MEASUREMENT OF SCOUR IN BRIDGE PIERS AND ABUTMENTS

By

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EXTENDED ABSTRACT

INTRODUCTION

Innumerable bridges have been constructed, all over the world, across rivers, canals, drains etc for communication purpose. Estimation of scour in bridge piers and abutments is extremely important in deciding their foundation level. Any under estimation of scour may result in failure of the bridge whereas over-estimation of scour will lead to escalation of cost. A large number of bridges have collapsed in the past due to scouring around piers and abutments and failure of substructures e.g. piers, abutments, protection works etc. during the passage of high flood.. In major bridges, cost of substructures is found to be about 50% of the total cost of a bridge. It is, therefore, extremely important to estimate scour around piers and abutments in a bridge precisely for their safe design and monitoring. of foundation. The central and state governments of India are spending millions of rupees every year for the construction of bridges for the development of infrastructures e.g. highways, railways, irrigation, drainage etc.

LACEY'S METHOD OF SCOUR ESTIMATION FOR PIER AND ABUTMENT FOUNDATIONS

In India, the present practice of finding scour depth in bridge piers and abutments is based on Lacey's regime theory (1930) developed from data collected from stable canals flowing in very fine alluvial soils of Bari Doab areas of west Punjab (now in Paistan).. Lacey's regime dopth is given by the empirical equation -1

$$R = 0.473\ (Q/f)^{1/3} \quad (1)$$

where R is Lacey's regime depth in m ; Q is the design discharge in cumec; f is Lacey's silt factor given by Eq.-2

$$f = 1.76\ (d_{50})\ ½ \quad (2)$$

where d_{50} is the mean size of non-cohesive sediments in the river bed.
IRC/RDSO/IS codes followed for design of bridges in India provide correction factors for finding maximum scour depths (MSD) measured below HFL in bridge piers, abutments and guide bunds given below:

Correction factors for Determining Maximum Scoured Depth (y_{max}) below HFL

Location of scour	**Correction Factor (Ymax/R)**
At Nose of Pier	2.0
In Abutments with protected approaches	1.27
In Spill through Abutments	2.0
Straight Reach of Guide Bund	
In the Curved Head of Guide Bund	2.5 to 3.0

Where the waterway under the bridge is less than the normal waterway of the stream, R is determined from Eq..3 as recommended in IRC/IS codes (IRC-5, 1994, IS:).

$$R = 1.34\ (q^2/g)^{1/3} \quad (3)$$

Where q is the design discharge intensity i.e. q = Q/W, where W is the effective waterway under the bridge.
The codes prescribe that R should be found for a higher discharge intensity for determining scour depths in bridge piers and abutments by increasing the design discharge (Q_{50}) by adding 10% to 25% of the design discharge (Q_{50}) depending upon the area of catchments. Codes recommend that all bridges should be designed for a flood of 50 year return period i.e.Q_{50}. One third of Y_{max} is added to find the minimum level of pier and abutment foundation which may have to be lowered further depending on the bearing capacity of foundation soil. and for passive pressure

required for resisting the tractive forces from vehicles moving above the bridge as well as earthquake considerations
.

LIMITAIONS OF LACEY"S THEORY IN PREDICTION OF SCOUR DEPTH

Lacey's regime theory was developed for design of stable canal sections in non-cohesive fine alluvial soils. Extension of Lacey's theory for finding localized scour depths in bridge piers and abutments in rivers is unscientific and irrational. Some of the limitations of Lacey's theory for finding scour depth in bridge piers and abutments are

- It does not distinguish between general, contraction and local scour.
- It finds MSL with respect to HFL resulting in level scoured surface.
- It does not consider many of the important parameters e.g. flow shallowness ; geometry, length & alignment of piers and abutments; incoming sediment load and debris; size, shape and non-uniformity of sediments; time etc
- Lacey's R-value is applicable for steady flow in fine incoherent alluvial soils only
- Lacey's silt factor ($f = 1.76\sqrt{d_{50}}$) depends on many other parameters besides mean size of sediments- d_{50}.
- It neglects the morphology of a river-its various plan and bed forms.
- Lacey's theory is applicable for steady canal flow only and is independent of time of flow
- It can at best be used for finding approximate general scour depth but definitely not for localized scour depth around bridge piers and abutments governed by several parameters
- Sediment transport principles and scouring under live bed and clear water conditions ignored.. It is well established universally that scour is maximum at threshold/critical/incipient condition of bed motion when $Q= Q_c$ or $V=V_c$ or $\tau=\tau_c$ at $t=t_c$ (where Q, V, V τ, t are discharge, velocity, shear stress and time respectively and the critical values of the same are denoted by subscript c) . Scour reduces thereafter with further increase of the parameters i.e. when Q>Qc (V>Vc or Q>Qc) and attains an equilibrium state at about V=4Vc(Fig.1). In Lacey's method, however, scour is independent of the critical conditions and it goes on increasing with increasing discharge, Q, V , τ and it is independent of time which is far from truth.

