LOCAL SCOUR WITH ANGLE OF ATTACK

by

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ABSTRACT

The purpose of this research is to study the influence of an angle of attack to the maximum depth of scour. An aligned pier at normal discharge may change to an angle of attack at flood flows and vice versa, as a result of the river bed changes. Unfortunately, the maximum depth of scour at an angle of attack will be larger than that of an unskewed pier.

This study is limited to blunt-nosed piers since a skewed pier will act as a blunt-nosed pier, eventhough it is a sharp-nosed pier at zero angle of attack.

Theoretical analysis shows that maximum depth of scour depends on the strength of horseshoe vortex system which is initially a function of pier Reynolds number. Therefore, maximum depth of scour should be a function of pier Reynolds number also.

The influence of an angle of attack to the maximum depth of scour can be expressed as a coefficient of pier skewness which is defined as the ratio of the maximum depth of scour at an angle of attack to that of unskewed condition. Since the maximum depth of scour is a function of pier Reynolds number, therefore coefficient of pier skewness can be expressed as a function of the ratio of pier Reynolds number, and for the same flow condition it will be a function of the ratio of pier projected width.

Experimental results show a good agreement with the theoretical consideration. A general formula for design purposes of the influence of pier skewness to the maximum depth of scour has been derived.

It was concluded that the expression from Shen et al (1966) may be used as an upper envelope of the coefficient of pier skewness.

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Symbol	Definition	Dimension	Unit
A	Area of the vortex area	L	m^2
$d\bar{A}$	Elemental surface area		
a	Length of obstruction perpendicular to the flow	L	cm
B	Pier diameter	L	cm
b	Pier width	L	cm
C	Chezy coefficient	$L^{\frac{1}{2}}T^{-1}$	$m^{\frac{1}{2}}/s$
C	A constant in Eq. 5.5		
D	Diameter of sand	L	mm
D_{50}	Median diameter of bed material	L	mm
d_{se}	Equillibrium scour depth	L	cm
d_{sm}	Maximum scour depth	L	cm
d_{smo}	Maximum depth of scour at 0 angle of attack	L	cm
Δd_s	Elemental scour depth		
F_h	Flow Froude number		
F_L	Pier projected width Froude number		
F_*^2	Shield's parameter		
f	Silt factor		
f_1, f_2	Sediment transport functions into and out of the scour hole, respectively		

g	Gravity acceleration	LT^2	m/s^2
h	Depth of flow	L	cm
i	Imaginary number $= \sqrt{-1}$		
K	Coefficient depending on pier shape		
K_2	A constant in Eq.3.6		
$K_{\alpha L}$	Coefficient of pier skewness		
k	Roughness coefficient		
ℓ	Pier projected width	L	cm
l	Pier length	L	cm
m	An exponent in Eq. 5.5		
n	Manning's roughness coefficient		
ΔQ_s	Volume of sediment removed in excavating scour hole by Δd_s		
$\bar{q}$	Velocity along the line BC in Fig.3.5	LT^{-1}	m/s
q	Unit discharge	L^3T^{-1}	$m^3/s/m$
q_a, q_s	Sediment transport rate of the approach flow and scour hole respectively	L^3T^{-1}	m^3/s
R	Hydraulic radius	L	m
Re_ℓ, Re_b, Re_L	Pier Reynolds number based on the length of pier, width of pier and projected width, respectively		
$Re_{\alpha\ell}$	$Re_\ell \sin\alpha$		
$Re_{\alpha b}$	$Re_b \cos\alpha$		
Reo	Pier Reynolds number at zero angle of attack		

r	Radius of the pier roundness	L	cm
r	Correlation coefficient		
S	Slope of energy gradient		
S	Specific gravity of sand		
S_o	$\sqrt{x_0^2 + y_0^2}$		
$d\bar{s}$	Elemental length of path about control volume		
T	Temperature		°C
t	Time	T	minute
U	Approach flow velocity	LT^{-1}	m/s
u_*	Shear velocity	LT^{-1}	m/s
V_1	Vertical velocity in front of the pier	LT^{-1}	m/s
V_2	Velocity component out of the scour hole	LT^{-1}	m/s
$\bar{v}$	Velocity vector		
X, Y, Z	Coordinate directions defined by Fig. 3.5		
x, y, z	Ordinat distance		
x_o, y_o	Distance to the face AB in Fig. 3.5 where there is no longer any vertical flow component		
y	Regime flow depth	L	m
y_n	Normal flow depth upstream of the pier	L	m
$\bar{z}$	Complex variable and its conjugate		
α	Angle of attack		degree
Γ	Circulation		

