FIELD ASSESSMENT OF SCOUR AT THE OUTLET OF SELECTED ROAD CULVERTS

By
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DECEMBER, 2011
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A project report submitted to the Department of Water Resources Engineering of Bangladesh University of Engineering and Technology, Dhaka, in partial fulfillment of the requirements for the degree Of

MASTER OF ENGINEERING IN WATER RESOURCES

DECEMBER, 2011
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF WATER RESOURCES ENGINEERING

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Entitled

Field assessment of scour at the outlet of selected road culverts is accepted as fulfilling this part of the requirements for the degree of Master of Engineering in Water Resources.

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It is hereby declared that the prepared project or any part of it has not been submitted elsewhere for the award of any degree or diploma.

_________________________
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LIST OF NOTATIONS

$u_a$ approach bed shear velocity
$f$ “a function of”
g acceleration due to gravity
BMD Bangladesh Metrological Department
$\tau$ bed shear stress
$\tau_c$ critical shear stress of bed material
C cohesiveness of sediment
$C_d$ coefficient of discharge
$K_s$ culvert shape factor
$K_G$ channel geometry factor
$m^3/s$ Cubic meter per second
$V_C$ critical mean approach flow velocity for entrainment of bed sediment
$ft^3/s$ Cubic feet per second
$R$ channel hydraulic radius
$S_o$ channel slope
$b/h$ culvert width depth ratio
$u_{*c}$ critical shear velocity
$X,Y,Z$ Cartesian coordinate system
$\theta_c$ critical Shield value
$D_i$ Depth of scour from Water Level
$d_i$ depth of local scour at culvert outlet from bed level
$H$ Depth of water in the down stream of culvert
$Q$ discharge
$\mu_0$ dynamic viscosity
S energy level slope
$Fr$ Froude number
$K_I$ flow intensity factors
$V/V_C$ flow intensity
$Re_*$ grain Reynolds number
$\sigma_g$ geometric standard deviation of sediment particle size distribution
$\nu$ kinematics viscosity
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<td>( W )</td>
<td>Linear water width</td>
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<td>median size of sediment particle size distribution</td>
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<td>( k_s )</td>
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<td>( m/s )</td>
<td>meter per second</td>
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<tr>
<td>( n )</td>
<td>Manning’s roughness coefficient</td>
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<td>( V )</td>
<td>mean approach flow velocity</td>
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<td>( V_a )</td>
<td>mean velocity of flow at the “armour peak” for non uniform sediment which is equivalent to ( V_C ) for uniform sediment</td>
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<td>( \tau_o )</td>
<td>minimum shear stress required to move a particular exposed grain on surface of bed</td>
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<td>( G )</td>
<td>parameter describing effects of lateral distribution of flow in approach channel and cross-sectional shape of approach channel</td>
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<td>( d )</td>
<td>particle diameter</td>
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<td>( d_{84.1} )</td>
<td>particle size for which 84.1% are finer by weight</td>
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<td>( K_d )</td>
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*\( \rho \): water density*
ACKNOWLEDGEMENT

The author express his deepest gratitude to his supervisor Dr. Md. Abdul Matin, Professor, Department of Water Resources Engineering, BUET for his worthy guidance, valuable suggestion and helpful comments throughout the study. His best leveled specialized knowledge and experience helped the author for better understanding and successful completion of this study. Without his keen supervision and efforts this project would not be a successful one.

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The author desire to thanks to the official of Upazila Engineering office, Sonargaon for their cooperation during data collection and field measurement.

The author would like to express with gratitude to his mother who spent many of her time praying for successful completion of the project task properly. At last, the author intends to remember his wife for her great sacrifice and providing him continuous moral supports that enabled him to complete the work.

Md. Anowar Hossain
December, 2011
ABSTRACT

Scour downstream of culverts outlet is a common problem that can lead to damage to the culvert structure and bank erosion to the adjacent channel. Traditional scour prediction equations are applicable only to a limited range of situations, although offering the engineer some guidance on the likely magnitude of maximum scour depth. A general prediction equation of scour that applicable to all circumstances is not presently available. Moreover, there is a need for an assessment of applicability of available equations based on field data for a particular type of structure like a culvert. Field data can be collected to verify the equation used to estimate the design scour of the selected culverts.

Four culverts on different type of road located at Sonargaon Upazila under Narayanganj district have been selected for assessment of field scour at culvert outlets. At the immediate downstream of the culvert an area of 18 m x 18m was taken for field measurement of scour. This measurement has been done at an interval of 1m x1m grid spacing. Pre and Post monsoon conditions have also been considered for scour measurements in same location. Scour depth measured in the field has been compared with anticipated maximum depth of scour based on different available formula. In this work, the Lacey, the Blench, the Ahmed and the Chitale equations are used to calculate the maximum scour depth. Flow velocity through the culverts is measured in field and the flow rate has been estimated through culvert. In addition, rational formula has been applied to estimate the maximum runoff discharge through the culverts and compared with the measured flow rate by using area velocity method. The sediment samples are also collected and analyzed to obtain representative size of bed material.

The contour maps have been plotted and analyzed to investigate the extent and location of maximum scour hole. Predictive capacity of equations used is also compared with result obtained from field assessment. It is found that the depth of maximum scour found in the field is relatively closer to predicted depth calculated with the Lacey equation.
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Chapter-1
INTRODUCTION

1.1 Background

The Local Government Engineering Department (LGED) under the ministry of Local government, Rural Development and Cooperative is responsible for planning, design, constructions and maintenance of Upazila Road, Union Road and Rural Roads in Bangladesh. A large number of road structures are built annually by the Department all over the country. A great majority of these road structures represent small bridges and culverts. The implementation of project with an aim to improve rural road networks to decrease rural transportation cost through development of continuous alignments. In order to reduce the construction cost of culvert, the cross-section at a crossing is often reduced by encroachment of the embankment on the flood plain or even on the river channel (Breusers & Raudkivi, 1991). However for designing the foundation of such bridge/culvert the proper choice of scour is always necessary.

An important feature in the design of drainage-crossing hydraulic structures such as culverts, is determining the design of flow capacity (Lim 1995). The problem of failure of culvert foundation is one of the major concerns to the design engineers and one major cause of such failure is the scour holes created by the flowing water around the structures. A number of empirical formulas have been developed in the past to estimate scour depth at culvert outlets including Opie (1967), Rajaratnam and Berry (1977), Rajaratnam (1981), Ruff et al (1982), Rajaratnam and MacDougali (1983), Blaisdell and Anderson(1988), Abida and Townsend (1991), Lim (1995), and Chiew and Lim(1996). Azamathulla and Ghani (2010). Most of these studies are based on experiments and are applicable only to a limited range of field conditions.

It is a common practice that the foundation of any structure must be deep enough to sustain the scour depth developed by the changes of local flow around the structure. The major damage to bridge/culvert at canal crossing occurs during floods. The damage can be erosion in the vicinity of land which may spread from the culvert outlet and lead to complete failure of the culvert. During flood 1998 some culverts
were failed at some locations of Bangladesh. The primary reasons of such failure were identified as the flow slides initiated by the removal of material in the scour hole. This means that the failure was initiated due to very fast scouring process. Complete failure results in severe disruption to local traffic flows. Knowledge of maximum depth of scour under various conditions specially, scour outlet of culverts for different type of bed material of the stream is essential for design of the culvert foundation as well as for proper maintenance of the culvert after its construction. Accurate prediction of scour depth downstream of culvert structures is required to ensure foundations to prevent damage to the structure as a result of undermining. Many studies had been carried out in the past are mainly experimental in nature. Therefore, a field investigation have been attempted in this study to assess the scour at culvert outlets

1.2 Objective of the study

The following objectives with specific aims and possible outcome have been setup for this present study.

i) To conduct field measurement of scour of selected culverts.

ii) To assess the hydraulic design parameters required for scour at down stream of culverts.

iii) To suggest a suitable method of estimating scour at the culverts outlet.

1.3 Organization of the study

This project report has been arranged into six chapters. Chapter one provides an introduction with background and present state of the problem. Chapter two reviews the literature in connection with the present study. The detail description of the study area is given in Chapter three. In Chapter four, detailed methodology and field data collection of the present study has been reported. Result and discussion is given in Chapter five. The conclusion of this study and recommendation for further study are also incorporated.
2.1 Introduction
Scour at the culvert outlet is a common problem worldwide. This may cause the undermining of shallow foundation and thus resulted in failure of structure. Many work has been conducted on scouring downstream of culverts but most of the studies are experimental nature. Also prediction of scouring downstream of culvert however not available. The purpose of this chapter is to present an overview of relevant theory, scouring process, mechanism, on scour downstream of a culvert.

2.2 Scour process
Scour is process of lowering of bed by water erosion. Amount of this reduction below an assumed natural level is termed as depth of scour or scour depth (Melville and Coleman 2000). This scouring process is result of interaction between secondary currents and vortices that occur in conjunction with channel features like bends, abrupt flow direction, obstruction, constrictions, confluences, control structures etc. depth and dimensional extent of scour is dependent upon strength of secondary currents developed at concerned canal features.

2.3 Different Types of Scour
In broad categories, two types of scour occurs to obtain total scour at hydraulic structures, these are i) General scour and ii) Local scour. Scouring can be either one or a combination of following types of scour processes, which are shown in flow diagram (Figure 2.1). However, the scour components outlined in Figure 2.1 are generally applicable for the structures constructed a very dynamic river.
2.4 Variables affecting the scour depth

The variables influencing the equilibrium scour depth at culvert outlets are listed as below (Liriano and Day 2001)

\[ d_s = \left( \rho, \mu_0, u_0, d_0, H, W, W_0, g, \rho_s, d_{50}, \sigma_g, K_s \right) \]  

Where

- \( d_s \) = maximum depth of scour;
- \( \rho \) = density of water;
- \( \mu_0 \) = dynamic viscosity of water;
- \( d_0 \) = outlet height of culvert;
- \( H \) = depth of water in the downstream of the receiving channel;
- \( W \) = width of the receiving channel;
- \( W_0 \) = width of the outlet;
- \( g \) = acceleration due to gravity;
- \( \rho_s \) = density of sediment bed material;
- \( d_{50} \) = median sediment size;
- \( \sigma_g \) = geometric standard deviation of the bed material.

Assuming that the viscous effect is not important and that the bed material consist of sand and gravel with constant \( \rho_s \), a dimensional analysis of equation 2.1 can be reduced to

\[ \frac{d_s}{d_0} = \left( F_0, \frac{H}{d_0}, \frac{W}{d_0}, \frac{W_0}{d_0}, \frac{d_{50}}{d_0}, \sigma_g, K_s \right) \]  

Equation 2.2 can be used to develop scour prediction equation considering most dominant dimensionless groups.
2.5 Threshold condition for sediment motion

A particle on a channel bed will be set in motion when disturbing forces (i.e. drag and lift forces due to over crossing flow) overcome resisting forces (gravity and cohesion). Scour criteria are involved with physical conditions pertaining to threshold of motion for material. Incipient motion analysis based on Shield’s diagram (Figure 2.2) can be used to evaluate threshold flow conditions for motion of given sediment.

Shield diagram indicates that for flows less than threshold conditions for boundary material, a channel is stable with no motion of sediment. For flows exceeding these conditions, boundary sediment will be entrained in flow. Depending on continuity of sediment supply along channel, transport of sediment may not necessarily result in erosion of channel boundary.

![Figure 2.2: Shield’s diagram](Source: Breusers and Raudkivi, 1991)

Shield’s diagram depicts relation between grain Reynolds number \( (Re_\ast) \) and critical Shield value \( (\theta_\ast) \) defined as below:

\[
Re_\ast = \frac{u_\ast d}{\nu}
\]  
(2.3)
\[ \theta_c = \frac{u_s^2}{g \Delta d} = \frac{\tau}{[(S_s - 1) \rho g d]} \]  

(2.4)

Where,

\( u_s \) = shear velocity = \( \sqrt{ghS} \)

\( \Delta = \frac{\rho_s - \rho}{\rho} \) = relative submerged sediment density

\( \rho_s \) = sediment density

\( \rho \) = water density

\( d \) = particle diameter

Thus, Shield’s diagram describes incipient flow conditions in terms of a critical shear stress, \( \tau_c = \rho U_{c50}^2 \), associated with incipient entrainment of bed sediment.

However, a critical mean channel velocity of flow \( (V_c) \) that will transport bed material of size \( d_{50} \) and smaller is also preferred to describe incipient sediment motion. It can be determined from critical shear velocity using:

\[ \frac{V_c}{u_s} = \left( \frac{R}{g n^2} \right)^{\frac{1}{3}} \]  

(2.5)

also

\[ \frac{V_c}{u_s} = 5.75 \log \left[ 5.53 \frac{y}{d_{50}} \right] \]  

(2.6)

Critical shear velocity \( u_s \) for a particular \( d_{50} \) size can be determined from Shield’s diagram or using following formulae:

\[ u_s = 0.0115 + 0.0125d_{50}^{1.4} \text{ for } 0.1 \text{ mm} < d_{50} < 1 \text{ mm} \]  

(2.7)

\[ u_s = 0.0305d_{50}^{0.5} - 0.0065d_{50}^{-1} \text{ for } 1 \text{ mm} < d_{50} < 100 \text{ mm} \]  

(2.8)
Alternatively, various empirical relations exist for critical mean velocity of flow at threshold condition for sediment movement. Following equation is given by Neill (1968):

\[
V_c = 1.41 \left[ (S_t - 1) y d_{50} \right]^{0.5} \left( \frac{y}{d_{50}} \right)^{\frac{1}{6}}
\]  

(2.9)

With \( S_c = 2.65 \) for quartz sediment, above equation can be simplified to:

\[
V_c = 5.67 y^{\frac{1}{3}} \]  

(2.10)

2.6 Shear velocity
Flow of water can empirically be analyzed by its mean depth \( (y) \), channel slope \( (S_o) \) and gravitational acceleration \( (g) \). In uniform flow, shear stress \( (\tau_o) \) associated with a certain channel slope and flow depth can be expressed as \( \tau_o = \gamma y S_o \) or more conveniently as shear velocity \( u_0 = \sqrt{\gamma y S_o} \). When flow over an initially plane bed of granular material exceeds critical velocity erosion of particle occur for given flow depth and sediment bed material.

