"Comparative Analysis of the Total Scour in the Pillars and Abutments of a Bridge, between a 1D and 2D Model"

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Abstract— In this article, a comparative analysis is performed between one-dimensional (HEC-RAS) and two-dimensional (IBER) models, in the evaluation of total scour in the pillars and abutments of a bridge. The case study is the Huallaga bridge, located in the San Martín region, Peru.

Based on the geomorphological, hydrological and hydraulic data of the study area and after carrying out an analysis of the different equations for local, general scour; Numerical modeling was performed on the HEC-RAS and IBER software in order to calculate the depths of the scour.

The following results were obtained: That in the local scour calculations, the scour depths were less with the 2D software, compared to the values obtained in the 1D software; while in general scour calculations, we obtain greater depths when modeling with 2D software, compared to the values obtained in 1D software

Key words— Total Scour, Comparative Analysis, 1D Numerical Model, 2D Numerical Model, HEC-RAS, IBER

I. INTRODUCTION

Fluvial hydraulics is the branch of hydraulics that is responsible for studying rivers and their interactions with the environment, in particular when human actions make a change in a negative or positive way, such as the construction of infrastructure such as bridges, which aims to generate interconnection between cities [1].

The bridges have been innovated in their construction, providing durability and functionality. However, in the investigation "Optimized hydraulic dimensioning of bridges with embankments" [2], about the failure causes of bridges, a statistical analysis from the year 1976 is shown on the causes of failure or breakage of 143 bridges around all the world. They concluded that 46% of the bridges failed due to scour, which placed it as a major cause of bridge failure.

In the work "Causes of the collapse of some bridges in Colombia" [3], sixty-three cases of failures registered from 1986 to 2000 are presented, in which the causes of the collapse of bridges in Colombia are evaluated. The results of the study revealed that 23% failed due to the undermining of the foundations of their piers or abutments, which happens especially in bridges built more than 20 years ago, where the foundation design criteria was carried out giving more importance to bearing capacity than to scour phenomena.

Generally, scour in structures such as the bridge is defined as the removal of sediment (eg sand and gravel) from the pillar's surroundings [4]. Scour is due to the rapid movement of water that produces holes in the base of the structure. This leads to deterioration of the integrity of the bridge structure [5].

Some studies carried out with the aim of reducing scour in bridges to avoid their failure are: "Effect of fenders on local pier scour" [6] the placement of floating fences around the piers is observed and they concluded that the scour depth is reduced between 15% and 50% depending on the submerged depth of the fence. When these fences were built it was evidenced that, indeed, the depth of scour decreased; but that the scour hole was getting wider.

On the other hand, in the investigation of "Scour Protection around Vertical-Wall Bridge Abutments with Collars" [7], a test was carried out in an open channel to evaluate the reduction of scour in an abutment by placing a disc 5 cm below the level of the bed. This test was carried out with 2 types of materials, the first with d_{50} = 1.48mm and the second with d_{50} = 0.9mm. It was shown that under all flow conditions and for any combination of bed material the scour depth was reduced by at least 65%.

In the study "Plant dimensions of a protection" [8] an experiment was carried out to analyze the scour holes of the protected abutment of a bridge. For the protection of the bridge, concrete blocks were used adhered to a geotextile that was placed around the abutment. The main results of their research were that as the protection dimensions increase, the scour basin moves downstream and becomes wider. Similarly, the depth of scour increases, and this causes the scour volume to increase.

To represent the implementations that are adapting to nature, numerical models have been used, which are innovative since it is very necessary to predict in order to anticipate preventive and corrective measures on the area of influence to the passage of the fluid.

In the investigation "Mathematical modeling in fixed bed of the flow in rivers. 1D and 2D models in permanent and variable regime" [9] research was done on the numerical modeling of the water flow in a river, which was used for the analysis of the effects of the propagation of floods in rivers, velocities and water levels in gradually varied steady state in

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a one-dimensional model due to the fact that little complex geometry was presented. Also, a 2D model was analyzed that is closer to reality for more complex phenomena.

For the analysis of the aforementioned scour problem, numerical, hydraulic 1D and 2D mathematical models have been implemented that allow to systematically predict the real behavior of a river and its interaction with a bridge when faced with the avenue and transport of sediments. For this reason, this article focuses on the modeling of the Huallaga river in the vicinity of the bridge with the same name in the HEC-RAS and IBER programs, with the intention to carry out a comparative analysis of both programs, in order to determine the best alternative that more realistically represents this type of problem.