γ, γ_s	Specific weight of fluid and sand, respectively	ML^{-3}	kg/m^3
Δ	Relative density of submerged grain		
λ	Porosity of the bed		
ν	Kinematic viscosity	L^2T^{-1}	m^2/s
ρ, ρ_s	Density of water and sand, respectively		
τ_2	Shear stress in the scour hole	ML^{-2}	kg/m^2
ϕ	Angle of repose of the bed material		degree
$\bar{\Omega}$	Vorticity vector		
ω	Angular velocity		rad/s

I INTRODUCTION

1.1 Statement of Problem

One of the reasons of the failure of the bridge foundation is caused by the scour hole near the pier. Bridge piers are usually supported by friction piles, which are the bearing capacity depending on the shear force between the skin pile and the surrounding soil. If the scour depth is great enough to uncover the supporting piles, the shear force will be reduced and pier may fail.

River bed changes under a bridge may depend on the four factors which are related to each other:

a). Progressive or temporary degradation or aggradation associated with a change of river regimes and may change the entire river bed elevation.

b). River morphology. A non-uniformity of a river channel in the transverse direction due to large dunes on the bed or shifting of the thalweg. This is perhaps the most difficult factor to analyze on bridge design, eventhough its effects can be rather detrimental.

c). Scour due to contractions. The reduction of cross section flow areas may be caused by any combination of 1). presence of bridge piers, 2). constriction due to bridge approach, 3). accumulation of debris at the bridge section, 4). any others mean, will increase the flow velocity under the bridge and therefore the scour capability of the flow.

d).Local scour, which is caused directly by the flow disturbances induced by piers. It occurs adjacent to the pier, and may be present even in the absence of the first three factors.

This study primarily concerns with the local scour occured by the presence of bridge piers. In order to minimize local scour, it is well known that the piers should be as nearly aligned with the flow as possible. But a pier aligned with the flow at normal discharge may not be at flood flows and vice versa. The river bed changes like the presence of a dune or the meander of the thalweg can easily change the direction of the flow locally near the pier and hence the major axis of the pier is not aligned to the flow anymore. The magnitude of the maximum depth of scour with an angle of attack may be larger than that of unskewed pier.

Some investigators have studied this problem theoretically (Arunachalam, 1965; Shen et al, 1966) and experimentally (Keutner, 1932; Ishihara, 1942; Romita,1953; Laursen and Toch, 1953; and Varzeliotis, 1960). Among these investigators, only Arunachalam and Shen et al proposed a formula of the effect of pier skewness, while Laursen and Toch presented the multiplying factors for angle of attack graphically.

At blunt-nosed piers, a very strong different pressure between the stagnation point and the separation point occur. This situation form a three dimensional separation which causes a horseshoe vortex system. A wake vortex system usually occurs at the sharp-nosed pier which aligned to the flow. However, when the flow direction changes the pier will be characterized as a blunt-nosed pier in which a horseshoe vortex system occurs. Therefore, an experimental study of local scour with an angle of attack is better done by using a blunt-nosed pier rather than a sharp-nosed pier.

1.2 Objective of Study

The objectives of this study are :

(1) to investigate the effect of angle of attack to local scour of round-nosed pier through analytical approach and experimental work.
(2) to formulate the coefficient of pier skewness of round-nosed piers for various magnitude of length/width ratio.
(3) to determine the significant factors influence the maximum depth of scour.

1.3 Scope of Study

The investigation was done in the following stages:

(1) The existing literature on the topics of local scour with angle of attack was reviewed and summarized in literature review section.
(2) A theoretical analysis of the local scour by momentum approach and the influence of angle of attack by using control volume approach as derived by Shen et al(1966) was presented in Chapter III.
(3) A series of laboratory experiments in a recirculating flume has been done at AIT Hydraulic Laboratory. Totally 52 runs with various angle of attack, velocity and flow depth have been conducted, and the data on maximum depth of scour, characteristics of flow, and characteristics of pier were collected.
(4) The variation of the maximum depth of scour with changes in flow condition with some various angle of attack were analyzed and a formula to predict the maximum depth of scour and the coefficient of pier skewness was developed.

(5) The results and findings were compared with the theoretical analysis and the findings of previous investigators.