Available *online* at: http://journal.unj.ac.id

Jurnal Pensil Pendidikan Teknik Sipil

Journal homepage: http://journal.unj.ac.id/unj/index.php/jpensil/index

STUDY OF PIER DIMENSION VARIATIONS MODELLING ON RIVER GEOMORPHOLOGY

Iman Muhardiono[1*]

[1] Balai Pengujian Standar Instrumen Agroklimat dan Hidrologi Pertanian, Kementerian Pertanian

Jalan Tentara Pelajar No.1A, Kampus Penelitian Cimanggu, Bogor, 16111, Indonesia

[*1]imanmuhardiono@gmail.com

P-ISSN: 2301-8437
E-ISSN: 2623-1085

ARTICLE HISTORY

Accepted:
5 Januari 2023
Revision:
21 September 2023
Published:
29 September 2023

ARTICLE DOI:
10.21009/jpensil.v12i3.32680

Abstract

The behavior of river flow patterns on the condition of the pier dimensions can affect the geomorphology conditions of the river, namely the unbalanced local scouring between sediment transport and sediment supply so that it will affect the strength of the pier. This study aims to study the effect of pier dimensions on scour depth and channel base changes in the pier area. The method of observation was carried out by simulations using Nays2DH with the same parameters for each test of each dimension with discharge (Q) = 0.5 m^3/s, sediment diameter (D50) = 0.35 mm, channel width (B) = 5 m, channel length (L) = 25 m, slope (i) = 0.005 and drainage time (t) = 7200 s. The simulation results show the basic scour pattern of the channel which has the smallest value, the diamond type pier. Degradation - Basic channel agitation on diamond type piers, showing a pattern that tends to be evenly distributed compared to semi rounded, rectangle, or octagonal types. Period (t) 7200 s downstream of the pier, semi rounded type scours change <0.3 m, rectangle type scours changes <0.4 m, octagonal type scours changes <0.4 m, and diamond type scours changes <0.2 m. So the dimensions of the diamond type are more effective in reducing the depth of scour.

Keywords: Pier, River, Scour

Introduction

Scouring is a phenomenon that occurs in building structures in watersheds due to obstructed flow so that the speed is blocked and changes in flow patterns. Scour is accountable for about 50%-60% bridge failure (Chaudhuri et al., 2020; Khan et al., 2016; Topczewski et al., 2016; Ulfah et al., 2023; Zaid et al., 2019). The scour will increase with the change in river geometry (Brandimarte et al., 2012). Scour is divided into three types, namely general scouring in the river channel which is generally not related to the building of the river, local scouring in the river which occurs due to the narrowing of the centralized river flow, and local scouring around the building due to the pattern of local flow around building. The change in flow on the surface is the beginning of the scour phenomenon due to the displacement of the speed and direction of the flow so that the bottom sediment granules come transported and cause scour widening (Duarte et al., 2019). The pier is part of a building construction that serves to hold the load stretch between two abutments and forward it to the basic foundation . Pier is a structure that provides vertical support to the irrigation structure, i.e. siphon (Gartina & Roestaman, 2015). The condition of the piers in the flow of the river in its planning always pays attention to the strength and security of the dimensions. A recent study conducted by Abed & Majeed (2020 and Maritz1 et al. (2023), showed that the grinding of rectangular piers with pier-shaped ends was larger than the circular, where the smallest scouring occurred at the ends of triangles.

