SCOUR MEASUREMENT AT BRIDGE SITE FOR VALIDATION OF MATHEMATICAL MODELS

S. K. Mazumder
Individual Consultant
(Former AICTE Emeritus Professor of Civil Engg., DCE)
E-mail Address: somendrak64@yahoo.com

ABSTRACT

Scour measurement in bridges is needed for validation of mathematical models developed for prediction of scour. The different mathematical models used for scour estimation in India and abroad have been mentioned. Large discrepancies between predicted scour depths by advanced mathematical models and IRC/IS formula as well as the discrepancies between predicted and measured scour have been illustrated with examples. Indian codes are still based on Lacey/Blench type empirical model primarily due to the fact that there is hardly any measured scour data from our bridge sites for validation of mathematical models. Instrumentations needed for measurement of scour depth, flow and geometric parameters for validation of mathematical models have been discussed.

INTRODUCTION

Estimation of scour in bridges is extremely important for the design of bridge foundation, guide bunds, protection works etc. Any under estimation of scour may result in failure of the bridge whereas over-estimation of scour will lead to escalation of costs. Precise estimation of scour in bridges will help in economic and safe design of a bridge.

In India, scour estimation is done by use of Lacey's empirical theory (1930) based on which Indian codes/guidelines e.g. IS:6966 (1989), IS:10751(1994) IRC-5 (1998), IRC:SP-13 (2004), IRC-78 (1980) etc are prepared. In the developed countries, however, precise estimation of scour is made by using scientific mathematical models, which have been developed over the years through extensive and dedicated research by eminent river engineers e.g. Laursen (1981),Breusers et al (1991) and others. Most of these mathematical models have been validated by comparison of scour estimated by the models and actual scour measured at bridge sites by USGS (Hubbard,1955). Sophisticated instrumentations (Mellvile-1982, USGS-1999) have been developed for precise measurement of scour at bridge sites for validation of the models and to find those bridges which are in scour critical conditions and need protections.

In India too, extensive research on bridge scour has been performed by Garde& Kothyari (1996), Kothyari, Garde & RangaRaju (1992a, 1992b), Gangadharaiah (1985), and others for the development of mathematical models for scour estimation. Unfortunately, none of these mathematical models have been considered in framing our national codes primarily due to the fact that we have hardly any field data to validate the model under Indian river conditions. This is very urgently needed for revising our national codes still following Lacey's regime equations for estimation of scour in bridges .

Lacey's equations were developed in India when there was very little knowledge about mechanics of sediment transport and scouring processes. Limitations of Lacey's model has been discussed elsewhere(Mazumder,2007a). In a paper presented by the author (Mazumder, 2006) at the 67th Indian Roads Congress, scour computed by Lacey's method in five major bridges in India are compared with those computed by four different mathematical models. It is found that in all the cases Lacey's model overestimates scour and the error varies from 5% to 272% (Table-1a&b). However, without measuring scour data from bridge sites, it is not possible to conclude which model is better for scour prediction. One of the primary objectives of writing this paper is to discuss the necessity of scour measurement and instrumentations required for reliable measurement of scour at bridge sites in India for the validation of mathematical models and for updating Indian codes.

MATHEMATICAL MODELS FOR SCOUR ESTIMATION

In all other mathematical models (Mazumder,2006), except Lacey, total scour depth in bridge piers and abutments are found by adding (i) general scour (ii) constriction scour and (iii) local scour. Some of the popular models which are used for estimating scour are briefly discussed below.

General Scour

General scour is the scour which occurs irrespective of the presence of the bridge due to the various morphological processes in a river, namely, aggradations and degradation of river bed, meandering, braiding, cut-off formation, confluence of streams upstream of bridge sites, etc. Lacey (1930), Blench(1957), Neill (1973), Chitale (1981),Yalin (1999), Diplas (1990), Garde and Rangaraju (2000), and many eminent river engineers have done commendable work to find the dimensions of a stable channel section or a regime section. In India, general scour depth below HFL is found by using Lacey/Blench equations. However, there is hardly any measurement of scoured bed profile of a river during high flood needed for validation of Lacey's/Blench's models.