2.7 Sediment parameters
Sediment can be defined in terms of its specific gravity and sieve diameter of its particles. Uniformity of particle size distribution can be defined by its geometric standard deviation \( (\sigma_g) \). Other factors, which come into consideration, are cohesiveness of sediment \( (C) \), shape factor \( (Sh) \), angle of repose, fall velocity etc.

2.8 Scour as a function of time
Scouring is a process in which scour geometry of sediment bed approaches its new equilibrium shape gradually. Consequently, it takes time for such equilibrium to be established. This is especially significant in case of flood. Duration of flood determines if flood peak lasts long enough to establish maximum scour depth. Particularly duration of early stages of flood recession may be important. This is because maximum scour depth can occur during early stages of receding flood at which stage; elevation of bed level is at its lowest level due to general scour and with decreasing flow and general sediment transport is reduced to such an extent that clear
water scour condition can prevail. At this time, rate of scour development can have an important role on maximum scour depth. Figure 2.3 represents scour depth for both clear water and live bed scour as a function of time.

![Figure 2.3: Scour depth as a function of time (Source: Breusers and Raudkivi, 1991)](image)

2.9 Selection of equation available for scour depth calculation.

Selection of formula for determination of scour at culvert outlet is important. A literature review by McIntosh (1989) found that more than 35 equations had been proposed for predicting depth of scour at a bridge pier. But there are few equations found to predict the maximum scour depth at culvert outlet. Most of the Engineering Organization in our country like, LGED, BWDB uses Lacey’s formula for determination of scour depth at culvert outlet. Considering in our country context, in the following some well-known equations used for maximum scour prediction are described.

2.9.1 Blench's equation (1969):

\[ y_{ms} = 1.20 \left( \frac{q^{2.5}}{d_{50}^{6.5}} \right) \quad \text{for sand of } 0.06 < d_{m} \text{ mm} \]  

(2.11)

Where, \( y_{ms} \) = maximum scour depth below water level

\( q \) = discharge per unit width

\( d_{50} \) = median diameter of the particle
\[ y_{ms} = 1.23 \left[ \frac{q^{\frac{2}{3}}}{d^{\frac{1}{30}}} \right] \quad \text{for gravel of } S_s = 2.65 \text{ and } d_{50} > 2.0 \text{mm} \quad (2.12) \]

The unit of \( y_{ms}, q, \) and \( d_{50} \) are m, \( m^2/s \), and mm respectively.

### 2.9.2 Maza Alvarez and Echavarria Alfaro's equation (1973):

\[ y_{ms} = 0.365 \left( \frac{Q^{0.784}}{W^{0.784} d_{50}^{0.157}} \right) \quad (2.13) \]

Where, \( y_{ms} \) = maximum scour depth below water surface in meter,
\( Q \) = flow rate in \( m^3/s \) and
\( W \) = water width in meter. This method is valid only for sediments of \( d_{75} < 6 \) mm, principally sands and gravels, with predictions being noted to differ to observations for finer materials. For a narrow river, the channel hydraulic mean radius is adopted in lieu of \( W \). Watson (1990) reports extensive use of this method for gravel-bed.

### 2.9.3 Chi tale's equation (1960)

\[ \frac{d_s}{y_0} = 6.65 Fr - 0.51 - 5.49 Fr^2 \quad (2.14) \]

Where \( d_s \) = Scour depth below bed level
\( y_0 \) = depth of flow
\( Fr^2 = \frac{V^2}{g y_0} \)
\( Fr \) = Froude number of the approach flow
\( V_0 \) = Mean velocity of flow
2.9.4 Ahmed's equation (1962)

\[ D_s = kq_1^{2/3} \]  

(2.15)

Where \( D_s \) = scour depth below the water surface in meter

\[ q_1 = \text{Local discharge intensity in the contracted channel in } m^2/sec \]

\[ k = \text{a multiplying factor depend on the shape of the culvert ranging from 1.90 to 3.4} \]

2.9.5 Lacey's equation (1930):

\[ y_{ms} = 0.473 \left( \frac{Q}{f} \right)^{1/3} \]  

(2.16)

Where \[ f = 1.76 \sqrt{d_m} \]

and scour depth \( d_s = y_{ms} - y \)

Where, \( y_{ms} = \text{maximum scour depth below water surface}, \)

\( Q = \text{flow rate}, \quad f = \text{Lacey's silt factor and } d_m = \text{the median sediment size}. \) The units of \( y_{ms}, Q, \) and \( d_m \) are \( m, \quad m^3/s, \) and \( mm, \) respectively. This approach is indicated to be too conservative for large sediment. The relation for \( f \) applies for \( d_m < 1.3 \) mm. The Lacey's equation is commonly used in design of small hydraulics structures as reported in LGED (1990).
Chapter-3

STUDY AREA

3.1 Introduction
Sonargaon Upazila is located within the Narayanganj district at a distance of 15 km. from the district and on the north-east part of Narayanganj district. It is located at 23.6583 N 0.6083E. The study area is about 171.66 Sq.km and appears to have embraced a wide tract bounded on the east, west and south by the Meghna, the Sitalakshya and the Dhaleshwari respectively and on the north by the Old Brahmaputra, (Fig3.1). Four culverts on different type of road located at Sonargaon upazila have been selected for field assessment of scour. At the immediate down stream of the culvert an area of 18mx18m was taken for field measurement of scour. This measurement has been done at an interval of 1mx1m grid spacing. Pre and Post monsoon conditions have been considered for same scour measurement. The scour depth measured in the field has been compared with calculated maximum depth of scour based on different available formula. Here Lacey’s (1930), Blench's (1969), Ahmed’s (1962), Chi tale's (1960) equation is used to calculate the maximum scour depth.
Figure 3.1: Location map of the study area
Figure 3.2: Position of the culvert under study area from satellite image
3.2 Topographic Condition

Sonargaon Upazila falls in alluvial plain. This is part of the larger plain of Bengal, which is sometimes called the Lower Gangetic Plain. Elevations of the plains are less than 10m above the sea level; elevation further decline to a near sea level in the coastal south.

3.3 Meteorological Condition

Rainfall

Sonargaon Upazila lies in the tropical monsoon climatic region and more specially, represents the climate of Dhaka district. Average annual rainfall is about 2550 mm of which occurs in six months from May to October. The dry season extends from November to February and is cool and almost rainless, receiving less than an average of 4 inches for the total 4 months period. March to May is the pre-monsoon season, with high temperatures and periodic thunderstorms.

Sonargaon Upazila has three distinct seasons: winter (November-February), dry with temperature 12° to 20°C; the pre-monsoon season (March-May), some rain and hot with temperature reaching up to 40°C; and the monsoon (June-October), very wet with temperatures around 30°C. Sonargaon upazila experiences about 2,000 mm rain annually, of which about 80% falls during the monsoon.

Table 3.1: Average Normal Rainfall in mm for Sonargaon Upazila (BMD, 2009)

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7.7</td>
<td>28.9</td>
<td>65.8</td>
<td>156.3</td>
<td>339.4</td>
<td>340.4</td>
<td>373.1</td>
<td>316.5</td>
<td>300.4</td>
<td>172.3</td>
<td>34.4</td>
<td>12.8</td>
</tr>
</tbody>
</table>
Figure 3.3: Annual rainfall of Sonargaon Upazila (BMD, 2009)
3.4 Geological Condition
Sonargaon Upazila falls in the region of old Brahmaputra and Meghan floodplain. In 1787, a remarkable change in the course of the Brahmaputra took place. In that year, the river shifted from a course around the eastern edge to the western side of the Madhupur Tract. This new portion of the Brahmaputra is named Jamuna. The old course (old Brahmaputra) between Bahadurabad and Bhairab shrank through silting into a small seasonal channel only two kilometer wide. The old river had already built up fairly high levees on either side over which the present river rarely spills. The Old Brahmaputra floodplain stretching from the southwestern corner of the Garo Hills along the eastern rim of the Madhupur Tract down to the Meghna exhibits a gentle morphology composed of broad ridges and depressions. The latter are usually flooded to a depth of more than one meter, whereas the ridges are subject to shallow flooding only in the monsoon season.

On the other hand, geosynclinals Basin in the southeast is characterized by the huge thickness (maximum of about 20 km near the basin centre) of elastic sedimentary rocks, mostly sandstone and shale of Tertiary age. It occupies the greater Dhaka-Faridpur-Noakhali-Sylhet-Comilla-Chittagong areas. The huge thickness of sediments in the basin is a result of tectonic mobility or instability of the areas causing rapid subsidence and sedimentation in a relatively short span of geologic time. The geosynclinals basin is subdivided into two parts i.e. fold belt in the east and a fore deep to the west.

3.5 Selection of site
Where there is any choice, a site for culvert should be selected which:

   i) is situated on a straight reach of the stream, sufficiently away from bends
   ii) makes approach roads straight
   iii) offers a square crossing as far as practicable

3.6 Channel type and waterway opening
The water paths under a road structure are usually classified as either a well defined channel of an ill defined channel. A well defined channel is one where the flow is contained within raised banks for most of the year. On the other hand, where no
definite stream exists and the flow at the location is caused by a natural depression in the terrain, the water path may be termed an ill defined channel. An ill defined channel is often characterized by inundation of a large area and a sheet like flow of water.

3.7 Location of culverts for present study

Location of the selected culverts under the study area of Sonargaon Upazila has been given in Table 3.2

<table>
<thead>
<tr>
<th>Culvert No</th>
<th>Place of location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Size(width x height)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Culvert-1</td>
<td>Mirertek</td>
<td>23°43′7.4″(N)</td>
<td>90°35′49.6″(E)</td>
<td>6.0mx4.70m</td>
</tr>
<tr>
<td>Culvert-2</td>
<td>Taltola</td>
<td>23°43′20″(N)</td>
<td>90°38′2.4″(E)</td>
<td>4.20mx3.70m</td>
</tr>
<tr>
<td>Culvert-3</td>
<td>Katchpur</td>
<td>23°43′11.5″(N)</td>
<td>90°32′15.7″(E)</td>
<td>4.30mx4.30m</td>
</tr>
<tr>
<td>Culvert-4</td>
<td>Pachani</td>
<td>23°36′53.3″(N)</td>
<td>90°34′47.7″(E)</td>
<td>3.30mx3.30m</td>
</tr>
</tbody>
</table>
Chapter-4

METHODOLOGY AND FIELD DATA COLLECTION

4.1 Introduction
In this present study, an attempt has been made to carry out a field observation of scour at the downstream of selected road culvers. For this reason these culverts on different type of road located at Sonargaon upazila under Narayanganj district have been selected for assessment of field scour. At the immediate downstream of the culvert, an area of 18 m x18m field space was taken for field measurement. Bed level measurement has been done at an interval of 1m x 1m grid spacing. Pre and Post monsoon conditions have been considered for same scour measurement.

4.2 Delineation of catchments area
The catchments area is delineated from the topographic features and consultation with the LGED officials and local people of that area. The delineated area of each culvert has been shown from figure 4.1 to 4.4 and catchments area of the culverts has been shown in Table 4.1.
Figure 4.1: Delineated area of culvert-1, Mirertek

Figure 4.2: Delineated area of culvert-2, Taltola
Figure 4.3: Delineated area of culvert-3, Katchpur

Figure 4.4: Delineated area of culvert-4, Pachani
### Table 4.1: Catchment area of the culvert

<table>
<thead>
<tr>
<th>Culvert no.</th>
<th>Catchment area (A) in acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Culvert-1, Mirertek</td>
<td>700</td>
</tr>
<tr>
<td>Culvert-2, Taltola</td>
<td>440</td>
</tr>
<tr>
<td>Culvert-3, Katchpur</td>
<td>550</td>
</tr>
<tr>
<td>Culvert-4, Pachani</td>
<td>230</td>
</tr>
</tbody>
</table>

#### 4.3 Time of concentration ($t_c$)

The time of concentration for the catchments area of each culvert has been calculated and found nearly 1-h. The detailed calculation of time of concentration has been given in Appendix A.

#### 4.4 Estimation of Discharge

The methods for estimating discharge at culvert site outlined below:

(a) **Rational Method**

The rational method is the most widely used method for the analysis of runoff from small catchments. This method is widely used for ungaged catchments. At the culverts location this discharge was calculated using this rational method.

$$ Q = CIA $$  \hspace{1cm} (4.1)

Where, $Q$=discharge in ft$^3$/s  
$C$ = runoff coefficient  
$I$ = rainfall intensity in inch / h  
$A$ = catchment areas in acres

The value of Runoff coefficient($C$) is taken as 0.60 for rural areas and cultivated land (Ponce, 1989). The value of Rainfall Intensity ($I$) is taken from IDF-curve of 20-years return period. Estimated discharge by using rational method has been compared with measured flow rate by using area velocity method.
Comparison of discharge by using rational method and measured flow rate by using area velocity method are presented Table: 4.4

**Table 4.2**: Point Rainfall Intensity- Duration- Frequency Data

Point Rainfall Intensity- Duration- Frequency for Narayanganj from Hourly Data

<table>
<thead>
<tr>
<th>Return period (yr)</th>
<th>5 mins</th>
<th>10 mins</th>
<th>15 mins</th>
<th>30 mins</th>
<th>1-Hr</th>
<th>2-hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>6.808</td>
<td>5.28</td>
<td>4.456</td>
<td>3.088</td>
<td>1.955</td>
<td>1.472</td>
</tr>
<tr>
<td>5</td>
<td>9.012</td>
<td>6.992</td>
<td>5.904</td>
<td>4.092</td>
<td>2.59</td>
<td>1.618</td>
</tr>
<tr>
<td>10</td>
<td>10.644</td>
<td>8.262</td>
<td>6.976</td>
<td>4.834</td>
<td>3.06</td>
<td>1.912</td>
</tr>
<tr>
<td>20</td>
<td>12.324</td>
<td>9.558</td>
<td>8.072</td>
<td>5.594</td>
<td>3.54</td>
<td>2.212</td>
</tr>
<tr>
<td>50</td>
<td>14.472</td>
<td>11.232</td>
<td>9.484</td>
<td>6.572</td>
<td>4.16</td>
<td>2.6</td>
</tr>
<tr>
<td>100</td>
<td>16.152</td>
<td>12.528</td>
<td>10.58</td>
<td>7.332</td>
<td>4.64</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Source: Saad, M.Engineering Project (1993)

**Table 4.3**: Discharge estimation from Rational Method.

<table>
<thead>
<tr>
<th>Culvert.no</th>
<th>Catchment area A (Acres)</th>
<th>Runoff coefficient C (for rural cultivated land)</th>
<th>1-hour Rainfall Intensity, I in inch/hour (from IDF curve)</th>
<th>Discharge Q= CIA (ft³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Culvert-1, Mirertek</td>
<td>700</td>
<td>0.6</td>
<td>3.54</td>
<td>1486.8</td>
</tr>
<tr>
<td>Culvert-2, Taltola</td>
<td>440</td>
<td>0.6</td>
<td>3.54</td>
<td>934.56</td>
</tr>
<tr>
<td>Culvert-3, Katchpur</td>
<td>550</td>
<td>0.6</td>
<td>3.54</td>
<td>1168.2</td>
</tr>
<tr>
<td>Culvert-4, Pachani</td>
<td>230</td>
<td>0.6</td>
<td>3.54</td>
<td>488.52</td>
</tr>
</tbody>
</table>
Figure 4.5: Rainfall Intensity -Duration-Frequency curve.

