E-proceedings of the 38th IAHR World Congress
September 1-6, 2019, Panama City, Panama
doi:10.3850/38WC092019-1433

INFLUENCE OF PERMEABILITY ON THE LOCAL SCOUR IN AN ELJ GROYNE

J.D. HUARACA(1), J.M. KUROIWA (2) & L.F. CASTRO(3)

(1) Graduate. School of Civil Engineering. Universidad Nacional de Ingeniería. Lima, Peru
(2) Director, National Hydraulics Laboratory, and Professor, School of Civil Engineering. Universidad Nacional de Ingeniería. Lima, Peru.
(3) Graduate Student and Teaching Assistant. School of Civil Engineering and Researcher, National Hydraulics Laboratory. Universidad Nacional de Ingeniería. Lima, Peru.
e-mail deivi.jdhc@gmail.com, jkuroiwa@uni.edu.pe, lfcastro@uni.edu.pe

ABSTRACT

This article summarizes the result of an experimental program in which the main objective was studying the influence of permeability on the maximum local scour caused by a stream on an Engineered Log Jam (ELJ) groyne. A series of 5 experiments was conducted to study the influence of groyne permeability on the local scour at the groyne tip. One permeable groyne, whose length (perpendicular to the flow direction) was 0.475 m and whose width was 0.26 m was placed on the right side of a rectangular channel. Groynes were made up of cylindrical wood pieces that represented tree trunks. They were interlocked to form a rectangular prism that was a scaled down ELJ groyne. Permeabilities of these structures ranged from 28 % to 51 %. Tests were conducted in a 12 m long flume whose net width was 1.9 m. Maximum discharge was 155 L/s. Initial bed slope was 0.008 m/m. The streambed was composed by sand whose average diameter, D_{50}, was 0.204 mm. An Acoustic Doppler Velocimeter (ADV) was used to measure and map 3D velocities at selected cross sections and around the groyne. A 3D laser scanner was used to capture bed topography before and after the tests. As a result of the experiments it was observed that local scour at the groyne tip decreases when groyne permeability increases. ELJ groyne permeabilities were 28%, 36%, 42.5%, 45.5% and 51%. For these permeabilities local maximum local scour, recorded at the groyne tip were 0.225 m, 0.092 m, 0.090 m, 0.088 m and 0.087 m, respectively. A practical lower limit for maximum local scour was found when the groyne permeability was between 42.5 and 51%. ELJ groyne permeability may be included as a design criterion when local scour is to be reduced in an erosion control project.

Keywords: Engineered Log Jams (ELJ), Permeable Groynes, Local Scour, Riverbank Erosion Control, River Hydrodynamics

1 INTRODUCTION

Riverbank protection constitutes a challenge where no suitable materials for erosion control can be found in the vicinity of the reach of interest. Where stony material is available, training structures are usually made of loose rocks (riprap) and gabions. In the latter case, cobbles are used to fill wire boxes. Such solutions are described in Richardson et al (2001). Large Wood Debris (LWD) were first used as a method to protect riverbanks in the early 80s (House & Boehne, 1985). Bakker et al. (1985) presented the results of 20 years of practice using wooden screens to protect coastal sites. Site measurements indicated that current velocities can be reduced up to 65 %.

Researchers in North America and United Kingdom have proposed the use of logs deposited along riverbanks to build erosion control structures (Herrera Environmental Consultants 2006). Shields et. al (2001) tested the so-called Engineered Log Jams (ELJ) in small streams in Mississippi, USA. This measure proved to be effective for controlling erosion along the banks of the streams when this technique was implemented in a reach draining a 37-km^2 basin. Failure only occurred in structures with no adequate anchoring. ELJ, like other structures built within a stream, are prone to local erosion. The jammed nature of an ELJ provides additional stability when local erosion occurs near its head (Brooks, 2006). Long-term effect of LWD deposited across rivers on river morphology has been studied by Abbe et al. (2003), among others.

There are not rock quarries in the lowlands of the Amazon Jungle, at least within the Peruvian borders. Reports from Consorcio Hidrovia Huallaga (2005) indicate that floating logs cover the entire water surface at maximum floods in rivers of the Amazon Basin. Deposited logs and trees could be used to form ELJ groynes to control erosion along the riverbanks of the lower reaches of the Amazon basin. They could be collected in the outer bank of a river bend where groynes may induce stagnation and deposition of LWD within the groyne field (Chuan et al, 2019).

