

Time Development of Local Scour around Semi Integral Bridge Piers and Piles in Malaysia

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Abstract—Scouring around a bridge pier is a complex phenomenon. More laboratory experiments are required to understand the scour mechanism. This paper focused on time development of local scour around piers and piles in semi integral bridges. Laboratory data collected at Hydraulics Laboratory, University of Malaya was analyzed for this purpose. Tests were performed with two different uniform sediment sizes and five ranges of flow velocities. Fine and coarse sediments were tested in the flume. Results showed that scour depths for both pier and piles increased with time up to certain levels and after that they became almost constant. It had been found that scour depths increased when discharges increased. Coarser sediment also produced lesser scouring at the piers and combined piles.

Keywords—Pier, pile, scour, semi integral bridge, time.

I. INTRODUCTION

BRIDGE scour is a natural phenomenon that damages bridge structures greatly and in extreme cases it may be responsible for bridge failure. Each year, an innumerable number of bridges are damaged by the pier and abutment scour. Scour is a natural phenomenon that occurs without warning and can cause bridges collapse during flooding and heavy rain. Scour is defined as the erosion of bed materials around any structure in a flow field [1]. Flowing water can excavate and carry away materials from the river bed and from around the piers and abutments of bridges, thus resulting in scour hole (Fig. 1). Formation of scour may weaken bridge foundation and in extreme cases bridge failures occur [2]. During the last decades, a number of bridges fail due to scouring around the pier and abutments rather than structural reasons [3]-[5]. Scour is a dynamic process that varies with water depth, flow angle, pier geometry, strength, pier and abutment shape and width, material properties of the sediment and other factors [6]. Lack of proper considerations and guidelines on bridge foundation may result in scouring that potentially affect bridge structural stability and finally collapse the bridges [7]. Collapse of bridges results in costly repairs, disruption of traffic and possible death of passengers travelling on the bridge, when collapse occurs.

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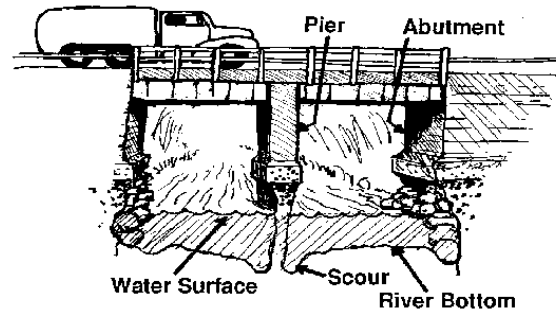


Fig. 1 Formation of bridge scour

Although the scientific basis for the structural design of bridges is well established, the piers and piles of semi-integral bridges have attained special attention as they are highly susceptible to scour because of their location. Semi-integral bridge structures have single or multiple spans where their superstructure is casted integrally on one part of substructure and discontinuous to another part of the substructure. The design requirements and procedures for piers of semi integral bridges are almost similar to traditional bridge pier design. In semi integral bridges, piers must be designed to accommodate the movements of the superstructure. In Malaysia, the use of semi integral bridge has dramatically increased for the recent years. This is because they are cheap to construct and require less maintenance compared to conventional bridges with expansion joints. Another benefit of using semi-integral bridges is that bridge piers can reduce the pile stresses in the contraction mode of the bridges.

The main purposes of the present study are:

- To investigate the effect of sediment size on scour depth at semi integral bridge piers and combined piles for low and high flows.
- To explore the time evolution on the developments of scour at semi integral bridge piers and combined piles for a range of water depths and flow velocities.

II. LITERATURE REVIEW

Many researchers have studied the scour phenomenon experimentally or theoretically around bridge piers and considered a number of parameters affecting the phenomenon [8]-[13]. There are generally three types of scours that affect the performance and safety of bridges, namely, local scour, contraction scour and degradation scour [14] (Fig. 2).