Publications and studies related to scouring on pier abutments have been carried out (Yen et al., 2001) carried out Large Eddy Simulations to simulate the flow field and bed evolution around bridge piers. Lam et al. (2008) studied two- and three-dimensional (3-D) numerical simulations of cross-flow around four cylinders in an in-line square configuration are performed using a finite-volume method. Man et al. (2019) did assessment of turbulence model adopted with the parameters of the Melville experiment to estimate the maximum scour-depth was performed. Purnomo et al. (2017) where the simulation results on 2 models the greater the simulation discharge given, the vertical wall gives deeper scouring than the semi-end-circular. Cambodia (2020) and Widia Khairinnisa Rustawa & Setio Budianto (2020) studied of the maximum scour on the bridge pillars was carried out using the HEC-RAS software. Research on the shape of the piers was carried out by Yunar (2006) the research emphasizes more on the blinds and piers of the rounded rectangular shape where the lowest relative maximum local scour depth is achieved by the T1R2A1 piers with a reduction value of 68.64% at the time of base subsidence. Research into the effectiveness of vertical wall and semi-end-circular bridge abutments with different discharge variations shows that the semi-end-circular model can effectively reduce scour into laboratory-scale research conducted by Ariyanto (2010) on the three pier forms of discharge verification. The potential techniques also showed by Bento et al. (2018), which used Kinect sensor and close-range photogrammetry for semi rounded shape scour modelling that most common used in Portugal. Previous studies have been researched to investigate the flow pattern and scouring by modelling software (Ali et al., 2017; Kadono et al., 2020; Lee et al., 2019). Therefore, it is of utmost importance to consider different types of pier shapes and determine the most suitable pier geometry in terms of reducing scour (Al-Shukur & Obeid, 2016; Melville, 1997; Murtaza et al., 2018; Török et al., 2017).

This process will continue and scour holes will develop as time goes by, reaching a maximum depth. Sediment transport increases with increasing sediment shear stress, scouring occurs when changes in flow conditions cause an increase in shear stress at the bottom (Pudyono, 2013). The influence of flow velocity will be more dominant (U/Uc) so that it causes the outflow and entry of elementary particles into the scour hole, but the depth remains constant, in a balanced depth the maximum depth will be greater than the average in the scour (Sucipto, 2011).

Research Methodology

This research is an experimental study in the form of a simulation with the Nays2DH assistance program (Habib & Nassar, 2019; Ilham & Sufrianto, 2022; Shimizu et al., 2014). Simulation test parameters performed take the condition of the channel where the parameters entered are the same parameters for each test each dimension with a discharge (Q)= 0.5 m3/s, sediment diameter (D50)=0.35 mm, channel width (B)= 5 m, n-manning = 0.020 (earth channel type, straight, clean, uniform) channel length (L)= 25 m, slope (i) = 0.005 and flow time (t)= 7200 s. Analysis of the behavior of flow patterns and scour based on variations in the shape of the pliar consists of four types namely: Semi-rounded, rectangle, octagonal, diamond type piers where each size is made to resemble a length 3.6 meter, width 1.1 meter.

The generation of the Nays2DH model passes through few steps, pre-processing, solver, and post-processing. Running modelling takes time depending on computer ability and the number of grids. The density grid used in this simulation di=0.20 meters and dj=0.20 meters.

Below is continuity equation used by Nays 2DH solver in orthogonal coordinate (Wardana & Budiman, 2021).

$$\frac{\partial H}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} = 0 \quad (1)$$

$$\frac{\partial (uh)}{\partial t} + \frac{\partial (hu^2)}{\partial x} + \frac{\partial (huv)}{\partial y} = -gh\frac{\partial (H)}{\partial x} - \frac{\partial (\tau_x)}{\rho} + D^x + \frac{F_x}{\rho} \quad (2)$$

$$\frac{\partial (vh)}{\partial t} + \frac{\partial (huv)}{\partial x} + \frac{\partial (hv^2)}{\partial y} = -gh\frac{\partial (H)}{\partial x} - \frac{\partial (\tau_x)}{\rho} + D^x + \frac{F_x}{\rho} \quad (3)$$

Where h is water depth, t is time, u is velocity in x direction, v is velocity in y direction, g is gravitational acceleration, H is water depth, τ is shear stress, and F is dragging force caused by vegetation.

Research Results and Discussion

The results of the simulation analysis carried out there is an influence between the flow velocity and the local scouring around the pier with the variations in the dimensions of the running pier. The parameters of the pier. dimensions are very influential on the local scouring around the piers and their flow patterns so that with the change in flow velocity that is different, the forces acting to transport the sediment grains are also different. The strength of the downflow undoubtedly affects the scour of the pier. However, scour depth is pier shape-dependent (Carnacina et al., 2019). The scour depth in water flow declined due to a reduction in the strength of the downflow (Omara et al., 2022; Saleh Pallu & Arsyad Thaha dan Farouk Maricar, 2014; Syarifudin & Sartika, 2019).