II. METHODOLOGY

The investigation is carried out in three phases, in the first one the compilation of geomorphological, hydrological and hydraulic data of the area under study is carried out; In the second phase, the equations used to calculate the local scour in the towers are indicated, since the software provides only general scour; in the third phase, the calibration and simulation are carried out in the numerical models of the HEC-RAS and IBER softwares in order to calculate total scour depths.

A) PHASE 1

The study area is located in the San Martín region, Tocache province, Uchiza district, Santa Lucía population center. For scour calculations, a flow of 500 years of return period is used in accordance with the Peruvian standard. The maximum flows for the hydraulic design of the Huallaga bridge were obtained from data of maximum 24-hour precipitation from 6 pluviometric stations of the Huallaga river basin. The values obtained for different return periods that were obtained by the HEC-HMS model are:

$$Q_{2.33} = 2019\ \frac{m^3}{s} \qquad Q_{500} = 8625\ \frac{m^3}{s}$$

The values of $Q_{2.33}$ will be used for the validation of both models, while the values of Q_{500} will be used to obtain the scour calculations, as indicated by Peruvian regulations.
Both in the HEC-RAS model and in the IBER model, the geometry obtained from the topographic survey and the bathymetric survey was used. The section under study of the Huallaga River, which includes the Huallaga Bridge, has a length of 560 m downstream from the bridge and a length of 700 m upstream from the Bridge. Table I shows the starting and ending coordinates of the evaluated section of the river.

TABLE I
UTM WGS84 TERRAIN TOPOGRAPHIC COORDINATES

Limit	UTM WGS84 coordinates	
	East (m)	*North (m)*
Section Start	348009	9076568
Section End	347544	9077747

In the one-dimensional model, 0.03 was used as the value of the bottom slope of the channel, while in the two-dimensional model, a constant slope was not placed because the program does not need that input data.

Taking into account the results of the study of the channel material, for the calculations a diameter such that 50% of the sample mass is composed of particles with a diameter of 0.011 mm of the channel material and a specific gravity of 1.51.

The Manning roughness values used for the simulations and subsequent differentiated calculations were 0.04 for the main channel and 0.08 for the flood plains. This last value corresponds to the value assigned to the vegetation of the area.

B) PHASE 2

The scour phenomenon affects both the base of the pillars and abutments (with the vertical vortex that erodes the soil and generates the maximum depth of scour) and the wake that leaves downstream of the structure (with the wake vortex that the scour pot generates). The calculation of the total scour includes the sum of the local scour and the general scour, none of the models gives us the totality of results, so it was decided to calculate the scour indirectly. The one-dimensional model gives local scour values in piers and abutments, while the two-dimensional model does not. However, scour values can be found indirectly for the 2D model and compared with the 1D model. A very important aspect that should be highlighted is that the bridge being studied has a complex foundation system in the pillars, which is why the local scour was calculated for both models with the following equations, these equations give us the maximum depths of scour at the base of the pillars and abutments.

y_s: Local scour in towers:

$$y_s = y_{s\ pillar} + y_{s\ pc} + y_{s\ pg} \tag{1}$$

ys_{pillar}: Local scour in pillars:

$$\frac{y_{s\ pillar}}{y_1} = K_{h\ pillar}\left[2.0K_1K_2K_3K_4\left(\frac{a_{pillar}}{y_1}\right)^{0.65}\left(\frac{V_1}{\sqrt{gy_a}}\right)^{0.43}\right] \tag{2}$$

ys_{pc}: Local scour in footings:

$$\frac{y_{s\ pc}}{y_2} = \left[2.0K_1K_2K_3K_w\left(\frac{a^*_{pc}}{y_2}\right)^{0.65}\left(\frac{V_2}{\sqrt{gy_2}}\right)^{0.43}\right] \tag{3}$$

ys_{pg}: Local scour in pilings:

$$\frac{y_{s\ pg}}{y_3} = k_{hpg}\left[2.0K_1K_3K_4\left(\frac{a^*_{pg}}{y_3}\right)^{0.65}\left(\frac{V_3}{\sqrt{gy_3}}\right)^{0.43}\right] \tag{4}$$

The aforementioned equations are detailed in “Evaluating Scour at Bridges” [10] and are used to calculate the local scour in a pillar with a complex foundation exposed to the flow of water. This complex foundation is made up of a footing and pilings.

For the calculations of local scour in the abutments, the Froehlich formula was used because the relationship between the projected length of the abutment and the flow depth is less than 25, while for the calculation of the general scour the method of Lischtvan-Levediev, since this method will avoid calculating shrinkage scour [11].

