Oct 27th, 12:00 AM

Effect of Diameter and Inlet-Depth on Hydro-Suction Performance of a Suction Pipe

A. Jaiswal
IIT Roorkee, ajaiswal@wr.iitr.ac.in

Z. Ahmad
IIT Roorkee

S. K. Mishra
IIT Roorkee

Recommended Citation

Jaiswal A., Ahmad, Z., and Mishra, S.K. (2022). "Effect of Diameter and Inlet-Depth on Hydro-Suction Performance of a Suction Pipe" in "9th IAHR International Symposium on Hydraulic Structures (9th ISHS)". *Proceedings of the 9th IAHR International Symposium on Hydraulic Structures – 9th ISHS*, 24-27 October 2022, IIT Roorkee, Roorkee, India. Palermo, Ahmad, Crookston, and Erpicum Editors. Utah State University, Logan, Utah, USA, 8 pages (DOI: 10.26077/aa4f-76f0) (ISBN 978-1-958416-07-5).

ISBN: 978-1-958416-07-5 DOI: https://doi.org/10.26077/aa4f-76f0

Effect of Diameter and Inlet-depth on Hydro-suction performance of a Suction pipe

A. Jaiswal[1], Z. Ahmad[1] & S.K. Mishra[1]
[1]*IIT Roorkee, Roorkee, India*
E-mail: ajaiswal@wr.iitr.ac.in

Abstract: *Sedimentation in rivers and reservoirs leads to inundation of surrounding areas, topsoil degradation, low depth for navigation, loss of reservoir capacity, etc. Hydro-suction is a process of sediment removal in which sediment is sucked along with water using a suction pipe placed vertically on/above/below the sediment bed. This paper deals with the effect of diameter and inlet-depth of suction pipe on performance of hydro-suction. A series of experiments are performed using five suction pipes of diameter of* 5.08×10^{-2} *m,* 7.62×10^{-2} *m,* 10.16×10^{-2} *m,* 12.70×10^{-2} *m, and* 15.24×10^{-2} *m, placed at inlet depth of 0.015 m and 0.03 m, under discharge ranging from* 0.5×10^{-3} m^3/s *to* 3×10^{-3} m^3/s *and median sediment size of 0.33 mm. Hydro-suction performance is evaluated by the sediment volume removed, which is calculated from the experimental data of scour profile. The investigation inferred that for a constant diameter, hydro-suction performance decreases with an increase in suction inlet depth. An increase in hydro-suction performance is seen up to suction pipe diameter of* 10.16×10^{-2} *m, and any further increase in suction pipe diameter decreases the hydro-suction performance.*

Keywords: *Hydro-suction, Suction pipe diameter, Suction inlet-depth, Scour profile, Scour volume.*

1. Introduction

Deposition of sediment over time decreases the reservoir capacity, thus creating an acute problem for its functioning. Sedimentation induces several adverse impacts within reservoirs and upstream and downstream areas of river systems with dams (CWC Handbook, 2019). May it be a passage of ships through a port, water storage capacity of dams, electricity production, or flow in a river. It ultimately leads to a loss in the economy and the purpose of the built structure. The removal of deposited bed materials is still a frantic problem. Removing bed material using manual dredging machines is worthwhile only after emptying the water bodies. Instead, hydro-suction removal can be a more effective and economical solution.

A suction pipe is a dredging tool used to deepen the ports and harbors, reclamation of dams and reservoirs, and sediment removal from a riverbed. In hydro-suction, a pipe is placed vertically above/below/on deposited material, and through suction, the bed material is removed. In hydro-suction, fluid flow is arranged in a pattern that covers the shortest path with minimal total energy loss (Mousa et al., 2020). Flow patterns near the suction inlet and its periphery play a vital role in sediment removal efficiency. The flow field, created by velocity variation near the suction inlet, produces a lift force that creates the bed material in resuspension, which is then removed by suction (Brahme et al., 1986). The experimental studies have been reported by Brahme et al. (1896), Hotchkiss et al. (1995), Ullah et al. (2005), Su-Chin et al. (2010), Shrestha (2012), Zhou et al. (2013), Sadatomi (2015), Wun-Tao Ke et al. (2016), Asiaban et al. (2017), Pishgar et al. (2018), and Pu Yang et al. (2020) on scour pattern formed during hydro-suction removal of sediment.