Brown (1985) studied different parameters for designing flow control structures. Among these parameters was the structure's permeability. He concluded that depth of scour was inversely proportional to the structure's permeability and values between 30 % and 50 % were proposed for designing this type of structures. A value of 30 % was indicated as optimal to control flow velocities near the riverbank. Julien (2002) indicated that permeability is one of the most important properties of erosion control structures and defines permeability as the proportion of area of net openings through which flow passes by divided by the total area of the structure perpendicular to the flow. An increase of permeability induces reduction of the flow near a groyne's head but the minimum velocities near the bank tend to increase (Mahmoud et al., 2012). A number of flow experiments on fixed and mobile beds have been conducted to observe flow patterns around ELJs. For example, the effect of long logs on bed morphology has been studied by Wallerstein et al (2001) and Svoboda and Russel (2011). The effects of orientation of the larger LWD elements on bed morphology was studied by Cherry and Beschta (1989) whereas drag coefficients of logs and morphologic changes due to LWD was studied by Gallisdorfer et al (2013).

Use of ELJ structures has been studied at the National Hydraulics Laboratory, a water resources research center of the National University of Engineering in Lima, Peru. For instance, Bautista (2018) and Bautista et al. (2019) presented erosion and deposition patterns in an ELJ groyne field. This paper summarizes the result of an experimental study in which permeability of an ELJ structure was modified in a series of tests to find a relationship between permeability and local scour. Froelich's best fit equation, which does not include a safety factor for design purposes, for estimating local scour was used as a basis.

2 THEORETICAL BACKGROUND, MAIN ASSUMPTIONS AND METHODOLOGY

A single groyne can be thought of a structure that contracts the flow in a cross section in a similar manner as an abutment. Richardson et al (2001) summarize a number of studies conducted to estimate local depth of scour near the abutment. Main variables that affect local scour, y_s, are discharge, cross sectional area, A; flow depth, y; abutment intrusion, L; abutment shape, represented by a factor K_1 and flow direction, represented by a factor K_2, as follows.

$$y_s = f\ (Q, A, V, y, L, K_1, K_2) \qquad [1]$$

Little is known of the effect of permeability on local scour that occurs near ELJ groynes. It is presumed that by allowing flow passage through the structure interstices, effect of flow separation near the tip of the groyne may be reduced.

Froelich (1989) proposed an equation to find maximum local scour, y_s, as a function of y, L, and the Froude number. Data was gathered from 170 laboratory flume experiments in which sand was the bed material. Therefore, Froelich´s equation may be suitable for comparison. The equation, that included a safety factor for design (the term +1 on the right-hand side), follows:

$$\frac{y_s}{y} = 2.27. K_1. K_2 \left(\frac{L}{y}\right)^{0.43} Fr^{0.61} + 1 \qquad [2]$$

The factor K_1 is a function of the abutment shape and the factor K_2 is $(\theta/90)^{0.13}$. Where θ is equal to the angle between the approach embankment and a line drawn normal to the main flow. The direction of the flow, given by θ in sexagesimal degrees, is greater than 90º when the embankment points upstream and less than 90º when it points downstream. Fr in the previous equation is the Froude number. When the scour depth is to be estimated and no safety factor is considered, the + 1 term on the right-hand side is dropped. If a factor that takes into account the structure permeability is called C, to estimate the maximum depth of scour could be written as:

$$\frac{y_s}{y} = 2.27. C(P). K_1. K_2 \left(\frac{L}{y}\right)^{0.43} Fr^{0.61} \qquad [3]$$

Where C (P) is a factor that depends on the structure´s permeability. K_1 is 1 in vertical abutments and K_2 is also 1 as groynes were installed perpendicular to the direction of the flow. C(P) can be obtained by dividing (y_s/y) by 2.27 $(L/y)^{0.43}$ $Fr^{0.61}$. After the factor C is obtained, a correlation with P may be obtained.

3 EXPERIMENTAL FACILITIES, EQUIPMENT AND PROCEDURES

3.1 Experimental Facilities and equipment

The experimental phase of this research program was conducted at the National Hydraulics Laboratory “Alfonso Alcedan La Cruz” (LNH, acronym in Spanish), a research center of the National University of Engineering in Lima, Peru.

The experimental stand was housed by the Didactic Division building of the LNH. An underground reservoir stores up to 80 m^3. Four sump pumps deliver a total nominal discharge of 700 L/s. In this case, only one 37.3-kw (50 HP) pump capable of delivering a maximum nominal discharge of 200 L/s was used to convey water to an elevated reservoir outside the building. A 356 mm diameter overflow pipe returned excess flow to the underground reservoir. A 356 mm slide gate and a 50 mm by-pass valve controlled incoming discharge. Flow was controlled in by a 1.58-meter rectangular weir placed upstream of a dissipation basin, which is located on the upstream end of the flume. Tests were conducted on a 12-meter-long flume whose width and height were 1.9 m and 1.4 m, respectively. Bed slope was set at 0.0008.

An ELJ groyne was placed on the right side of the flume in each test. Permeability varied by modifying separation between ELJ elements.

At the downstream end, a rectangular tilting gate was used to control water levels. Downstream of the tilting gate, a rectangular canal conveyed return flows. Grates located at the bottom on the downstream of the canal allowed flows to return to the underground reservoir from where water was recirculated. Figure 1, below, shows a schematic of the main components of the experimental stand.