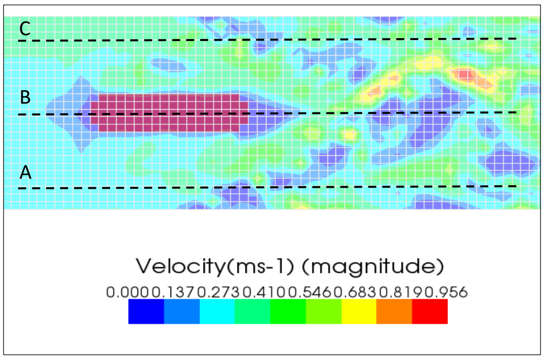
Velocity and Flow Pattern

1. Semi rounded
   The velocity in the semi rounded form, in piece A, the flow velocity in the upstream of the pier is at 0.5 m/s and Fr = 0.4 (subcritical), the height of the flow is at 0.22 m. In section B the flow velocity is at 0.35 m/s and Fr = 0.05 (subcritical), the height of the flow is at 0.2 m. C-section shows the condition of flow velocity of 0.7 m/s with Fr = 0.4 (subcritical), the height of the flow is at 0.35 m.
2. Rectangle
   The velocity in the rectangle, in piece A, the flow velocity slowly decreases at 0.4 m/s, Fr = 0.3 (subcritical) the height of the flow is at 0.32 m. In section B the flow velocity is at 0.375 m/s and Fr = 0.05 (subcritical) the

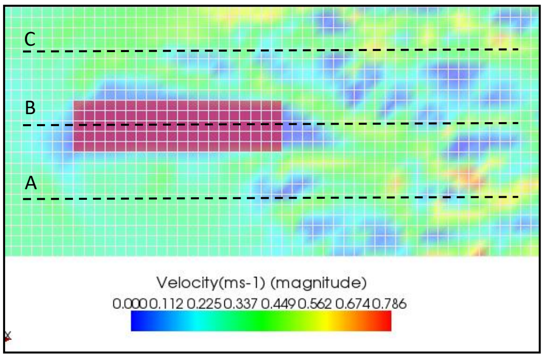
flow height is at 0.3 m. The location of C-section of the flow is at 0.5 m/s and Fr <0.32, the height of the flow is at 0.25 m.

3. Diamond
   The velocity in the diamond shape, in section A the flow velocity is at 0.3 m / s and Fr = 0.2 (subcritical) the flow height is at 0.32 m. At location B the flow velocity is 0.3 m/s and Fr = 0.05 (subcritical) the flow height is at 0.3 m. At C-section the flow velocity is 0.4 m/s and Fr = 0.5, the flow height is 0.3 m.
4. Octagonal
   The speed on the octagonal shape, in piece A, the flow velocity is at 0.6 m/s and Fr = 0.65 (subcritical) the flow height is at 0.28 m. Cut B flow velocity is at 0.3 m/s and Fr = 0.05 (subcritical) flow height is at 0.3 m. At C-section the flow velocity is 0.7 m/s and Fr = 0.75 (subcritical) and the flow height is 0.3 m.