Constriction Scour

Constriction or contraction scour occurs in a bridge where the road or railway approach embankment restricts the normal waterway. Lowering of the bed occurs locally within the contracted reach (i.e. under the bridge) due to flow acceleration and increased velocity of flow. Estimation of constriction scour should be done depending on whether the bed is stable (rigid) or live (mobile). The bed becomes mobile when the mean velocity of flow (V) in the channel exceeds the critical velocity (V_c) or the bed shear stress (τ_o) exceeds the critical shear stress (τ_c) at which the stream bed material just starts moving.HEC-18 model based on a paper by Richardson and Davis (1995), is very popular in estimating contraction scour.

Local Scour

Local scour around piers and abutments occur due to the horse-shoe type vortices developed by these obstructions as illustrated in Fig.1.A large numbers of mathematical models have been developed in India and abroad for estimating local scour depths around bridge piers and abutments due to the flow obstruction and formation of vortices. Some of the popular models are **(**a)Melville and Coleman Model (2000), (b) HEC-18 Model (Richardson and Davis, 1995), (c) IAHR Model (Breussers & Raudkivi, 1991), (d) Kothyari – Garde - RangaRaju Model (1992)

The methodology of estimating total scour depth around piers using different mathematical models are given in a paper by Mazumder (2006). Results are given in table-1(a) & (b) prepared with the objective of comparison of the total scour depth obtained by these models with Lacey/Blench model prescribed by the Indian codes.

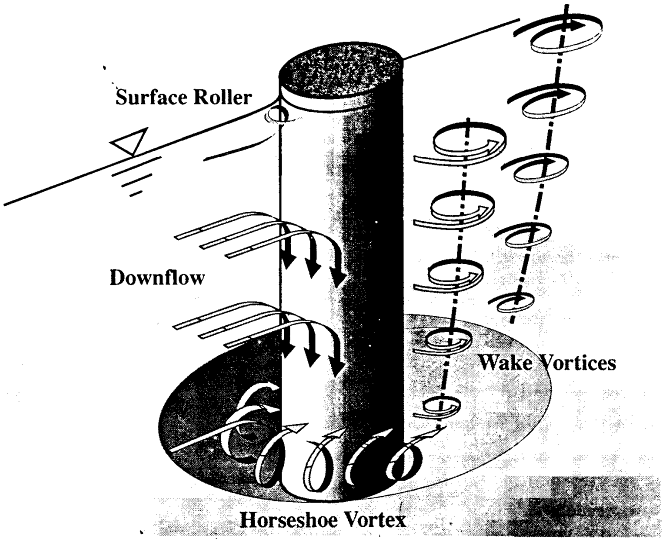

Fig.1 Showing Development of Local Scour due to Vortices around a Cylidrical Pier

NECESSITY OF SCOUR MEASUREMENT FOR VALIDATING MATHEMATICAL MODELS

It may be noticed from table-1 that the scour estimated by IRC/BIS/RDSO codes based on Lacey/Blench model is always higher than that found by other mathematical models popular in the developed countries e.g. USA (using HEC-18 model) , Europe (using IAHR model), Newzealand (using Mellvile&Coleman model).The error is found to vary from 2.4% to 90% in case (a) and 10.8% to 275.2% in case (b) for the bridges investigated. In case (a), it is assumed that the low water bed profile develops to Lacey's regime profile whereas in case (b), it is assumed that the bed profile as observed during low flow season remains unchanged during flood. The error will further increase if the predicted depths of scour by different mathematical models could be compared with values measured during passage of floods.

Table - 1 Scour Depths Computed By Different Methods

(a) Assuming that the low water bed profile develops to Lacey's regime profile during flood

Maximum scour depth (m) in Bridge Piers computed by different methods											
Name of River Crossing (NH No.)	**General scoured depth below HFL (As per Regime theory)**	**Constriction scour depth below mean bed level**	**Total scour depth by Lacey (IRC/IS method)**	**Local scour below bed and total scour below HFL (i.e., sum total of general scour, consriction scour and local scour)**							
				Melville & Coleman		**Richardson & Davis (HEC-18)**		**Breussers & Raudkivi (IAHR)**		**Kothyari, Garde & Ranga Raju**	
				Local	**Total**	**Local**	**Total**	**Local**	**Total**	**Local**	**Total**
Chambal (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%)	13.18	43.81 (5.6%)
Saryu (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%)	4.51	15.81 (64.6%)
Raidak-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%)	6.12	15.19 (2.4%)
Raidak-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%)	6.29	15.67 (4.9%)
Sankosh (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%)	5.73	11.74 (16.7%)