Dimensions of the ELJ groyne remained constant for all tests. Length of the structure, L_T, perpendicular to the flow, was 500 mm. Width (dimension in the flow direction) and total height of the structure were 250 mm and 600 mm, respectively. Bed material was a sand whose d_{50} was 0.204 mm. D_{84} and d_{16} were 0.514 and 0.151 m, respectively, rendering a standard deviation of 1.84. Coefficient of uniformity was 2.2.

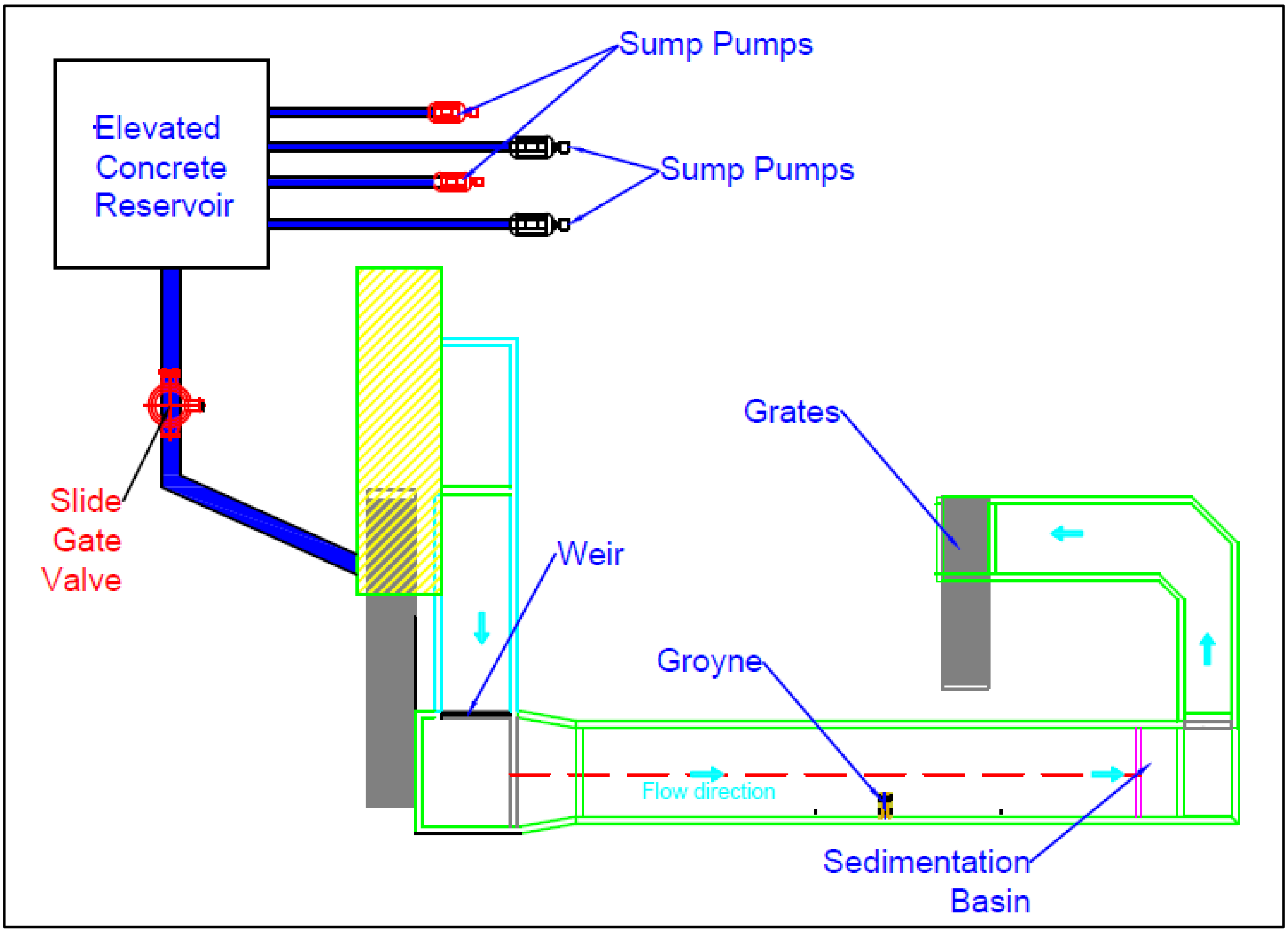

Figure 1. Schematics of module used in the experimental phase.

A steel platform was used to safely measure water and bed levels and velocity fields. A limnimeter was mounted on a geared steel bar and an engineer´s level was used to read water level. An Acoustic Doppler Velocimeter (ADV) was used to gather data of the velocity fields at selected cross sections. This device was connected to a laptop where data was temporarily stored for posterior processing. Bed topography before and after the tests was obtained by 3D laser scanning. Paraview, an open-source code developed by Sandia

National Labs, was used for visualization of the bed topography, obtaining cross sections and average and maximum velocities.