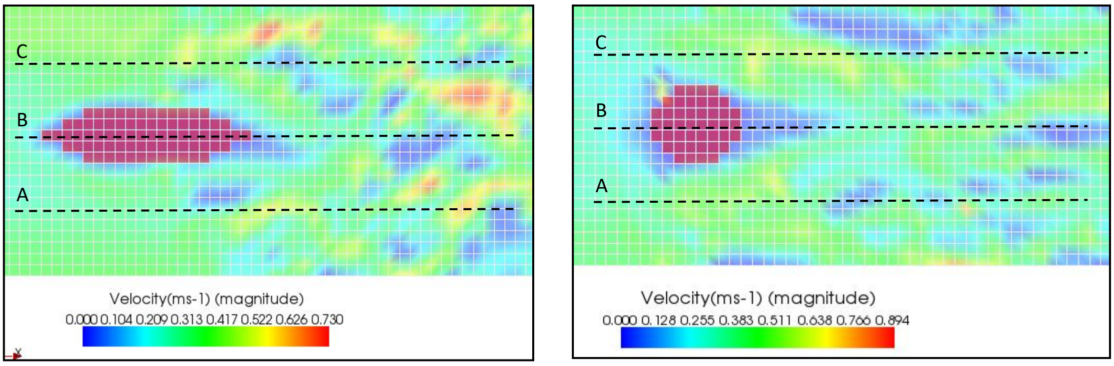
The flow pattern in Figure 1 showed that the semi rounded shape forms a curved direction line parallel to the side that is blocking the flow, then turns slightly conical downstream of the pier to form the same S curve on both sides but tends to be dense towards the left side of the flow, if overlayed with the flow velocity informed in Figure 2, at this shape the velocity flow at maximum conditions. Previous study by Muhsen & Khassaf (2023), semi rounded was more scoured 10.8% than lenticular shape. In the rectangle, the flow forms an unbalanced line upstream of the pier and tends to flow tightly to the left of the pier, then cone downstream of the pier and tends to be dense in the right direction of the flow, if overlayed with the flow velocity in this form the flow velocity is at a maximum but not as high semi rounded. In the form of diamond flow forming a conical triangle pattern on the side that blocks the flow, then forming a cone forming an S curve which tends to be rather wide and not narrowing like the previous two, when overlayed by the speed function, the speed is distributed on the right and left sides of the flow. In the octagonal shape, the flow facing upstream is divided wider than the previous three and the maximum speed is characterized by the density of the flow, then tends to cone rather meet at the downstream of the pier but not as close as the previous third. Based on the simulation results, it appears that the diamond and octagonal shapes produce a similar flow pattern, but the diamond shape is more consistent, this also has discussed in previous study that shape is nature geometry which can decrease the energy of the horse shoe vortex (Shariyar, 2021). The octagonal is denser on the left and right sides of the channel where these conditions give more consideration to the safety of the left and right cross section of the flow.



(a)

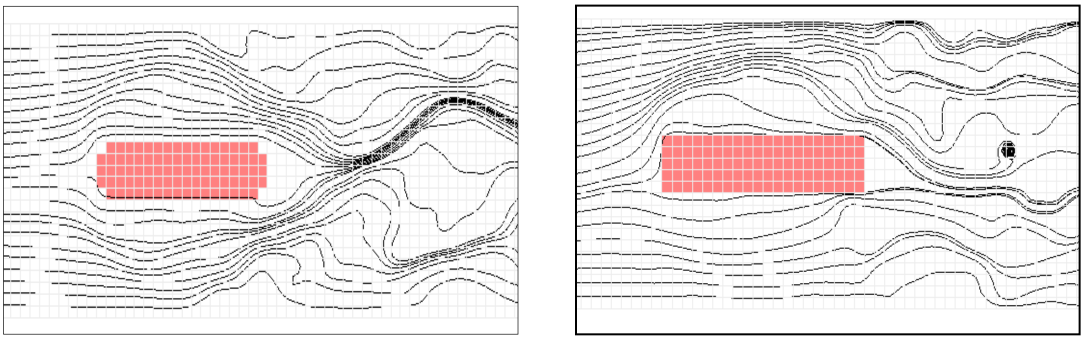


(b)

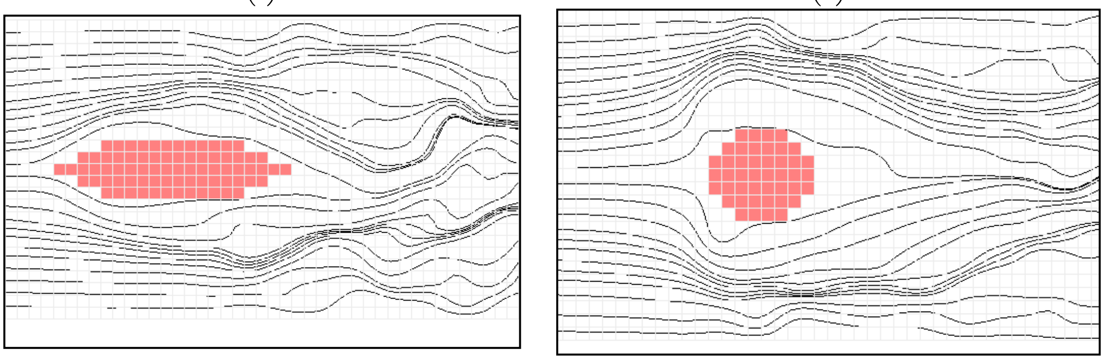


(c) (d)

