers or abutments in flowing water. The flow mechanism around a pier structure is so complex that it is impossible to develop a generic empirical model to produce reliable scour estimates. However, underestimating scour depth can lead to costly bridge collapses, whilst overestimating might result in excessive building expenses. As a result, understanding the projected maximum scour depth is critical for properly designing the bridge pier foundation. Attempts are made in the study to determine the scour depth by a series oflaboratory model tests. For that purpose various flow conditions and pierconfigurations were considered. Experiments were conducted to study local scour atcylindrical bridgepiers in both uniform & non-uniformcohesionless sediment. The study's goal was to gain a better knowledge of local scouraround bridge piers and its relationship to sediment movement. Four empirical equations relating equilibrium depth of scour to approach velocity, flow depth, & sediment size were developed for homogeneous and non-uniformsediments.This research provides a means of assessing some important aspects of scouringprocess and various factors that influence the scour depth. The program of workperformed in this study includes the following:Local scour at cylindrical bridge piers in both uniform and non-uniformcohesion less sediments was investigated experimentally. Experiments were conducted to study the scouring effect for different shapes of pier and scouring behaviour for different shapes under different flow conditions.

Keywords- Local Scour, types of Scour, parameters etc.

INTRODUCTION

The scour rate of various materials varies. Moving water rapidly erodes loose granular soils, whereas cohesive or cemented soils withstand scour better. The ultimate scouring in cohesion or consolidated soils, on the other hand, might be as deep as the fine sand stream. In sand & gravel bedding materials, scor reaches itsmaximum depth inhours, days in adhesive bedding materials, & months in glacial tills, sandstone, shale, & limestone.

Due to significant local scouring, many river bridges collapse or are severely destroyed during large floods. Highly localized diarrhea occurs on the bridge piers & abutments owing to bed material removal caused by strong flow patterns near and foundations. Bridges should be built to withstand such unfavourable impactssince severescouring causes significant riverbed deterioration. In addition to appropriate design, bridges should be inspected on a regular basis and their current scour criticality assessed. The amount of scour in relation to the bridge's footing elevation determines a bridge's scour criticality. If ultimate bed level eroding surrounding reaches the bridge's foundation higher elevation of its footing, the bridge is classed as scour critical.

Many river bridges fail or are extremely damaged due to excessive local scouring

Submitted: 27 March 2023, Revised: 09 April2024, Accepted: 18 April 2024, Published: May 2024

during high floods. Excessive local scour occurs around bridge piers and abutments as a result of removal of bed material due to severe flow patterns surrounding the foundations. Since excessive scouring leads to considerable riverbed degradation, bridges should be designed to resist such unfavourable effects. In addition to proper design, bridges should be monitored periodically and existing scour criticality of them should be evaluated. Scour criticality of a bridge is assessed according to the level of scour with respect to the footing elevation of that bridge. A bridge is said to be scour critical if the final eroded bed level around the bridge foundation reaches the upper elevation of its footing.

Therefore, hydraulic aspects of bridge design are most important part of the success for planning, designing and construction of a durable bridge structure. This aspect consists of selection of sites, optimum orientation and waterway, design of guide bunds, approach embankments and design of bridge piers. Scour depth is one of the most important factors for deciding the foundation levels of the bridge. Under prediction of it can lead to costly bridge failures while over prediction can result in unnecessary construction cost.

SCOUR TYPES

AGGRADATION AND DEGRADATION

Aggradation & degradation areIlong-term changes in streambed elevation induced by natural or man-made sources that may have an influence on river reach where bridge is located. A decrease in supply of sediment from stream is referred to as subsidence or erosion of the stream bed, while elevation refers to the depositionof eroded material from a channel or water shed upstream of bridge.

GENERAL SCOUR

General score refers to the flow of a stream or water way across bridge over the bridge. This reduction may beuniform over bed, which means that hoof depth can be particularly large in cross section. General scour can occur as a result of flow contraction, which takes material from the bed throughout the whole or nearly complete channel width, or as a result of other common scourconditions, such as flow around abend, when score is centered on the circumference of the curve. Common diarrhea differs from long-term decline in that it can be cyclical or associated with a flood pathway.

CONTRACTION SCOUR

The high speed in the narrowing score of the river & shear stress on bed results in loss of material frombed across all or most of channelwidth in bridge span When bridgeembankments cross floodplain or into main channel, contraction diarrhea often occurs. There are 2 kinds of contractionscour to think about. Live bed scouroccurs when bedmaterial is moved across a bridge cross section from an upstream access. As a result of the live bedcontraction score, area of the compacted portion expands until the sediment from the contracted area is equal to sediment brought in transport. Clearwater diarrhea occurs when bedding material is not transported by upstream access. Downstream access, or when content is moved to upstream access, is mostly suspended and at a rate below throughput.

LOCAL SCOUR

The major process causing localscour are formation ofvortices at base of bridge piers & abutments. Thevortex clears obstruction's bedmaterial foundation. When sediment transport rate leaving scour hole exceeds rate entering it, a scourIhole occurs. As depth of scrape increases, strength of vortices decreases. In contrast, wake vortices are vertical vortices that originate on the underside of structure. Local scourdepths are typically tentimes larger thangeneral or contraction scourdepths.