This study investigates the effect of the diameter and inlet depth of the suction pipe on its hydro-suction performance. A suction pipe of five different diameters was placed vertically above the sediment bed at different suction inlet depth. A series of experiments were performed under a discharge range of 0.5×10^{-3} m^3/s to 3×10^{-3} m^3/s, and the scour profile for each run was noted. The hydro-suction performance of the suction pipe was evaluated by the sediment volume removed during hydro-suction. Sediment volume removed was calculated by considering maximum scour depth and scour radius.

A definition sketch of a hydro-suction is shown in Fig. 1, where V_i is inlet velocity, D is suction pipe diameter, C is suction inlet depth (the distance between the suction inlet and sediment bed level), d_{50} is sediment median size, R_s is scour radius, D_s is scour diameter ($2R_s$), d_s is scour depth just below the suction pipe, R_{sm} is scour radius at maximum scour depth (d_{sm}), and d_r is scour depth at any scour radius R_r.

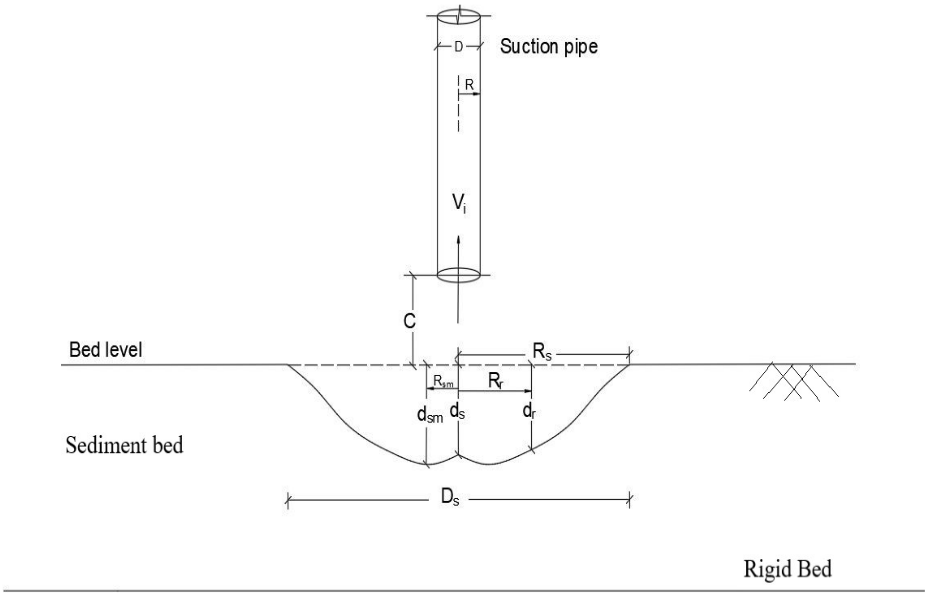


Figure 1. Definition sketch of hydro-suction.

2. Experimental Setup and Methodology

The experiments were performed in the Hydraulic engineering laboratory of the Department of Civil Engineering, IIT Roorkee. A tank of 2.25 m length, 1.25 m depth, and 1.25 m width was used for the experiment. The tank was divided into two parts by a perforated baffle wall. The test portion was 1.25 m long, 1.25 m wide and 1.15 m depth and filled with sediment in a thickness of 0.45 m. The experimental set up was re-circulating as shown in the Figs. 2a and 2b. Water was supplied to the second portion of the tank and the same was re-circulated. Depth of water above the sediment bed was kept 0.55 m for all the experimental runs. The suction pipe was placed vertically above the center of the test portion of the tank. Water was sucked using a centrifugal pump connected to the suction pipe at one end and recirculated the water in the same tank through a pipe connected to the other end.

The discharge was measured using an orifice meter fitted in the suction pipe. An ultrasonic flow meter (UFM) was used to calibrate the orifice meter.

In this study, suction pipes of diameter (D) of 5.08×10^{-2} m, 7.62×10^{-2} m, 10.16×10^{-2} m, 12.70×10^{-2} m, and 15.24×10^{-2} m, placed vertically above the sediment bed at two inlet depths (C) of 0.015 m, and 0.03 m were used for investigation. Sediment has a median diameter, d_{50} of 0.33 mm. As per Raudkivi (1988), the grain size distribution of sediment is considered uniform if, $d_{95}/d_5 < 4$ and $s_g= d_{84.1}/d_{15.9} < 1.35$. In this study, the geometric standard deviation of bed material used was 1.33, thus representing uniform gradation.

