E3S Web of Conferences **422**, 03005 (2023) https://doi.org/10.1051/e3sconf/202342203005
ICRES 2023

Evaluation through 2D Modelling of Scour around Piers with Collars in the CÁCeres Bridge in Piura, Peru

Shamir Luliquis[1], *Samuel* Vinces[2], and *Rubén* Mogrovejo[3]

[1,2,3]Universidad Peruana de Ciencias Aplicadas, Faculty of Civil Engineering, 2390 Primavera Avenue, Peru

Abstract. This paper analyzes the results of the scour calculations around the group of piers of a bridge through two-dimensional modelling using the Iber software. The case under study is that of the Andrés Avelino Cáceres Bridge, located in the Piura region, Peru, which has an approximate free span of 120 meters and has 10 pillars equally distributed on two decks. Currently, the referred bridge has pillars of rectangular section with narrowing towards the base, this type of geometry was considered as the first scenario for scour calculations; the pillars with the collars installed are part of the second scenario under study. Based on geotechnical, hydrological and hydraulic studies of the area, two-dimensional numerical modeling has been developed for each scenario in order to obtain the depths of scour. The following results were obtained: The installation of collars in the second scenario achieved a reduction of the scour depth by 29.51% on average, the observed reduction range was from 15.73% to 43.77%.

1 Introduction

Bridges are important structures that require high investments in their construction and play a key role in economic development because of the connectivity and communication they enable. Their collapse means costly re-pairs, traffic disruptions and potential fatalities [1]. The significance of the losses of these structures can be exemplified by the occurrence of the El Niño Costero weather phenomenon in 2017 in Peru, which caused the collapse of 449 bridges across the country [2]. The incessant rains recorded between December 2016 and March 2017 caused the main rivers of the Peruvian coast to overflow. Piura was the most affected region, as this phenomenon led its main river to reach a maximum instantaneous flow of 3468 m3/s, flooding thousands of homes, causing human losses, destroying kilometers of roads and causing 27 bridges to fail [2,3].

Due to the importance of maintaining the stability of these structures, the causes of collapse have been studied for many years. For example, in 1976, a statistical analysis of 143 bridges around the world showed that 46% of bridges failed due to scour [4]. Scour is the removal of bed material due to the erosive action of water. It is composed of three types: Contraction scour, which occurs when the flow area of the river is reduced due to bridge construction; local scour, which occurs at pillars and abutments (or other structure obstructing the natural flow of the river). These obstructions cause flow acceleration and create vortices that accelerate and reinforce the erosive pro-cess; long-term degradation, this is called scour caused by river flow dis-charges over a long period of time [5].

Several authors have found a relationship between the geometry of the pillars and the depth of scour produced around them. Through the one-dimensional numerical modelling performed in HEC-RAS, Mehta and Yadav [6] determined that the best choice of location for the projection of the bridge parallel to the Sardar Bridge was upstream, due to the lower local scour depths obtained. However, they recommended an analysis of the spatial distribution of the abutments of the new bridge to be projected, since the scour prediction is affected by this factor. This last indication shows the limitations of the 1D models.

On the other hand, Moussa [5] in his research on the Aswan and El Minia bridges located over the Nile River, concluded that his modelling results achieved lower local scour with sharp-pointed pillars, and also that the re-duction of their section size contributed to minimize the erosive effect.

Meanwhile, Gelmiran et al. [7] in an investigation using physical models focused on finding the relationship between pillar geometry, pillar spacing and erosive effects by recording the local scour produced around 5 groups of 3 pillars with varying diameters and spacing. The pillars were grouped with a constant diameter of 10 cm downstream for all cases, and diameters of 2, 4, 6, 8 and 10 cm respectively upstream for each of the pillars in each grouping. In relation to spacing, distances of 20, 30 and 50 cm were considered. The two geometric conditions mentioned above were subjected to 3 test flows at 38, 48 and 57 l/s, resulting in 45 simulated scenarios. The authors concluded that both an increase in abutment diameter and an increase in abutment spacing lead to increase local scour. They also observed a decrease in this erosive effect when increasing the number of piers.

Along the same lines, Bestawy et al. [8] carried out an experimental model, in which they applied the installation of different types of collars at the bases of pillars in order to estimate the reduction of local scour produced by these elements. The types of collars tested were the flat collar, the collar with eaves every 90°, the collar with eaves every 45° and the tapered collar. The authors found that the placement of collars proved to be an effective method for scour reduction, especially the truncated cone collar geometry, which achieved a scour reduction of 61.10%.