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LITERATURE REVIEW

Amir Ghaderi, RasoulDaneshfaraz, and Mehdi Dasineh et al. (2019), have stated that scour depth around the piers of the Simineh Rood Bridge in Miandouab, Iran were investigated using empirical relationships and the HEC-RAS numerical model, and the results are compared with each other. Firstly, a hydraulic software model was created from the river where the bridge was located using field data. Then, by entering the scouring data of bridge piers for discharges with a return period of 5 to 1000 years, changes in flow discharge were investigated for scouring around the middle and lateral sides of the bridge. Results of the empirical equations showed that some of equations are not sensitive to increases in flow discharge, and for each return period, the results are near each other. Also, numerical model results showed that with an increase in discharge, scouring increases in the bridge's middle and lateral piers. In all discharges, the first and the seventh pier had the lowest and highest scour depth, respectively.

Halah Kais Jalal et al. (2020) aim to explore the impacts of bridgepier form on the localscour in orderto build an ideal hydraulicdesign for minimal scour depth.Local scouring around diverse pier shapes (circular, rectangular, square, octagonal, elliptic, & lenticular) in non-cohesive bedsediment under clearwater scour circumstances was therefore simulated foreach pier shape at varying flow intensities, fluid levels, & pier diameters. When numerical findings for anticipated scour deptharound a circularpier were compared to Melville's laboratory experimental results from 1975, model was determined tohave roughly a 10 percent error rate for scour depth prediction, indicating high agreement with the experimental models.

RedaAbd El-HadyRady et al. (2020) combine two artificial intelligence modeling approaches, namely genetic programming (GP) and the adaptive neural fuzzy inference system (ANFIS), to forecast pier scour depth based on clear water parameters from 320 laboratory and field observations. The scour depth was calculated utilizing five unknown parameters: pier width, approach flow depth, Froude number, standard error of particle size distribution, and stream open ratio. The trained GP models was used to construct a functional link, and the results were contrasted to those produced by the model trained by ANFIS and seven classic regression-based equations to ensure their correctness. Numerical experiments demonstrated that the GP model outperformed the ANFIS model and all other empirical equations. The GP model's benefit was demonstrated by applying the derived GP equation to anticipate scour depth within the Imbaba Viaduct piers in Egypt.

Hamidifar, H.; Zanganeh-Inaloo, F.; Carnacina, I. (2021), focused on the different parameters that could affect the maximum scour depth and the model accuracy. One of the main parameters individuated is the critical velocity of the approaching flow. The results of the selected models were compared with experimental data, and the best hybrid models were identified using statistical indicators. The accuracy of the best models, including YJAF-VRAD, YJAF-VARN, and YJAI-VRAD models, was also evaluated using field data available in the literature. Finally, correction factors were implied to the selected models to increase their accuracy in predicting the maximum scour depth.

HaipengDuan and others (2021), researched on the local scour around bridge pier has been carried out for many years, there are few research results on the evaluation of scour hazard of built bridge piers and that of unbuilt bridge piers. On the basis of previous research results at home and abroad, this paper systematically analyzes the research results related to the evaluation of local scour of bridge piers in recent decades, including the prediction of

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scour pit depth, the risk assessment of local scour failure and the prediction of scour depth based on risk theory. In this paper, the trend of local scour evaluation of bridge piers is also discussed.

Al-Mussawi and others (2021), is to predict local scour around the piers by developing new empirical equations using two effective approaches, i.e., gene expression programming (GEP) and artificial neural networks (ANN). Various important parameters were used to derive the empirical equations such as pier shape, flow depth, flow intensity, pier width, and flow direction angle (attack angle). The results of the comparison indicated that the ANN model (RMSE=0.102, R 2 = 0.94 and MAE=0.076) is performed better than the GEP model (RMSE= 0.124, R 2 =0.90 and MAE=0.103) slightly. The latter is preferred on account of its ability to produce explicit and compressed arithmetic expressions. Furthermore, the sensitivity analysis results show that the index of flow depth/width ratio (y/b) has the significant influence on local scour depth predictions compared to other input variables.

Hassan, W.H., Jalal, H.K. (2021), is thus to offer a new formula for the prediction the local depth of scouring around the pier of a bridge using a modern fine computing modelling technique known as gene expression programming (GEP), with data obtained from numerical simulations used to compare GEP performance with that of a standard non-linear regression (NLR) model. The results suggest that the formula from the GEP model provides better performance for predicting the local depth of scouring as compared with conventional regression with the NLR model, with $R^2 = 0.901$, $MAE = 0.111$, and $RMSE = 0.142$. The sensitivity analysis results further suggest that the ratio of the depth of flow has the greatest impact on the prediction of local scour depth as compared to the other input parameters. The formula obtained from the GEP model gives the best predictor of depth of scouring, and, in addition, GEP offers the special feature of providing both explicit and compressed arithmetical terms to allow calculation of such depth of scouring.