(b) Assuming that the low water bed profile remains uncharged during flood

Name 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., sum total of general scour, consriction scour and local scour)**							
				Melville & Coleman		**Richardson & Davis (HEC-18)**		**Breussers & Raudkivi (IAHR)**		**Kothyari, Garde & Ranga Raju**	
				Local	**Total**	**Local**	**Total**	**Local**	**Total**	**Local**	**Total**
Chambal (NH-3)	17.92	6.83	46.27	7.20	31.95 (44.8%)	6.23	30.98 (49.5%)	6.90	31.65 (46.2%)	13.18	37.93 (22.0%)
Saryu (NH-28)	3.44	1.10	26.04	2.88	7.42 (250.9%)	2.86	7.40 (251.9%)	2.40	6.94 (275.2%)	4.51	9.05 (187.7%)
Raidak - 1 (NH-31C)	4.88	2.84	15.57	6.00	13.72 (13.4%)	4.26	11.98 (30.0%)	3.12	10.84 (43.6%)	6.12	13.84 (12.5%)
Raidak-II (NH-31C)	4.76	3.41	16.43	6.66	14.83 (10.8%)	4.75	12.93 (27.1%)	2.70	10.87 (51.1%)	6.29	14.46 (13.6%)
Sankosh (NH1-C)	4.69	0.15	13.71	6.96	11.80 (16.2%)	5.46	10.3 (33.1%)	3.50	8.34 (64.4%)	5.73	10.57 (29.3%)

USGS (2002) measured scour in bridges all over USA and.compared the predicted and measured scour depths in piers using HEC-18 model. Table-2 shows the predicted and measured scour depths in bridges over rivers in Maine basin during high flows. Fig.2 is a plot to indicate the discrepancy between measured and predicted scour depths.

It is highly unfortunate that although a large amount of public money is being spent in bridge construction in India, hardly there is any concerted effort to measure, preserve and analyze precious scour data from bridge sites in India. Developed countries in the world have proved their models by comparison of scour estimated by the different mathematical models with that measured at bridge sites (USGS, 2002). A MoU was recently signed between IIT (Roorkee) and ICT (New Delhi) and a joint research proposal on bridge scour was submitted to the Ministry of Shipping, Road Transport and Highways (MOSRTH), Govt. of India, for research funding. The primary objectives of this joint research program were to collect field data in 10 selected bridges, develop suitable mathematical model and software and validate the model with the intention of updating the relevant Indian codes. But the Ministry's observation was that the proposed research do not fall in its areas of priority.

Table 2. Predicted and observed maximum pier-scour depths in Maine River Basin during high flows

	Predicted (ft)	**Observed(ft)**
Kenduskeag River at Bangor	8.3	1.1
Aroostook River at Ashland 1	8.8	3.1
Androscoggin River at Bethel 1	19.3	2.3
Penobscot River at Lincoln 1	11.9	0
Penobscot River at Lincoln 2	18.5	4.1
Penobscot River at Lincoln 6	16.6	1.9
Kennebec River at Gardiner 1	19.5	1.7
Kennebec River at Gardiner 2	18.6	6.8
Aroostook River at Ashland 2	16.5	1.9
Kennebec River at Gardiner 3	12.6	3.4
St. John River at Van Buren 1	12.0	4 41
St. John River at Van Buren 2	12.7	12.0
Austin Stream at Bingham 1	19.9	3.5
Austin Stream at Bingham 2	11.2	0.5
Penobscot River at Lincoln 3	18.3	0 18
River at Hiram	10.5	7.0

Note: Numbers indicate pier numbers from left side of the river where scour was measured during Passage of flood for which scour depths were predicted by using HEC-18 Model