In view of the existing problem, this article develops for the Andrés Avelino Cáceres Bridge, located in the Peruvian region of Piura, a comparative analysis of the local scour depths obtained by applying the installation of collars at the bases of the existing piers. Using two-dimensional modelling in the Iber software, 10 pillars are tested under the action of a flow with a return period of 500 years. For the first scenario, the real geometry of the pillars is considered, a rectangular section with narrowing towards the base. For the second scenario, the placement of the collars is considered in the modelling. Thus, using two-dimensional numerical modelling, the present study analyses the interrelation between the geometry of the pillars, the geology, hydrology and hydraulics of the area with the calculated scour depth; in this way, the results can be considered for the future design of bridge piers located over the Piura River.

2 Materials

2.1 Topography

A topographical survey of the study area was performed considering an average width of 140 m along 2.40 km of the Piura riverbed for an extension of 0.80 km downstream and 1.60 km upstream of the Andrés Avelino Cáceres Bridge, an area in compliance with Peruvian regulations.

2.2 Geotechnical tests

The SPT type tests carried out for a soil study of an infrastructure project have been considered [9]. The two samples used are located 60 meters from the riverbed under study. The results analyzed are those of the D50 (particle size corresponding to the 50% that passes and represents the average grain size), percentage porosity and angle of internal friction.

2.3 Hidrology and hydraulics

The design flow was determined from 93 recorded data of maximum instantaneous flows per year, which were recorded at the Sanchez Cerro Bridge hydrometric station and located 1.20 km downstream of the bridge under study. As part of the hydraulic scenario, the bridge has two 150 m long decks with a gauge of 8.50 m each. Furthermore, the ten piers under study have a trapezoidal section with tapering towards the base (see fig. 1).

Fig. 1. Condition of the piers of the Andrés Avelino Cáceres bridge.

3 Methodology

The research was executed in four phases. The first consisted of collecting hydrological, hydraulic and geotechnical information of the study area. During the second phase, the two-dimensional numerical modeling is performed in Iber software based on the data collected in the previous phase. The third phase, the numerical model is calibrated to enable the simulation. Finally, the results are analyzed, which will lead to conclusions and recommendations.

3.1 Phase 1

The study zone is an area with a history of flooding due to the extraordinary flows produced by the climatological phenomena that have occurred in recent decades known as El Niño and El Niño Costero. The Andrés Avelino Cáceres Bridge is located on the Piura River, in the lower basin of this river [10]. Politically, it is located in the district of Piura, province of Piura and region of Piura.

Regarding the topographic information, the contour lines originated from the topographic survey are processed by geographic information system software obtaining the land surface file in ASCII format, which Iber can process. Fig. 2 shows the contour lines obtained from satellite images of the study area.

Fig. 2. Contour lines generated from the topographic survey of the study area within 2.40 km of the Piura River.

The geotechnical information used is based on the results of two SPT tests, for each case the D50 was determined, obtaining an average value of 0.165 mm. Similarly, the porosity was determined, equal to 0.30; the friction angle, equal to 31.51° and the relative density equal to 2. For the assignment of Manning's coefficients, the values in tables [11] were considered, where the value of 0.03 was determined for the main channel and 0.011 for the banks, since the latter are made of concrete, the material of the riparian defenses for the river section under study.

Finally, the flow rate considered for the simulations is the projected flow rate for a return period of 500 years, specified for the analysis of scour for bridges in the Peruvian regulations, which was equal to 6239 m3/s.

3.2 Phase 2

The two-dimensional numerical modelling phase considers the creation of two models corresponding to each study scenario. The common procedure for all scenarios is as described below: delimitation of land uses, assignment of roughness and mesh sizes and the assignment of boundary conditions for both the hydrodynamic module and the transport model.

All these described conditions are the ones designated for the two scenarios, which only differ in the geometrical shape of the pillars. Scenario 1 is the one with the actual abutment geometry, a rectangular base with dimensions of 2.00 m long and 0. 70 m wide at its base. Scenario 2 considers the installation of the collars at each of the pillar bases, the diameter dimension of the collars was determined by tripling the length of the existing pillar base, and the rest of the measurements were determined by considering the 30° to the truncated cone. The geometries described are shown in figures 3 and 4.