Figure 1. Flow speed (m/s) in period (t) = 7200 s (a = semi rounded, b = rectangle, c = diamond, d = octagonal)



(a) (b)



(c) (d)

Figure 2. Flow patterns in period (t) = 7200 s (a = semi rounded, b = rectangle, c = diamond, d = octagonal)

Bed Elevation

Complex interactions and feedbacks between the turbulent flow and the sediment bed give rise to these organized dynamic sedimentary patterns at the interface. In general, bed forms exhibit a remarkable dynamics and a wide range of time and length scales, with multiple structures traveling at different speeds, and merging events that give shape to the interface between water and sediment (Escauriaza & Sotiropoulos, 2011). The transport of sediment particles from the vicinity of the pier is done by saltation, traction and suspension (Gazi & Afzal, 2020).

1. Semi rounded
   Changes in channel elevation in the semi rounded shape upstream facing the direction of the flow occur scours as deep as 0.33 m, then in the downstream di-rection of the flow tendency as the flow pattern forms a

triangular cone, maxi-mum deposition occurs, but at the confluence of two streams forming an S curve the deposition occurs again ΔH = 0.33 into 0.42 m.

2. Rectangle
   Changes in elevation in the form of a rectangle seen in the upstream of the pier facing the flow where scours occur as deep as 0.29 m, then in the downstream direction of the flow deposition tendency occurs in small scattered spots and do not have a long deposition pattern.
3. Diamond
   Changes in the elevation of the diamond shape upstream of the pier scours occur in 0.13 m, then in the downstream direction where the tendency to form a cone but the deposition pattern is formed quite a lot of spots and lengths where ΔH = 0.06 into 0.45 m.
4. Octagonal
   Changes in the elevation of the octagonal shape in the upper part of the pier scours in 0.37 m then in the downstream direction on the right and left sides forming a deposition pattern similar to ΔH = 0.07 into 0.371 m, and spread out with spots that tend not to be long where if you look at the flow pattern that cones downstream in the middle there is a scour as deep as 0.67 m. Furthermore, the simulations results are showed in Figure 3.