Table 4.4: Variation of discharge between field assessment and rational formula

<table>
<thead>
<tr>
<th>Culvert.No</th>
<th>Discharge calculated (From measured velocity) (m³/s)</th>
<th>Discharge calculated (from Rational method) (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Culvert-1, Mirertek</td>
<td>49.01</td>
<td>42.10</td>
</tr>
<tr>
<td>Culvert-2, Taltola</td>
<td>30.01</td>
<td>26.46</td>
</tr>
<tr>
<td>Culvert-3, Katchpur</td>
<td>30.52</td>
<td>33.07</td>
</tr>
<tr>
<td>Culvert-4, Pachani</td>
<td>16.38</td>
<td>13.83</td>
</tr>
</tbody>
</table>

(b) Area Velocity Method
The most common type of indirect measurement of flood discharge in made through a reach of river channel by computing on the basis of uniform flow equation.
\[ Q = \frac{1}{n} AR^{\frac{2}{3}} S^{\frac{1}{3}} \]  

(4.2)

Where \( Q \) is the discharge in m/s, \( S \) is the defined as \( hw/L \), \( h_w \) is water level of two successive sections, \( L \) is the distance apart of sections, \( R \) is the hydraulic radius, \( n \) is the Manning’s roughness coefficient for the channel bed.

(c) **Direct Measurement: Float Method**

\( Q = AV \),

Where \( Q \) is the discharge in m\(^3\)/s, \( A \) is the area of cross section and \( V \) is the surface velocity. The velocity of flood or the surface velocity can be measured by observing the time taken by a floating object, preferably a wooden block, to move a known distance.

\[ v = \frac{d}{t} \]

Where \( v \) = surface velocity at the point a float crosses the mid cross section in m/sec, \( d \) = distance from upper to lower cross section in meter, \( t \) = time required for the float to travel from upper to lower cross section in seconds.

4.5 **Linear waterway of culverts**

The length of a linear waterway of a bridge or culvert across an alluvial channel may be determined using following empirical relation (Breusers and Raudkivi, 1991)

\[ L = W = 4.8Q^{\frac{1}{2}} \]  

(4.3)

Where, \( L \) = the linear waterway in meter, \( W \) = regime width, \( Q \) = design discharge in m\(^3\)/s.

If the normal depth of scour \( (D) \) is less than the existing scour depth \( (D') \), the deepest point in the cross section under consideration, then the width of crossing may be modified to:
\[ L = W \left( \frac{D}{D''} \right)^{1.64} \]  \hspace{1cm} (4.4)

The existing scour depth \( D'' \) is the deepest point in the cross section measured from the water level corresponding to the design discharge.

\[ D = \frac{1.21Q^{0.63}}{W^{0.6} f^{-0.33}} \]  \hspace{1cm} (4.5)

If the linear waterway is, kept less than the regime width of the stream for some special reason, then the normal scour depth will be greater than the regime depth of the stream. The modified normal scour depth \( D' \) shown in Fig. 2.5 may be calculated from the regime depth \( D \) by the equation.

\[ D' = D \left( \frac{W}{L} \right)^{0.61} \]  \hspace{1cm} (4.6)

The flow rate through the culvert has been estimated using continuity equation. The sediment sample have been collected and analyzed to obtain silt factor. Necessary correction factors will be applied for both channel constriction and configuration of the channel like bend at the vicinity of the channel associated with the scour

### 4.6 Determination of scour depth

For quasi alluvial channel, the normal scour depth may be calculated by using the following equation. \{LGED,RSM(1997)\}
Maximum scour depth can also be found by the following formula.

\[ D_{\text{max}} = D \left( \frac{W}{L} \right)^{1.56} \]  \hspace{1cm} (4.7)

The greater of the two depths calculated above from equation (4.6) and equation (4.7) may be used as design depth of scour depth.

4.7 Field Data Collection
In following subsections, data collection of present study is discussed in details.

4.7.1 Sample of bed material from the culvert outlet.
In this study, bed material sample of each culvert outlet has been collected to obtain the mean diameter of the sediment size. This sample was analysis in the LGED's laboratories. The distribution of the particle smaller than .075mm is determined by a sedimentation process, using a hydrometer. Grain size distribution curves has been plotted for each culvert bed material and shown in Figure 4.7. to Figure 4.10. Median particle size \(d_{50}\) for bed material of each culvert is taken as characteristic particle size for all investigation and value is calculated from the Grain size distribution curves. The value of median particle size\(d_{50}\) for each culvert have been shown in Table 4.5
**Figure 4.7:** Grain size distribution curves for bed material of culvert-1, Mirertek.

**Figure 4.8:** Grain size distribution curves for bed material of culvert-2, Taltola.
Figure 4.9: Grain size distribution curves for bed material of culvert-3, Katchpur.
Figure 4.10: Grain size distribution curves for bed material of culvert-4, Pachani.

Table 4.5: Median size and type of material downstream of culverts

<table>
<thead>
<tr>
<th>Culvert no.</th>
<th>Median size($d_{50}$) (mm)</th>
<th>classification*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Culvert-1, Mirertek</td>
<td>0.038</td>
<td>Coarse silt</td>
</tr>
<tr>
<td>Culvert-2, Taltola</td>
<td>0.04</td>
<td>Coarse silt</td>
</tr>
<tr>
<td>Culvert-3, Katchpur</td>
<td>0.05</td>
<td>Coarse silt</td>
</tr>
<tr>
<td>Culvert-4, Pachani</td>
<td>0.043</td>
<td>Coarse silt</td>
</tr>
</tbody>
</table>

* Source: Chang (1990)
4.7.2 Culvert information from field survey
Field visits have been conducted to obtain culvert information's. Photograph 4.1, 4.2, 4.3 and 4.4 shows different types of culverts selected for present study. Culverts positions are taken from GPS (Photograph 4.4). Detail information of culverts is presented in Table 4.6.

Photograph 4.1: Culvert-1, Mirertek, Sonargaon, Narayanganj

Photograph 4.2: Culvert-2 Taltola, Sonargaon, Narayanganj
Photograph 4.3: Culvert-3 Katchpur, Sonargaon, Narayangonj

Photograph 4.4: Location of culvert taken by GPS
Table 4.6: Details of Culverts Information

<table>
<thead>
<tr>
<th>Name of the Culvert</th>
<th>Size (b x h)</th>
<th>Culvert Position (Latitude and Longitude)</th>
<th>Width/height ratio (b/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Culvert-1 Mirertek</td>
<td>6.0m x 4.70m</td>
<td>23°43'7.4&quot;N, 90°35'49.6&quot;E</td>
<td>1.28</td>
</tr>
<tr>
<td>Culvert-2 Taltala</td>
<td>4.20m x 3.70m</td>
<td>23°43'20&quot;N, 90°38'2.4&quot;E</td>
<td>1.13</td>
</tr>
<tr>
<td>Culvert-3 Kachpur</td>
<td>4.30mx4.30m</td>
<td>23°43'11.5&quot;N, 90°32'15.7&quot;E</td>
<td>1.00</td>
</tr>
<tr>
<td>Culvert-4 Pachani</td>
<td>3.30mx3.30m</td>
<td>23°36'53.3&quot;N, 90°34'47.6&quot;E</td>
<td>1.00</td>
</tr>
</tbody>
</table>

4.7.3 Water Level

In this study water level is taken from the selected culvert site at different date during flood. Detailed information of water level data are presented in Table 4.7.

Photograph 4.5: Water level data measured at the culvert site
Table 4.7: Water Level data observed at different culvert locations

<table>
<thead>
<tr>
<th>Date</th>
<th>Water level (m)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Culvert-1 Mirertek</td>
<td>Culvert-2 Taltola</td>
<td>Culvert-3 Katchpur</td>
<td>Culvert-4 Pachani</td>
<td></td>
</tr>
<tr>
<td>Aug15_98</td>
<td>7.93</td>
<td>8.23</td>
<td>8.63</td>
<td>8.78</td>
<td></td>
</tr>
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<td>9.22</td>
<td>9.37</td>
<td></td>
</tr>
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<td>Sep12_98</td>
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<td>8.69</td>
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<td>8.79</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Temporary Bench Mark (TBM) was taken as 10m which was on North-West corner of slab

Photograph 4.6: Typical Measurement of bed level at culvert Site
4.8 Scour depth observed at different time interval

Bed level data at culvert down stream have been taken at different time interval during pre monsoon and monsoon. At the immediate down of culvert an area of 18mx18m was taken for field measurement of scour. This measurement was done at an interval of 1mx1m grid spacing. Pre and post monsoon condition was considered for same scour measurement Observed scour depth have been taken at culvert downstream from measured bed level data. A sample data sheet of bed measurement is given in Table 4.7. Scour depth found in the field with respect to water level have been shown in Table 4.8 to Table 4.11. A summary of observed scour depth is presented in Table 4.12 to 4.13. Some Photograph 4.8 to 4.12 are shown during field data collection.
Table 4.8: Sample of grid for bed level data taking for culvert-1, Mirertek
(19 September, 1998)

<table>
<thead>
<tr>
<th>18 (m)</th>
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</table>

Photograph 4.8: Photograph during bed level data collection.
Table 4.9: Observed scour depth for culvert-1, Mirertek (down stream)

<table>
<thead>
<tr>
<th>Date of measurement</th>
<th>Culvert opening (m)</th>
<th>Water level RL (m)</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth w.r.t WL ($D_s$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug 15, 98</td>
<td>6.00</td>
<td>7.93</td>
<td>3.92</td>
<td>4.01</td>
</tr>
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<td>Sep 08, 98</td>
<td>6.00</td>
<td>8.52</td>
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<td>4.70</td>
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<td>5.20</td>
</tr>
<tr>
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<td>8.26</td>
<td>3.21</td>
<td>5.05</td>
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<tr>
<td>Sep 19, 98</td>
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<td>7.66</td>
<td>2.14</td>
<td>5.52</td>
</tr>
<tr>
<td>Sep 26, 98</td>
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<td>2.52</td>
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</tbody>
</table>

Table 4.10: Observed scour depth for culvert-2, Taltola (down stream)

<table>
<thead>
<tr>
<th>Date of measurement</th>
<th>Culvert Opening (m)</th>
<th>Water level RL (m)</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth w.r.t WL ($D_s$)</th>
</tr>
</thead>
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</table>

Table 4.11: Observed scour depth for culvert-3, Katchpur (down stream)

<table>
<thead>
<tr>
<th>Date of measurement</th>
<th>Culvert Opening (m)</th>
<th>Water level RL (m)</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth w.r.t WL ($D_s$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug 15, 98</td>
<td>4.30</td>
<td>8.63</td>
<td>5.35</td>
<td>3.28</td>
</tr>
<tr>
<td>Sep 08, 98</td>
<td>4.30</td>
<td>9.22</td>
<td>5.39</td>
<td>3.83</td>
</tr>
<tr>
<td>Sep 12, 98</td>
<td>4.30</td>
<td>9.29</td>
<td>5.39</td>
<td>3.90</td>
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<td>4.30</td>
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<td>5.33</td>
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### Table 4.12: Observed scour depth for culvert-4, Pachani (down stream)

<table>
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<th>Culvert opening (m)</th>
<th>Water level RL (m)</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth w.r.t WL (Ds)</th>
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<td>9.37</td>
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<td>9.44</td>
<td>5.53</td>
<td>3.91</td>
</tr>
<tr>
<td>Sep_15,'98</td>
<td>3.30</td>
<td>9.10</td>
<td>5.31</td>
<td>3.79</td>
</tr>
<tr>
<td>Sep_19,'98</td>
<td>3.30</td>
<td>8.50</td>
<td>5.02</td>
<td>3.48</td>
</tr>
<tr>
<td>Sep_26,'98</td>
<td>3.30</td>
<td>7.88</td>
<td>5.19</td>
<td>2.69</td>
</tr>
</tbody>
</table>

### Table 4.13: Summary of observed scour depth w.r.t. water level

<table>
<thead>
<tr>
<th>Date of measurement</th>
<th>Observed scour depth with respect to water level(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Culvert-1</td>
</tr>
<tr>
<td>Aug_15_98</td>
<td>4.01</td>
</tr>
<tr>
<td>Sep_08_98</td>
<td>4.70</td>
</tr>
<tr>
<td>Sep_12_98</td>
<td>5.20</td>
</tr>
<tr>
<td>Sep_15_98</td>
<td>5.05</td>
</tr>
<tr>
<td>Sep_19_98</td>
<td>5.52</td>
</tr>
<tr>
<td>Sep_26_98</td>
<td>4.54</td>
</tr>
</tbody>
</table>

### Table 4.14: Summary of observed scour depth w.r.t. pre-monsoon bed

<table>
<thead>
<tr>
<th>Date of measurement</th>
<th>Observed scour depth with respect to bed level, d_s (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Culvert-1</td>
</tr>
<tr>
<td>Aug_15_98</td>
<td>0.19</td>
</tr>
<tr>
<td>Sep_08_98</td>
<td>0.29</td>
</tr>
<tr>
<td>Sep_12_98</td>
<td>0.72</td>
</tr>
<tr>
<td>Sep_15_98</td>
<td>0.90</td>
</tr>
<tr>
<td>Sep_19_98</td>
<td>1.97</td>
</tr>
<tr>
<td>Sep_26_98</td>
<td>1.59</td>
</tr>
</tbody>
</table>
Photograph 4.9: Photograph shows during culvert outlet field data collection.
Photograph 4.10: Field velocity data collection.