Noor A.A. Muhsen et al. (2022) want to conduct laboratory testing with a vertical-wall superstructure and two pier types (oblong and lenticular) at three distinct spacings to determine the maximum scour depth and demonstrate the effect of piers-abutment scour interference. The results revealed a significant rise in the scour depth ratio when flow quantity, Froude amount, and flow depth decreased. They also discovered that increased pier-abutment separation enhanced pier scour in both configurations while decreasing abutment scour. The scour depth induced by an oblong form was roughly 10.8% more than that of a conical shape. In addition, new empirical equations were developed using Statistics from IBM SPSS 21, with coefficients of determination of 0.969, 0.974, and 0.978 for oblong, lenticular, and abutment, correspondingly. They demonstrated a link between expected & data found.

In Mia Marrocco et al.'s (2022) study, artificial neuralnetworks (ANNs) were upgraded & utilized to search data in laboratory, field, & combination settings. To improve scour predictions, physics-based factors were used as input parameters to the ANNs instead of empirical parameters (e.g., form variables) & parameters that account for blockage effects. Finally, ANNs were employed to estimate scour widths in order toassess suitability of machine learning approaches for scour width prediction. Each ANN was subjected to a sensitivity analysis to determine that each of input parameters selectedhad a significant impact on predictionmodels. Sensitivity analysis also improves knowledge of each parameter's impact on the models.

Kedian Luo et al. (2022) suggested a horn-shaped collar for preventing local scour near bridge piers. The three specifications of the horn-shaped collar (bottom width, vertical

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height, and curving form index) were analyzed in clear water conditions, and the number of field tests was reduced to 25 using Taguchi's approach. The principal effect analysis was performed to establish the best specifications for the horn-shaped collars. The findings reveal that the three design factors have significant impacts on the scour mitigation capabilities of the horn-shaped collar, with the bottom width having the greatest impact. The best values for the bottom width, vertical height, and curved shape index are 5D, 0.25D, and 4, respectively (D denotes the diameter of the pier), and the optimum horn-shaped collar decreases the depth of scour around the pier by 100% compared to the unprotected situation. The highest possible scour depth is estimated using empirical data and a horn-shaped collar.

AnubhavBaranwal et al. (2023) The studyof exploration aroundbridge piers is critical to safe & cost-effective designof bridge piers. Scouring is the process of wearing away and removing bed particles along the perimeter of a pier to a specific depth, resulting in construction of a scour hole around bridge. The findings of this study might be utilized to assist select best shape of bridge piers since the sharp nose form of the bridgepiers is superior to shape of the other sixbridge piers for design purposes.

According to Muhanad Al-Jubouri et al. (2023), a hydraulic model is a good tool for employing the Colorado State University's equation, and it correlates well with actual models despite differences in pier size and shape. Furthermore, it yielded more consistent results than the the authors of Fro and Florida Ministry of Transportation techniques. Cour is the most typical reason of bridge collapse beneath any bridge pier located in a river. A numerical-based hydraulic model known as the Hydrologic Technology Centre River Evaluation System and a computational model from the state of the state's Department of Shipping were used to examine their performance and accuracy in calculating the deepest possible level of scour below bridge piers, with large and small-scale businesses physical models serving as a benchmark.

Virendra Kumar et al. (2023) employed adaptive neuro-fuzzy systems for inference (ANFIS) and the expression of genes programming (GEP) to model bridge pier scour depth. A periodic scour depth link has been suggested utilizing ANFIS and GEP approaches. In this study, 500 data sets were used to simulate periodic scour depth using ANFIS and GEP designs, with 80% (400) trained and 20% (100) tested. The GEP model's performance is proven through contrasting the resulting ANFIS model results to other actual equations. The GEP-based scour depth forecasting approach proved to be effective in validation as well as training. The present GEP model correctly predicts scour depth, with a mean percentage absolute error (MAPE) of less than 12% and an R2 value in excess of 0.85. Thus, the GEP model may be used to anticipate scour depth surrounding the bridge pier in the presence of unstable flow conditions.

Hu Bingtao et al. (2023) determined that the primary elements impacting the local scour depth on bridge piers are pier diameter,water flow depth,water flow speed, median particle size, & particle size standarddeviation. The sensitivity evaluation technique is utilized to estimate the sensitivity of the five elements and their impact on the pier's local scour depth. A technique for forecasting the local scour depth of bridge piers with a use of least-squares support vector algorithms (LS-SVM) is proposed. The results clearly show that the model's predictions beat the current specification's computing results. The coefficient of reliability of the prediction model rises from 0.624 to 0.824 following the absence of dimensionality treatment. The expected value of the pier's local scour depth is similar to the observed value, which makes it a helpful reference for bridge design and safe operations.

Ricardo Daza-González et al.'s (2023) study examines numerous local scour

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techniques by measuring depth of scour at abridge pier on the Toribio River, which originates in the Sierra Nevada Mountains north of Colombia and flows west to the Caribbean Sea. The construction of a railway bridge on the Toribio River in Colombia necessitates determining the level of the bridge pier that would cause damage to the bed level, therefore assuring a safe design for the bridge foundations, applying seven distinct Different computational algorithms are evaluated using a variety of factors.