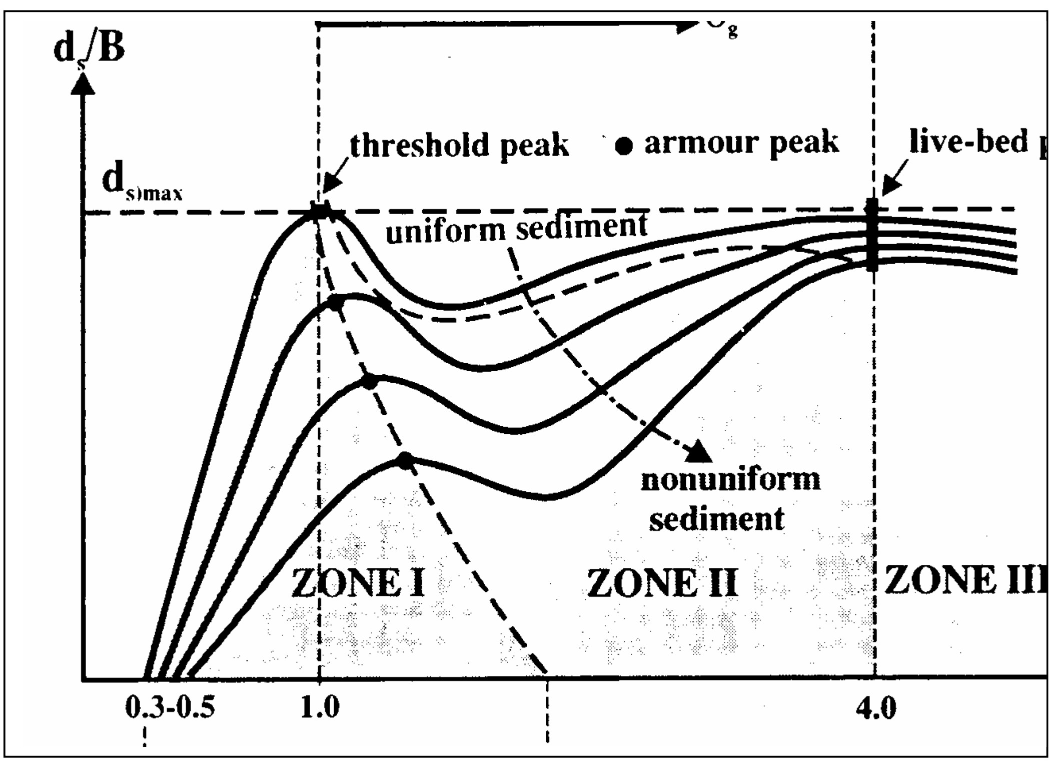

FIG.1, Showing local scour depth variation with sediment non-uniformity and illustrating clear-water and live-bed scour in bridge piers.

MATHEMATICAL MODELS USED FOR SCOUR ESTIMATION IN BRIDGE PIERS & ABUTMENTS

Total scour depth in a bridge pier consists of both general and localized scour. The general scour is due to the general morphologic behavior of the river e.g. degradation, meandering, braiding, confluence with another stream, meandering and cut-off formation etc. General scour will occur even though the bridge is not constructed. Localized scour has two components, namely, constriction scour due to restriction of waterway and local scour due to obstruction by pier and its foundation. A number of mathematical models have been developed for estimation of both general and localized scour by eminent river engineers e.g.Blench(1957), Laursen (1960),Melville (1984) Breussers (1977), Raudkivi (1983), Richardson and Davis (1995), Laursen (1956), Shen (1969) from abroad and Garde (1996), RangaRaju ( ), Kothyari (1992,1993), Jain (1981), Gangadharaiah (1985) and others. Unfortunately, most of the mathematical models are developed by using laboratory flume data ard require validation by field measurement of scour in prototype piers and abutments.