Photograph 4.11: Photograph shows flow through the culvert during water recession.
Photograph 4.12: Photograph shows flow through different culvert during flood recession.
4.9 Comparison against other equations

The scour depth measured in the field has been compared with calculated maximum depth of scour based on different available formula. Most of the Engineering Organization in our country like, LGED, BWDB uses Lacey's formula for determination of scour depth at culvert outlet. Considering in our country context, the Lacey (1930), the Blench (1969), the Ahmed (1962), the Chitale (1960) equation is used to calculate the maximum scour depth.
Chapter-5

RESULTS AND DISCUSSIONS

5.1 Observed Scour Depth from Field

For each culvert, the beds materials are different, maximum scour depth observed at culvert downstream are shown in Table 5.1 to Table 5.4. A summary of various hydraulic parameters of culverts is also presented in Table 5.5. Variation of scour depth with respect to time is shown in Figure 5.1 Generally it has been observed that higher discharge causes higher scour in each culvert outlet and scour depth has a downward tendency to decrease with decreasing discharge. Scour depth for culvert-1 \((d_{50}=0.038\text{mm})\) shows higher than that of other three culvert as their sediment size is coarser than that of culvert-1. Moreover, the width-height \((b/h)\) ratio of culvert-1 is equals 1.28. Higher width-height ratio shows higher scour in the field .For culvert-3, scour depth found less among the four culverts as the sediment size of culvert-3 \((d_{50}=0.05\text{mm})\) is largest among the four. Between culvert-2 and culvert-4,scour depth is comparatively higher of culvert-2\((d_{50}=0.040\text{mm})\) than that of culvert-4\((d_{50}=0.043\text{mm})\) in case of same discharge .The reason may be that sediment size of of culvert-2 is smaller in compare with bed material of culvert-4\((d_{50}=0.043\text{mm})\) The width-height ratio of culvert-2 ,culvert-3 and culvert-4 is respectively 1.13, 1.00 and 1.00.Here is also observed that the higher width-height ratio follow the higher scour depth.

Table 5.1: Observed maximum scour depth for culvert-1, Mirertek (down stream)

<table>
<thead>
<tr>
<th>Date of measurement</th>
<th>Water level RL (m)</th>
<th>Velocity (m/s)</th>
<th>Discharge Q ((\text{m}^3/\text{s}))</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth w.r.t WL ((D_s))</th>
<th>Observed maximum scour depth w.r.t.bed ((d_s))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug_15_98</td>
<td>7.93</td>
<td>0.95</td>
<td>21.77</td>
<td>3.92</td>
<td>4.01</td>
<td>0.19</td>
</tr>
<tr>
<td>Sep_08_98</td>
<td>8.52</td>
<td>0.96</td>
<td>25.46</td>
<td>3.82</td>
<td>4.70</td>
<td>0.29</td>
</tr>
<tr>
<td>Sep_12_98</td>
<td>8.59</td>
<td>1.20</td>
<td>33.05</td>
<td>3.39</td>
<td>5.20</td>
<td>0.72</td>
</tr>
<tr>
<td>Sep_15_98</td>
<td>8.26</td>
<td>1.90</td>
<td>48.45</td>
<td>3.21</td>
<td>5.05</td>
<td>0.90</td>
</tr>
<tr>
<td>Sep_19_98</td>
<td>7.66</td>
<td>2.04</td>
<td>49.08</td>
<td>2.14</td>
<td>5.52</td>
<td>1.97</td>
</tr>
<tr>
<td>Sep_26_98</td>
<td>7.06</td>
<td>0.93</td>
<td>18.80</td>
<td>2.52</td>
<td>4.54</td>
<td>1.59</td>
</tr>
</tbody>
</table>
### Table 5.2: Observed maximum scour depth for culvert-2, Taltola (down stream)

<table>
<thead>
<tr>
<th>Date of measurement</th>
<th>Water level RL (m)</th>
<th>Velocity (m/s)</th>
<th>Discharge Q (m³/s)</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth w.r.t. WL (Ds)</th>
<th>Observed maximum scour depth w.r.t.bed (dₛ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug_15 98</td>
<td>8.23</td>
<td>0.98</td>
<td>13.42</td>
<td>4.90</td>
<td>3.33</td>
<td>0.28</td>
</tr>
<tr>
<td>Sep_08,'98</td>
<td>8.92</td>
<td>1.10</td>
<td>18.25</td>
<td>4.84</td>
<td>4.08</td>
<td>0.34</td>
</tr>
<tr>
<td>Sep_12,'98</td>
<td>8.89</td>
<td>1.60</td>
<td>26.34</td>
<td>4.75</td>
<td>4.14</td>
<td>0.43</td>
</tr>
<tr>
<td>Sep_15,'98</td>
<td>8.55</td>
<td>1.91</td>
<td>29.84</td>
<td>4.16</td>
<td>4.39</td>
<td>1.02</td>
</tr>
<tr>
<td>Sep_19,'98</td>
<td>7.95</td>
<td>2.24</td>
<td>30.01</td>
<td>3.34</td>
<td>4.61</td>
<td>1.84</td>
</tr>
<tr>
<td>Sep_26,'98</td>
<td>7.33</td>
<td>0.98</td>
<td>10.58</td>
<td>3.53</td>
<td>3.80</td>
<td>1.65</td>
</tr>
</tbody>
</table>

### Table 5.3: Observed maximum scour depth for culvert-3, Katchpur (down stream)

<table>
<thead>
<tr>
<th>Date of measurement</th>
<th>Water level RL (m)</th>
<th>Velocity (m/s)</th>
<th>Discharge Q (m³/s)</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth w.r.t. WL (Ds)</th>
<th>Observed maximum scour depth w.r.t.bed (dₛ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug_15 98</td>
<td>8.63</td>
<td>0.93</td>
<td>13.16</td>
<td>5.35</td>
<td>3.28</td>
<td>0.25</td>
</tr>
<tr>
<td>Sep_08,'98</td>
<td>9.22</td>
<td>1.13</td>
<td>18.85</td>
<td>5.39</td>
<td>3.83</td>
<td>0.21</td>
</tr>
<tr>
<td>Sep_12,'98</td>
<td>9.29</td>
<td>1.64</td>
<td>27.86</td>
<td>5.39</td>
<td>3.90</td>
<td>0.21</td>
</tr>
<tr>
<td>Sep_15,'98</td>
<td>8.96</td>
<td>1.83</td>
<td>28.49</td>
<td>5.33</td>
<td>3.63</td>
<td>0.27</td>
</tr>
<tr>
<td>Sep_19,'98</td>
<td>8.36</td>
<td>2.35</td>
<td>30.52</td>
<td>5.12</td>
<td>3.24</td>
<td>0.48</td>
</tr>
<tr>
<td>Sep_26,'98</td>
<td>7.76</td>
<td>0.89</td>
<td>9.26</td>
<td>5.22</td>
<td>2.54</td>
<td>0.38</td>
</tr>
</tbody>
</table>

### Table 5.4: Observed maximum scour depth for culvert-4, Pachani (down stream)

<table>
<thead>
<tr>
<th>Date of measurement</th>
<th>Water level RL (m)</th>
<th>Velocity (m/s)</th>
<th>Discharge Q (m³/s)</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth w.r.t. WL (Ds)</th>
<th>Observed maximum scour depth w.r.t.bed (dₛ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug_15,98</td>
<td>8.78</td>
<td>0.90</td>
<td>7.19</td>
<td>5.60</td>
<td>3.18</td>
<td>0.14</td>
</tr>
<tr>
<td>Sep_08,'98</td>
<td>9.37</td>
<td>1.10</td>
<td>10.93</td>
<td>5.55</td>
<td>3.82</td>
<td>0.19</td>
</tr>
<tr>
<td>Sep_12,'98</td>
<td>9.44</td>
<td>1.48</td>
<td>15.04</td>
<td>5.53</td>
<td>3.91</td>
<td>0.21</td>
</tr>
<tr>
<td>Sep_15,'98</td>
<td>9.10</td>
<td>1.78</td>
<td>16.09</td>
<td>5.31</td>
<td>3.79</td>
<td>0.43</td>
</tr>
<tr>
<td>Sep_19,'98</td>
<td>8.50</td>
<td>2.32</td>
<td>16.38</td>
<td>5.02</td>
<td>3.48</td>
<td>0.72</td>
</tr>
<tr>
<td>Sep_26,'98</td>
<td>7.88</td>
<td>0.89</td>
<td>4.46</td>
<td>5.19</td>
<td>2.69</td>
<td>0.55</td>
</tr>
</tbody>
</table>
### Table 5.5: Summary of observed hydraulic parameter and corresponding scour depth

<table>
<thead>
<tr>
<th>Culvert No.</th>
<th>Particle size((d_{50})) mm</th>
<th>Maximum velocity (m/s)</th>
<th>Maximum discharge Q ((m^3/s))</th>
<th>Width-height ratio</th>
<th>Maximum observed scour depth w.r.t. WL (m)</th>
<th>Maximum observed scour depth w.r.t. bed (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Culvert-1</td>
<td>0.038</td>
<td>2.04</td>
<td>49.08</td>
<td>1.28</td>
<td>5.52</td>
<td>1.97</td>
</tr>
<tr>
<td>Culvert-2</td>
<td>0.04</td>
<td>2.24</td>
<td>30.01</td>
<td>1.13</td>
<td>4.61</td>
<td>1.84</td>
</tr>
<tr>
<td>Culvert-3</td>
<td>0.05</td>
<td>2.35</td>
<td>30.52</td>
<td>1</td>
<td>3.9</td>
<td>0.48</td>
</tr>
<tr>
<td>Culvert-4</td>
<td>0.043</td>
<td>2.32</td>
<td>16.38</td>
<td>1</td>
<td>3.91</td>
<td>0.72</td>
</tr>
</tbody>
</table>

**Figure: 5.1** Variation of scour depth with respect to time

#### 5.2 Analysis of scour and bed profile

Bed level collected from each culvert outlet at different time interval during monsoon and pre-monsoon. Collected data have been plotted using surfer software to analyze shape, extend and depth of scour at the downstream of the selected culvert with respect to variable discharge and time. For this purpose, 2D contour maps of scour at the downstream of each culvert have been plotted. In each plotted map, location of maximum scour has been marked. All relevant Photographs during field measurement have been provided for necessary evidence of actual situation. Longitudinal and Lateral cross section for each culvert outlet profile have been provided to show the differences of bed level changes with time due to flow through the culvert. In addition of these, X-Y-Z perspective plot of bed profile are created to get a clear idea about scour at culvert outlets.
5.2.1 Scour contour Map

2-D scour contour maps for variable discharge in water rising and recession condition in each culvert outlet are presented from Figure 5.2 to Figure 5.13. Location of maximum scour depth is shown in all cases. The individual and comparative observations of scour for each culverts outlet are discussed below:

Culvert-1, Mirertek

Scour maps of culvert-1 are shown in Figure 5.2 to Figure 5.4 for various discharges and date of observation. From the Figures, it is observed that maximum scour occurred at location 2 m from the downstream face of the culverts. Higher the discharge through the culvert more the scour depth observed. The spatial extent of scour hole also increases with increase of discharge also.

The width-height ratio of culvert-1 is equals 1.27 which is highest ratio among the four selected culverts. Scour depth increase at higher width-height ratio as also shown in Table 5.5. It is also observed that the maximum scour depth occurs during recession period than rising period of water level. For culvert-1, maximum scour depth observed during recession period and bed level fall from RL 4.11m to 2.14m.After recession some sediment siltation observed. On the other hand, maximum upstream scouring of culvert-1 is found 1.22m which is relatively less in compare with down stream side.

Culvert-2. Taltola

Scour maps of culvert-2 are shown in Figures 5.5 to Figure 5.7 for various discharges and date of observation. From the Figures, it is observed that maximum scour occurred at location 2 m from the downstream face of the culverts. Higher the discharge through the culvert more the scour depth observed. The spatial extent of scour hole also increases with increase of discharge also.

The width-height ratio of culvert-2 is equal 1.13 which is second highest among the four selected culverts. From the Figures, it is also observed that maximum scour occurred at location approximately 2 m from the downstream face of the culverts. For culvert-2, maximum scour depth observed during recession period and bed level fall from RL 4.90m to 3.34m. After recession some sediment siltation observed. On the other hand, maximum up stream scouring of culvert-2 is found 0.56m which is also relatively less in compare with down stream side.
Culvert-3, Kachpur
Scour maps of culvert-3 are shown in Figure 5.8 to figure 5.10 for various discharges and date of observation. From the Figures, it is observed that maximum scour occurred at location nearly 1.5m from the downstream face of the culverts. Higher the discharge through the culvert more the scour depth observed. The spatial extent of scour hole also increases with increase of discharge also.

The width-height ratio of culvert-3 is equals 1 and observed scour depth found less among the four selected culverts. It is observed that the maximum scour depth occurs during recession period and bed level fall from RL 5.06m to 5.02m .After recession some sediment siltation observed. On the other hand, upstream scouring of culvert-3 is found 0.32m which is relatively less in compare with down stream side.

Culvert-4, Pachani
Scour maps of culvert-4 are shown in Figures 5.11 to Figure 5.13 for various discharges and date of observation. From the Figures, it is observed that maximum scour occurred at location nearly 1.2m from the downstream face of the culverts. Higher discharge through the culvert more the scour depth is observed. The spatial extent of scour hole also increases with increase of discharge also.

The width-height ratio of culvert-4 is equals 1 and observed scour depth found less among the four selected culverts.