In Hongwu Tang et al.'s (2023) paper, we proposed anew designmethod for clear water local scour depth based ontemporal evolution aspects. Wecollected data from 167 tests in referenced literature & carried out fourin-house trials. We created a new temporal equation for the evolution of local scour depth using factor analysis and trial calculations. A comparison found that largest predicting error of 71 experiments wasreduced from 162 percent to 534 percent using four existing temporal percent equations to 34 percent using new equation. An idealized scenario was utilized to demonstrate the appropriate design method. In addition to being clear and useable, the new technique was more adaptable and fault tolerant since it did percent not use concept of maximum scour percent depth, which lacked objective & universal standards.

A. M. Aly et al. (2023) found that LES is a more effective approach for examining bridge scouring than RANS (Reynolds average Navier-Stokes). The LES calculations investigate local scour-induced outcomes and compare them to the RANS simulation findings. In addition, two defensive policies, delta vane as well as plate foundations, are designed to reduce scour near piers. The findings suggest that both remedies efficiently decrease shear stress, and we propose a delta vane and plate footing combine as a suitable option for reducing both upstream and downstream bed shear stress. The paper emphasizes the need of conducting thorough investigations into bridge scouring and adopting appropriate remedies to prevent infrastructure from scour-related damage or collapse. The proposed solutions hold great promise for lowering the building and upkeep costs while enhancing infrastructure lifetime.

Bhabani Shankar Das et al. (2024) intend to combine: (1) available preliminary and field research data on various types of bridge pier scouring, (2) the impact of flow and texture factors on both clear water looking (CWS) and live bed scanning (LBS), and (3) existing mathematical equations suitable for determining equilibrium scour depth underneath a bridge pier under CWS and LBS constraints. Over the previous eight decades, more than 60 scour-predicting equations and 80 experimental/field data sets were created developed for CWS and LBS conditions. The efficiency of many empirical models in estimating the depth of scouring ratio is utilized to choose relevant models for CWS and LBS scenarios.

MATERIALS

Three sediments viz. uniformly graded sand, sandgravel and river silt wereselected as bed materials for the experiments. The average thickness of bed material is625mm placed over the flat concrete floor of the channel. The mean particle size of a sediment, d50, was taken asthe representative particle size of the sediment. The properties of each sediment andpier width to d50 ratio are listed in Table 1.

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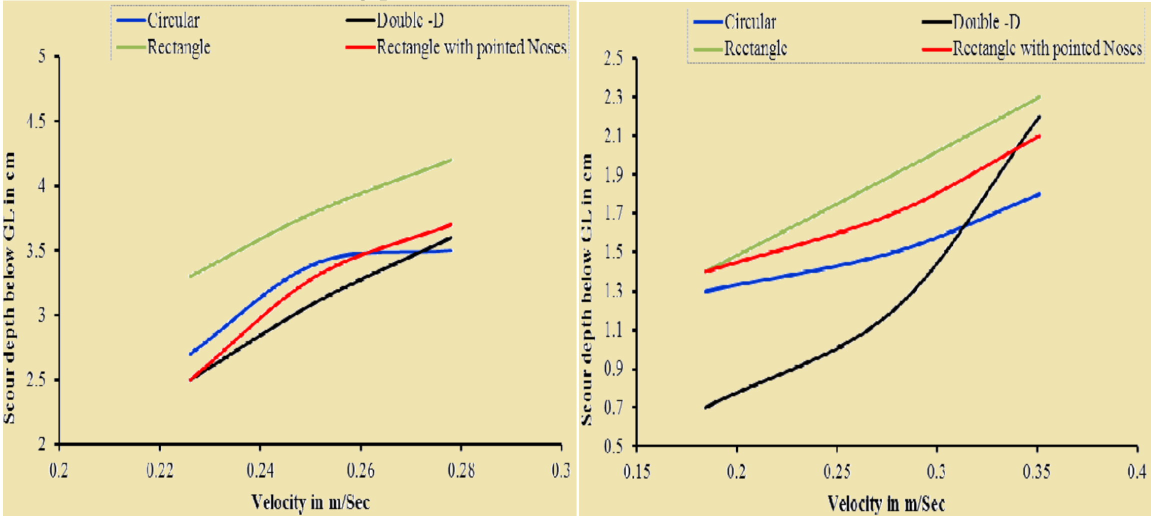
Table 1 Properties of bed sediment and pier width to d_{50} ratio

Bed sediment	d_{50} (mm)	D/d_{50}			
		Circular shape pier	Double-D shape pier	Rectangular shape pier	Rectangle with point noses pier
Sand gravel	4.2	12.1	8.6	8.6	8.6
Uniformly graded sand	0.42	121.4	85.7	85.6	85.5
River silt	.10	511	365	365	360

INFLUENCE OF DIFFERENT PARAMETERS ON SCOUR DEPTH

EFFECT OF APPROACH FLOW VELOCITY

From the experimental observation it is found that scour depth increases withthe increase of approach velocity as can be observed from the plots shown in Fig. 1(a) & (b). It is recognized that clear-water scour occurs for approach flow velocity up tothe critical velocity U_c for bed sediments, that is $U/U_c \leq 1$; while live-bed scour occurswhen $U/U_c > 1$ (Barbhuiya and Dey, 2004). For non-uniform sediments, Melville andSutherland (1988) defined an armour velocity U_a, which marks the transition fromclear-water to live-bed conditions for sediment-transporting flow and is equivalent toU_c for uniform sediments. Thus, for non-uniform sediments, live-bed conditions prevailwhen $U/U_a > 1$. However, if $U/U_a < 1$, armoring of the bed occurs as scouring proceedsand clear-water conditions exist.