IS./IRC/RDSO codes, currently being used in India for scour estimation in bridge piers and abutments, recommend use of Lacey's model due to the fact that mathematical models are not yet proved/validated by actual scour observations in bridge sites under Indian river conditions. In a paper (Mazumder,2006), maximum scour depths in piers on alluvial non-cohesive soil were computed for five bridges using four different mathematical models e.g. HEC-18 (Richardson and Davis,1995), IAHR (Breussers and Raudkivi, 1991), Melville and Coleman (2000), and Kothyari-Garde-Rangaraju (1992). The maximum scour depths were compared with those obtained by Lacey's method. It is found that Lacey's method overestimates the total scour depth in all the cases and the error varies from 5% to 255%.(Table-1(a) & Table -1(b)).

Table-1 (a)

ame of River Crossing (NH No.)	Maximum scour depth (m) in Bridge Piers computed by different methods										
	General scoured depth below HFL (As per Regime theory)	Constrict-ion scour depth below mean bed level	Total scour depth by Lacey (IRC method)	Local scour below bed and total scour below HFL (i.e., s general scour, consriction scour and local scou							
				Melville & Coleman		Richardson & Davis (HEC-18)		Breussers & Raudkivi (IAHR)		Kot	
				Local	Total	Local	Total	Local	Total	Lo	
mbal (NH-3)	23.80	6.83	46.27	7.20	37.83 (22.3%)	6.23	36.86 (25.6%)	6.90	37.53 (23.4%)	13	
u (NH-28)	10.20	1.10	26.04	2.88	14.18 (83.6%)	2.86	14.16 (84.0%)	2.40	13.7 (90.0%)	4	
ak - 1 (NH-31C)	6.23	2.84	15.57	6.00	15.07 (3.2%)	4.26	13.33 (17.0%)	3.12	12.19 (28.8%)	6	
ak-II (NH-31C)	5.97	3.41	16.43	6.66	16.04 (2.4%)	4.75	14.13 (16.3%)	2.70	12.08 (36.0%)	6	
osh (NH1.C)	5.86	0.15	13.70	6.96	12.97 (5.6%)	5.46	11.47 (19.4%)	3.50	9.51 (44.0%)	5	

Table-1 (b)

ame of River	Maximum scour depth (m) in Bridge Piers computed by different methods

Crossing (NH No.)	General scoured depth below HFL (As per Regime theory)	Constrict-ion scour depth below mean bed level	Total scour depth by Lacey (IRC method)	Local scour below bed and total scour below HFL (i.e., s general scour, consriction scour and local scou							
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le - 1 Scour Depths Computed By Different Methods (a) Assuming that the low water bed profile develop ey's regime profile during passage of design flood (b) Assuming that the low water bed profile remains u ing the passage of design flood)

es

(i) All scour depths are in meter. Total scour depth is from Design HFL to maximum scour level (MSL) around th Constriction and local scour depths are below mean bed level of the stream.

(ii) Figures in brackets indicate percentage excess total scour by Lacey's (IRC) method with respectto other methods

(iii) General scoured depth of flow is computed as the average of regime flow depths computed by Lacey's and Blench's theories

NECESSNECESSITY OF SCOUR MEASUREMENT IN PIERS & ABUTMENTS AT BRIDGE SITES

It is apparent from table 1(a) and 1(b) that there is a large percentage variation in scour depth obtained by Lacey's thod w ith respect to those found by different mathematical models, it cannot be ascertained which method is the be st for scour computati on. Most of the mathematical models are developed by using data obtained from laboratory me study and there may be considerable error between model and prototype scour due to scale effect as well as dis parity in flow fields in models and prototypes It is extremely difficult to reproduce the prototype flow and bed condition in the physical model. It is essential, therefore, that before the use of any mathematical model for computing scour in bridge piers and abutments, the model must be proved /va lidated by means of actual prototype scour observations under identical condition of flow and other parameters used in scour esti mation. It is highly unfortunate that even though a large amount of public money is being spent in bridge construction in India, hardly there is any effort to collect, preserve and systematically analyze precious scour data from bridge sites for the validation of mathematical models which have been developed in a scientific manner and are in use in most of the developed countries In the world after proving their models by comparison of scour estimated by the models with that measured at bridge sites (USGS,2002). Unless the mathematical models (Indian or foreign) are duly verified by comparison of estimated and observed scour und er Indian river conditions, codal authorities (e.g. IRC , BIS, RDSO etc in India) are reluctant to modify the codes by replacing Lacey model by any other mathematical model, however scientific they may be. .