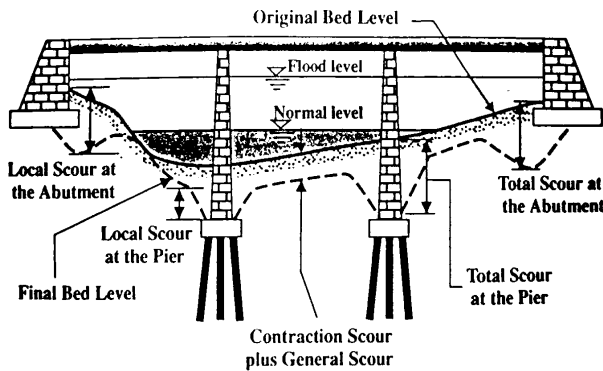


Fig. 2 The types of scour that can occur at a bridge [5]

Local scour is the removal of sediment from around bridge piers or abutments. When water is flowing through the piers or abutments, it may evacuate sediment around the pier and creates scour holes. This removal of sediment is caused mainly due to the formation of both horse vortex and down flow in front of the piers [15]. Fig. 2 [16] shows the schematic of the flow development in the vicinity of a circular pier situated in a scour hole. As can be seen from Fig. 3, wake vortices are formed as the flow, which is separated by the pier, converges at the downstream of the pier. With the increase in scour depth, the horseshoe vortex strength reduces, which automatically leads to a reduction in the sediment transport rate from the base of the pier [17]. Other types of scour are contraction scours which involve removal of sediment from the bottom and sides of the river. Degradation scour is the general removal of sediment from the river bottom by the flow of the river.

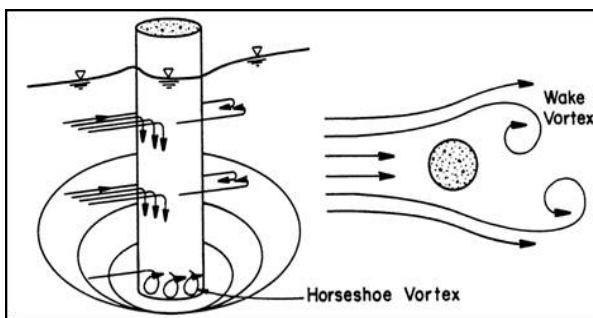


Fig. 3 Flow around a circular pier in a scour hole [16]

Local scour at piers was classified as clear water scour and live bed scour based on the mode of sediment transport by the approaching stream [18]. Factors affecting local scour development are flow intensity, flow shallowness, sediment coarseness, time and velocity distribution. The present study mainly examined the effects of time on local scouring process around piers and combined pile of semi integral bridges.

In Malaysia a number of bridges are affected by scouring problems. Scouring of river bed, either general scour or local scour around the piers causes instability of the bridges. During the last few years, scouring occurred around many of the

bridges in Kedah, Pahang, Sabah, Kelantan, Perak, Selangor areas and caused damages to the bridge structures. Huge costing had been spent for the repair and maintenance of these scour affected bridges. Chiew et al. [19] had presented the experience in facing hydraulic problems in Malaysia. Revetment of Pukin River Bridge, Keratong River Bridge and Plentong River Bridge were cited as case history. It is later learned that the Pukin River Bridge was badly scoured at both abutments during heavy flooding in December 2006. As a solution two spans were added in February 2008. Figs. 4 to 8 show some bridge damage cases in Malaysia due to flooding and scouring at pier and abutments.



Fig. 4 General scouring of river bed at Sg. Jeniang, Kedah



Fig. 5 Bridge failure due to scouring at Bokah Rasau Stungkor Road, Kuching, Sarawak [20]



Fig. 6 Bridge in Seremban, Negeri Sembilan collapsed due to heavy rain and flooding [20]



Fig. 7 Scour at Sg. Langar and Sg. Semenyih bridges



Fig. 8 Bailey bridge collapse due to heavy floods [20]

Hydraulic studies on the bridges scour have been developed to provide guidance to the engineer on evaluating scour problems at bridges. It is necessary to consider it as a part of the preliminary design of a bridge to avoid risk in the complexity of the scouring phenomenon and high degrees of uncertainties in governing parameters.