Equation (5) is used to find the local scour in the abutments:

$$\frac{y_s}{y_a}=2.27K_1k_2\left(\frac{a}{y_a}\right)^{0.43}Fr^{0.61} \tag{5}$$

Equation (6) is used to find the general scour:

$$H_s=\left[\frac{\alpha H_0^{5/3}}{0.60\beta\mu\phi\gamma_s^{1.18}}\right]^{(1/(1+X))} \tag{6}$$

C) *PHASE 3*

In both models the data from the topographic survey and bathymetry survey carried out in the area were entered.

The validation of both models consisted in obtaining the value of the water level for the flow $Q_{2.33}$ in a control section (Section 0 + 560 Km), the water level value registered *in situ* was 487.90 meters above sea level.

1. 1D Validation and modeling (HEC-RAS)

The creation of the spaced sections was carried out every 40 m as can be seen in Figure 1, then the simulation parameters were entered to validate the water level

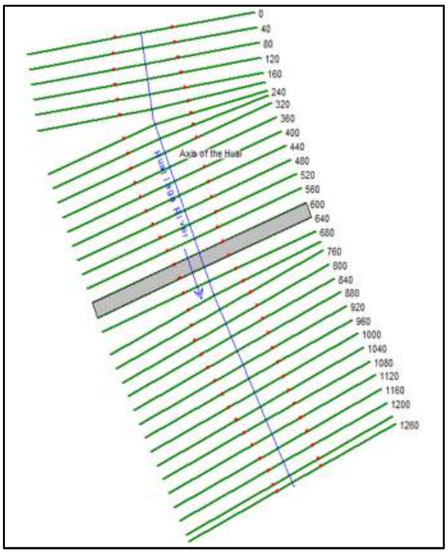

Fig. 1. Distribution of cross sections (HEC-RAS Program)

The water level obtained in the HEC-RAS model in the control section was 487.90 meters above sea level, as seen in Figure 2, with which the model was validated for subsequent simulations and calculations.

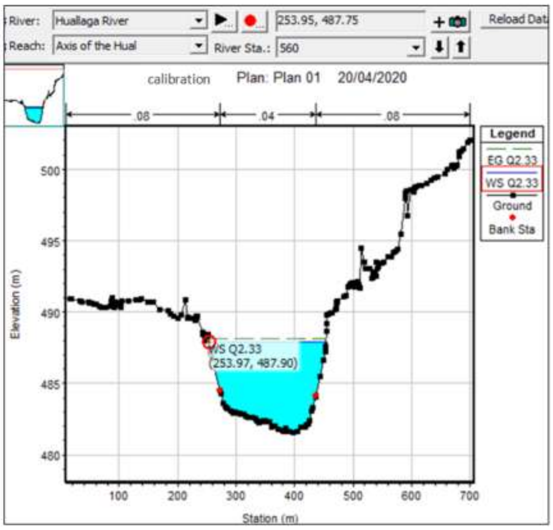

Fig. 2. Water level validation in 1D (HEC-RAS Program).

Finally, the geometry of the bridge was placed in the 1D model and the simulation was performed for the Q_{500} flow. The 1D model is seen in Figure 3.

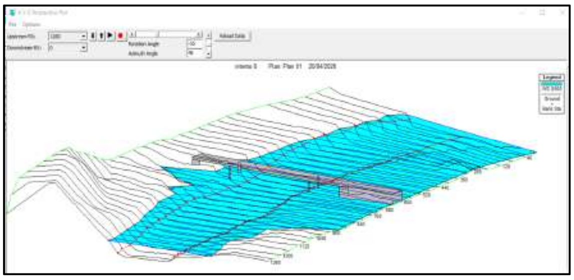

Fig. 3. 1D modeling (HEC-RAS Program).

2. 2D Validation and modeling (IBER)

The geometry was imported in DXF format from the CIVIL 3D model, then the model was collapsed to eliminate duplicate entities, all the necessary parameters for the

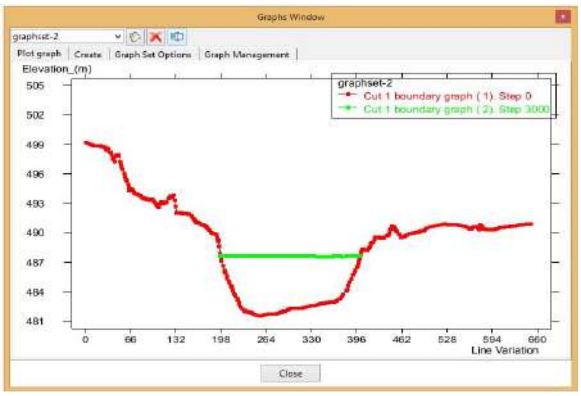

Fig. 4. Water elevation validation in 2D (IBER Program).

validation simulation were assigned and, as shown in Figure 4, the value of 487.65 masl in the control section (0 + 560Km).