A MoU has recently been signed between IIT(Roorkee) and ICT (New Delhi} and a joint research proposal on bridge scour has been submitted to the Ministry of Shipping, Road Transport and Highways (MOSRTH), Govt. of India. The primary objectives of this joint research program are to collect field data in 10 bridges, develop suitable mathematical model and software and validate the model by compare is of computed scour with the measured values with the objectives of updating of the relevant Indian codes related to scour estimation of bridge piers and abutments.

SCOUR MEASURING DEVICES AND EQUIPOMENTS USED FOR IN-SITU MEASUREMENT OF SCOUR

Analysis of maximum scour and associated hydraulic, geometric and sediment parameters require real time measurements. However, development of integrated continuous systems of measuring scour during major floods received little attention before 1991, until USGS and FHWA in USA ( ) took major initiatives in the area after failure of several bridges in…….Scour measurements are needed not only for safe design and analysis of scouring process, it is vitally needed for motoring and identifying the bridges which are in scour critical conditions. The primary objective of the proposed research scheme by ICT in association with IIT(Roorkee) is to validate the mathematical models for estimation of scour. It is ,therefore, essential to use an integrated system of measuring scour together with the parameters e.g. discharge, water surface elevation, velocity, flow obliquity, turbulence, sediments, debris flow etc governing scour

In any scour measuring device, the four important components are (i)Scour measuring instrument (ii) Deployment of the measuring system (iii) Identification of the location of measuring probe. And (iv) storage and retrieval of measured data.

Various instruments used for field measurement of bridge scour have been described by Parola. (1996). Portable instrumentation for real time measurement of scour in bridge piers and abutments have been discussed in the publication by US Deptt. of Transportation (1999) approved by FHWA and USGS in USA. Fixed scour measuring and monitoring instruments can be grouped into four categories, namely, (i) Sounding method – manual or mechanical (ii) Buried or driven rods with sensors (iii) Fathometers i.e. sonic depth finders (iv) Other buried devices with buried sensors/transmitters.

Sounding method does not provide any continuous record of scouring. For depths greater than 2 to 3 m, sounding method does not give accurate results. In the second method, deployment of sensors on the buried rods or pier faces are to be done during construction. The devices like "Tell Tail" developed at Wallingford ,UK (Waters,1994) and " Scubamouse"(Melville, 1992) belong to this category. In the former, transducers are embedded in pier and abutment faces for transmitting scour levels. In the later, horse-shoe shaped collars slides down a vertical pipe installed near the nose of piers and a radioisotope detector (Scubamouse) determines the exact level of the collars which contains a radioisotope source .

Fathometers which are multiple echo-sounders have been extensively used by US Marines for fishing urposes.USGS(2002) used fathometers for measuring maximum scour depths in large number of bridge piers in river Maine and other rivers in USA for validation of HEC-18 model developed through extensive research by Richardson and Davis (1995). The magnetic sliding collar device consists of a stainless steel pipe driven into the channel bottom with a sliding collar that drops down the pipe as the scour progresses. The location of the collar is detected by the magnetic field created by magnets on the collar. This simple, low-cost instrument is adapt-able to various field situations, and can be installed with the equipment and technical skills normally available with a state highway agency.

Amongst the other buried devices are float out sensors which are buried at different depths under the bed of a river. When the scour reaches the sensor depth, the float-out device rises to the surface and begins transmitting a radio signal that is detected by a receiver in an instrument sheltered on the bridge. Piezometric polymer films, popularly used in electronic industries, along with magnetic switches can also be used for finding scour levels. These devices can be connected with data logging devices for storage of data recorded. .

Portable scour measuring instruments are used for bridge inspection, limited detailed data collection and detailed data collection. Bridge inspection system is intended for determining stream bed elevation around piers and abutments to ensure stability and safety of bridge foundations. The system consists of a low cost echo sounder powered by a battery for measuring depths and a tethered float for deploying the transducer around bridge piers and abutments. Scour data are recorded on a chart-recording echo sounder or in a note book in case the echo sounder has only graphical or numerical diplay.The limited detailed data collection system is used for measuring scour as well as evaluation of scour equations. Obviously, data collection includes depth, discharge, channel sections, bed materials, water temperature, pier and abutment geometry etc. governing scour. Float is used to deploy the echo sounder. A costly digital echo sounder is used for measuring depths; a broad band acoustic Doppler current profiler (BB - ADCP) is used for measuring three dimensional components of velocity vector and turbulent components; a range-azimuth positioning system or a differential global positioning system (GPS) is used for determining the locations of the measured data. All data are transmitted to a data logger or a field computer placed on the bridge deck or river bank.

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