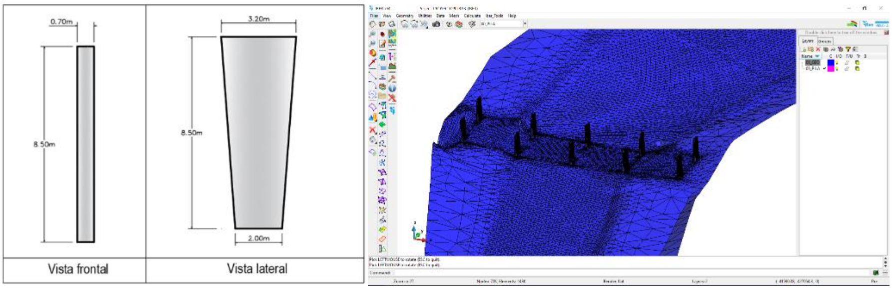

Fig. 3. Diagram of the geometry of the existing piers (left). Mesh of the numerical model of the first scenario considering its geometry (right).

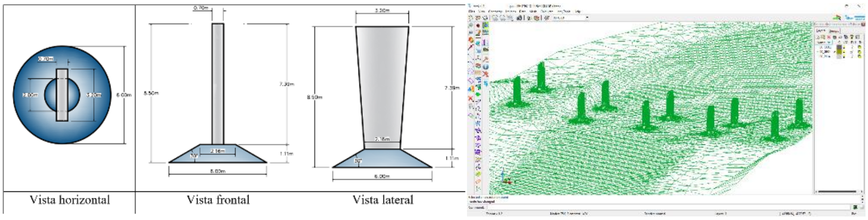

Fig. 4. Diagram of the geometry of the piers with the collars installed (left). Mesh of the numerical model of the second scenario considering this application (right).

3.3 Phase 3

The hydraulic model has been calibrated using the level-flow relationship curve of the hydrometric station of the Sánchez Cerro bridge, located down-stream of the Andrés Avelino Cáceres bridge. This curve considers the records obtained by water level gadgets during 1983, the year in which a maxi-mum flow of 3200 m3/s was recorded as a result of the FEN (see fig. 5).

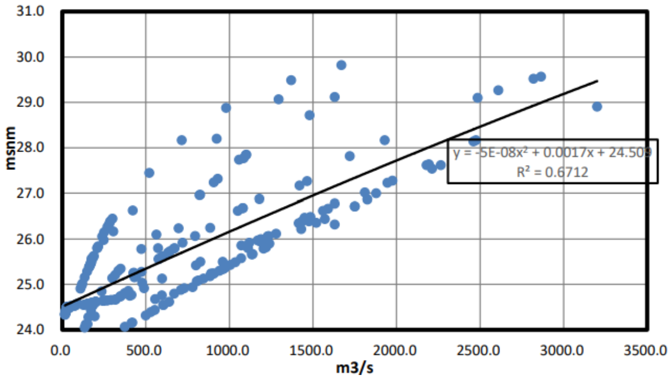

Fig. 5. Chart of the level-flow of the Sánchez Cerro bridge hydrometric station, taken as a reference for the calibrations of the numerical model.

The procedure consisted of carrying out the simulation using three test flows (2000, 2500 and 3000 cubic meters per second), followed by a comparison of the results between the three water level-flow pairs in the models and the calibration curve.

The simulation results are shown in Table 1, which also shows that the relative percentage errors averaged 0.15%.

Table 1. Table of results of the calibration process for the three test flow rates.

Test flow value (m3/s)	**Water level (m.a.s.l.)**		**Relative percent error**
	Result	Calibration curve	
2000	27.64	27.71	0.249%
2500	28.39	28.45	0.199%
3000	29.16	29.16	0.003%

3.4 Phase 4

Once all conditions were established, each scenario was simulated. Iber shows the results in its post-processing module. In this study, the contour map of the erosion results for the two simulated scenarios is shown in images (see fig. 6).

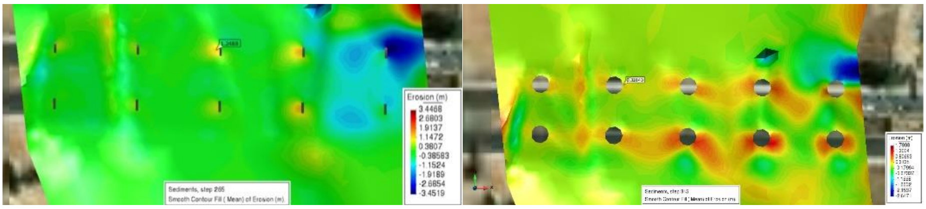

Fig. 6. Sample visualization of erosion results for the first scenario (left) and second scenario (right).

4 Results and analysis

The results obtained are shown for each pillar, coded as P1 to P10 (see fig. 7), and for each scenario. The comparative results are based on the maximum erosive depths achieved in each model around each pillar, so the scour effect in each proposed scenario is represented. The positive results shown belong to the scour erosive effect, that is, they indicate the depths obtained. On the other hand, the negative values represent bed aggradation heights.