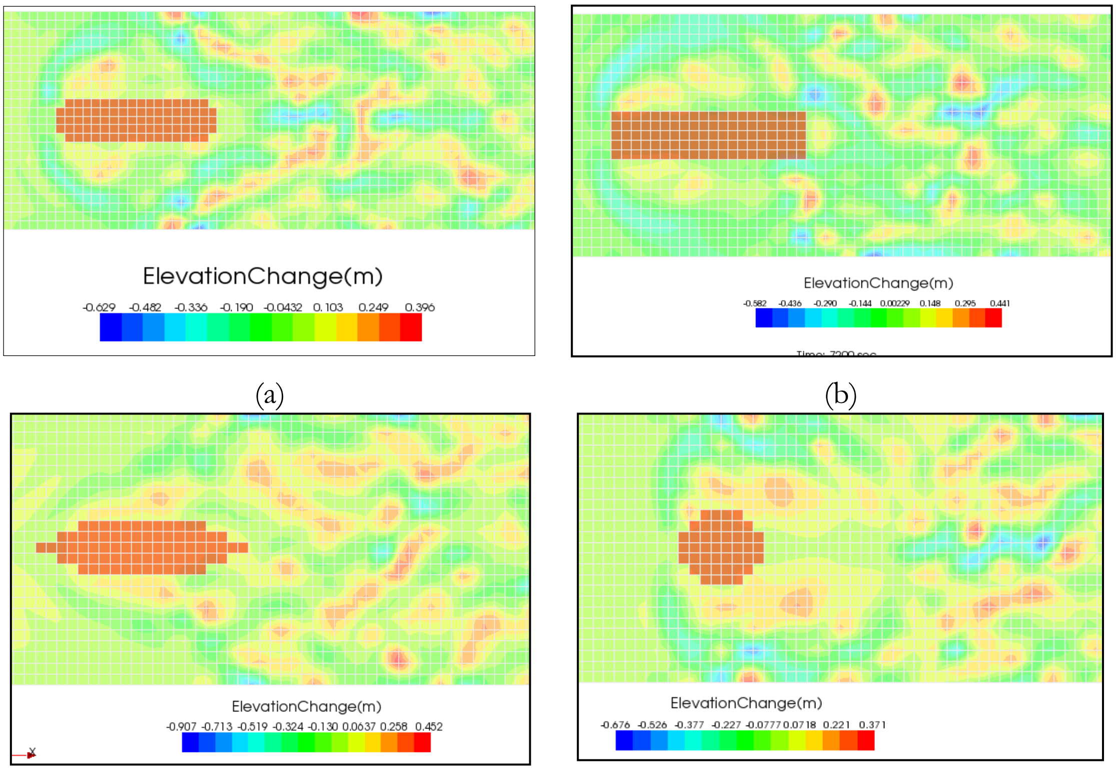


Figure 3. Change in elevation (m) (t) = 7200 s (a = semi rounded, b = rectangle, c = diamond, d = octagonal)

Conclusion

The conclusion obtained from this study, Flow velocity in the downstream of the semi-rounded pier forms increased to 0.7 m/s, rectangle 0.5 m/s, diamond 0.4 m/s, octagonal 0.7 m/s. The faster the flow velocity, the more particles are carried and the potential for scour holes is greater so that the diamond shape is the form with the lowest potential scour rate compared to other forms. The flow pattern in the semi rounded shape forms a curved angle parallel to the side of the part that obstructs the pier, in the form of the rectangle the flow forms an unbalanced angle line from the direction of flow which tends to be dense on the right side, in the diamond shape the pattern forms a flatter triangular angle on the octagonal shape flow patterns form a wider angle than others. The diamond shape shows a more consistent flow pattern than the other shapes, where the non-round shape in fact gives a sharper angle to the incoming flow and reduces the horseshoe vortex force. The depth of the scour elevation in the channel of each form semi rounded, rectangle, diamond, octagonal, in the upstream of the pier facing the direction of the flow of each 0.33 meters; 0.29 meters; 0.13 meters; 0.37 meters. These results indicate the diamond shape has a lowest depth of scour compared to other forms.

References

Abed, B. S., & Majeed, H. Q. (2020). The Behavior of Scouring Around Multiple Bridge Piers Having Different Shapes. IOP Conference Series: Materials Science and Engineering, 745(1). https://doi.org/10.1088/1757-899X/745/1/012158

Ali, M. S., Hasan, M. M., & Haque, M. (2017). Two-Dimensional Simulation of Flows in an Open Channel with Groin-Like Structures by iRIC Nays2DH. Mathematical Problems in Engineering, 2017, 1–10. https://doi.org/10.1155/2017/1275498

Al-Shukur, A.-H. K., & Obeid, Z. H. (2016). Experimental Study of Bridge Pier. International Journal of Civil Engineering and Technology (IJCIET), 7(1), 162–171.

Ariyanto, A. (2010). Analisis Bentuk Pilar Jembatan Terhadap Potensi Gerusan Lokal. Jurnal APTEK, 2(1), 41–51.

Bento, A. M., Couto, L., Pêgo, J. P., & Viseu, T. (2018). Advanced characterization techniques of the scour hole around a bridge pier model. E3S Web of Conferences, 40. https://doi.org/10.1051/e3sconf/201840050 66

Brandimarte, L., Paron, P., & Di Baldassarre, G. (2012). Bridge pier scour: A review of processes, measurements and estimates. Environmental Engineering and Management Journal, 11(5), 975–989. https://doi.org/10.30638/eemj.2012.121

Cambodia, M. (2020). Analisis Gerusan Lokal pada Pilar Jembatan Kereta Api BH. 337 akibat Aliran Sungai Cikao. Teknika Sains : Jurnal Ilmu Teknik, 5(2), 44–53. https://doi.org/10.24967/teksis.v5i2.1085

Carnacina, I., Leonardi, N., & Pagliara, S. (2019). Characteristics of flow structure around cylindrical bridge piers in pressure-flow conditions. Water (Switzerland), 11(11). https://doi.org/10.3390/w11112240

Chaudhuri, S., Das, V. K., & Debnath, K. (2020). Comparison of Scour Mechanisms and Downstream Bed Modification Around Circular Pier For Different Stream Bed - Characteristics - An Experimental Approach (Issue November).