(a) d_{50}=0.42 mm **(b) d_{50}=4.2 mm**

Fig. 1 Variation of scour depth with approach velocity

EFFECT OF SIZE AND GRADATION OF BED SEDIMENTS

The two most commonly used parameters to represent characteristics of the bedsediments are mean diameter (d_{50}) and geometric standard deviation $\sigma_g[= (d_{84}/d_{16})^{0.5}]$ ofparticle size distribution, which is a measure of uniformity of the bed sediments. It isobserved (Table 4.1) that scour depth decreases with the increase of size (d_{50}) of bedsediment. It is also observed that in a very fine sediment bed (d_{50}=0.1mm), the live-bedscour is more prominent than the local scour depth. From the literature some of theobservations regarding effect of bed sediment are-

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Table 4.1 Maximum observed scour depth at different bed sediment

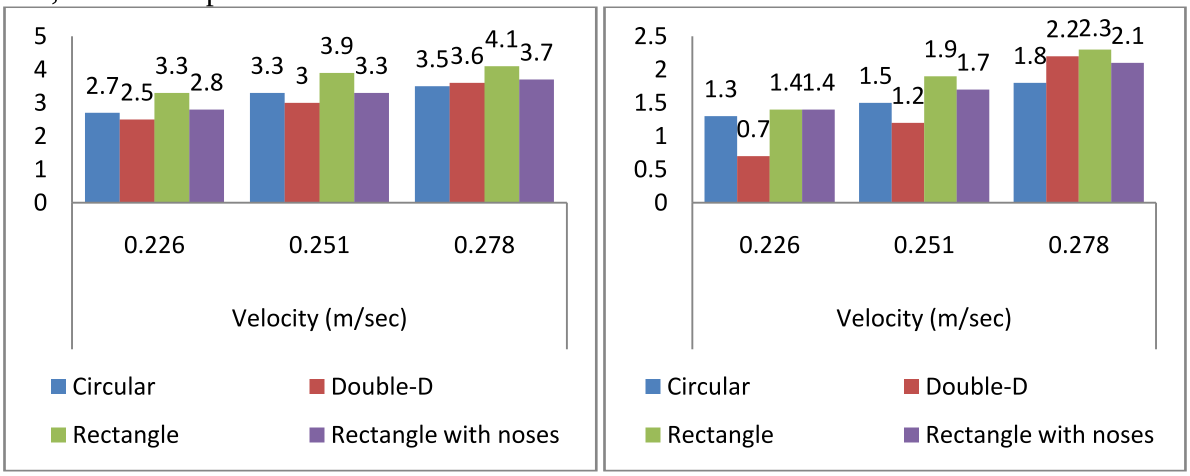
Velocity (m/sec)	Maximum observed scour depth below bed level (cm)							
	Circular shape **D_{50} (mm)**		Double-D shape **D_{50} (mm)**		Rectangular shape **D_{50} (mm)**		Rectangle with pointed noses **D_{50} (mm)**	
	0.42	**4.2**	**0.42**	**4.2**	**0.42**	**4.2**	**0.42**	**4.2**
.226	2.7	1.3	2.4	.7	3.3	1.4	2.8	1.4
.251	3.4	1.5	3.0	1.2	3.8	1.8	3.2	1.7
.278	3.5	1.8	3.7	2.2	4.2	2.3	3.6	2.1

Raudkivi and Ettema (1983) commented that for small values of D/d_{50}, the grainsize is large relative to the size of the entrainment zone excavated at the base, in frontof the pier, by the down flow so that further erosion is impeded. Ettema divided therange of sediment size parameter into four groups as follows:

- *D/d_{50}> 130; the sediment is fine relative to the pier diameter. The sediment isentrained directly from the base of the pier by the down flow and from the slopeby the horseshoe vortex.*
- *130 > D/d_{50}> 30; the sediment is of an intermediate size relative to the diameterof the pier. The entrainment of the sediment is due to a groove formed by thedown flow impinging on the base of the scour hole. Entrainment by thehorseshoe vortex on the slope is negligible.*
- *30 > D/d_{50}> 8; the sediment is coarse relative to the pier diameter. A largeproportion of the down flow energy is dissipated in the coarse bed at the base ofthe scour hole.*
- *D/d_{50}< 8; the sediment is so large that the erosion phase does not occur.*

EFFECT OF SHAPE OF PIER

The shape of the pier plays an important role on equilibrium scour depth.Stream-lined bodies, such as Double-D Shape and circular shape are found moreeffective in reducing depth of scour (Fig. 2 (a) & (b)). This is because;stream-lined bodies produce vortices of feeble strength; while blunt obstructions, forexample rectangular piers, are capable of producing strong turbulent vortices.Consequently, a relatively large scour depth is observed at a blunt obstruction. Melville(1997), Richardson and Devis (1995) has recommended to use shape factor Ks in theirequation to account for the effect of the shape of pier on equilibrium scour depth.HEC-18, suggested to consider shape factor as 1.1 for square nose, 1.0 for round nose,0.9 for sharp nose.