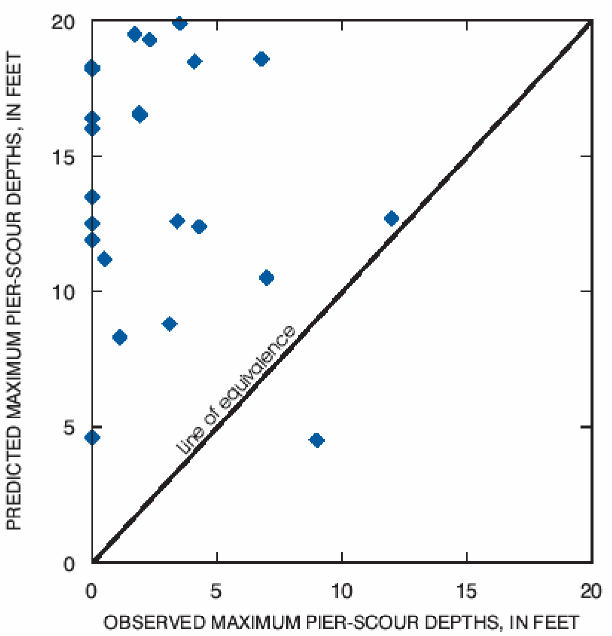

Fig.2 Comparison of Predicted and Measured Scour Depths by HEC-18 in Maine River Bridges

INSTRUMENTAIONS FOR IN-SITU MEASUREMENT OF BRIDGE SCOUR

Real time measurement of maximum scour depths in bridges and the parameters governing scour, namely, hydraulic, geometric and sediment parameters, are needed not only for validation of mathematical model for estimation of scour for safe and economic design of bridge foundations; it is vitally required for monitoring and identifying the bridges which are in scour critical conditions and need protection. Development of scour measuring instrumentations received very little attention before 1991, until USGS (1999) and FHWA in USA (Landers& Mueller, 1996, Richardson, Fredrick and Lagasse, 1999) took major initiatives after failure of several bridges in USA. An integrated and continuous system of scour measurement along with different parameters governing scour e.g. discharge, water surface elevation, velocity, flow obliquity, turbulence, sediments, bridge pier/abutment geometry etc is, therefore, essentially needed for analysis of scouring processes, development and validation of mathematical models for prediction of scour in bridges.

Various instruments used for field measurement of bridge scour are available in publications by Melville. (1982), Mazumder (2007 b). However, the various methodologies and instrumentations are briefly discussed underneath.

(i) Sounding method

In the sounding or logging method of determining bed profile, the flow depth below a known water surface elevation is measured with the help of a pole or a chain with weight at the bottom. It does not give any continuous record of scoured bed profile as the high flood passes under a bridge. For depths greater than 2 to 3 m, sounding method will give a lot of error.

(ii) Buried or driven rods with sensors

In this method, sensors/transducers are installed on buried rods or pier/abutment faces. The "Tell Tail" device developed at Wallingford laboratory in UK and "Scubamouse" (Melville, 1992) belong to this category. In the "Tell Tail" device, signals are transmitted as soon as the scour level reaches the transducer levels. In "Scubamouse" device, a vertical pipe is installed near the pier nose where the scour is maximum. Horse-shoe shaped collars, which contain a radioisotope source, slide down the pipe at different depths as the scouring progresses, A radioisotope detector (Scubamouse) determines the exact level of the collars when they reach the bottom of scour hole.

(iii) Echo - Sounders

Echo sounders are extremely popular in measuring water depths, especially when depths are high. Fathometers which are multiple echo-sounders have been extensively used by US Marines for fishing purposes. United States Geological Survey (USGS, 2002) made extensive use of fathometers for measuring maximum scour depths in large number of bridge piers in river Maine and other rivers in USA.

(iv)Buried Device

This device consists of float - out sensors which are buried at different depths under the bed of a river.The float-out devices rise to the surface and begin transmitting a radio signal that is detected by a receiver in an instrument sheltered on the bridge when the scour reaches the sensor depth. Piezometric polymer films, popularly used in electronic industries along with magnetic switches can also be employed for finding scour levels.

(v) Electrical Devices

Utilizing the difference in conductivity of water and a sand-water mixture, electrical apparatus has been developed to record the scour depth at a point near a bridge pier or abutment in Iowa. (Hubbard, 1955).