3.2 Experimental procedures and data collection

The 12-m-long flume was slowly filled to avoid initial scour of the bed. The downstream tilting gate was raised to increase water level and avoid initial scour around the ELJ groyne. The gate was lowered afterwards to reach the target water surface level. The 50-HP pump was turned on to deliver water to the elevated reservoir. Water was conveyed to the upstream end of the experimental stand. A 356 mm slide gate and a 50 mm by-pass valve were used to control flow during the tests. This experimental module was the same used as Bautista (2019), although in this case a single groyne was installed and mainly local scour data was gathered. Collection of velocity field and water level data started half an hour after flow was stable.

Velocity fields were measured using the ADV profiler at 11 cross sections and along 13 verticals in each vertical section. Schematics of the cross sections and longitudinal alignments where velocity fields were measured is given in Figure 2. The first measurement was taken 75 mm above the bed level Additional readings were taken in 35 mm increments until reaching a point near the surface where readings were erratic due to water level fluctuations and aeration. Fluorescein, dissolved in water, was used as a tracer for flow visualization. Polystyrene balls were also released from the upstream end for visualizing the flow field. Figure 3a, below shows schematics of the ELJ groyne and dimensions L_T, B and H. Elements that represent tree logs and are assembled to form the ELJ groyne were made of mahogany. The trunk´s diameter was 10 mm and the diameter of the disk at the bottom end, simulating the rootwad was 25 mm. Permeability varied by changing spacing between simulated logs. Figure 3b shows a 28 % permeability groyne.

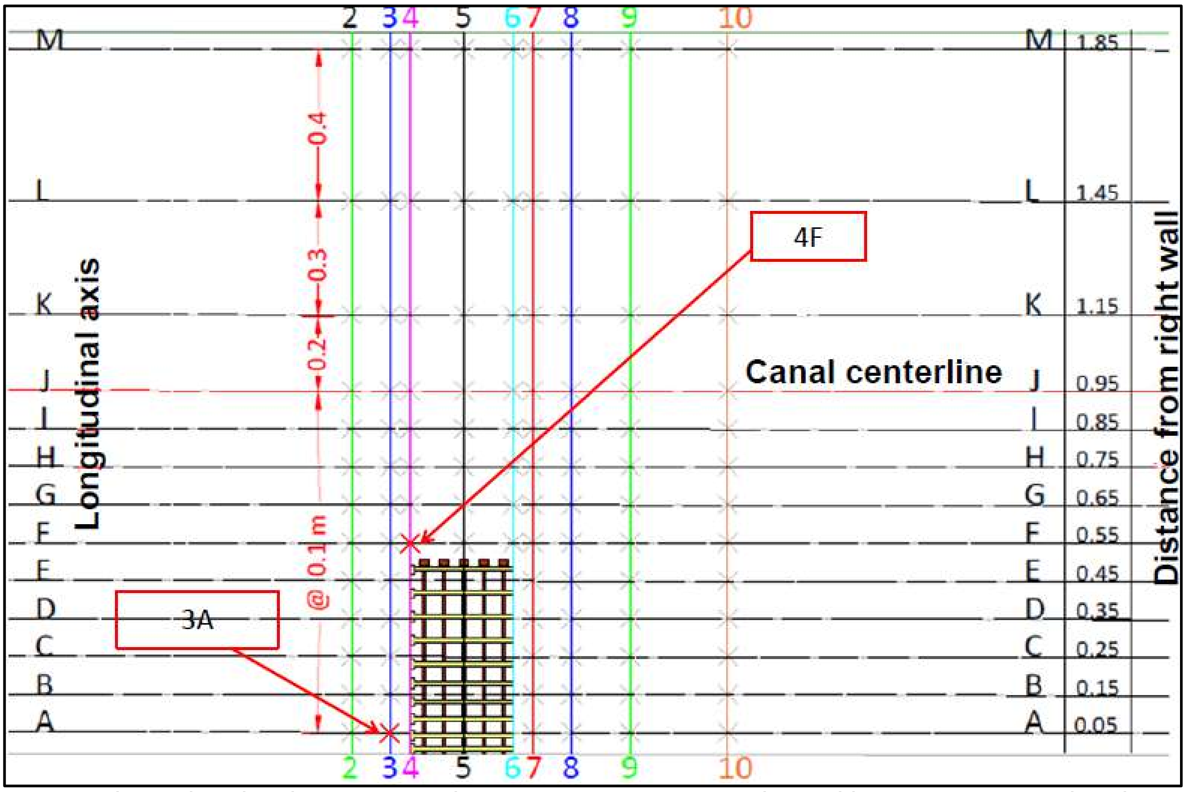

Figure 2. Schematics showing cross sections were water levels and velocities were measured. Alignments were instruments gathered data are labeled A through M. Velocities measured in points 4F and 3A are used for data analysis.