Duarte, C. F., Nadim, N., & Chandratilleke, T. T. (2019). Experimental study of granular bed erosion and sedimentation subjugated to the secondary flow structures in curved ducts. Advances in Mechanical Engineering, 11(11), 1–14. https://doi.org/10.1177/1687814019885255

Escauriaza, C., & Sotiropoulos, F. (2011). Initial stages of erosion and bed form development in a turbulent flow around a cylindrical pier. Journal of Geophysical Research: Earth Surface, 116(3), 1–24.

https://doi.org/10.1029/2010JF001749

Gartina, R., & Roestaman. (2015). Analisis Kekuatan Struktur Beton Pilar 2 Penahan Siphon Cisangkan. Jurnal Konstruksi, 13(1), 1–10.

Gazi, A. H., & Afzal, M. S. (2020). A review on hydrodynamics of horseshoe vortex at a vertical cylinder mounted on a flat bed and its implication to scour at a cylinder. Acta Geophysica, 68(3), 861–875. https://doi.org/10.1007/s11600-020-00439-8

Habib, A. A., & Nassar, M. A. (2019). Modelling of Deposition and Erosion Processes along A 180° Open Canal Bend by NAYS2DH in iRIC. Engineering Heritage Journal, 3(2), 01–05. https://doi.org/10.26480/gwk.02.2019.01.05

Ilham, V. A., & Sufrianto. (2022). Effect of Flow Velocity on bedload Sediment Transport at the Jeneberang River Estuary with Nays2DH Model Simulation. Jurnal on Management and Education Human Development, 02(01), 50–57.

Kadono, T., Okazaki, S., Kabeyama, Y., & Matsui, T. (2020). Effect of angle between pier and center of river flow on local scouring around the bridge pier. Water (Switzerland), 12(11), 1–13. https://doi.org/10.3390/w12113192

Khan, M. K., Muzzamil, M., & Javed Alam. (2016). Bridge Pier Scour: A review of mechanism, causes and geotechnical aspects. Age Amu Aligarh, April 2016, 1–6. https://www.researchgate.net/publication/312499136_Bridge_Pier_Scour_A_review_of_mechanism_causes_and_geotechnical_aspects

Lam, K., Gong, W. Q., & So, R. M. C. (2008). Numerical simulation of cross-flow around four cylinders in an in-line square configuration. Journal of Fluids and Structures, 24(1), 34–57. https://doi.org/10.1016/j.jfluidstructs.2007.06.003

Lee, F. Z., Lai, J. S., Lin, Y. Bin, Liu, X., Chang, K. C., Lin, C. F., & Chang, C. C. (2019). Monitoring and simulation of bridge pier scour depth. Scour and Erosion IX - Proceedings of the 9th International Conference on Scour and Erosion, ICSE 2018, 03007, 633–637. https://doi.org/10.1201/9780429020940-91

Man, C., Zhang, G., Hong, V., Zhou, S., & Feng, Y. (2019). Assessment of Turbulence Models on Bridge-Pier Scour Using Flow-3D. World Journal of Engineering and Technology, 07(02), 241–255. https://doi.org/10.4236/wjet.2019.72016

Maritz1, J. A., Malan1, D. F., Malan, D. F., Malan, J. A., & Maritz, J. A. (2023). A study of the effect of pillar shape on pillar strength Dates: How to cite. The Journal of the Southern African Institute of Mining and Metallurgy, 123(5), 235–244. https://doi.org/10.17159/2411

Melville, B. W. (1997). Pier and Abutment Scour: Integrated Approach. Journal of Hydra, 125–137.