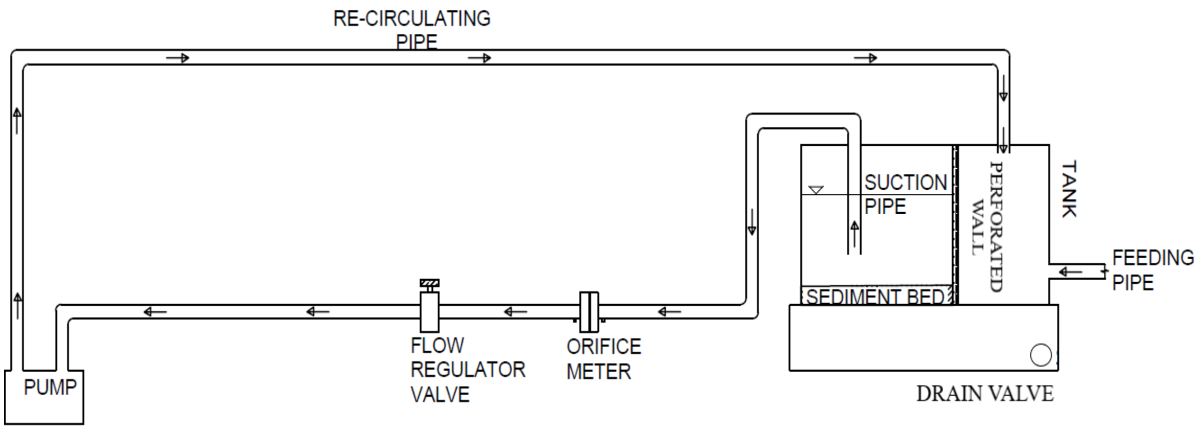


Figure 2 (a). Sketch of a side view of the experimental setup.

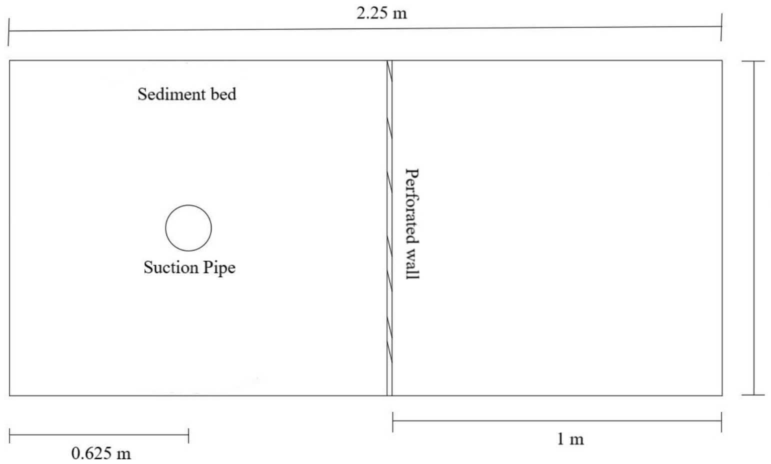


Figure 2 (b). Sketch of a top view of the experimental setup.

A series of experiments were performed for a discharge range of 0.5×10^{-3} m^3/s to 3×10^{-3} m^3/s, and the scour profile for each run was measured. Scour depth was measured throughout the scour diameter at spacing of 0.01 m to get the scour profile. Fig. 3 below shows the matrix of the total observations taken during this study.

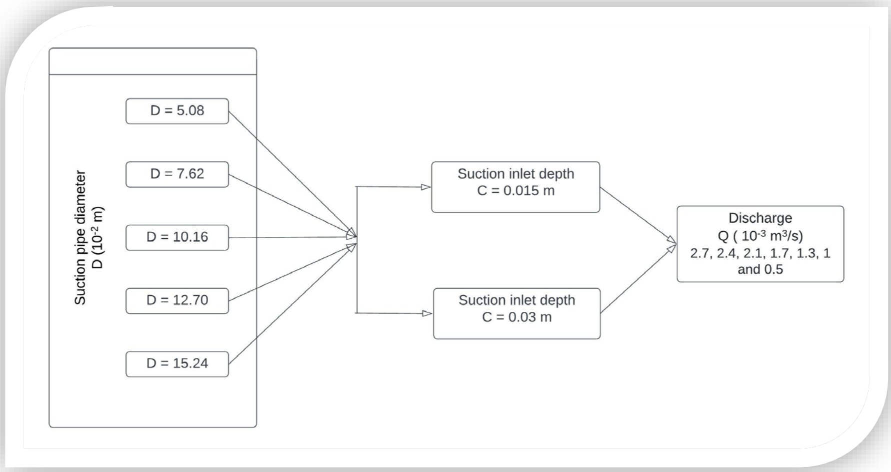


Figure 3. Matrix for total observation taken during experimentation.