PORTABLE SCOUR MEASURING INSTRUMENTS

Portable instrumentation for real time measurement of scour in bridge piers and abutments has been discussed in the publication by US Dept. of Transportation (1999) approved by FHWA and USGS in USA. Portable scour-measuring systems consist of the following five components: (i) A method to measure the horizontal position of the data collected, (ii) The instrument(s) for measuring streambed-elevation (iii) Instrument for discharge/water-velocity measurements, (iv) A deployment system, and (v) a data-storage device.

(i) Horizontal position of the data collected,

Range-azimuth tracking systems and Differential Global Positioning Systems (DGPS) are used to obtain positions of the boat and instruments to within 1 meter. Radars have also been successfully deployed for locating positions of instruments

(ii) Instrumentation for Measuring Stream Bed Elevation.

Acoustics are the primary means of collecting streambed-elevation and velocity data. A digital echo sounder with analog paper chart is the preferred instrument for making detailed bathymetric surveys. For inland waterway applications, an echo sounder operating at a frequency of 200 kHz, with three-degree transducer, and with a peak digitization algorithm generally works well.

(iii) Instrument for discharge/velocity measurements,

The Broadband Acoustic Doppler Current Profiler (BB-ADCP) allows three-dimensional velocity profiles and discharge to be measured in rivers from a moving boat. The BB-ADCP measures water-velocity magnitude and direction by use of the Doppler shift associated with the reflection of acoustic energy off particles transported in the water column.

(iv) Deployment system

Echo-sounders and Fathometers (i.e. multiple echo-sounders) have been deployed from bridge deck by means of truck mounted cranes by USGS (2002). For measuring maximum scour depth at the pier nose..

Development of an unmanned remote-control boat has eliminated the restrictions of collecting data from a manned boat. Collection from a manned boat, however, is faster and more efficient; but launching facilities and safety considerations prevent the use of manned boat. The remote-control boat allows collection of data in areas that are inaccessible.

(v) Data recording / storage device.

All data can be radio linked to a data logger / field computer located either on shore or on the manned boat so that the position of the instrument and the data collected are recorded simultaneously.

ACKNOWLEDGEMENT

Author wishes to thank ICT authorities for providing facilities of computations and valuable data for bridges. Help received from the bridge division of ICT is gratefully acknowledged.

REFERNCES

1. Blench, T. (1957) “Regime Behaviour of Canals and Rivers” Butterworth Scientific Publishing, London
2. Breussers, H.N.C.and Raudkivi, A.J.(1991) “Hydraulic Structures Design Mannual-Hydraulic Design Considerations”, Chapter-5, Scour at Bridge Piers, Balkama Publications, Rotterdam, The Netherlands.
3. Chitale, S.V. (1981), “: Shape and Mobility of River Meanders” Proc. XIX Congross of IAHR, Vol. 2, pp 281
4. Diplas, P. (1990), “Characteristics of Self Formed Straight Channels” J. of Hyd. Engg., ASCE, Vol. 116, No. 5.
5. Garde, R.J. and Kothyari, U.C. (1996) “State of Art Report on Scour around Bridge Piers”, Indian Institute of Bridge Engineers, Mumbai, India
6. Garde, R.J. and RangaRaju, K.G.(2000) “Mechanics of Sediment Transport and Alluvial Stream Problems” 3rd Ed. New Age Int. Pub.Pvt. Ltd. , New Delhi.
7. Gangadarhiah, T., Muzzammil, M. and Subramanya, K (1985) “Vortex Strength Approach to Scour Depth Prediction Around Bridge Piers”, Proc. 2nd Int. Workshop on Alluvial River Problems held at University of Roorkee, Roorkee, India.
8. Hubbard, P.G. (1955)”Field Measurement of Bridge Pier Scour”, Highway Research BoardProceedings, Vol. 34, PP 184-188, Highway Research Board, Washington DC, USA
9. IRC:5 (1998) “Standard Specifications and Code of Practice for Road Bridges – Section 1” Published by Indian Roads Congress, R.K.Puram, New Delhi.
10. IRC:78: (1980) “Standard Specifications and Code of Practice for Bridge, Section VII ,Foundation and Substructures, Part-I, General Features of Design”. Published by Indian Road Congress, New Delhi.
11. IRC:SP:13(2004) “Guidelines for the Design of Small Bridges and Culverts”, Published by Indian Roads Congress, New Delhi.
12. IS:6966 (1989)”Guidelines for hydraulic design of barrages and weirs”, Part 1 Alluvial reaches. Bureau of Indian Standards, Water Resources Department, New Delhi.
13. IS: 10751 (1994) “Planning and design of guide banks for alluvial river – Guidelines”, Bureau of Indian Standards, Water Resources Division, New Delhi.
14. Kothyari, U.C., Garde, R.J. and Ranga Raju, K.G. (1992a) “Temporal Variation of Scour Around Circular Bridge Piers”, JHE, A.S.C.E., 118(8), PP 1091-1106.
15. Kothyari, U.C. Garde, R.J. and Ranga Raju, K.G. (1992-b), “Live Bed Scour around Cylindrical Bridge Piers”, JHR, IAHR, 30(5), PP 701-715.
16. Lacey, G.(1930) “Stable Channels in Alluvium” Paper 4736, Proc. of The Institution of Civil Engineers, Vol. 229, William Clowes & Sons Ltd., London, U.K. P. 259-292.
17. Landers, M..N., and Mueller, D.S., (1996) ”Channel scour at bridges in the United States”: Federal Highway Administration Report FHWA-RD-95-184, 140 p