(a) d_{50}=0.42 mm **(b) d_{50}= 4.2mm**

Fig. 2 Variation of scour depth with shape of pier

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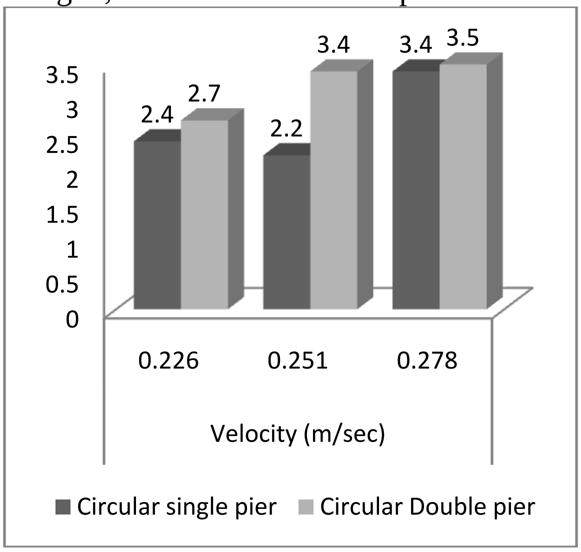
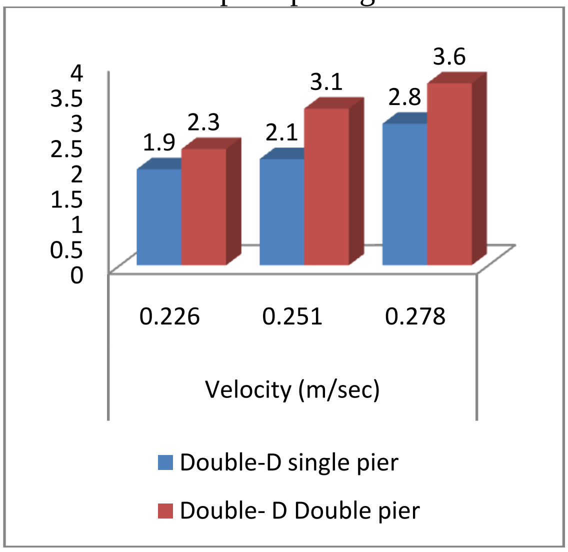
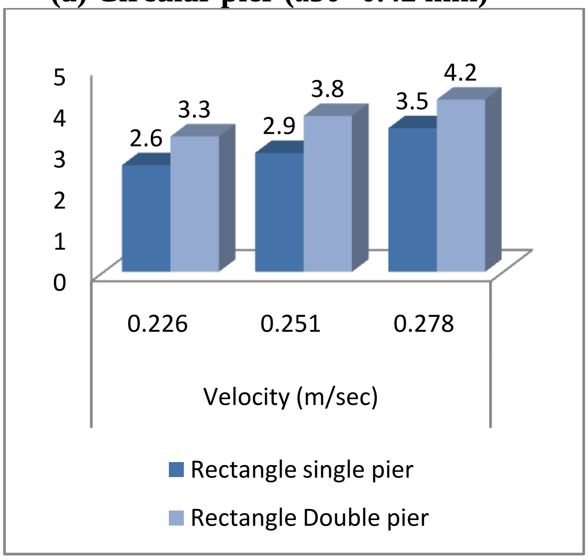
INFLUENCE OF SPACING BETWEEN PIERS

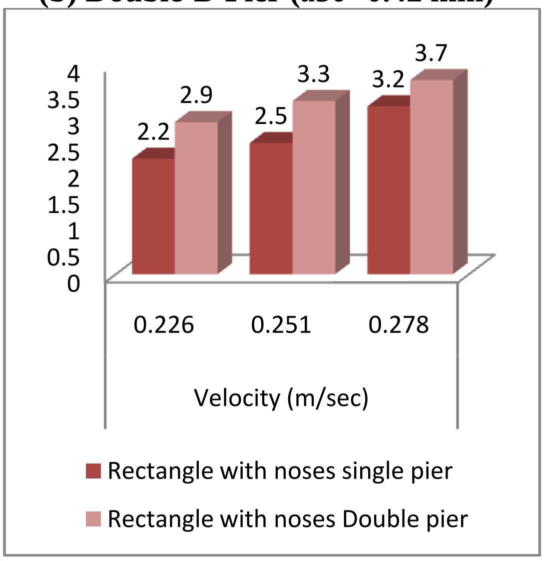
Spacing between the piers is one of the most important factor in estimating localscour depth around piers. The scour depth reduces, as the spacing between the piersincreases due to less interference from the adjacent piers. As the distance between thepiers decreases, the scouring process will be affected by two processes. First, thevortices created around the piers will interact with each other, and secondly, the flowwill be accelerated due to contraction created by the adjacent piers.From the experimental observation and the relevant plot in Fig. 3 to Fig. 4,observed that scour depth increases with reduction in pier spacing.