III. EFFECTS OF TIME

A number of researchers conducted experiments to explore the time evolution on the developments of scour depths [21]. The scour depth develops asymptotically towards the equilibrium depth of scour under clear water scour. On the other hand, for the live bed scour, equilibrium depth could be attained rapidly. Thus, the scour depth oscillates cause by the passage of bed features past the pier. To achieve equilibrium condition in laboratory experiments, it would take times to achieve equilibrium scour depth for clear water condition. It could be more than 1 weeks or unlimited to exhibits scour depths. In a research by Federal Highway Administration of US Transportation Department, Evaluating Scour at Bridges, 2001, it published that clear water scour takes more time to reach maximum depth compared to live bed scour (Fig. 9). Clear water scour requires several consequences flooding to attain maximum value. Maximum local clear water pier scour is about 10% greater than the equilibrium local live bed pier scour. Most of the formulas for scour action give appropriate and conservative results for equilibrium depths under live bed condition. In case of clear-water scour conditions, the equilibrium depth of scour is typically overly conservative. During the flood period piers are mostly affected by clear water scour conditions because vegetation restricts sediment movement. Again flood duration is also important in determining equilibrium scour depth.

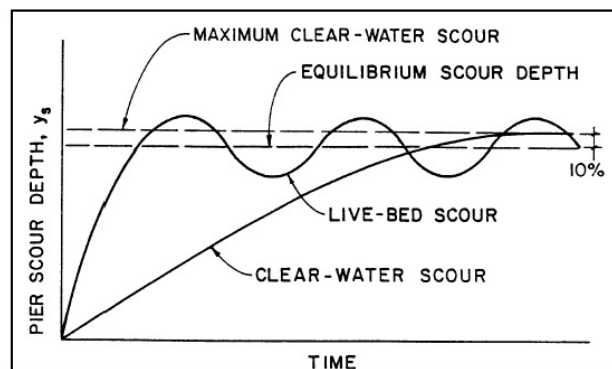


Fig. 9 Pier scour depth in a sand-bed stream as a function of time (FHWA, USDOT, Washington, D.C, 2001)

A number of laboratory experiments were performed that describe the time development of local scour at narrow circular bridge piers under clear-water conditions [22], [23]. Experiments on scour depths showed that equilibrium depth of scour and time to develop it, were subjected to similar influences of flow and sediment properties [23].

Active process of scour is a result of imbalance between supply and capacity [8]. The development of the scour hole must consider the general transport condition. After achieving the maximum value the rate of scour starts decreasing gradually. If the rate of scour approached zero, it does not mean that the transport out of the scour hole is equal to zero. It indicates that the transport out of scour hole was almost replenished by the incoming sediment. Complete equilibrium

between transport and scour depth fluctuate from their temporal mean values. Fig. 10 shows the excess of depth scour that often occurred before attained the equilibrium conditions [8]. A number of experiments on skewed integral bridges were performed to observe the effects of flow velocities on scour depths [24], [25].

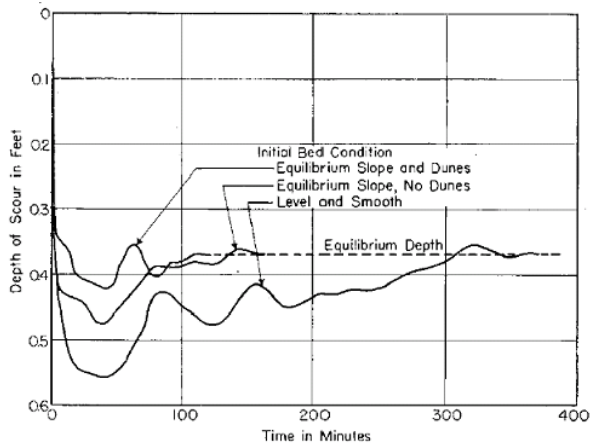


Fig. 10 Excess depth of scour [8]

Reference [26] presented laboratory data on the time-dependent local scour at circular bridge pier under clear water flows in uniform beds. The data in Fig. 11 shows the temporal variation of scour depths. The scour hole had a shape of a truncated cone. All computations for the graph follow as suggested by Kothyari et al. [27].