A total of 70 observations were taken during the investigation. Tables 1 and 2 provide the experimental values of maximum scour depth and scour radius for different D and Q, at C = 0.015 m and 0.030 m, respectively.

Table 1. Collected experimental data for maximum scour depth and scour radius for C = 0.015 m.

D (10^{-2} m) → / Q ↓	5.08		7.62		10.16		12.7		15.24	
Q (10^{-3} m^3/s)	d_{sm} (10^{-2} m)	R_r (10^{-2} m)	d_{sm} (10^{-2} m)	R_r (10^{-2} m)	d_{sm} (10^{-2} m)	R_r (10^{-2} m)	d_{sm} (10^{-2} m)	R_r (10^{-2} m)	d_{sm} (10^{-2} m)	R_r (10^{-2} m)
2.7	-6.9	12	-8.5	18	-11.5	20	-5	14	-4.5	14
2.4	-6	12	-8	14	9.5	18	-4.1	12	-2	12
2.1	-5.1	10	-6.9	12	-8.4	18	-2.5	12	0	0
1.7	-4.3	10	-5.9	12	-7.6	15	0	0	0	0
1.3	-3.8	10	-4.5	9	-6	12	0	0	0	0
1	-3.2	9	-3.3	9	-5.1	10	0	0	0	0
0.5	-2.4	8	-2.9	8	-4.2	10	0	0	0	0

Table 2. Collected experimental data for maximum scour depth and scour radius for C = 0.03 m.

D (10^{-2} m) → / Q ↓ (10^{-3} m^3/s)	5.08		7.62		10.16		12.7		15.24	
	d_{sm} (10^{-2} m)	R_r (10^{-2} m)	d_{sm} (10^{-2} m)	R_r (10^{-2} m)	d_{sm} (10^{-2} m)	R_r (10^{-2} m)	d_{sm} (10^{-2} m)	R_r (10^{-2} m)	d_{sm} (10^{-2} m)	R_r (10^{-2} m)
2.7	-5.5	10	-6.9	16	-11	20	-4	14	-3.3	11
2.4	-4.6	9	-6	12	-9	18	-2.6	12	0	0
2.1	-4.3	9	-5.5	10	-7.8	16	-1.9	12	0	0
1.7	-4	9	-5	10	-5.6	14	0	0	0	0
1.3	-3.5	9	-3.9	10	-4.6	12	0	0	0	0
1	-2.9	8	-2.6	9	-3.6	10	0	0	0	0
0.5	-2.1	8	-2.3	8	-3.3	10	0	0	0	0

3. Results and Discussion

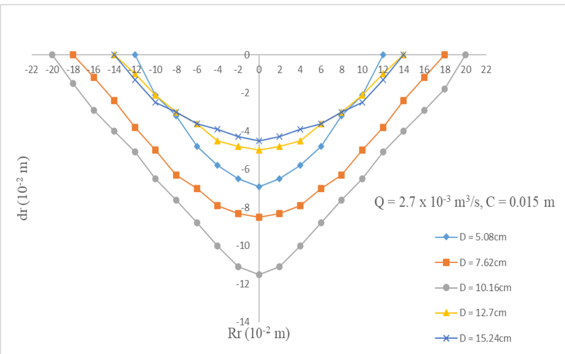
Effect of diameter and inlet depth of suction pipe on the scour profile and scour volume during hydro-suction were analysed and discussed below.

3.1. Scour Profile

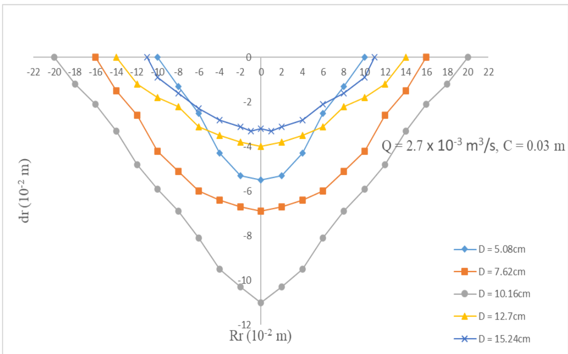
Scour profile is resembled by scour depths taken at 1cm intervals along the scour diameter during experimentation. Since the scour hole is symmetric, a 2D plot of scour profile at any section along its diameter will be sufficient to understand its variation for different suction pipes. Scour depth values at 1cm intervals are taken throughout the scour diameter, and these scour depths are plotted along with the scour diameter to get the scour profile.