(a) Circular pier (*d50*=0.42 mm) **(b) Double-D Pier (*d50*=0.42 mm)**





(c) Rectangular Pier (d_{50}=0.42 mm) (d) Rectangle Pier with Pointed Noses (d_{50}=0.42)

Fig. 3 Variation of scour depth with pier spacing

EFFECT OF SUSPENDED SEDIMENT ON FLOWING WATER

Another important thrust of this thesis is to investigate the effects of the suspended fine sediment (SFS) on scouring process. It is observed from the laboratory data that depth of scour hole reduces with increase of suspended fine sediment on approaching flow (fig. 5). Previous researcher observed the drag reduction due to SFS concentrations. Li and Gust (2000) defined drag reduction as the decrease in shear stress in the viscous sub-layer with respect to the apparent shear stress of the logarithmic layer in the upper water column.

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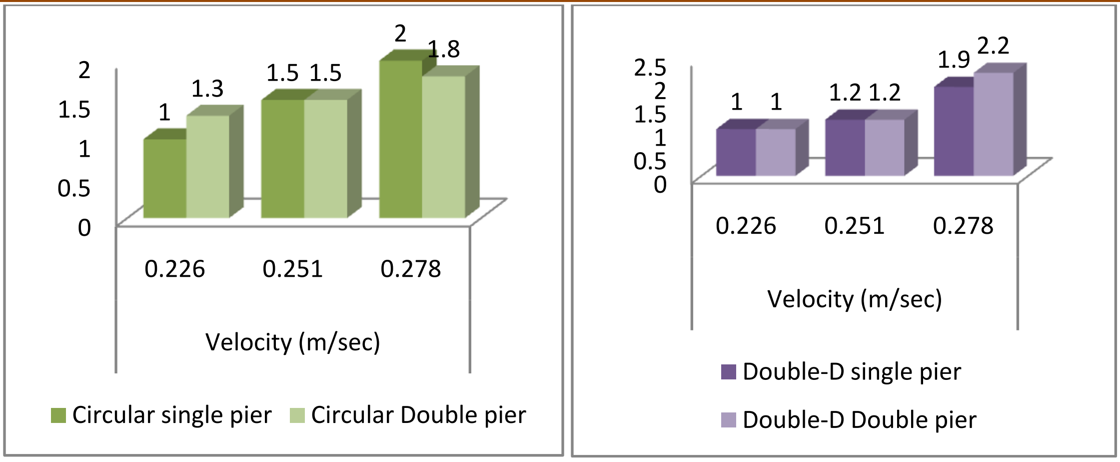
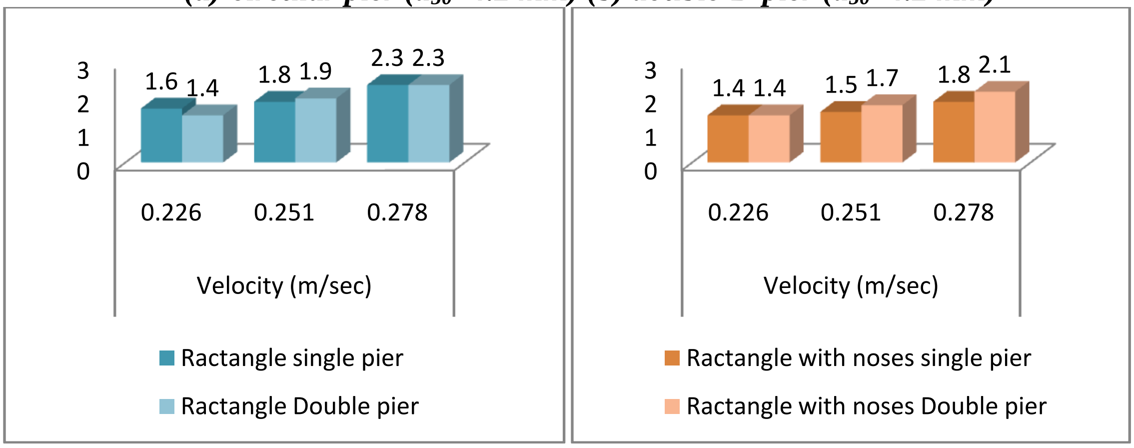
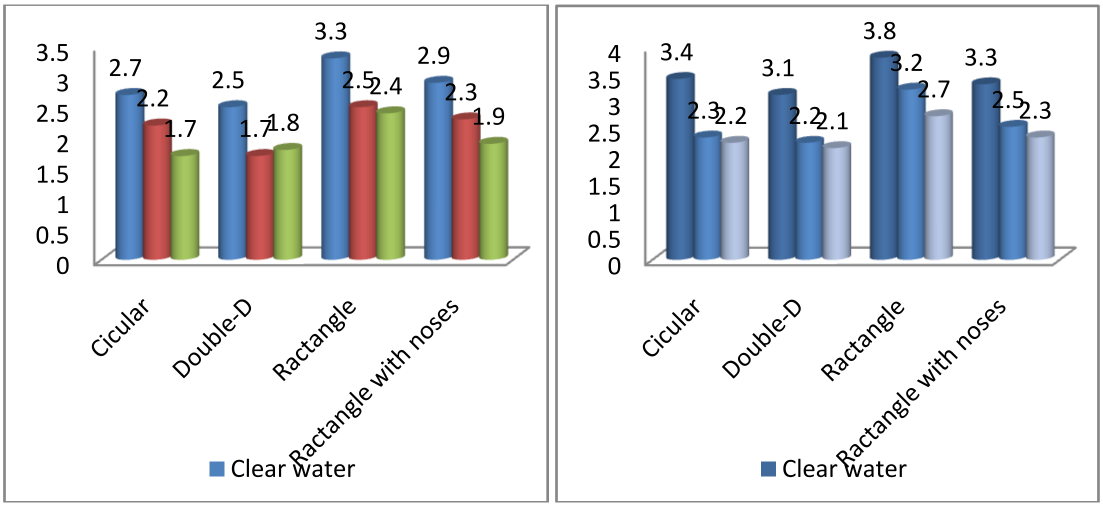