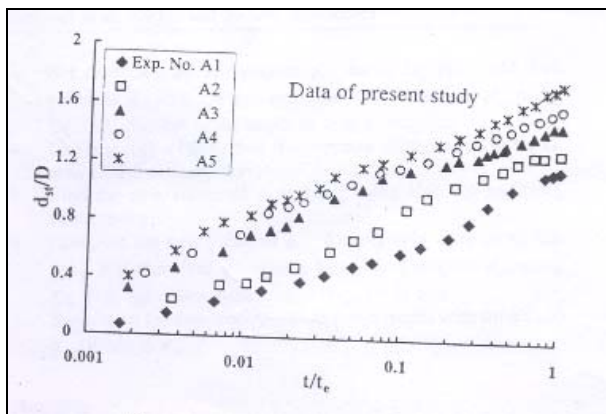


Fig. 11 Pier scour data of the present study [27]

IV. EXPERIMENTAL WORK

In order to identify the effects of time on local scouring, some experimental works had been done. The test flume was 16m long, 0.60m wide and 0.57m deep with a fixed slope and located at Hydraulic Laboratory in Department of Civil Engineering, University of Malaya. The sediment used is the coarse sand that filled up the main channel. The characteristic of bed sediment was considered to be uniform. The bridge model was made up of Perspex material. The bridge deck, end

diagram and bridge abutments were connected by strong adhesive material to imitate the integral connection between bridge deck and abutments. The vertical scale was fixed at the piers and piles to take reading of scour depth easily. A control block with a height of 8cm was placed inside the test flume that was filled with levelled bed sediment. The bridge model was then put inside the control block.

Scour depths were measured as a function of discharge and sediment size for semi-integral bridge piers and combined piles. Flow velocity for each run was measured from several points. Scour depths were measured both at the beginning of each run and then achieving maximum value. The scour depths at the bridge piers were recorded for every 1 minute interval until 10 minutes. After that readings were taken for 10 minutes interval until 100 minutes and then for 100 minutes interval until 600 minutes. The last reading was taken after 24 hours from the experiment starting time. Both experiments involved similar time interval for scour reading until final reading at 24 hours. The procedure was repeated with five discharges, and three types of sediment sizes for both pier and combined pile. Fig. 12 shows the maximum scour depths at piers and combined piles after 24 hours.



Fig. 12 Maximum scour depths at piers and combined piles after 24 hour

V. RESULTS AND ANALYSIS

The present investigation focused on the time development of scour for semi-integral piers and combined piles. Results have been collected for each type of uniform sediments for semi-integral piers and combined piles by applying five flow rates. The temporal scour evolution technique was used to measure the scour rate at the piers and pile groups. This paper presents time development of scour depth on individual pier and piles for two different sediment sizes with flow rate of $0.0106\text{m}^3/\text{s}$ and $0.0172\text{m}^3/\text{s}$. Three different piers (A, B, C) and four types of piles (identified as 1, 2, 3, 4) were considered where scour depths were observed with two different sediment sizes. The graphs of relative scour against time are presented below.

Fig. 13 represents the time development of scour depths for pier A, B and C with two different sediment sizes. At Sediment size 0.26mm, up to 200 minutes scour depths were similar for three of the pier. After that scour depths for pier A increased to its peak value and then started decreasing. From 400 minutes, scour depths around pier A became constant up to the end of the experiment. For Pier B scour depths remained constant up to 600 minutes and after that it started increasing until the end of the experiment. For the case of pier C, scour depths remained constant until 150 minutes and after that it decreased until 200 minutes. After 200 minutes, it again started to increase up to 600 minutes. Then it became almost constant for the rest of the experiment period. With sediment size 0.8mm, scour depths around pier A, B and C firstly remained constant up to 170 minute and then they increased to their peak value from where then they started decreasing. From 600 minutes, scour depths around three of these piers remained constant during the whole test.

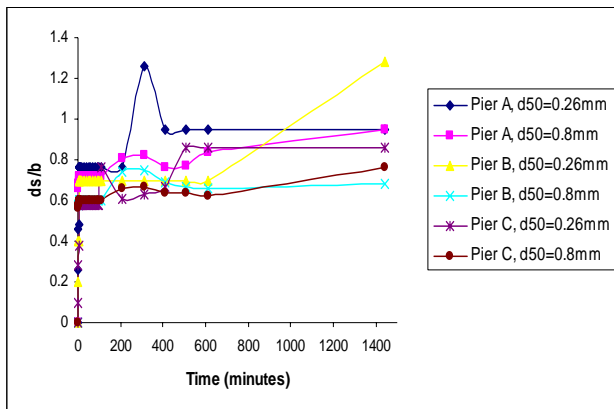


Fig. 13 Development of scour depth with respect to time at semi integral piers Run No. 1 for sediment size $d_{50} = 0.26[\text{mm}]$ and $d_{50} = 0.8[\text{mm}]$ for $Q = 0.0106 [\text{m}^3/\text{s}]$