After having validated the control section, the geometry of the bridge was entered and the model was simulated with the Q_{500} flow, for a period of 3000 s. The 2D model can be seen in Figure 5. The simulation process on the 2D model took around 8 hours.

The draft, flow velocity and Froude number values of both models were obtained to be able to perform the calculations of local scour in the towers (2D and 1D Models), local scour in abutments (2D Model) and general scour (2D and 1D Models). Next, Table II, Table III and Table IV show the values obtained, the calculations performed and the scour results.

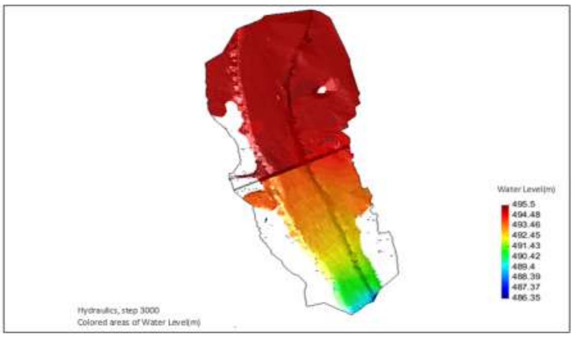

Fig. 5. 2D model (IBER Program).

TABLE II
GENERAL SCOUR CALCULATED FROM THE MODEL DATA

General Scour	Model	
	1D (HEC-RAS)	*2D (IBER)*
α	0.64	0.659
Q (m^3/s)	8625	8625
Hm (m)	12.63	8.281
Área (m^2)	2525.17	3229.71
Be (m)	200	390
M	0.99	0.99
d_0	11.16	13.242
γ_s (Tn/m^3)	1.51	1.51
B	1.01	1.056
Tr (years)	500	500
X	0.33	0.326
Φ	1.1	1.1
Hs (m)	14	17.204
Scour (m)	2.84	3.962

Table III
LOCAL SCOUR IN THE TOWERS FROM THE DATA OF THE MODELS

Local Scour in Towers (m)	Model	
	1D (HEC-RAS)	*2D (IBER)*
Right Pillar	-0.2331	0.048
Left Pillar	-0.2331	-0.04
Right shoe	5.9094	1.619
Left shoe	5.9094	0.304
Right Piles	8.60	3.091
Left Piles	8.60	10.213

TABLE IV
LOCAL SCOUR IN THE ABUTMENT BASED ON THE MODEL DATA

Local Scour in Abutments (m)	Model	
	1D (HEC-RAS)	*2D (IBER)*
Right Abutment	0	0
Left Abutment	7.85	5.527

III. ANALYSIS AND DISCUSSION OF RESULTS

A) Analysis of the modeling in HEC-RAS

Local scour calculations were made with equations (1), (2), (3) and (4), for the Q_{500}, the calculations are shown in Tables V and VI. The scour heights are measured from the bottom of the riverbed and can be seen in Figure 6.

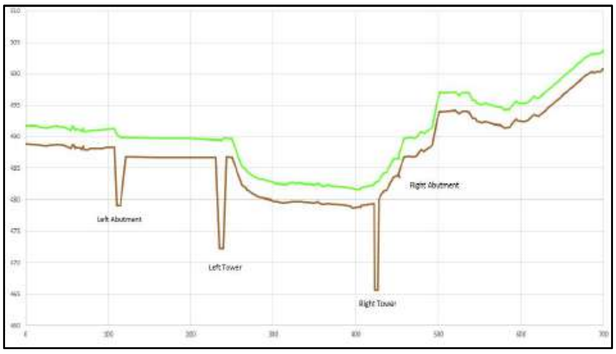

Fig. 6. Cross Section 0 + 560 km, without scour (green line) and with total scour depths (brown line)

TABLE V
SCOUR CALCULATED USING HEC-RAS AND EXCEL

Types of Scour	Scour Depth (m)			
	Right Abutment	***Left Abutment***	***Right Tower***	***Left Tower***
General	2.9	2.9	2.9	2.9
Shrinkage	0	0	0	0
Local	0	7.85	14.27	14.27

TABLE VI
TOTAL SCOUR CALCULATED USING HEC-RAS AND EXCEL

Scour Type	Scour Depth (m)			
	Right Abutment	***Left Abutment***	***Right Tower***	***Left Tower***
Total	2.9	10.75	17.17	17.17

For the design of the foundations of the bridge towers, these scour values must be considered.
Since the river has only one floodplain, located on the left bank, it is important to place a scour defense system on the right abutment and on a section of the access road on the left bank.