3.1.1. Effect of diameter of suction pipe on scour profile

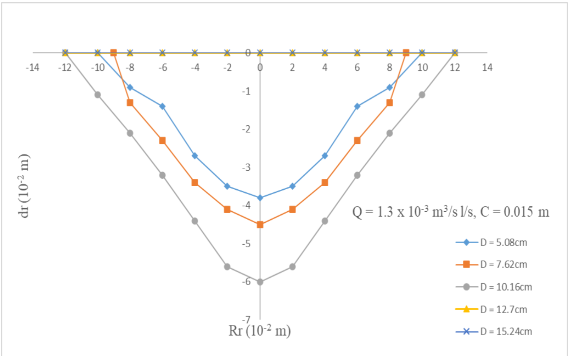
Scour profile graphs are plotted for all the five suction pipes taking constant values of Q and C. Scour profile approximately resembles a semi-circle, having a hump at the midsection in cases having the lowest discharge. Fig. 4 a, b, c, d, e, and f show the scour profile variation with suction pipes diameter at varying discharges and inlet depths. Fig. 4 a, c, and e are plots of scour profiles varying with suction pipe diameters, placed at a suction inlet depth of 0.015 m for discharges Q = 2.7×10^{-3} m^3/s, 1.3×10^{-3} m^3/s, and 0.3×10^{-3} m^3/s, respectively. And Fig. 4 b, d, and f are plots of scour profiles varying with suction pipe diameters, placed at a suction inlet depth of 0.03 m for discharges Q = 2.7×10^{-3} m^3/s, 1.3×10^{-3} m^3/s, and 0.3×10^{-3} m^3/s, respectively. These plots show the change in scour depth along the scour diameter and its variation for different suction pipe diameters. From Fig. 4 a, it is observed that scour depth is maximum at the center of the scour hole, and it decreases along the scour radius while going away from the center. The scour depth is maximum for D = 10.16×10^{-2} m, followed by D = 7.62×10^{-2} m, 5.08×10^{-2} m, and 12.7×10^{-2} m, and it is minimum for D = 15.24×10^{-2} m. A small hump at the mid of scour profile is seen for the discharge = 0.5×10^{-3} m^3/s. Similar observations of scour profile are seen in all the figures in Fig. 4. Fig. 4 c, d, e, and f, show no scour for suction pipe diameters of 12.7×10^{-2} m and 15.24×10^{-2} m.



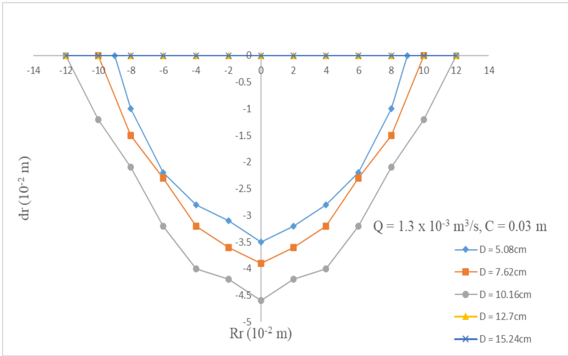
(a)



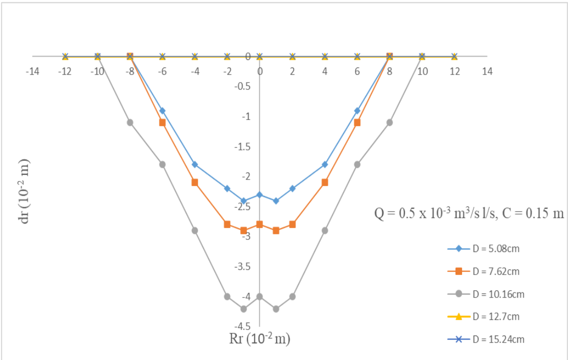
(b)



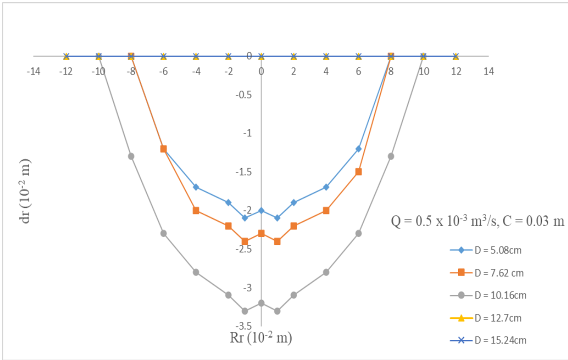
(c)



(d)



(e)



(f)

Figure 4. Scour profile at C = 1.5cm, (a) Q = 2.7×10^{-3} m^3/s, (c) Q = 1.3×10^{-3} m^3/s, and (e) Q = 0.5×10^{-3} m^3/s, and at C = 3 cm, (b) Q = 2.7×10^{-3} m^3/s, (d) Q = 1.3×10^{-3} m^3/s, and (f) Q = 0.5×10^{-3} m^3/s.