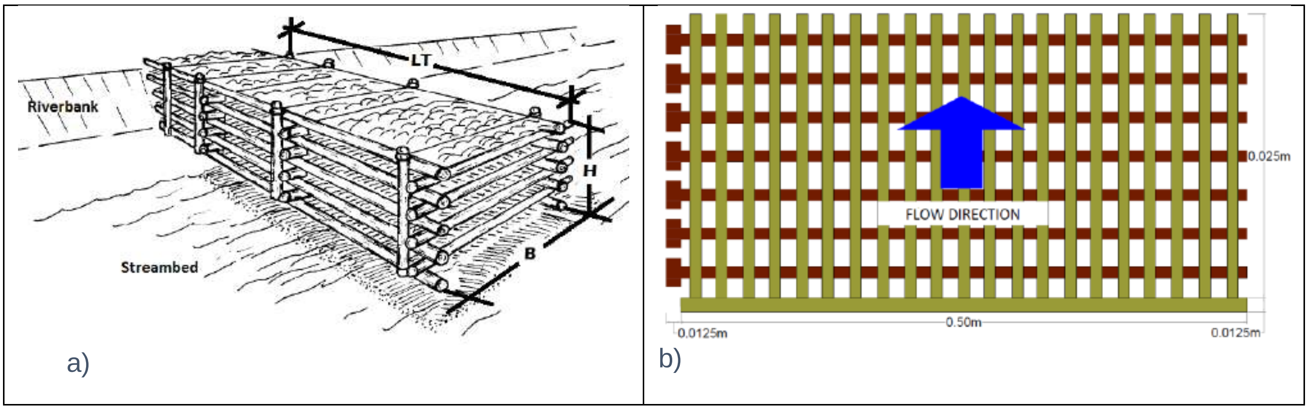

Figure 3. Schematics of ELJ groyne is shown in a). Plan view of an ELJ groyne is shown in b).

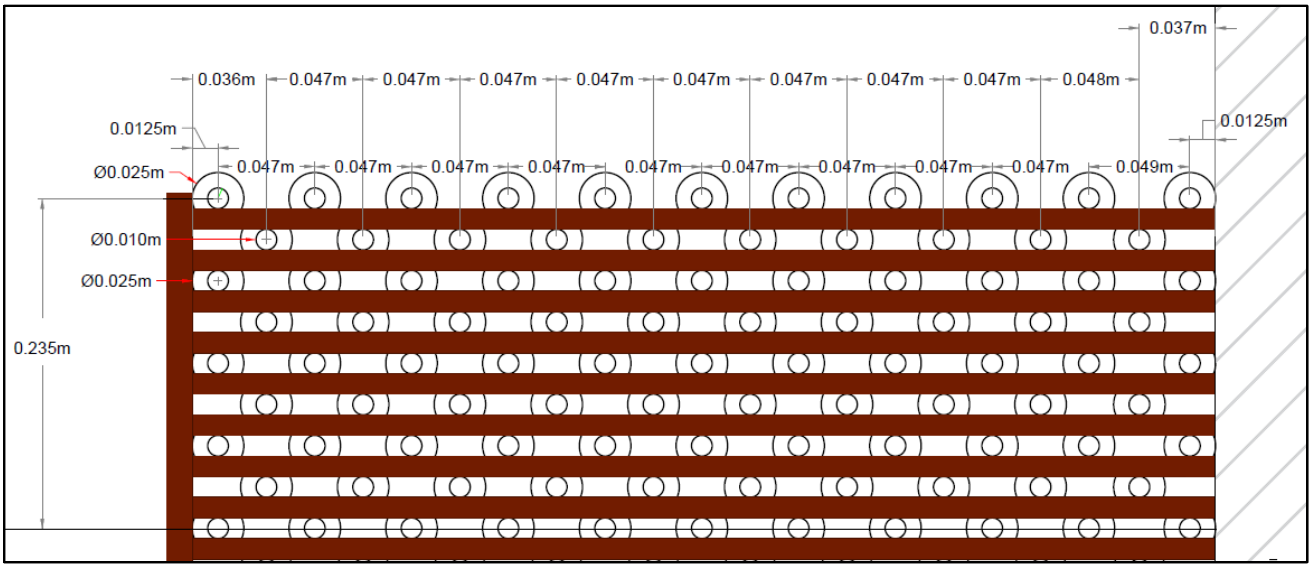

Figure 4. Front view of an ELJ groyne whose permeability is 28 %.

Figure 5. Velocity field data acquisition using an ADV profiler near the ELJ groyne. This photograph was taken looking in the downstream direction.