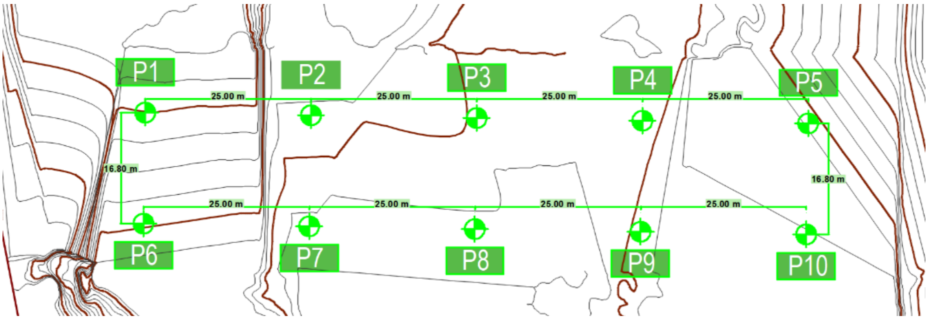

Fig. 7. Coding scheme of the piers and spacing between them.

Fig. 8 shows the development over time of the erosion and aggradation process for each point identified as critical. The maximum value for each pillar has been considered for the comparative analysis of each scenario.

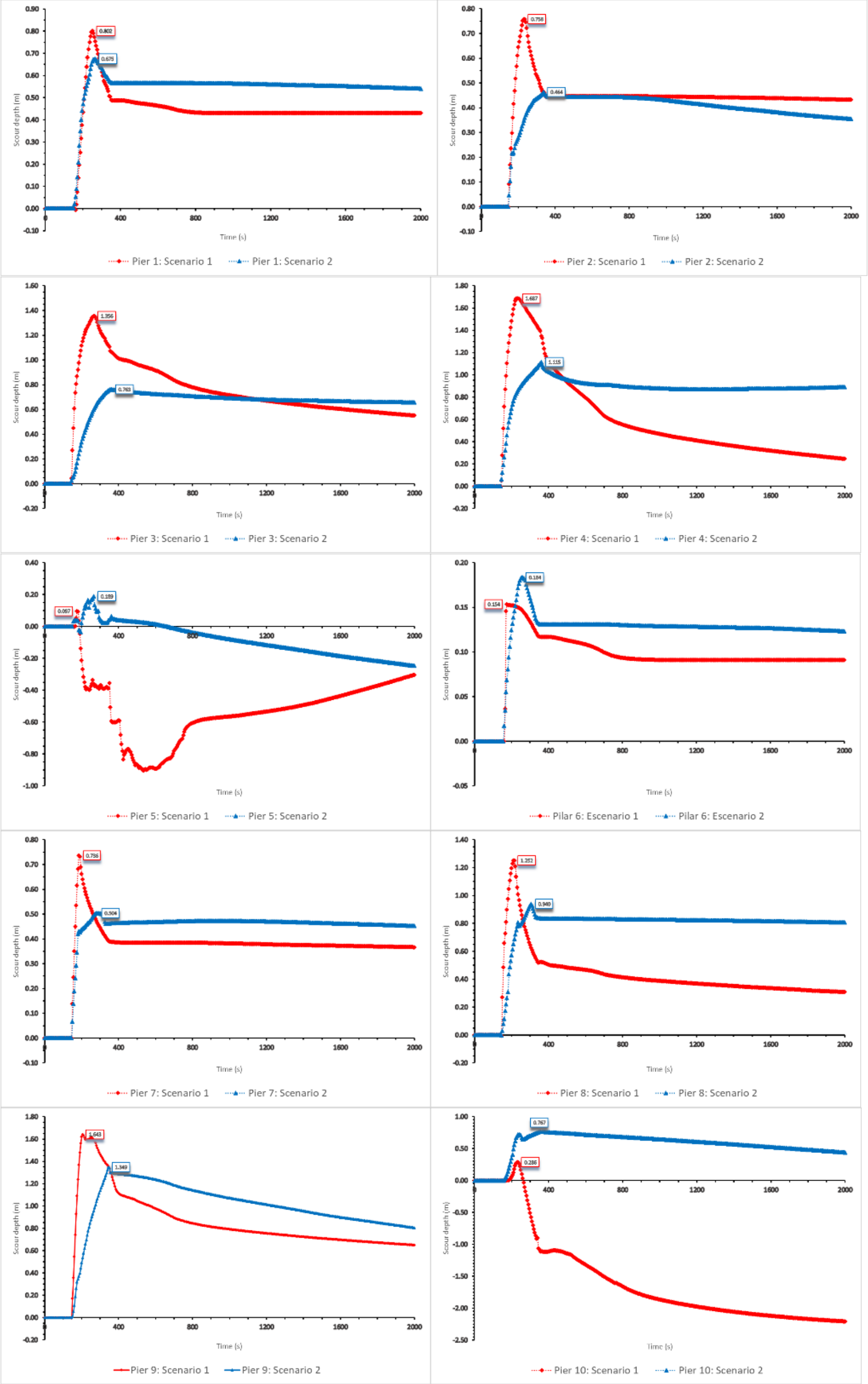

Fig. 8. Record of the development of bed erosion and aggradation processes for each of the piers in each scenario.