It can be inferred from the above figures that maximum scour depth increases with suction pipe diameter up to D = 10.16 $\times10^{-2}$ m, and any further increase in pipe diameter decreases the maximum scour depth. It is also seen that scour depth decreases with discharge for a constant diameter and suction inlet depth.

3.1.2. Effect of suction inlet depth on scour profile

The effect of suction inlet depth on scour profile is observed by comparing Fig. 4 a and b, c and d, e and f of Fig. 4. A decrease in scour depth throughout the scour diameter is seen in Fig. 4 a and b, as suction inlet depth increases from 0.015 m to 0.03 m. Maximum scour depth, d_{sm} is decreased from 0.069 m to 0.055 m when suction inlet depth increases from 0.015 m to 0.030 m at a discharge of 2.7×10^{-3} m^3/s as shown in Fig. 4a and 4b. Similarly, for the discharge of 1.5×10^{-3} m^3/s, d_{sm} is decreased from 0.038 m to 0.035 m when suction inlet depth increases from 0.015 m to 0.030 m as shown in Fig 4 c and 4 d. The same observations are by comparing Fig. 4e and 4f.

Comparing the plots in Fig. 4, it can be inferred that maximum scour depth decreases with an increase in suction inlet depth at constant D and Q.

3.2. Scour volume

Maximum the scour volume is indicator of high hydro-suction efficiency. Graphs of the scour volume with other parameters are plotted and analysed below:

3.2.1. Effect of diameter of suction pipe on scour volume

Variation of scour volume with discharge and suction pipe diameter at C = 1.5 cm is shown in Fig. 5. At a discharge of 2.7×10^{-3} m^3/s and C = 0.015 m, scour volume is maximum for D = 10.16×10^{-2} m, followed by D = 7.62×10^{-2} m, 5.08×10^{-2} m,12.7×10^{-2} m, and 15.24×10^{-2} m, with scour volume of $\forall$ (10^{-6} m^3) = 9630, 2080, 5765, 2051 and 1846, respectively. A similar variation in scour volume with suction pipe diameter is observed for other discharges also.

It can be concluded that at a constant value of Q and C, scour volume increases with suction pipe diameter up to D = 10.16×10^{-2} m, after which it decreases with any further increase in D.

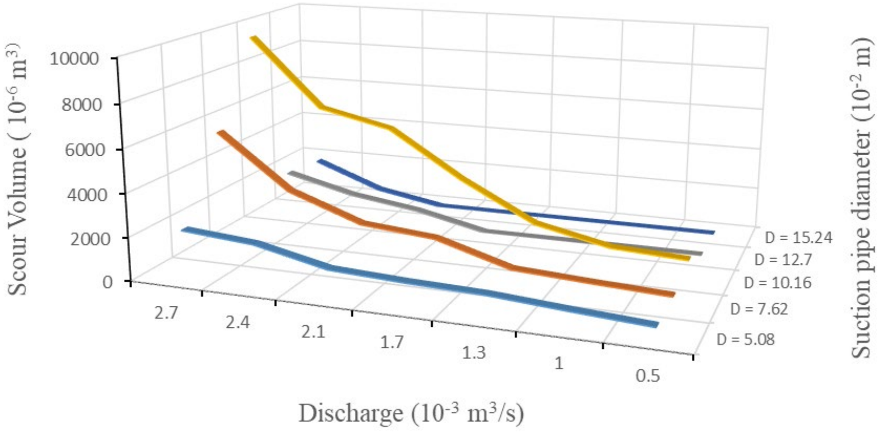
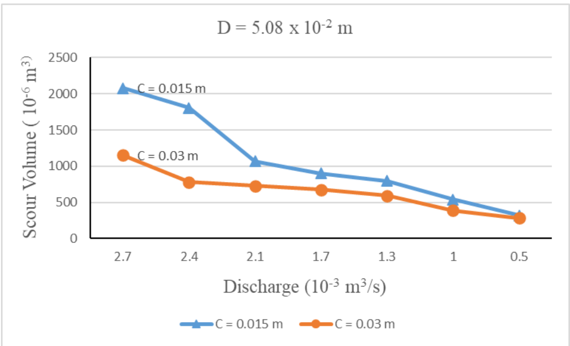


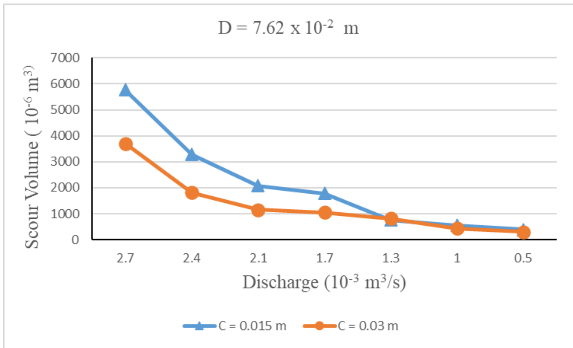
Figure 5. Effect of suction pipe diameter on scour volume.