It is observed that the maximum scour depth of culvert-4 are relatively higher than culvert-3 and bed level fall from RL5.70m to 5.19m .After recession some sediment siltation observed. On the other hand, upstream scouring of culvert-4 is found 0.35m which is relatively less in compare with down stream side.
Figure: 5.2 Contour map of culvert-1, Mirertek (up and down stream) on dated 12 Sep 1998.

\[ \text{Indicate the deepest point.}\]

\[ \text{contour interval 0.1m}\]
Figure: 5.3 Contour map of culvert-1, Mirertek (up and down stream) on dated 15 Sep 1998

diamond Indicate the deepest point.

contour interval 0.1m
Figure: 5.4 Contour map of culvert-1, Mirertek (up and down stream) on dated 19 Sep 1998.

- Indicate the deepest point.
- Contour interval 0.1m
Figure: 5.5 Contour map of culvert-2, Taltola (up and down stream) on dated 12 Sep 1998.

Indicate the deepest point.
contour interval 0.1m
Figure: 5.6 Contour map of culvert-2, Taltola (up and down stream) on dated 15 Sep 1998.

- Indicate the deepest point.
- Contour interval 0.1m
Figure: 5.7 Contour map of culvert-2, Taltola (up and down stream) on dated 19 Sep 1998.

- Indicate the deepest point.
- Contour interval 0.1m
Figure: 5.8 Contour map of culvert-3, Katchpur (up and down stream) on dated 12 Sep 1998.

◊ Indicate the deepest point.
contour interval 0.1m
Figure: 5.9 Contour map of culvert-3, Katchpur (up and down stream) on dated 15 Sep 1998.

Indicate the deepest point.
contour interval 0.1m
Figure: 5.10 Contour map of culvert-3, Katchpur (up and down stream) on dated 19 Sep 1998.

*Indicate the deepest point.*

contour interval 0.1m
Figure: 5.11 Contour map of culvert-4, Pachani (up and down stream) on dated 12 Sep 1998.

- Indicate the deepest point.
- contour interval 0.1m
Figure: 5.12 Contour map of culvert-4, Pachani (up and down stream) on dated 15 Sep 1998.

Indicate the deepest point. contour interval 0.1m
Figure: 5.13 Contour map of culvert-4, Pachani (up and down stream) on dated 19 Sep 1998.

* Indicate the deepest point.
  contour interval 0.1m
5.3 Bed Profile

Longitudinal and lateral cross sectional bed profiles for each culvert outlet during monsoon and pre monsoon condition both downstream and upstream are presented from Figure 5.14 to 5.29. For Culvert-1, both lateral and longitudinal section show the higher depth and extent of scour than those of upstream side. In culvert-2, less scour depth is observed compared to Culvert -1. The lowest bed level both down stream and upstream side is observed in Culvert-3. The bed level changes found at culvert-4 are relatively higher than Culvert-3 both at downstream and upstream side.

Figure: 5.14 Lateral bed level variation of culvert-1 (Down Stream).

Figure: 5.15 Longitudinal bed level variation of culvert-1 (Down Stream).
Figure: 5.16 Lateral bed level variation of culvert-1 (Up Stream).

Figure: 5.17 Longitudinal bed level variation of culvert-1 (Up Stream).

Figure: 5.18 Lateral bed level variation of culvert-2 (Down Stream).
Figure: 5.19 Longitudinal bed level variation of culvert-2 (Down Stream).

Figure: 5.20 Lateral bed level variation of culvert-2 (Up Stream).

Figure: 5.21 Longitudinal bed level variation of culvert-2 (Up Stream).
Figure: 5.22 Lateral bed level variation of culvert-3 (Down Stream).

Figure: 5.23 Longitudinal bed level variation of culvert-3 (Down Stream).

Figure: 5.24 Lateral bed level variation of culvert-3 (Up Stream).
Figure: 5.25 Longitudinal bed level variation of culvert-3 (Up Stream).

Figure: 5.26 Lateral bed level variation of culvert-4 (Down Stream).
5.4 X-Y-Z perspective plot of bed profile

A significant and clear view of scour and bed profile at culvert outlet can be obtained from X-Y-Z perspective plots (3D plots) of bed profile. These perspective plots of bed profiles can be able to give a better understanding about shape, extent, slope, and deposition etc of scour at culvert outlet. Comparative changes of bed level scour can also be achieved at a glance as these 3 dimensional figures present the variation of bed level scouring situation at a time. From these 3D plots, it is very easy to notify the temporal variation of scour hole during monsoon and pre-monsoon condition. They made real observation from the field. X-Y-Z perspective plots have been presented in
Figure 5.30 to Figure 5.38 These perspective plots represent scour and bed forms of the culvert outlet.
Figure: 5.30 Perspective view of culvert-1 (down stream) dated 5 May 1998.

Figure: 5.31 Perspective view of culvert-1 (down stream) dated 19 September 1998.
Figure: 5.32 Perspective view of culvert-1 (down stream) dated 26 September 1998.

Figure: 5.33 Perspective view of culvert-2 (down stream) dated 5 May 1998.
Figure: 5.34 Perspective view of culvert-2 (down stream) dated 19 September 1998.

Figure: 5.35 Perspective view of culvert-2 (down stream) dated 26 September 1998.
Figure: 5.36 Perspective view of culvert-3 (down stream) dated 19 September 1998.

Figure: 5.37 Perspective view of culvert-4 (down stream) dated 5 May 1998.

Figure: 5.38 Perspective view of culvert-4 (down stream) dated 19 September 1998.
5.5 Comparison of observed and calculated scour depth

In this present study four culverts was chosen at different locations of Sonargaon Upazila under Narayangonj District. For field scour measurement, bed level data at culvert outlet was measured during pre-monsoon and monsoon. The observed scour depth is then compared with calculated scour depth. Observed and calculated scour depths using different formula are given in the following Table 5.6 to Table 5.25. For each culvert observed verses predicted scour depth using Lacey, Blench, Ahmed, Chi tale's formula are also plotted. It is observed that Lacey's and Chi tales formula shows best fit with the ideal curve.

Table 5.6: Comparison between observed and calculated scour depth for culvert-1 using Lacey's equation.

<table>
<thead>
<tr>
<th>Date of measurement</th>
<th>WL (m)</th>
<th>BED RL (m)</th>
<th>Water depth (m)</th>
<th>Velocity (m/s)</th>
<th>Discharge Q (m³/s)</th>
<th>Scour depth from WL (Ds) (m)</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth w.r.t WL (D₉) (m)</th>
<th>Observed /Calculated scour depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug 15 98</td>
<td>7.93</td>
<td>4.11</td>
<td>3.82</td>
<td>0.95</td>
<td>21.77</td>
<td>4.25</td>
<td>3.92</td>
<td>4.01</td>
<td>0.94</td>
</tr>
<tr>
<td>Sep 08 98</td>
<td>8.52</td>
<td>4.10</td>
<td>4.42</td>
<td>0.96</td>
<td>25.46</td>
<td>4.48</td>
<td>3.82</td>
<td>4.70</td>
<td>1.05</td>
</tr>
<tr>
<td>Sep 12 98</td>
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<td>4.00</td>
<td>4.59</td>
<td>1.20</td>
<td>33.05</td>
<td>4.89</td>
<td>3.39</td>
<td>5.20</td>
<td>1.06</td>
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Table 5.7: Comparison between observed and calculated scour depth for culvert-1 using Blench.'s equation.

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<th>Velocity (m/s)</th>
<th>Unit discharge Q (m³/s)</th>
<th>Scour depth from WL (Ds) (m)</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth from WL (D₉) (m)</th>
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Table 5.8: Comparison between observed and calculated scour depth for culvert-1 using Ahmed.'s equation

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<th>Velocity (m/s)</th>
<th>Unit discharge q (m³/s)</th>
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<th>Deepest bed level RL (m)</th>
<th>Observed scour depth from WL (Dₛ)</th>
<th>Observed/Calculated depth</th>
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Table 5.9: Comparison between observed and calculated scour depth for culvert-1 using Chitale's equation

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<th>Scour depth (below bed) (Dₛ)</th>
<th>Scour depth from WL (Dₛ)</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth from WL (Dₛ)</th>
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### Table 5.10: Summary of observed versus calculated Scour depth for Culvert-1, Mirertek

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<th>Measured Velocity (m/s)</th>
<th>Discharge (Q) (m³/s)</th>
<th>Predicted scour depth (From WL) (m)</th>
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### Table 5.11: Comparison between observed and calculated scour depth for culvert-2 using Lacey's equation

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<th>Water depth (m)</th>
<th>Velocity (m/s)</th>
<th>Discharge Q (m³/s)</th>
<th>Scour depth from WL (m)</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth from WL (m)</th>
<th>Observed / Calculate d depth</th>
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<td>1.01</td>
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<td>3.19</td>
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Table 5.12: Comparison between observed and calculated scour depth for culvert-2 using Blench.'s equation.

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<th>BED RL (m)</th>
<th>Depth of water (m)</th>
<th>Velocity (m/s)</th>
<th>Unit discharge q (m$^3$/s)</th>
<th>Scour depth form WL (D_s)</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth form WL (D_s)</th>
<th>Observed/calculated depth</th>
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<td>7.66</td>
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<td>4.39</td>
<td>0.57</td>
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Table 5.13: Comparison between observed and calculated scour depth for culvert-2 using Ahmed.'s equation

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<th>Depth of water (m)</th>
<th>Velocity (m/s)</th>
<th>Unit discharge q (m$^3$/s)</th>
<th>Scour depth from WL (D_s)</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth from WL (D_s)</th>
<th>Observed/calculated depth</th>
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<td>5.05</td>
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<td>0.81</td>
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Table 5.14: Comparison between observed and calculated scour depth for culvert-2 using Chitale’s equation.

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<th>Velocity (m/s)</th>
<th>Unit discharge ( q ) (( m^3/s ))</th>
<th>Froude Number</th>
<th>Scour depth (below bed) (( ds ))</th>
<th>Scour below from WL (( D_s ))</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth from WL (( D_s ))</th>
<th>Observed/Calculated depth</th>
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</thead>
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<td>4.35</td>
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Table 5.15: Summary of observed versus calculated scour depth for culvert-2

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<th>Measured Velocity (m/s)</th>
<th>Discharge ( Q )</th>
<th>Predicted scour depth(From WL) (m)</th>
<th>Observed Scour depth From WL,(m)</th>
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</thead>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>Blench</td>
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<td>1.10</td>
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<td>7.05</td>
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Table 5.16: Comparison between observed and calculated scour depth for culvert-3 using Lacey's equation.

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<th>Water level RL (m)</th>
<th>BED RL (m)</th>
<th>Water depth (m)</th>
<th>Velocity (m/s)</th>
<th>Discharge ( Q ) (( m^3/s ))</th>
<th>Scour depth from WL (m)</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth from WL (D_s)</th>
<th>Observed/Calculated depth</th>
</tr>
</thead>
<tbody>
<tr>
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<td>3.29</td>
<td>0.93</td>
<td>13.16</td>
<td>3.05</td>
<td>5.35</td>
<td>3.28</td>
<td>1.07</td>
</tr>
<tr>
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<td>9.22</td>
<td>5.34</td>
<td>3.88</td>
<td>1.13</td>
<td>18.85</td>
<td>3.44</td>
<td>5.39</td>
<td>3.83</td>
<td>1.11</td>
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<td>5.34</td>
<td>3.95</td>
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<td>27.86</td>
<td>3.92</td>
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<td>3.90</td>
<td>1.00</td>
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<td>3.95</td>
<td>5.33</td>
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<td>0.92</td>
</tr>
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<td>0.80</td>
</tr>
<tr>
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<td>2.42</td>
<td>0.89</td>
<td>9.26</td>
<td>2.72</td>
<td>5.22</td>
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<td>0.94</td>
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</table>
Table 5.17: Comparison between observed and calculated scour depth for culvert-3 using Blench's equation

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<th>Water level RL (m)</th>
<th>BED RL (m)</th>
<th>Water depth (m)</th>
<th>Velocity (m/s)</th>
<th>Unit discharge $q$ (m$^3$/s)</th>
<th>Scour depth from WL $D_s$ (m)</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth from WL (Ds) (m)</th>
<th>Observed/Calculated depth</th>
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<tbody>
<tr>
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<td>4.21</td>
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<td>0.78</td>
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<td>1.13</td>
<td>4.38</td>
<td>5.34</td>
<td>5.39</td>
<td>3.83</td>
<td>0.72</td>
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<td>3.95</td>
<td>1.64</td>
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<td>6.93</td>
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<td>3.62</td>
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</tr>
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<td>2.42</td>
<td>0.89</td>
<td>2.15</td>
<td>3.33</td>
<td>5.22</td>
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<td>0.76</td>
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</table>

Table 5.18: Comparison between observed and calculated scour depth for culvert-3 using Ahmed's equation

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<th>Date of measurement</th>
<th>Water level RL (m)</th>
<th>BED RL (m)</th>
<th>Water depth (m)</th>
<th>Velocity (m/s)</th>
<th>Unit discharge $q$ (m$^3$/s)</th>
<th>Scour depth from WL $D_s$ (m)</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth from WL (Ds) (m)</th>
<th>Observed/prediction</th>
</tr>
</thead>
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<tr>
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<td>4.00</td>
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<td>3.28</td>
<td>0.82</td>
</tr>
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<td>5.34</td>
<td>3.88</td>
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<td>6.59</td>
<td>5.39</td>
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<td>0.59</td>
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<tr>
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<td>3.62</td>
<td>1.83</td>
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<td>5.34</td>
<td>3.02</td>
<td>2.35</td>
<td>7.10</td>
<td>7.01</td>
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<td>0.46</td>
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<td>2.42</td>
<td>0.89</td>
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<td>3.17</td>
<td>5.22</td>
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Table 5.19: Comparison between observed and calculated scour depth for culvert-3 using Chitale’s equation.