Figure 6. View of the flume bed after a test. Notice bedforms and scour pattern around the ELJ groyne

Target discharge and flow depth were 155.4 L/s and 235 mm, respectively. These variables remained constant in all tests, being permeability the main changing variable. Tests lasted 12 hours and the target discharge remained constant for 9 hours. No appreciable scour was observed in the last two hours of the test.

4 DATA ANALYSIS AND DISCUSSION

Velocity data was processed using Matlab 2015b so that flow patterns upstream, at the groyne tip and downstream of the structures could be visualized. Figures 7 and 8 show maximum velocities and average velocities along the verticals, respectively, when the ELJ groynes permeability was 51 %. Figures 9 and 10 show maximum velocities and average velocities when the groynes permeability was 28 %. It can be clearly seen that groyne permeability affects flow patterns around this type of structure. The change of flow direction around the groyne’s head is more pronounced when permeability is lower. This can be explained by the fact that a more permeable structure allows a larger discharge to pass through the structure´s interstices. Flow is divided so that a fraction is diverted to the interior of the flume and the rest passes through the ELJ groyne, reducing both velocity and change in direction near the groyne’s head.

Figure 11 maximum velocities at point 4F. It can be clearly seen that velocities diminish as groyne permeability increases. This effect becomes less pronounced when permeability is greater than 45.5 %.

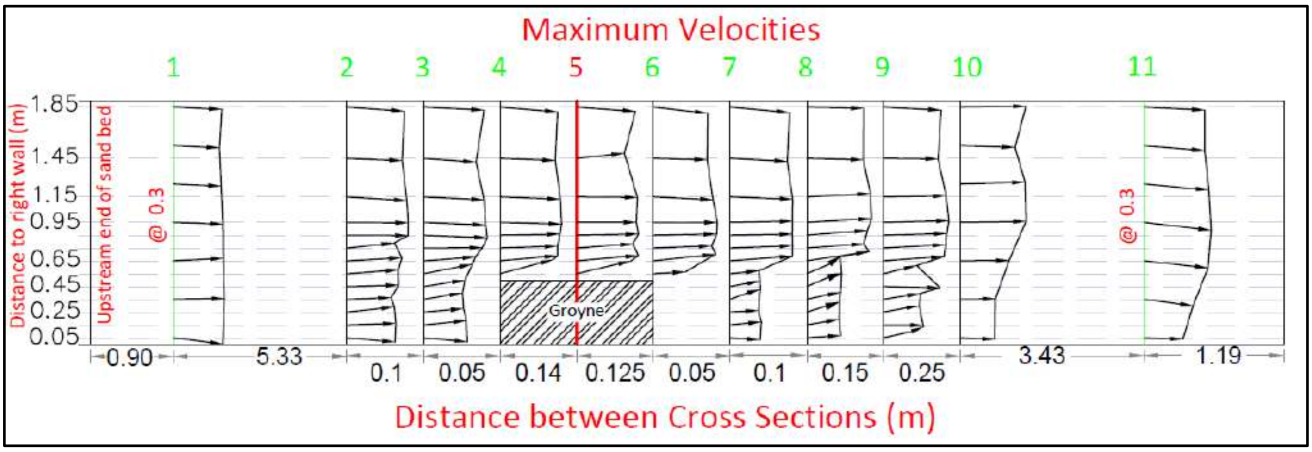

Figure 7. Maximum velocities when groyne permeability was 51 %.

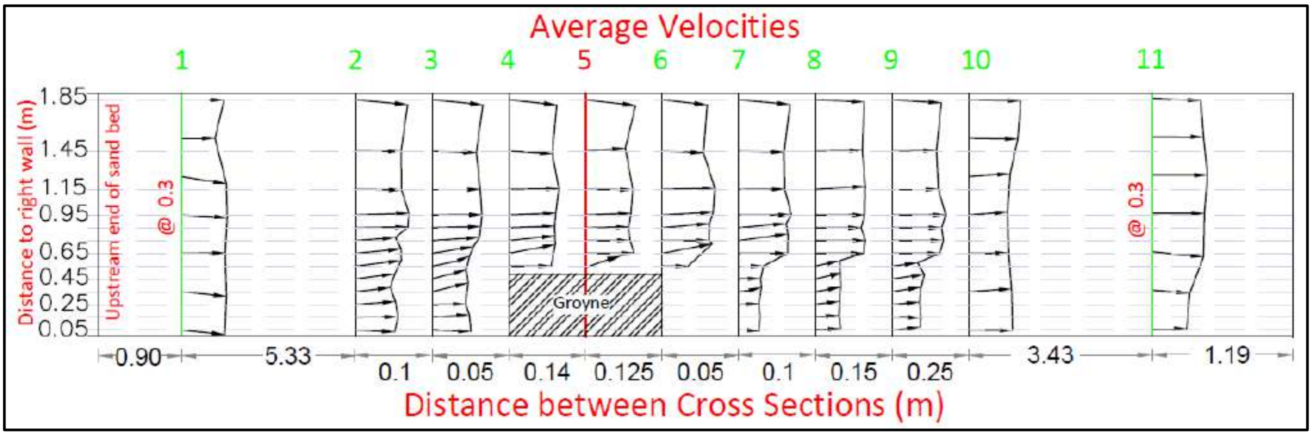

Figure 8. Average velocities along vertical alignments when permeability is 51 %.