3.2.2. Effect of suction inlet depth on scour volume

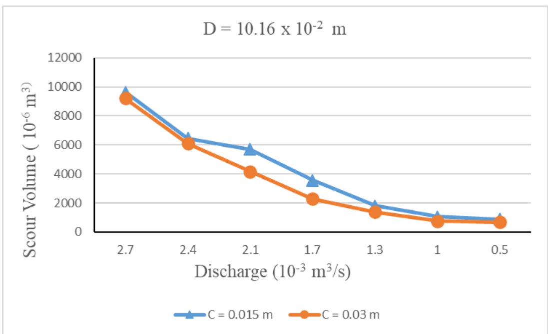
The effect of suction inlet depth on scour volume is analyzed herein. Figs. 6 a, b, c, d, and e show variation in scour volume with suction inlet depth at a constant suction pipe diameter, $D = 5.08\times10^{-2}$ m, 7.62×10^{-2} m, 10.16×10^{-2} m, 12.7×10^{-2} m, and 15.24×10^{-2} m. Fig 6 a shows that scour volume decreases from 2080×10^{-6} m^3 at C = 0.015 m to 1151×10^{-6} m^3 at C = 0.03 m for $D = 5.08\times10^{-2}$ m and $Q = 2.7\times10^{-3}$ m^3/s. A similar trend of the decrease in scour volume with an increase in suction inlet depth is seen in other plots of Fig. 6.



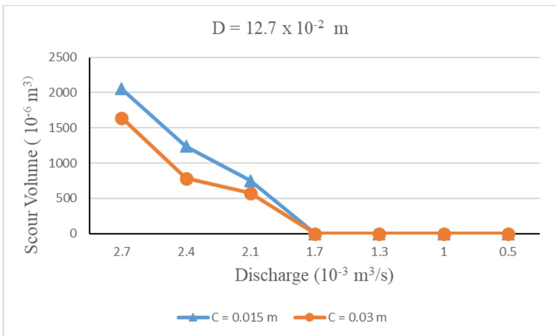
(a)



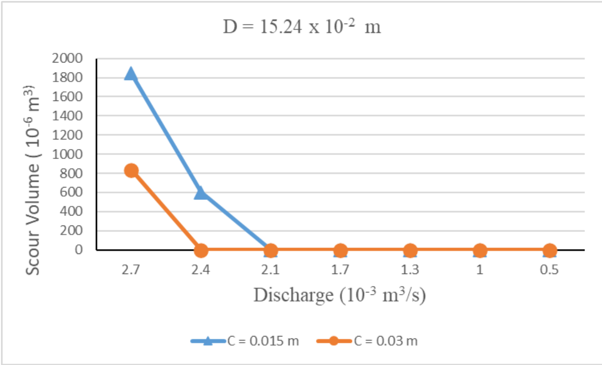
(b)



(c)



(d)



(e)

Figure 6. Effect of suction inlet depth on scour volume at a constant suction pipe diameter, a) D = 7.62×10^{-2} m, b) D =5.08×10^{-2} m, c) D = 10.16×10^{-2} m, d) D =12.7×10^{-2} m, and e) D = 15.24×10^{-2} m.

4. Conclusions

This study concludes that both scour profile and scour volume are a function of suction pipe diameter and suction inlet depth. The following conclusions are made on the effect of diameter and inlet depth on the hydro-suction performance of a suction pipe

a. For a given discharge and suction inlet depth, with an increase in suction pipe diameter up to D = 0.1016 m, hydro-suction performance increases, and any further increase in D leads to low hydro-suction performance.
b. For a given discharge and diameter of pipe, hydro-suction performance decreases with an increase in suction inlet depth.

This investigation is limited to cohesionless sediments, and also the suction inlet depth should not be less than zero. The hydro suction method can be positively used to remove sediment from the river for ship passage, storage reclamation, allowing the stream to flow through some hydraulic structure, unclogging of irrigational inlets, etc. The Hydro-suction method can be effectively used for sediment removal without stopping the functioning of the structures connected, such as inlets to electrical power plants and irrigational channels.