18. Laursen, E.M. (1981) “Scour at Bridge Crossings”, JHE, A.S.C.E. 86(2), P. 39-54.

19.Mazumder, S.K.and Yashpal Kumar (2006) “Estimation of Scour in Bridge Piers on Alluvial Non Cohesive Soil” Paper Published in the Highway Research Bulletin, Nov., 2006 and presented in the 67th IRC Annual Session, Panchkula (Haryana), Nov.,2006.

20.Mazunder, S.K. (2007a) “ Limitations of Lacey’s Theory for Estimation of Bridge Scour” Pub.in the Proc. of Hydraulics & Water Resources HYDRO -2007 org. by Indian Society for Hydraulics and VSNIT at Surat,.21-22 Dec., and Pub. By Elite Publishing House Pvt. Ltd., New Delhi.pp328-336.

21. Mazumder, S.K. (2007b) Instrumentation for Measuring Scour in Bridges for Validation of Mathematical Models” Proc. Of National Workshop on Hydrological & Geotechnical Instrumentation for Water Resources Projects, org.by National Water Academy, Pune & Indian Water Resources Society, Pune Center, 6-7 Sept.,2007

22.Melville, B.W. and Coleman, S.E., (2000), “Bridge Scour”, Water Resources Publications, LLC.

23.Melville, B.W.(1982) “Field Measurement of Scour using a Portable Gamma Spectrometer”,Reportno.287, School of Engineering, The University of Auckland, Auckland, New Zealand.

24.Neill, C.R. (1973), “Guide to Bridge Hydraulics” Roads and Transportation Association of Canada, University of Toronto Press, Toronto, Canada

25.Richardson, E. V. and Davis, S. R. (1995) “Evaluating Scour at Bridges” 3rd Ed., Hydraulic Engineering Circular no.18 (HEC-18), Publication no. FHWA-IP-90-017, Federal HighwayAdmn U.S. Deptt. of Transportation, Washington, D.C., U.S.A.

26,Richarson,E.V., Frederick, P. and Lagasse (1999) “Stream Stability and Scour at Highway Bridges”,ASCE Publication

27. U.S. Geological Survey (2002) “Observed and Predicted Pier Scour in Maine” Water-Resources Investigations Report 02-4229, Maine Department of Transportation.

28.USGS (1999) “Surface Geophysical Techniques used to detect existing and in filled scour holes near bridge piers, Water-Resources Investigations Report 95-4009

29. U.S. Department of Transportation (1999) “Portable instrumentation for real time measurement of scour at bridges” Publn. No. FHWA-RD-99-085, March (Approved by FHWA and USGS, USA)

30.Yalin, M.S. and Ferreira, D. Silva (1999) “Regime Channels in Chhesionless Alluvium” J of Hyd. Engg. Research, Special Issue on Fluvial Hydraulics, IAHR, Vol. 37, No. 6