Similarly, observation could be made on scour depths around piles (Fig. 14). With sediment size 0.26mm scour depths for all the pile increase up to 400 minutes and after that they remained constant until the end of the test. For sediment size 0.8mm, scour depths increased up to a certain level and then they remained constant around all the pile until the end of the experiment. From the graph, it can be concluded that coarser sediment produced lesser scour depths around combined piles. Another finding of this experiment was that with increasing discharge scour depth also increased.

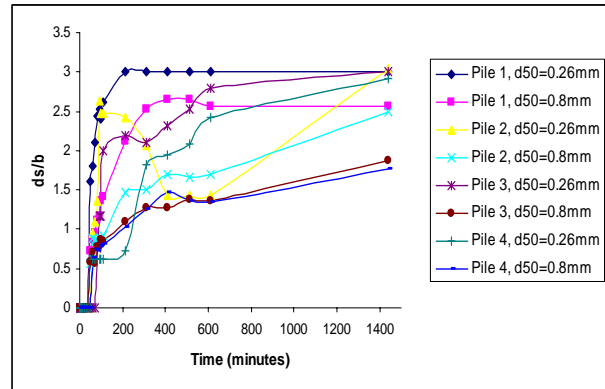


Fig. 14 Development of scour depth with respect to time at combined piles Run No. 5 for sediment size $d_{50} = 0.26[\text{mm}]$ and $d_{50} = 0.8[\text{mm}]$ for $Q = 0.0172 [\text{m}^3/\text{s}]$

VI. CONCLUSIONS

Scour is a complex phenomenon through which damages can occur in structures. Bridge structures are the most vulnerable components of scouring effects. This study focused on time development of local scouring at semi-integral piers and combined piles in uniform sand beds. The results of laboratory experiments of the scour on semi-integral bridges were analyzed. This paper presents the local scour by implementing temporal scour evolution method. The local scour tests were performed with two different uniform sediment diameters (0.26mm and 0.8mm) and five ranges of flow velocities. Results showed that scour depths for both pier and piles increase with time up to certain levels and after that they became almost constant. It had been found that scour depths increased when discharges increased. Coarser sediment also produced lesser scouring at the piers and combined piles.

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REFERENCES

- [1] H.H. Chang, "Fluvial processes in river engineering" John Wiley & Sons, pp. 432, (1988)
- [2] A. J. Raudkivi, R. Ettema, "Clear Water Scour at Cylindrical Piers, Journal of Hydraulics Engineering," ASCE, 109(3), pp 338-350 (1983)
- [3] P. F. Lagasse, P. L. Thompson, and S. A. Sabol, "Guarding against scour", Civil Engineering, June, 1995
- [4] P. A. Johnson and D. A. Dock, "Probabilistic bridge scour estimates. Journal of Hydraulic Engineering," Vol. 124, No. 7, pp. 750-754, (1996)
- [5] B. W. Melville and S. E. Coleman, "Bridge, Water Resources" Publications LLC, Littleton, Colorado, (2000)
- [6] P.E. Clopper, P.F. Lagasse and, L.W. Zevenbergen, "Bridge Pier Scour Countermeasures," Proceedings of the 2007 World Environmental and Water Resources Congress, May 15-19, 2007, Tampa, Florida
- [7] A. Masjedi, M.S. Bejestan and A. Esfandi, "Reduction of Local Scour at a Bridge Pier using Collar in a 180 Degree Flume Bend," Journal of Applied Sciences, 10: 124-13, (2010).
- [8] E.M. Laursen, A. Toch, "Scour Around Bridge Piers and Abutments," Bulletin No. 4, Iowa Highways Research Board, Ames, Iowa, U.S.A, (1956)
- [9] E.M. Laursen, "Analysis of Relief Bridge Scour," Journal of the