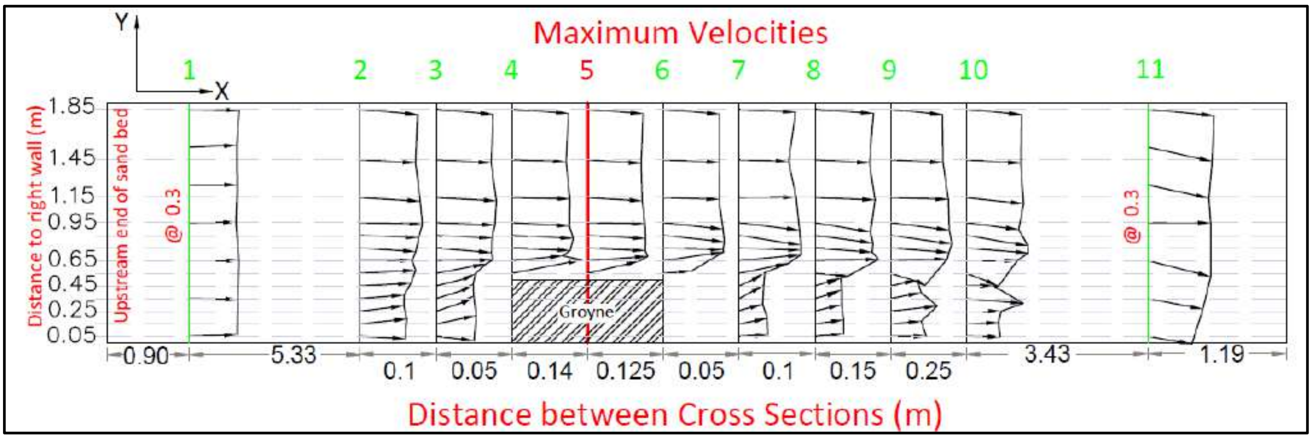

Figure 9. Maximum velocities when groyne permeability was 28 %.

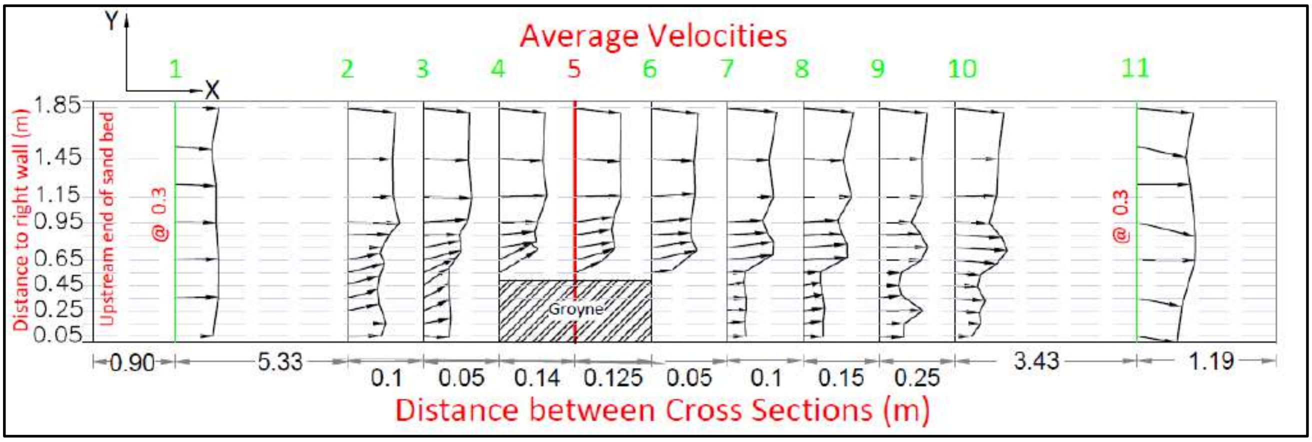

Figure 10. Average velocities in the vertical when groyne permeability was 28 %.