(a) circular pier (d_{50}=4.2 mm) (b) double-D pier (d_{50}=4.2 mm)



(c) rectangular pier (d_{50}=4.2 mm) (d) rectangle pier with pointed noses (d_{50}=4.2)
Fig. 4 Variation of scour depth with pier spacing



(a) velocity 0.226 m/sec, *d_{50}*=0.42 mm (b) velocity 0.251 m/sec, *d_{50}*=0.42 mm
Fig. 5 Effects of sediment concentration of flowing water on scour depth

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International Journal of Economic Perspectives,18(05) 55-67
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DEVELOPMENT OF REGRESSION BASED MODEL FOR PREDICTIONOF EQUILIBRIUM SCOUR DEPTH

The estimation of scour depth around bridge pier is essential for safe design.Numerous investigations are carried out for finding appropriate equations forestimation of maximum scour depth around bridge pier. Inaccuracy of equations arisesin different situation, as they are based on limited data obtained from laboratoryphysical models. Assessment of accuracy of various existing equations withexperimental and field data is important.

The most critical factors contributing to local scour are the velocity and depth offlow, both of which are significantly increased during heavy storms and floods. As thevelocity and/or depth increase, the amount of scour increases. Other factors affectingbridge scour include the dimensions and orientation of piers, bed configuration andmaterial size/gradation, and accumulation of ice and debris along the piers.

Because of several effective factors on local scour bridge piers, consideration ofall of them is difficult. Previous investigators also considered the most importantfactors that have extreme effect on scour depth.

In this study four new sets of equations are established for estimation of scourdepth around bridge piers considering flow velocity (U), depth of flow (d), flowFroud's No. (F_r), mean dia. of bed material (d_{50}) and shape of pier as parameters.

Using the observed data from laboratory physical models, non-linear regressionanalysis is done by using "XLSTAT" software ("XLSTAT" offers a wide variety offunctions to enhance the analytical capabilities of Excel, making it an ideal tool for dataanalysis and statistical requirements) and the following equations are formulated forestimation of clear-water scour depth around bridge piers.

(A) Circular Shape Pier (R^2 =0.958)

$D_{sc}=d+0.01\times(-0.99-0.52\times d_{50}-3.10\times U+63.76\times F_r+98.87\times U^2-149.08\times F_r^2)$.......**(1)**

(B) Double-D Shape Pier (R^2 =0.942)

$D_{sc}=d+0.01\times(1.82-0.50\times d_{50}+19.06\times U+27.30\times F_r+52.59\times U^2-90.01\times F_r^2)$.......**(2)**

(C) Rectangular Shape Pier (R^2 =0.959)

$D_{sc}=d+0.01x(5.32-0.51\times d_{50}+37.46\times U-4.07\times F_r+43.25\times U^2-61.48\times F_r^2)$............**(3)**

(D) Rectangular with Pointed Noses shape Pier (R^2 =0.966)

$D_{sc}=d+0.01x(5.71-0.48\times d_{50}+64.83\times U-30.97\times F_r-16.45\times U^2-14.37\times F_r^2)$..........**(4)**

Where,

D_{sc} = Scour depth below HFL in meter, d_{50} = Mean diameter of bed materials in mm

U = Approach velocity in m/sec, d = Depth of flow in meter, F_r = Froud's No.

CONCLUSION

The scouring is more around the pier than in the other locations of the channelbed.The intensity of scour is greater in the upstream face of the pier than in thedownstream face.For the same approach velocity and bed material, the scour depth observed to bemaximum in the rectangular pier which is followed by rectangle with pointednoses shape pier, circular pier and double D-shaped pier. Stream-lined bodies,such as Double-D shape pier and circular pier, was found more effective inreducing depth of scour. Hence, the double D-shaped pier is most effective forbridge foundation from scour reduction consideration. With the increase in approach flow velocity and flow depth, the depth of localscour increases.For a very fine sediment bed (d_{50}=0.1mm), the live bed scour is more prominentthan the local scour depth, because regime flow condition in very fine sedimentbed is possible only at low velocity of

Submitted: 27 March 2023, Revised: 09 April2024, Accepted: 18 April 2024, Published: May 2024

flow.With the increase of coarseness of the bed materials, scour depth will be reduced, because a large proportion of the down flow energy is dissipated inthe coarse bed at the base of the scour hole.As the spacing between the piers reduces, the scour depth will increase due to theinteraction of vortices created around the piers and thus the flow will beaccelerated due to contraction created by the adjacent piers.

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Submitted: 27 March 2023, Revised: 09 April2024, Accepted: 18 April 2024, Published: May 2024