Muhsen, N. A. A., & Khassaf, S. I. (2023). The study of the local scour behaviour due to interference between abutment and two shapes of a bridge pier The study of the local scour behaviour due to interference between abutment and two shapes of a bridge pier. Journal of Water and Land Development, 55(X–XIII), 240–250. https://doi.org/10.24425/jwld.2022.142327

Murtaza, G., Hashmi, H. N., Naeem, U. A., Khan, D., & Ahmad, N. (2018). Effect of Bridge Pier Shape on Scour Depth at Uniform Single Bridge Pier. Mehran University Research Journal of

Engineering and Technology, 37(3), 539–544. https://doi.org/10.22581/muet1982.1803.08

Omara, H., Ookawara, S., Nassar, K. A., Masria, A., & Tawfik, A. (2022). Assessing local scour at rectangular bridge piers. Ocean Engineering, 266(P3), 1–13. https://doi.org/10.1016/j.oceaneng.2022.112912

Pudyono, S. (2013). Aliran Superkritis Di Hilir Pintu Air Menggunakan End Sill Dan Buffle Block Dengan Simulasi Model. Jurnal Rekayasa Sipil, 7(2), 118–131.

Purnomo, S. N., Nasta'in, Widiyanto, W., & Salsabilla, L. (2017). Efektivitas Bentuk Abutmen Terhadap Gerusan Di Sekitar Abutmen Jembatan. Jurnal Teknik Sipil, 13(4), 323–331. https://doi.org/10.24002/jts.v13i4.940

Saleh Pallu, M., & Arsyad Thaha dan Farouk Maricar, M. (2014). Local Scour Analysis Study To Hexagonal Pillar By Using Shape Curtain Rectangular With Wedge Shape Curve (RWWSC). 9(10). www.arpnjournals.com

Shariyar, M. A. (2021). Numerical Investigation of Local Scour Around Different Shaped Bridge Piers Using Flow 3D Software. Islamic University of Technology.

Shimizu, Y., Takebayashi, H., Inoue, T., Hamaki, M., Iwasaki, T., & Nabi, M. (2014). Nays2DH solver manual. International River Interface.

Sucipto. (2011). Pengaruh Kecepatan Aliran Terhadap Gerusan Lokal Pada Pilar Jembatan Dengan Perlindungan Groundsill. Jurnal Teknis SIpil & Perencanaan, 13(1), 51–60. https://doi.org/10.15294/jtsp.v13i1.1326

Syarifudin, A., & Sartika, D. (2019). A Scouring Patterns Around Pillars of Sekanak River Bridge. Journal of Physics: Conference Series, 1167(1). https://doi.org/10.1088/1742-6596/1167/1/012019

Topczewski, Ł., Cieśla, J., Mikołajewski, P., Adamski, P., & Markowski, Z. (2016). Monitoring of Scour Around Bridge Piers and Abutments. Transportation Research Procedia, 14, 3963–3971. https://doi.org/10.1016/j.trpro.2016.05.493

Török, G. T., Baranya, S., & Rüther, N. (2017). 3D CFD modeling of local scouring, bed armoring and sediment deposition. Water (Switzerland), 9(1), 1–23. https://doi.org/10.3390/w9010056

Ulfah, A., Sudarsono, I., Gunawan Yahya, R., & Mulyawati, F. (2023). Evaluation of Bridge Structures Using Asset Survey Technology To be Used As Monitoring Data (Case Study: Kamojang Hill Bridge). Jurnal PenSil, 12(1), 87–99. https://doi.org/10.21009/jpensil.v12i1.29407

Wardana, P. N., & Budiman, R. (2021). Two Dimensional Sediment Transport Simulation Around Kamijoro Intake, Yogyakarta, Indonesia. 590–595. https://doi.org/10.5220/0010371305900595

Widia Khairinnisa Rustawa, N., & Setio Budianto, B. (2020). Modeling Local Scour Characteristics on The Batujajar Bridge Pillar Using HEC-RAS Software.

Yen, C. L., Lai, J. S., & Chang, W. Y. (2001). Modeling of 3D flow and scouring around circular piers. Proceedings of the National Science Council, Republic of China, Part A: Physical Science and Engineering, 25(1), 17–26.

Yunar, A. (2006). Karakteristik Gerusan Pilar Segi Empat Ujung Bulat Pada Kondisi Terjadi Penurunan Dasar Sungai Dengan Proteksi Tirai. Smartek, 146–155.

Zaid, M., Yazdanfar, Z., Chowdhury, H., & Alam, F. (2019). Numerical modeling of flow around a pier mounted in a flat and fixed bed. Energy Procedia, 160(2018), 51–59. https://doi.org/10.1016/j.egypro.2019.02.118