- Hydraulics Division, ASCE, 89(3) 93-118, (1963)
- [10] H.W. Shen, V.R. Schneider, S.S. Karaki, Local Scour around Bridge Piers, Journal of the Hydraulics Division, ASCE, 95(6), 1919-1940., (1969)
 - [11] H.N.C. Breusers, G. Nicollet, H.W. Shen, Local Scour around Cylindrical Piers. Journal of Hydraulic Research, IAHR, 15(3), 211-252 (1977)
 - [12] A.J. Raudkivi, Functional Trends of Scour at Bridge Piers, Journal of Hydraulics Engineering, ASCE, 112(1), 1-13 (1986)
 - [13] H.N.C. Breusers, A.J. Raudkivi, Scouring Hydraulic Structures Design Manual, No. 2, IAHR, Balkema, Rotterdam, 109-116, (1991)
 - [14] G. W. Parker, L. Bratton, and, D. S. Armstrong , "Stream stability and scour assessments at bridges in Massachusetts." *U.S. Geological Survey Open File Report No. 97-588* (CD-ROM), Massachusetts Highway Dept. Bridge Section, Marlborough, Mass., 53 (1997).
 - [15] A.T. Moncada - M, J. A.-P. "Scour Protection Of Circular Bridge Piers with Collars and Slots." *Journal of Hydraulic Research* , 119-126 (2009).
 - [16] E. V. Richardson, and, S. R. Davis "Evaluating scour at bridges 3rd ed." *Federal Highway Administration Hydraulic Engineering Circular No. 18: FHWA-IP-90-017*, U.S. Department of Transportation, Washington, D.C., 203. (2001).
 - [17] P.F. Lagasse and, E.V. "ASCE compendium of stream stability and bridge scour papers." Journal of Hydraulic Engineering, ASCE, 127(7): 531-533. Richardson (2001).
 - [18] J Chabert. and, P. Engeldinger, "Etude des affouillements autour des piles de points (Study of scour at bridge piers)." Bureau Central d'Etudes les Equipment d'Outre-Mer, Laboratoire National d'Hydraulique, France, (1956)
 - [19] Chiew Yee-Meng, Ng See King and Lim Siow-Yong, "Hydraulic Problem in Malaysia." Presentation in an International Symposium organized by the International Society of Soil Mechanics and Geotechnical Engineering Technical Committee TC- 33 on Scour of Foundations, Melbourne, Australia, 19 November 2000.
 - [20] D. A. M. Kueh, "Effects Of Scour On Semi-Integral Bridge In Main Channel" Bachelor Thesis, University of Malaya (2006)
 - [21] C.S. Lauchlan, S.E. Coleman, B.W. Melville, Temporal Scour Development at Bridge Abutments, 29th Congress of the international Association for Hydraulic Research, Beijing Proceedings (2002)
 - [22] Y.M. Chiew and, B.W. Melville, " Temporal development of local scour depth at bridge piers" North American Water and Environment Congress, A.S.C.E., Anaheim, California, U.S.A., June, 1996.
 - [23] B.W. Melville and, Y.M. Chiew, " Time scale for local scour at bridge piers," Journal of Hydraulic Engineering, A.S.C.E., Vol.125(1), pp.59-65, 1999.
 - [24] S. Akib, , M. M. Fayyadh and I Othman, "Structural Behavior of a Skewed Integral Bridge Affected by Different Parameters," *The Baltic Journal of Road and Bridge Engineering*, 6 (2), 107-114. (2011) DOI: 10.3846/bjrbe.2011.15,
 - [25] M.M. Fayyadh, S. Akib, I. Othman, H.A. Razak, "Experimental investigation and finite element modeling of the effects of flow velocities on a skewed integral bridge," *Simulation Modeling Practice and Theory*, 19, 1975-1810. (2011)
 - [26] M. Mia, and H. Nago", Design Method of Time-Dependent Local Scour at Circular Bridge Pier." *J. Hydraul. Eng.*, 129(6), 420-427., (2003).
 - [27] U.C. Kothiyari, R.J. Garde, K.G.R. Raju, "Temporal variation of scour around circular bridge piers." *J. Hyd. Eng.*, ASCE, 118(8), 1091-1106, (1992).