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<th>Water level RL (m)</th>
<th>BED RL (m)</th>
<th>Velocity (m/s)</th>
<th>Unit discharge $q$ (m$^3$/s)</th>
<th>Froude number</th>
<th>Scour depth below bed (ds)</th>
<th>Scour depth from WL (Ds)</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth from WL (Ds) (m)</th>
<th>Observed/prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug 15, 98</td>
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<td>0.93</td>
<td>3.06</td>
<td>0.16</td>
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<td>5.35</td>
<td>3.28</td>
<td>0.88</td>
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<tr>
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<td>1.13</td>
<td>4.38</td>
<td>0.18</td>
<td>0.52</td>
<td>4.40</td>
<td>5.39</td>
<td>3.83</td>
<td>0.87</td>
</tr>
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<td>1.64</td>
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<td>0.26</td>
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<td>5.39</td>
<td>3.90</td>
<td>0.81</td>
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<td>1.83</td>
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<td>5.33</td>
<td>3.63</td>
<td>0.78</td>
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<td>2.35</td>
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<td>0.43</td>
<td>1.34</td>
<td>4.36</td>
<td>5.12</td>
<td>3.24</td>
<td>0.74</td>
</tr>
<tr>
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<td>0.89</td>
<td>2.15</td>
<td>0.18</td>
<td>0.52</td>
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<td>5.22</td>
<td>2.54</td>
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### Table 5.20: Summary of observed versus calculated Scour depth for culvert-3

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<th>Date of measurement</th>
<th>Culvert Opening (m)</th>
<th>Water level RL (m)</th>
<th>Measured Velocity (m/s)</th>
<th>Discharge Q (m$^3$/s)</th>
<th>Predicted scour depth(From WL) (m)</th>
<th>Observed Scour depth From WL, (m)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.93</td>
<td>13.16</td>
<td>3.05</td>
<td>3.28</td>
</tr>
<tr>
<td>08 Sep, 98</td>
<td>4.30</td>
<td>9.22</td>
<td>1.13</td>
<td>18.85</td>
<td>3.44</td>
<td>4.40</td>
</tr>
<tr>
<td>12 Sep, 98</td>
<td>4.30</td>
<td>9.29</td>
<td>1.64</td>
<td>27.86</td>
<td>3.92</td>
<td>4.81</td>
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<tr>
<td>15 Sep, 98</td>
<td>4.30</td>
<td>8.96</td>
<td>1.83</td>
<td>28.49</td>
<td>3.95</td>
<td>4.63</td>
</tr>
<tr>
<td>19 Sep, 98</td>
<td>4.30</td>
<td>8.36</td>
<td>2.35</td>
<td>30.52</td>
<td>4.04</td>
<td>4.36</td>
</tr>
<tr>
<td>26 Sep, 98</td>
<td>4.30</td>
<td>7.76</td>
<td>0.89</td>
<td>9.26</td>
<td>2.72</td>
<td>2.94</td>
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### Table 5.21: Comparison between observed and calculated scour depth for culvert-4 using Lacey’s equation

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<th>Water level RL (m)</th>
<th>BED RL (m)</th>
<th>Depth of water (m)</th>
<th>Velocity (m/s)</th>
<th>Discharge Q (m$^3$/s)</th>
<th>Scour depth from WL (m)</th>
<th>Deepest bed level RL (m)</th>
<th>Observed scour depth from (Ds)</th>
<th>Observed / Calculated</th>
</tr>
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<tbody>
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<td>2.42</td>
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<td>2.88</td>
<td>5.60</td>
<td>3.18</td>
<td>1.10</td>
</tr>
<tr>
<td>Sep 08, '98</td>
<td>9.37</td>
<td>6.36</td>
<td>3.01</td>
<td>1.10</td>
<td>10.93</td>
<td>3.32</td>
<td>5.55</td>
<td>3.82</td>
<td>1.15</td>
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<tr>
<td>Sep 15, '98</td>
<td>9.44</td>
<td>6.36</td>
<td>3.08</td>
<td>1.48</td>
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<td>3.69</td>
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<td>2.32</td>
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<td>5.02</td>
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<td>0.92</td>
</tr>
<tr>
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<td>1.52</td>
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<td>4.46</td>
<td>2.46</td>
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### Table 5.22: Comparison between observed and calculated scour depth for culvert-4 using Blench's equation

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<th>Water level RL (m)</th>
<th>BED RL (m)</th>
<th>Depth of water (m)</th>
<th>Velocity (m/s)</th>
<th>Unit discharge q (m$^2$/s)</th>
<th>Scour depth from WL D$_s$ (m)</th>
<th>Deepest bed level RL D$_b$ (m)</th>
<th>Observed scour depth from (Ds)</th>
<th>Observed/Calculated depth</th>
</tr>
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<tbody>
<tr>
<td>Aug_15,'98</td>
<td>8.78</td>
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<td>0.90</td>
<td>2.18</td>
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<td>5.60</td>
<td>3.18</td>
<td>0.92</td>
</tr>
<tr>
<td>Sep_08,'98</td>
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<td>6.36</td>
<td>3.01</td>
<td>1.10</td>
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<td>4.55</td>
<td>5.55</td>
<td>3.82</td>
<td>0.84</td>
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<td>1.52</td>
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### Table 5.23: Comparison between observed and calculated scour depth for culvert-4 using Ahmed’s equation

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<th>BED RL (m)</th>
<th>Velocity (m/s)</th>
<th>Unit discharge q (m$^2$/s)</th>
<th>Scour depth from WL D$_s$ (m)</th>
<th>Deepest bed level RL D$_b$ (m)</th>
<th>Observed scour depth from (Ds)</th>
<th>Observed/Calculated depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug_15,'98</td>
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<td>0.90</td>
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<td>3.19</td>
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<td>1.00</td>
</tr>
<tr>
<td>Sep_08,'98</td>
<td>9.37</td>
<td>6.36</td>
<td>1.10</td>
<td>3.31</td>
<td>4.22</td>
<td>5.55</td>
<td>3.82</td>
<td>0.91</td>
</tr>
<tr>
<td>Sep_12,'98</td>
<td>9.44</td>
<td>6.36</td>
<td>1.48</td>
<td>4.56</td>
<td>5.22</td>
<td>5.53</td>
<td>3.91</td>
<td>0.75</td>
</tr>
<tr>
<td>Sep_15,'98</td>
<td>9.10</td>
<td>6.36</td>
<td>1.78</td>
<td>4.88</td>
<td>5.46</td>
<td>5.31</td>
<td>3.79</td>
<td>0.69</td>
</tr>
<tr>
<td>Sep_19,'98</td>
<td>8.50</td>
<td>6.36</td>
<td>2.32</td>
<td>4.96</td>
<td>5.53</td>
<td>5.02</td>
<td>3.48</td>
<td>0.63</td>
</tr>
<tr>
<td>Sep 26,'98</td>
<td>7.88</td>
<td>6.36</td>
<td>0.89</td>
<td>1.35</td>
<td>2.32</td>
<td>5.19</td>
<td>2.69</td>
<td>1.16</td>
</tr>
</tbody>
</table>

### Table 5.24: Comparison between observed and calculated scour depth for culvert-4 using Chitale's equation.

<table>
<thead>
<tr>
<th>Date of measurement</th>
<th>Water level RL (m)</th>
<th>BED RL (m)</th>
<th>Velocity (m/s)</th>
<th>Unit discharge q (m$^2$/s)</th>
<th>Froude number</th>
<th>Scour depth below bed d$_b$ (m)</th>
<th>Scour depth from WL D$_s$ (m)</th>
<th>Deepest bed level RL D$_b$ (m)</th>
<th>Observed scour depth from RL D$_s$ (m)</th>
<th>Observed/Calculated depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug_15,'98</td>
<td>8.78</td>
<td>6.36</td>
<td>0.90</td>
<td>2.18</td>
<td>0.18</td>
<td>0.53</td>
<td>2.95</td>
<td>5.60</td>
<td>3.18</td>
<td>1.08</td>
</tr>
<tr>
<td>Sep_08,'98</td>
<td>9.37</td>
<td>6.36</td>
<td>1.10</td>
<td>3.31</td>
<td>0.20</td>
<td>0.61</td>
<td>3.62</td>
<td>5.55</td>
<td>3.82</td>
<td>1.06</td>
</tr>
<tr>
<td>Sep_12,'98</td>
<td>9.44</td>
<td>6.36</td>
<td>1.48</td>
<td>4.56</td>
<td>0.27</td>
<td>0.88</td>
<td>3.96</td>
<td>5.53</td>
<td>3.91</td>
<td>0.99</td>
</tr>
<tr>
<td>Sep_15,'98</td>
<td>9.10</td>
<td>6.36</td>
<td>1.78</td>
<td>4.88</td>
<td>0.34</td>
<td>1.12</td>
<td>3.86</td>
<td>5.31</td>
<td>3.79</td>
<td>0.98</td>
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<tr>
<td>Sep_19,'98</td>
<td>8.50</td>
<td>6.36</td>
<td>2.32</td>
<td>4.96</td>
<td>0.50</td>
<td>1.45</td>
<td>3.59</td>
<td>5.02</td>
<td>3.48</td>
<td>0.97</td>
</tr>
<tr>
<td>Sep 26,'98</td>
<td>7.88</td>
<td>6.36</td>
<td>0.89</td>
<td>1.35</td>
<td>0.23</td>
<td>0.73</td>
<td>2.25</td>
<td>5.19</td>
<td>2.69</td>
<td>1.20</td>
</tr>
</tbody>
</table>
Table 5.25: Summary of observed versus calculated scour depth for culvert-4

<table>
<thead>
<tr>
<th>Date of measurement</th>
<th>Culvert Opening (m)</th>
<th>Water level RL(m)</th>
<th>Measured Velocity (m/s)</th>
<th>Discharge Q (m³/s)</th>
<th>Predicted scour depth(From WL) (m)</th>
<th>Observed Scour depth From WL (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lacey</td>
<td>Blench</td>
</tr>
<tr>
<td>15 Aug, 98</td>
<td>3.30</td>
<td>8.78</td>
<td>0.90</td>
<td>7.19</td>
<td>2.88</td>
<td>3.44</td>
</tr>
<tr>
<td>08 Sep, 98</td>
<td>3.30</td>
<td>9.37</td>
<td>1.11</td>
<td>10.93</td>
<td>3.32</td>
<td>4.55</td>
</tr>
<tr>
<td>12 Sep, 98</td>
<td>3.30</td>
<td>9.44</td>
<td>1.48</td>
<td>15.04</td>
<td>3.69</td>
<td>5.63</td>
</tr>
<tr>
<td>15 Sep, 98</td>
<td>3.30</td>
<td>9.10</td>
<td>1.78</td>
<td>16.09</td>
<td>3.77</td>
<td>5.89</td>
</tr>
<tr>
<td>19 Sep, 98</td>
<td>3.30</td>
<td>8.50</td>
<td>2.32</td>
<td>16.38</td>
<td>3.79</td>
<td>5.96</td>
</tr>
<tr>
<td>26 Sep, 98</td>
<td>3.30</td>
<td>7.88</td>
<td>0.89</td>
<td>4.46</td>
<td>2.46</td>
<td>2.51</td>
</tr>
</tbody>
</table>

Figure: 5.39 Observed versus calculated scour depth for culvert-1, Mirertek
Figure: 5.40 Observed versus calculated scour depth for culvert-2, Taltola.

Figure: 5.41 Observed versus calculated scour depth for culvert-3, Katehpur.
5.6 Present review of the culvert site.

From the field investigation it has been observed that the topographic features of the culvert site in some cases have changed. Especially for culvert-4, the major area of upstream land has been changed from agricultural land to homestead. In case of culvert-2, the road alignment has been shifted. It is also found that some portion of the catchments area of culvert-3 and culvert-1 have been changed from agricultural land to housing area. The present photograph of the culvert has been shown from photograph 5.1 to 5.4

Figure: 5.42 Observed versus calculated scour depth for culvert-4, Pachani
Photograph 5.1: Current Photograph of Culvert-1, Mirertek (dated 5 Dec 2011)
Photograph 5.2: Current Photograph of Culvert-2, Taltola (dated 5 Dec 2011)
Photograph 5.3: Current Photograph of Culvert-3, Katchpur (dated 5 Dec 2011)
Photograph 5.4: Current Photograph of Culvert-4, Pachani (dated 5 Dec 2011)
Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on detailed field investigation, and analysis made, the following conclusions are drawn:

i) Scour at the down stream of culvert is higher with increase of discharge intensity.

ii) Scour depth significantly increases with increase of discharge. Scour depth also increase with decrease of sediment size from coarse to fine sediment and scour depth decrease with increase of sediment size from fine to coarse.

iii) Scour at culvert outlet significantly increase during water recession time rather than water rising time.

iv) Extent of scour hole at the down stream is higher both lateral and longitudinal rather than that of upstream.

v) Culvert of earthen bed without apron and cut off wall results higher scour depth than with apron and cut-off wall.

vi) Lacey's formula gives better prediction when compared with field data and can be suggested for scour prediction at the downstream of culvert with multiplication factor 2 to 2.25.
6.2 Recommendations for further study

Based on present study, some recommendations can be suggested for further study of scour at culvert outlet. They are as follows:

- In present study, commonly rectangular type box culverts have been used. Scour downstream of other shapes, like circular culverts may be analyzed against field data.
- Similar type of study can be carried for more number of structure with variable width-depth ratio.
- Field scour data around bridge piers can be collected and similar analysis can be carried.
- Experimental investigation or scale model study can be carried for to assess scour downstream of small hydraulics structures like culverts.
- Equations related to scour downstream of a structure need to be explored and can be compared with field data.
REFERENCE


12. Lacey, G (1930)," Stable Channel in Alluviam" Minutes proc. Institute of Civil Engineers, Vol.133, No.4, pp 421-424.


APPENDIX-A

Sample calculation of time of concentration

Kirpich's formula (1940):

\[ t_c = 0.0078 \cdot L^{0.77} \cdot S^{-0.385} \]

Where, \( t_c \) = Time of concentration in min,
\( L \) = Length of channel/ditch from headwater to outlet in ft
\( S \) = Average watershed slope, ft/ft

For culvert-1, Mirertek

\[ L = 3680 \text{ ft}, \ S = 0.0009 \text{ ft/ft} \]
\[ t_c = 0.0078 \cdot 3680^{0.77} \cdot 0.0009^{-0.385} \]
\[ = 64.62 \text{ min} \]

For culvert-2, Taltola

\[ L = 2100 \text{ ft}, \ S = 0.00076 \text{ ft/ft} \]
\[ t_c = 0.0078 \cdot 2100^{0.77} \cdot 0.00076^{-0.385} \]
\[ = 44.78 \text{ min} \]

For culvert-3, Katchpur

\[ L = 2800 \text{ ft}, \ S = 0.00083 \text{ ft/ft} \]
\[ t_c = 0.0078 \cdot 2800^{0.77} \cdot 0.00083^{-0.385} \]
\[ = 55.88 \text{ min} \]

For culvert-4, Pachani

\[ L = 2297 \text{ ft}, \ S = 0.00066 \text{ ft/ft} \]
\[ t_c = 0.0078 \cdot 2297^{0.77} \cdot 0.00066^{-0.385} \]
\[ = 50.66 \text{ min} \]
APPENDIX-B

Sample calculation of maximum scour depth at culvert outlet

Culvert-1, Mirertek

Lacey’s equation (1930):

\[
y_{ms} = 0.473 \left( \frac{Q}{f} \right)^{\frac{1}{7}}
\]

Where, \(y_{ms}\) is equals mean scour depth below water level
\(Q\) equals discharge in \(\text{m}^3/\text{s}\)
\(f\) equals silt factor
correction factor for bend is equal 2.25
\[
f = 1.76\sqrt{d_m}
\]
and scour depth \(d_s = y_{ms} - y\)
\(d_m\) equals mean diameter of the particles in mm
Where the units of \(y_{ms}\), \(Q\), and \(d_m\) are m, \(\text{m}^3/\text{s}\), and mm, respectively.