The maximum values identified in each case are outlined in Table 2. A reduction in scour depth was observed in 70% of the cases.

Table 2. Table of scour depth results for both simulated scenarios.

Pier	**Maximum scour in piers (m)**		**Difference (m)**	**Percentage difference (%)**
	Scenario 1	Scenario 2		
P1	0.802	0.675	-0.13	-15.84
P2	0.758	0.464	-0.29	-38.79
P3	1.356	0.763	-0.59	-43.73
P4	1.687	1.115	-0.57	-33.91
P5	0.097	0.189	+0.09	+94.85
P6	0.154	0.184	+0.03	+19.48
P7	0.736	0.504	-0.23	-31.52
P8	1.252	0.940	-0.31	-24.92
P9	1.643	1.349	-0.29	-17.89
P10	0.286	0.767	+0.48	+168.18

5 Conclusions and recommendations

- It is concluded from the two-dimensional model that the range of scour reduction was from 15.84% to 43.73% around the pillars after the application of the collars.
- It is concluded that the two-dimensional model effectively represented the physical process of channel erosion, since through its sediment transport simulation, different values of local scour were obtained for each pillar (spatial distribution of properties), which allowed identifying that the pillars where the collars should be installed are P1, P2, P3, P4, P7, P8 and P9, where reductions in scour depths of 15. 84%, 38.79%, 43.73%, 33.91%, 31.52%, 24.92% and 17.89%, respectively. On the other hand, it was observed that, in the lateral areas of the section under study, where pillars P5, P6 and P10 are located, the aggradation process was predominant, since an elevation of the bottom level of 9, 3 and 48 cm, respectively, was recorded.
- The results obtained have only considered the variation of the geometry of the section of each pillar, and therefore, future lines of research could consider the influence of the spacing between pillars and the angle of at-tack of water in relation to the piers.
- The sediment transport model considered in this study only covers the bed transport. It is recommended to carry out tests on river water samples in order to observe the influence of suspended sediment transport.

References

1. Silvia, C. S., Ikhsan, M., Wirayuda, A., Mastiar, J.: Analysis of scour depth around bridge piers with round nose shape by HEC-RAS 5.0.7 software. Journal of Physics: Conference Series 1764(1), 1-11 (2021).
2. Instituto Nacional de Defensa Civil: Compendio estadístico. In: ASVI. Lima, Perú (2017).
3. Autoridad Nacional del Agua: Ficha técnica referencial de identificación de punto crítico sector margen izquierda en el río Piura. In: ANA. Lima, Perú (2020).
4. Rodríguez, D., Yataco, G., Santos, S.: Comparative analysis of the total scour in the pillars and abutments of a bridge, between a 1D and 2D model. CONIITI, 1-6 (2020).
5. Moussa, A.: Evaluation of local scour around bridge piers for various geometrical shapes using mathematical models 9(4), 2571-2580 (2018).
6. Mehta, D., Yadav, S.: Analysis of scour depth in the case of parallel bridges using HEC-RAS 20(8). Water Science & Technology Water Supply 20(8), 3419-3432 (2020).
7. Gelmiran, T., Othman, K., Gunal, M.: Investigation of local scour around group bridge pier with different shapes. AREJ 24(2), 10-22 (2019).
8. Bestawy, A., Eltahawy, T., Alsaluli, A., Alamliki, A., Alqurashi, M.: Reduction of local scour around a bridge pier by using different shapes of pier slots and collars. Water Science & Technology Water Supply 20(3), 1006-1015 (2020).
9. Inversiones Tuma: Reporte final estudio geotécnico del Hotel río Piura. In: TUMA. Piura, Peru (2016).
10. Gobierno Regional de Piura: Proceso de elaboración del plan de gestión de la cuenca del río Piura. In: GORE Piura. Piura, Peru (2009).
11. Chow, V.: Hidráulica de canales abiertos. In: McGraw-Hill. Bogotá, Colombia (1994).