5. References

Asiaban, P., Kouchakzadeh, S. and Asiaban, S., (2017). "Enhanced Hydro-suction Performance for Cohesive Sediment Removal in Low-head Reservoirs." *Ain Shams Engineering Journal*, 8(4), 491-497.

Patra, B., Gir, S., Narayan, P. (2019), "Reservoir Sedimentation in Indian Dams: Trends and challenges." *International Dam Safety Conference*., Bhubaneswar, India, Sr. 6.

Brahme, S.B. and Herbich, J.B.(1986). "Hydraulic Model Studies for Suction Cutterheads." *Journal of waterway, port, coastal, and ocean engineering*, 112(5), 591-606.

Dey, S., Ali, S.Z. and Padhi, E., (2020). "Hydrodynamic Lift on Sediment Particles at Entrainment: Present status and its prospect." *Journal of Hydraulic Engineering*, 146(6), 03120001.

Elgamal, M. and Fouli, H., (2020). "Sediment Removal From Dam Reservoirs Using Syphon Suction Action." *Arabian Journal of Geosciences*, 13(18), 1-10.

Handbook for Assessing and Managing Reservoir Sedimentation. February (2019). CWC. Ministry of Water Resources River Development & Ganga Rejuvenation, Government of India. Doc. No. CDSO_GUD_DS_04_v1.0.

Hotchkiss, Rollin H., and Xi Huang (1995). "Hydrosuction Sediment-removal Systems (HSRS): principles and field test." *Journal of Hydraulic Engineering,* 121(6), 479-489.

Ke, W.T., Chen, Y.W., Hsu, H.C., Toigo, K., Weng, W.C. and Capart, H., (2016). "Influence of Sediment Consolidation on Hydrosuction Performance.", *Journal of Hydraulic Engineering*, 142(10), 04016037.

Tajima, N., (2010). "Dredging of Sediment in Dam Utilizing Siphonage with Sliding Outer Tube. *Japanese Journal of Multiphase Flow*, 24(1), 70-76.

Obialor, C.A., Okeke, O.C., Onunkwo, A.A., Fagorite, V.I. and Ehujuo, N.N., (2019), "Reservoir Sedimentation: Causes, Effects, And Mitigation.", *International Journal of Advanced Academic Research, 5(10), 92-109.*

Pishgar, R., Ayyoubzadeh, S.A., Ghodsian, M. and Saneie, M., (2018). "The Influence of Burrowing-Type Suction Pipe Geometrical and Mechanical Specifications an the Hydro-Suction Method Performance". *ISH Journal of Hydraulic Engineering*, 27(6),1-10.

Raudkivi, A.J., (1988). "The Roughness Height Under Waves." *Journal of Hydraulic Research*, *26*(5), 569-584.

Rehbinder, G., (1994). "Sediment Removal with a Siphon at Critical Flux." *Journal of Hydraulic Research*, 32(6), 845-860.

Rehbinder, G., (1976). "Some aspects on the mechanism of erosion of rock with a high speed water jet." *Proc. of the 3rd International Symp. on Jet Cutting Technique,* Chicago, E1 1-20.

Sadatomi, M., Nagano, T. and Kawahara, A., (2015). "Siphonic Removal of Sediments in Water Reservoirs--Additional Experiment for Model Revision." *International Journal of Environmental Science and Development*, 6(6), 409.

Shrestha, H.S., (2012). "Application of Hydrosuction Sediment Removal System (HSRS) on Peaking Ponds."*Hydro Nepal: Journal of Water, Energy and Environment*, 11, 43-48.

Su-Chin, C.H.E.N., Shun-Chang, W.A.N.G. and Chun-Hung, W.U., (2010). "Sediment removal efficiency of siphon dredging with wedge-type suction head and float tank." *International Journal of Sediment Research*, 25(2), 149-160.

Ullah, S.M., Mazurek, K.A., Rajaratnam, N. and Reitsma, S., (2005). "Siphon removal of cohesionless materials."*Journal of waterway, port, coastal, and ocean engineering*, 131(3), 115-122.

Yang, P., Wang, G. and Zhong, L., (2020). "Suction Removal of Cohesionless Sediment." *Energies*, 13(20), 5436.

Zhou, Y., Zhang, Y., Tang, P., Chen, Y. and Zhu, D.Z., (2013). "Experimental study of the performance of a siphon sediment cleansing set in a CSO chamber." *Water science and technology*, 68(1), 184-191.