Maximum scour depth
Culvert opening =6.00m , Water level = 7.66m, Water depth =3.82m,
Temporary bench mark was taken as 10.00m which was on north-west corner of slab.
Measured velocity =2.04 m/s, Particle size \(d_{50} = 0.038\) mm (from grain size curve)
Silt factor, \(f = 1.76\sqrt{d_m}\)
\[
= 1.76*(.038)^{0.5}
= 0.34
\]
\(Q = AV\)
\[
= 6.00*4.01* 2.04
= 49.08 \text{ m}^3/\text{s}
\]
\[ y_{ms} = 0.473 (49.08/ 0.34)^{0.333} *2.25 = 5.57 \text{ m below water level} \]

Scour depth below bed level, \( ds \) is equals \( \{4.11-(7.66-5.57)\} = 2.02 \text{ m} \)

**Blench's equation (1969):**

\[
 y_{ms} = 1.20 \left[ \frac{q^{\frac{2}{3}}}{d_{50}^{\frac{1}{6}}} \right] \quad \text{for sand of } 0.06 < d_m \text{ mm}
\]

Where, \( y_{ms} \) is equals mean scour depth below water level  
\( q \) equals discharge per unit width in m\(^2\)/s  
\( d_{50} \) equals mean diameter of the particles in mm  
and scour depth \( ds = y_{ms} - y \)

Where the units of \( y_{ms}, q, \) and \( d_m \) are m, m\(^2\)/s and mm, respectively.

**Maximum scour depth**

\( q \) is equal 8.18 m\(^2\)/s  
\( y_{ms} \) is equals 8.48 m below water level  
Scour depth below bed level, \( d_s = \{4.11-(7.66-8.48)\} = 4.93 \text{ m} \)

**Ahmed's equation (1962)**

\[ D_s = kq_1^{\frac{2}{5}} \]

Where \( D_s = \)Scour depth below the water surface in meter  
\( q_1 = q \) equals discharge per unit width in m\(^2\)/s  
\( k = \)a multiplying factor depend on the shape of the culvert

**Maximum scour depth**  
\( q \) is equal 8.18 m\(^2\)/s  
\( D_s = 1.90*8.18^{0.333} =7.70\text{m} \text{ below water level} \)  
Scour depth below bed level, \( d_s = \{4.11-(7.66-7.70)\} = 4.15 \text{ m} \)
Chitale's equation (1960)

\[
\frac{d_s}{y_0} = 6.65Fr - 0.51 - 5.49Fr^2
\]

Where \(d_s\) = Scour depth below bed level

\(y_0\) = depth of flow

\[Fr^2 = \frac{V_0^2}{gy_0}\]

\(Fr\) = Froude number of the approach flow

\(V_0\) = Mean velocity of flow

**Maximum scour depth**

Fr is equals 0.32

\(d_s\) = 1.07 m below bed and

\(D_s\) = 1.07 + 4.01 = 5.08 m from water level

**Culvert- 2, Taltola**

Lacey’s equation (1930):

\[
y_{ms} = 0.473 \left( \frac{Q}{f} \right)^{\frac{1}{3}}
\]

Where, \(y_{ms}\) is equals mean scour depth below water level

\(Q\) equals discharge in m\(^3\)/s

\(f\) equals silt factor

correction factor for bend is equal 2.1

\[f = 1.76\sqrt{d_m}\]

and scour depth \(d_s\) = \(y_{ms}\) - \(y\)

\(d_m\) equals mean diameter of the particles in mm

Where the units of \(y_{ms}\), \(Q\), and \(d_m\) are m, m\(^3\)/s, and mm, respectively.
**Maximum scour depth**

Culvert opening = 4.20 m, Water level = 7.95m, Water depth = 3.19m, Temporay bench mark was taken as 10.00m which was on north-west corner of slab.

Measured velocity = 2.24m/s, Particle size $d_{50}$ = 0.04 mm (from grain size curve)

Silt factor, $f = 1.76 \sqrt{d_m}$

$$= 1.76 \times (0.04)^{0.5}$$

$$= 0.035$$

$Q = AV$

$$= 4.20 \times 3.19 \times 2.24$$

$$= 30.01 \text{ m}^3/\text{s}$$

$y_{ms} = 0.473 (30.01 / 0.34)^{0.333} \times 2.1 = 4.37 \text{ m below water level}$

Scour depth below bed level, $d_s$ is equals $\{5.18-(7.95-4.37)\} = 1.60 \text{ m}$

**Blench's equation (1969):**

$$y_{ms} = 1.20 \left[ \frac{2}{q^{3/2}} \right] \frac{d_{50}^{1/6}}{d_m}$$

for sand of $0.06 < d_m \text{ mm}$

Where, $y_{ms}$ is equals mean scour depth below water level

$q$ equals discharge per unit width in m$^2$/s

$d_{50}$ equals mean diameter of the particles in mm

and scour depth $d_s = y_{ms} - y$

Where the units of $y_{ms}$, $q$, and $d_m$ are m, m$^2$/s and mm, respectively.

**Maximum scour depth**

$q$ is equal 7.15 m$^2$/s

$y_{ms}$ is equals 7.68 m below water level

Scour depth below bed level, $d_s = \{5.18-(7.95-7.68)\} = 4.91 \text{ m}$
Ahmed's equation (1962)

\[ D_s = kq_1^{2/5} \]

Where \( D_s \) = Scour depth below the water surface in meter
\( q_1 = q \) equals discharge per unit width in m\(^2\)/s
\( k \) = a multiplying factor depend on the shape of the culvert

**Maximum scour depth**

\( q \) is equal 7.15 m\(^2\)/s

\( D_s = 1.90 \times 7.15^{0.333} = 7.04 \) m below water level

Scour depth below bed level, \( d_s = (5.18 - (7.95 - 7.04)) = 4.27 \) m

Chitale's equation (1960)

\[ \frac{d_s}{y_0} = 6.65Fr - 0.51 - 5.49Fr^2 \]

Where \( d_s \) = Scour depth below bed level
\( y_0 \) = depth of flow
\[ Fr^2 = \frac{V_0^2}{gy_0} \]

\( Fr \) = Froude number of the approach flow
\( V_0 \) = Mean velocity of flow

**Maximum scour depth**

\( Fr \) is equals 0.40

\( d_s = 1.27 \) m below bed and

\( D_s = 1.27 + 3.19 = 4.46 \) m from water level
Culvert- 3, Katchpur

Lacey’s equation (1930):

\[ y_{ms} = 0.473 \left( \frac{Q}{f} \right)^{\frac{1}{3}} \]

Where, \( y_{ms} \) is equals mean scour depth below water level
\( Q \) equals discharge in \( m^3/s \)
\( f \) equals silt factor

correction factor for bend is equal 2.5

\[ f = 1.76 \sqrt{d_m} \]

and scour depth \( ds = y_{ms} \cdot y \)

\( d_m \) equals mean diameter of the particles in mm

Where the units of \( y_{ms} \), \( Q \), and \( d_m \) are m, \( m^3/s \), and mm, respectively.

**Maximum scour depth**

Culvert opening =4.300m , Water level = 8.36m, Water depth =3.02m,

Temporary bench mark was taken as 10.00m which was on north-west corner of slab.

Measured velocity =2.35 m/s, Particle size \( d_{50} = 0.05 \) mm (from grain size curve)

Silt factor, \( f' = 1.76 \sqrt{d_m} \)

\[ = 1.76 \cdot (0.05)^0.5 \]

\[ = 0.39 \]

\( Q = AV \)

\[ = 4.30 \cdot 3.02 \cdot 2.35 \]

\[ = 30.52 \ m^3/s \]

\( y_{ms} = 0.473 \left( \frac{30.52}{0.39} \right)^{0.333} \cdot 2.00 = 4.04 \) m below water level

scour depth below bed level, \( ds \) is equals \( \{5.6 - (8.36 - 4.04)\} \cdot 1.28 \ m \)
Blench's equation (1969):

\[ y_{ms} = 1.20 \left[ \frac{q^{\frac{2}{3}}}{d_{50}^{1/6}} \right] \]  
for sand of 0.06 < \( d_m \) mm

Where, \( y_{ms} \) is equals mean scour depth below water level
\( q \) equals discharge per unit width in m²/s
\( d_{50} \) equals mean diameter of the particles in mm
and scour depth \( d_s = y_{ms} - y \)

Where the units of \( y_{ms} \), \( q \), and \( d_m \) are m, m²/s and mm, respectively.

**Maximum scour depth**

\( q \) is equal 7.10 m²/s
\( y_{ms} \) is equals 7.36 m below water level
Scour depth below bed level, \( d_s = \{5.60-(8.36-7.36)\} = 4.60 \) m

Ahmed's equation (1962)

\[ D_s = k q^{\frac{3}{5}} \]

Where \( D_s \) = Scour depth below the water surface in meter

\( q_1 = q \) equals discharge per unit width in m²/s
\( k \) = a multiplying factor depend on the shape of the culvert

**Maximum scour depth**

\( q \) is equal 7.10 m²/s
\( D_s = 1.90 \times 7.10 \times 0.333 = 7.01 \) m below water level
Scour depth below bed level, \( d_s = \{5.60-(8.36-7.01)\} = 4.25 \) m
Chitale's equation (1960)

\[ \frac{d_s}{y_0} = 6.65Fr - 0.51 - 5.49Fr^2 \]

Where \( d_s = \) Scour depth below bed level

\( y_0 = \) depth of flow

\[ Fr^2 = \frac{V_0^2}{gy_0} \]

\( Fr = \) Froude number of the approach flow

\( V_0 = \) Mean velocity of flow

**Maximum scour depth**

\( Fr \) is equals 0.43

\( d_s = 1.34 \) m below bed and

\( D_s = 1.34 + 3.02 = 4.36 \) m from water level

Culvert-4, Pachani

Lacey’s equation (1930):

\[ y_{ms} = 0.473 \left( \frac{Q}{f} \right)^{\frac{1}{7}} \]

Where, \( y_{ms} = \) mean scour depth below water level

\( Q = \) discharge in \( m^3/s \)

\( f = \) silt factor

Correlation factor for bend is equal 2.25

\[ f = 1.76 \sqrt{d_m} \]

and scour depth \( d_s = y_{ms} - y \)

\( d_m = \) mean diameter of the particles in mm

Where the units of \( y_{ms}, Q, \) and \( d_m \) are \( m, m^3/s, \) and mm, respectively.
Maximum scour depth
Culvert opening = 3.30 m, Water level = 8.50 m, Water depth = 2.14 m,
Temporary bench mark was taken as 10.00 m which was on north-west corner of
slab.
Measured velocity = 2.32 m/s, Particle size $d_{50} = 0.043$ mm (from grain size
curve)
Silt factor, $f = 1.76\sqrt{d_{m}}$

\[= 1.76 \times (0.043)^{0.5}\]
\[= 0.36\]

Q = AV

\[= 3.30 \times 2.14 \times 2.32\]
\[= 16.38 \text{ m}^{3}/\text{s}\]

$y_{ms} = 0.473 \times (16.38/0.36)^{0.333} \times 2.25 = 3.79$ m below water level
scour depth below bed level, $d_s$ is equals \{5.74-(8.50-3.79)\} = 1.03 m

Blench's equation (1969):

\[y_{ms} = 1.20 \left[ \frac{q^{2}}{d_{ms}^{6.5}} \right] \quad \text{for sand of } 0.06 < d_m \text{ mm}\]

Where, $y_{ms}$ is equals mean scour depth below water level
q equals discharge per unit width in m$^2$/s
$d_{50}$ equals mean diameter of the particles in mm
and scour depth $d_s = y_{ms} - y$

Where the units of $y_{ms}$, q, and $d_m$ are m, m$^2$/s and mm, respectively.

Maximum scour depth
q is equal 4.96 m$^2$/s
$y_{ms}$ is equals 5.96 m below water level
Scour depth below bed level, $d_s = \{5.74-(8.5-5.96)\} = 3.2$ m
Ahmed's equation (1962)

\[ D_s = kq_1^{2/3} \]

Where \( D_s = \) Scour depth below the water surface in meter

\[ q_1 = q \] equals discharge per unit width in m\(^2\)/s

\[ k = \] a multiplying factor depend on the shape of the culvert

**Maximum scour depth**

\( q \) is equal 4.96 m\(^2\)/s

\[ D_s = 1.90 \times 4.96^{0.333} = 5.53 \text{m below water level} \]

Scour depth below bed level, \( d_s = \{5.74-(8.5-5.53)\} = 2.77 \text{ m} \)

Chitale's equation (1960)

\[ \frac{d_s}{y_0} = 6.65Fr - 0.51 - 5.49Fr^2 \]

Where \( d_s = \) Scour depth below bed level

\[ y_0 = \text{depth of flow} \]

\[ Fr^2 = \frac{V_0^2}{gy_0} \]

\( Fr = \) Froude number of the approach flow

\( V_0 = \) Mean velocity of flow

**Maximum scour depth**

\( Fr \) is equals 0.50

\( d_s = 1.45 \text{ m below bed and} \)

\( D_s = 1.45 + 2.14 = 3.59 \text{m from water level} \)
APPENDIX-B

Sample calculation of maximum scour depth at culvert outlet

Culvert-1, Mirertek

Lacey’s equation (1930):

\[ y_{ms} = 0.473 \left( \frac{Q}{f} \right)^{\frac{1}{3}} \]

Where, \( y_{ms} \) is equals mean scour depth below water level
\( Q \) equals discharge in m\(^3\)/s
\( f \) equals silt factor

correction factor for bend is equal 2.25

\[ f = 1.76\sqrt{d_m} \]

and scour depth \( ds = y_{ms} - y \)

\( d_m \) equals mean diameter of the particles in mm

Where the units of \( y_{ms} \), \( Q \), and \( d_m \) are m, m\(^3\)/s, and mm, respectively.