B) Modeling analysis in IBER

Local scour calculations were made with equations (1), (2), (3) and (4), for the Q_{500}, the calculations are shown in Tables VII and VIII. The scour heights are measured from the bottom of the riverbed and can be seen in Figure 7.

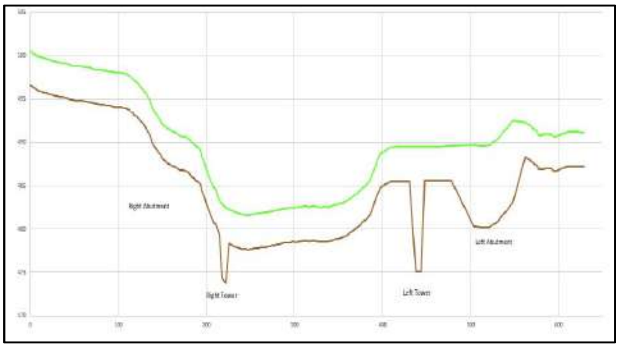

Fig. 7. Cross Section 0 + 560 km, without scour (green line) and with total scour depths (brown line).

Table VII.
TOTAL SCOUR CALCULATED USING IBER AND EXCEL

Types of Scour	Scour Depth (m)			
	Right Abutment	***Left Abutment***	***Right Tower***	***Left Tower***
General	3.96	3.96	3.96	3.96
Shrinkage	0	0	0	0
Local	0	5.53	4.66	10.48

It is noted that the shrinkage calculation is not taken into account, since when using the Lischtvan-Levediev method for the calculation of general scour in the vicinity of a bridge, the shrinkage scour should not be recalculated [11]. Furthermore, in the section under analysis, the river section does not present significant changes in its average width, as shown in Table IX.

TABLE VIII
TOTAL SCOUR CALCULATED USING IBER AND EXCEL

Scour Type	Scour Depth (m)			
	Right Abutment	***Left Abutment***	***Right Tower***	***Left Tower***
Total	3.96	9.49	8.62	14.44

TABLE IX
PERCENTAGE COMPARISON BETWEEN MODEL 1D AND 2D

Scoured Structure (m)	Total Scour		
	1D Model	***2D Model***	***Change (percentage)***
Right Abutment	2.9	3.96	36.6%
Left Abutment	10.75	9.49	-11.7%

Scoured Structure (m)	Total Scour		
	1D Model	***2D Model***	***Change (percentage)***
Right Tower	17.17	8.62	-49.8%
Left Tower	17.17	14.44	- 15.9%

IV. CONCLUSIONS

- After investigating the different calculation methods for scours, it was decided to choose:
  - For general scour, the Lischtvan-Levediev method, as using this calculation method for general scour avoids using an additional calculation to calculate shrinkage scour.
  - For local scour in abutments, the Froehlich method, because the projected length of the abutment divided by the flow depth is less than 25.
  - For local scour in towers (pillars), the method of superposition of scour components, due to the fact that a complex foundation system with footing and piles exposed to river flow was available.
- In the development of the investigation in both models it was identified that the following parameters have a direct influence on the scour calculation: D50, approach speed, Froude number and column geometry. At the same time, the Manning roughness coefficient indirectly affects the scour calculation as it directly varies the approach speed of the water stream.
- Taking into account that the modeling time was similar in both models, the most important variable was the simulation time of the model, while the model in HEC-RAS simulated in 10 seconds, the model in IBER simulated in 8 hours.
- The results of total scour in the Huallaga river bridge obtained from the IBER program vary by -15.9%, -49.8%, 36.6% and -11.7% in the left tower, right tower, right abutment and left abutment respectively compared to the data obtained in the HEC-RAS program. These results validate the hypothesis elaborated, since all the total scour values obtained in the 2D model are lower by more than 10% with respect to the total scour results obtained in the 1D model.
- Taking into account that the negative variation expresses a decrease in the scour depth and the positive variation reflects an increase in the scour depth. It can be stated that the 1D model (HEC-RAS) is more conservative for the calculation of total scour.

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