**Maximum scour depth**

Culvert opening =6.00m, Water level = 7.66m, Water depth =3.82m,
Temporay bench mark was taken as 10.00m which was on north-west corner of slab.

Measured velocity =2.04 m/s, Particle size \( d_{50} = 0.038 \) mm (from grain size curve)

Silt factor, \( f = 1.76\sqrt{d_m} \)

\[ = 1.76*(.038)^{0.5} \]
\[ = 0.34 \]

\( Q = AV \)

\[ = 6.00*4.01* 2.04 \]
= 49.08 m$^3$/s
\[ y_{ms} = 0.473 (49.08/0.34)^{0.333} * 2.25 = 5.57 \text{ m below water level} \]
scour depth below bed level, \( ds \) is equals \( \{4.11-(7.66-5.57)\} = 2.02 \text{ m} \)

Blench's equation (1969):

\[
y_{ms} = 1.20 \left[ \frac{q^{2}}{d_{50}^{6}} \right]^{1/3} \quad \text{for sand of } 0.06 < d_{m} \text{ mm}
\]

Where, \( y_{ms} \) is equals mean scour depth below water level
\( q \) equals discharge per unit width in m$^2$/s
\( d_{50} \) equals mean diameter of the particles in mm
and scour depth \( ds = y_{ms} - y \)
Where the units of \( y_{ms} \), \( q \), and \( d_{m} \) are m, m$^2$/s and mm, respectively.

Maximum scour depth
\( q \) is equal 8.18 m$^2$/s
\( y_{ms} \) is equals 8.48 m below water level
Scour depth below bed level, \( d_{s} = \{4.11-(7.66-8.48)\} = 4.93 \text{ m} \)

Ahmed's equation (1962)

\[ D_{s} = kq_{1}^{\frac{3}{4}} \]

Where \( D_{s} = \text{Scour depth below the water surface in meter} \)
\( q_{1} = q \) equals discharge per unit width in m$^2$/s
\( k = \text{a multiplying factor depend on the shape of the culvert} \)

Maximum scour depth
\( q \) is equal 8.18 m$^2$/s
Ds = 1.90*8.18^0.333 = 7.70m below water level

Scour depth below bed level, \( d_s = 4.11-(7.66-7.70) \) = 4.15 m

**Chitali's equation (1960)**

\[
\frac{d_s}{y_0} = 6.65Fr - 0.51 - 5.49Fr^2
\]

Where \( d_s \) = Scour depth below bed level

\( y_0 \) = depth of flow

\[
Fr^2 = \frac{V_o^2}{gy_0}
\]

\( Fr \) = Froude number of the approach flow

\( V_o \) = Mean velocity of flow

**Maximum scour depth**

\( Fr \) is equals 0.32

\( d_s \) = 1.07 m below bed and

\( D_s = 1.07+4.01 = 5.08m \) from water level

**Culvert- 2, Taltola**

**Lacey’s equation (1930):**

\[
y_{ms} = 0.473\left(\frac{Q}{f}\right)^{\frac{1}{3}}
\]

Where, \( y_{ms} \) is equals mean scour depth below water level

\( Q \) equals discharge in m\(^3\)/s

\( f \) equals silt factor

Correction factor for bend is equal 2.1

\( f = 1.76\sqrt{d_m} \)
and scour depth \( ds = y_{ms} - y \)

\[ d_m \text{ equals mean diameter of the particles in mm} \]

Where the units of \( y_{ms} \), \( Q \), and \( d_m \) are m, \( m^3/s \), and mm, respectively.

**Maximum scour depth**

Culvert opening = 4.20 m, Water level = 7.95m, Water depth = 3.19m,

Temporary bench mark was taken as 10.00m which was on north-west corner of slab.

Measured velocity = 2.24 m/s, Particle size \( d_{50} = 0.04 \text{ mm} \) (from grain size curve)

Silt factor, \( f = 1.76\sqrt{d_m} \)

\[ = 1.76*(.04)^{0.5} \]

\[ = 0.035 \]

\( Q = AV \)

\[ = 4.20*3.19*2.24 \]

\[ = 30.01 \text{ m}^3/\text{s} \]

\( y_{ms} = 0.473 \times (30.01 / 0.34)^{0.333} \times 2.1 = 4.37 \text{ m below water level} \)

scour depth below bed level, \( ds \) is equals \( \{5.18-(7.95-4.37)\} = 1.60 \text{ m} \)

**Blench's equation (1969):**

\[ y_{ms} = 1.20 \left[ \frac{q^{0.5}}{d_{50}^{0.6}} \right] \]

for sand of \( 0.06 < d_m \text{ mm} \)

Where, \( y_{ms} \) is equals mean scour depth below water level

\( q \) equals discharge per unit width in \( m^2/s \)

\( d_{50} \) equals mean diameter of the particles in mm

and scour depth \( ds = y_{ms} - y \)

Where the units of \( y_{ms} \), \( q \), and \( d_m \) are m, \( m^2/s \) and mm, respectively.
Maximum scour depth

q is equal 7.15 m²/s

\( y_{ms} \) is equals 7.68 m below water level

Scour depth below bed level, \( d_s = \{5.18-(7.95-7.68)\} = 4.91 \) m

**Ahmed's equation (1962)**

\[
D_s = kq_1^{2/3}
\]

Where \( D_s \) = Scour depth below the water surface in meter

\[
q_1 = q \quad \text{equals discharge per unit width in m}^2/\text{s}
\]

\( k \) = a multiplying factor depend on the shape of the culvert

Maximum scour depth

q is equal 7.15 m²/s

\( D_s = 1.90*7.15^{0.333} = 7.04 \) m below water level

Scour depth below bed level, \( d_s = \{5.18-(7.95-7.04)\} = 4.27 \) m

**Chitali's equation (1960)**

\[
\frac{d_s}{y_0} = 6.65Fr - 0.51 - 5.49Fr^2
\]

Where \( d_s \) = Scour depth below bed level

\( y_0 \) = depth of flow

\[
Fr^2 = \frac{V_0^2}{gy_0}
\]

\( Fr \) = Froude number of the approach flow

\( V_0 \) = Mean velocity of flow

Maximum scour depth

\( Fr \) is equals 0.40

\( d_s = 1.27 \) m below bed and
\[ D_s = 1.27 + 3.19 = 4.46 \text{ m from water level} \]

**Culvert-3, Katchpur**

**Lacey’s equation (1930):**

\[
y_{ms} = 0.473 \left( \frac{Q}{f} \right)^{\frac{1}{3}}
\]

Where, \( y_{ms} \) is equals mean scour depth below water level
\( Q \) equals discharge in \( m^3/s \)
\( f \) equals silt factor
correction factor for bend is equal 2.5
\[
f' = 1.76 \sqrt{d_m}
\]
and scour depth \( ds = y_{ms} - y \)
\( d_m \) equals mean diameter of the particles in mm
Where the units of \( y_{ms}, Q, \) and \( d_m \) are m, \( m^3/s \), and mm, respectively.

**Maximum scour depth**
Culvert opening = 4.300m , Water level = 8.36m, Water depth = 3.02m,
Temporary bench mark was taken as 10.00m which was on north-west corner of slab.
Measured velocity = 2.35 m/s, Particle size \( d_{50} = 0.05 \text{ mm (from grain size curve)} \)
Silt factor, \( f' = 1.76 \sqrt{d_m} \)
\[
= 1.76 \times (0.05)^{0.5}
= 0.39
\]
\( Q = AV \)
\[
= 4.30 \times 3.02 \times 2.35
= 30.52 \quad m^3/s
\]
\( y_{ms} = 0.473 \left( \frac{30.52}{0.39} \right)^{0.333} \times 2.00 = 4.04 \text{ m below water level} \)
scour depth below bed level, \( d_s \) is equals \( \{5.60-(8.36-4.04)\} = 1.28 \) m

**Blench's equation (1969):**

\[
y_{ms} = 1.20 \left[ \frac{2}{q^{\frac{1}{3}}} \right] \left[ \frac{1}{d^{\frac{1}{50}}} \right] \quad \text{for sand of } 0.6 < d_m \text{ mm}
\]

Where, \( y_{ms} \) is equals mean scour depth below water level
\( q \) equals discharge per unit width in \( m^2/s \)
\( d_{50} \) equals mean diameter of the particles in mm
and scour depth \( d_s = y_{ms} - y \)

Where the units of \( y_{ms}, q, \) and \( d_m \) are \( m, m^2/s \) and \( mm \), respectively.

**Maximum scour depth**

\( q \) is equal 7.10 \( m^2/s \)
\( y_{ms} \) is equals 7.36 m below water level
Scour depth below bed level, \( d_s = \{5.60-(8.36-7.36)\} = 4.60 \) m

**Ahmed's equation (1962)**

\[ D_s = k q_1^{\frac{2}{3}} \]

Where \( D_s \) = Scour depth below the water surface in meter
\( q_1 = q \) equals discharge per unit width in \( m^2/s \)
\( k \) = a multiplying factor depend on the shape of the culvert

**Maximum scour depth**

\( q \) is equal 7.10 \( m^2/s \)
\( D_s = 1.90*7.10^{0.333} = 7.01 \) m below water level
Scour depth below bed level, \( d_s = \{5.60-(8.36-7.01)\} = 4.25 \) m
Chitali’s equation (1960)

\[ \frac{d_s}{y_0} = 6.65Fr - 0.51 - 5.49Fr^2 \]

Where \( d_s \) = Scour depth below bed level
\( y_0 \) = depth of flow

\[ Fr^2 = \frac{V_0^2}{gy_0} \]

\( Fr \) = Froude number of the approach flow
\( V_0 \) = Mean velocity of flow

**Maximum scour depth**

\( F_r \) is equals 0.43
\( d_s \) = 1.34 m below bed and
\( D_s \) = 1.34 + 3.02 = 4.36 m from water level

Culvert-4, Pachani

Lacey’s equation (1930):

\[ y_{ms} = 0.473 \left( \frac{Q}{f} \right)^{\frac{1}{3}} \]

Where, \( y_{ms} \) is equals mean scour depth below water level
\( Q \) equals discharge in m\(^3\)/s
\( f \) equals silt factor
correction factor for bend is equal 2.25

\[ f = 1.76 \sqrt[3]{d_m} \]

and scour depth \( ds \) = \( y_{ms} \) - \( y \)
\( d_m \) equals mean diameter of the particles in mm

Where the units of \( y_{ms} \), \( Q \), and \( d_m \) are m, \( m^3/s \), and mm, respectively.

**Maximum scour depth**

Culvert opening =3.30 m, Water level = 8.50m, Water depth =2.14m, Temporay bench mark was taken as 10.00m which was on north-west corner of slab.

Measured velocity =2.32 m/s, Particle size \( d_{50} = 0.043 \) mm (from grain size curve)

Silt factor, \( f = 1.76 \sqrt{d_m} \)

\[
= 1.76 \times (0.043)^{0.5} \\
= 0.36
\]

\( Q = AV \)

\[
= 3.30 \times 2.14 \times 2.32 \\
= 16.38 \ m^3/s
\]

\( y_{ms} = 0.473 \ (16.38/ 0.36)^{0.333} \times 2.25 = 3.79 \) m below water level

scour depth below bed level, \( ds \) is equals \( \{5.74-(8.50-3.79)\} = 1.03 \) m

**Blench's equation (1969):**

\[
y_{ms} = 1.20 \left[ \frac{q^{2/3}}{d_{50}^{6/5}} \right] \quad \text{for sand of } 0.06 < d_m \text{ mm}
\]

Where, \( y_{ms} \) is equals mean scour depth below water level

\( q \) equals discharge per unit width in \( m^2/s \)

\( d_{50} \) equals mean diameter of the particles in mm

and scour depth \( ds = y_{ms} - y \)

Where the units of \( y_{ms} \), \( q \), and \( d_m \) are m, \( m^2/s \) and mm, respectively.

**Maximum scour depth**
$q$ is equal $4.96 \text{ m}^2/\text{s}$

$y_{ms}$ is equals $5.96 \text{ m}$ below water level

Scour depth below bed level, $d_s = \{5.74-(8.5-5.96)\} = 3.2 \text{ m}$

**Ahmed's equation (1962)**

$$D_s = kq_i^{2/3}$$

Where $D_s =$ Scour depth below the water surface in meter

$q_i = q$ equals discharge per unit width in m$^2$/s

$k =$ a multiplying factor depend on the shape of the culvert

**Maximum scour depth**

$q$ is equal $4.96 \text{ m}^2/\text{s}$

$D_s = 1.90*4.96^{0.333} = 5.53 \text{ m}$ below water level

Scour depth below bed level, $d_s = \{5.74-(8.5-5.53)\} = 2.77 \text{ m}$

**Chitali's equation (1960)**

$$\frac{d_s}{y_0} = 6.65Fr - 0.51 - 5.49Fr^2$$

Where $d_s =$ Scour depth below bed level

$y_0 =$ depth of flow

$$Fr^2 = \frac{V_0^2}{gy_0}$$

$Fr =$ Froude number of the approach flow

$V_0 =$ Mean velocity of flow

**Maximum scour depth**

$Fr$ is equals 0.50

$d_s =$1.45 m below bed and

$D_s =$1.45+2.14 = 3.59 m from water level