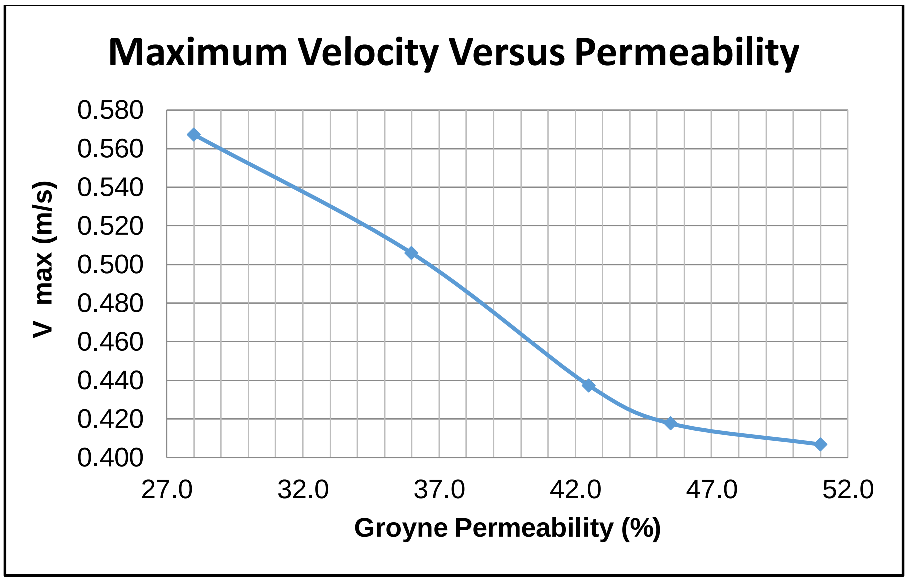

Figure 11. Maximum velocities at point 4F versus ELJ groyne permeability. Notice that velocities decrease as permeability increases. This effect is less pronounced when permeability is greater than 45.5 %.

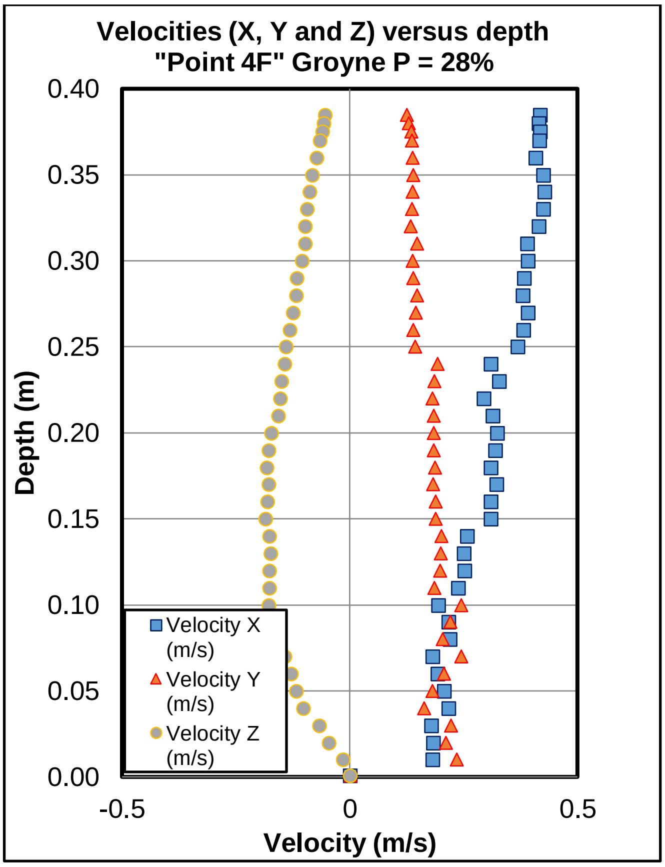

Figure 12. Velocities in the X, Y and Z directions at point 4F when the groyne permeability is 28 %.

Figure 12 (see previous page) shows that flow near the groyne's head is essentially tridimensional. Components of velocity in the Y and Z directions are of the same order of magnitude as the velocity in the X direction. When permeability increases, vortex intensity around the groyne head decreases and, consequently, scour potential also diminishes.

Paraview was used to obtain the cross sections shown in Figure 13. Also, Paraview allowed observing the bedforms. Dunes were the predominant bedform upstream and downstream of the groyne. The observed bedform was flat bed near the groyne's head. This became more evident in the less permeable groyne (P = 28%).

Maximum depth of local scour, y_s, was obtained by subtracting average contraction scour from total scour. Bed level in sections in the contracted reach were used for calculating average level due to contraction. Schematics in Figure 13 shows average bed level in the contracted section and scour in the contracted section. Notice that the average bed level coincides with the elevation at which the cross-section bed profile shows a sharp change in slope (inside the circle). Froude numbers were calculated using average velocities upstream of the groyne and flow depth. Factors K_1 and K_2 are equal to 1 as the ELJ groyne can be considered rectangular in shape and the structure's longest axis is perpendicular to the flow. Table 1 summarizes dimensionless parameters obtained from data gathered by Huaraca (2019). Factor C was estimated using Equation [3] presented in section 2 of this article. As it can be seen in Figure 14, C is approximately 0.3. However, there appears to be a linear correlation between C and the groyne permeability, particularly when this variable is greater than 36 %. Equation [4] shows the relation between C and P (in %).

$$C = 0.387 - 0.0019P \quad [4]$$

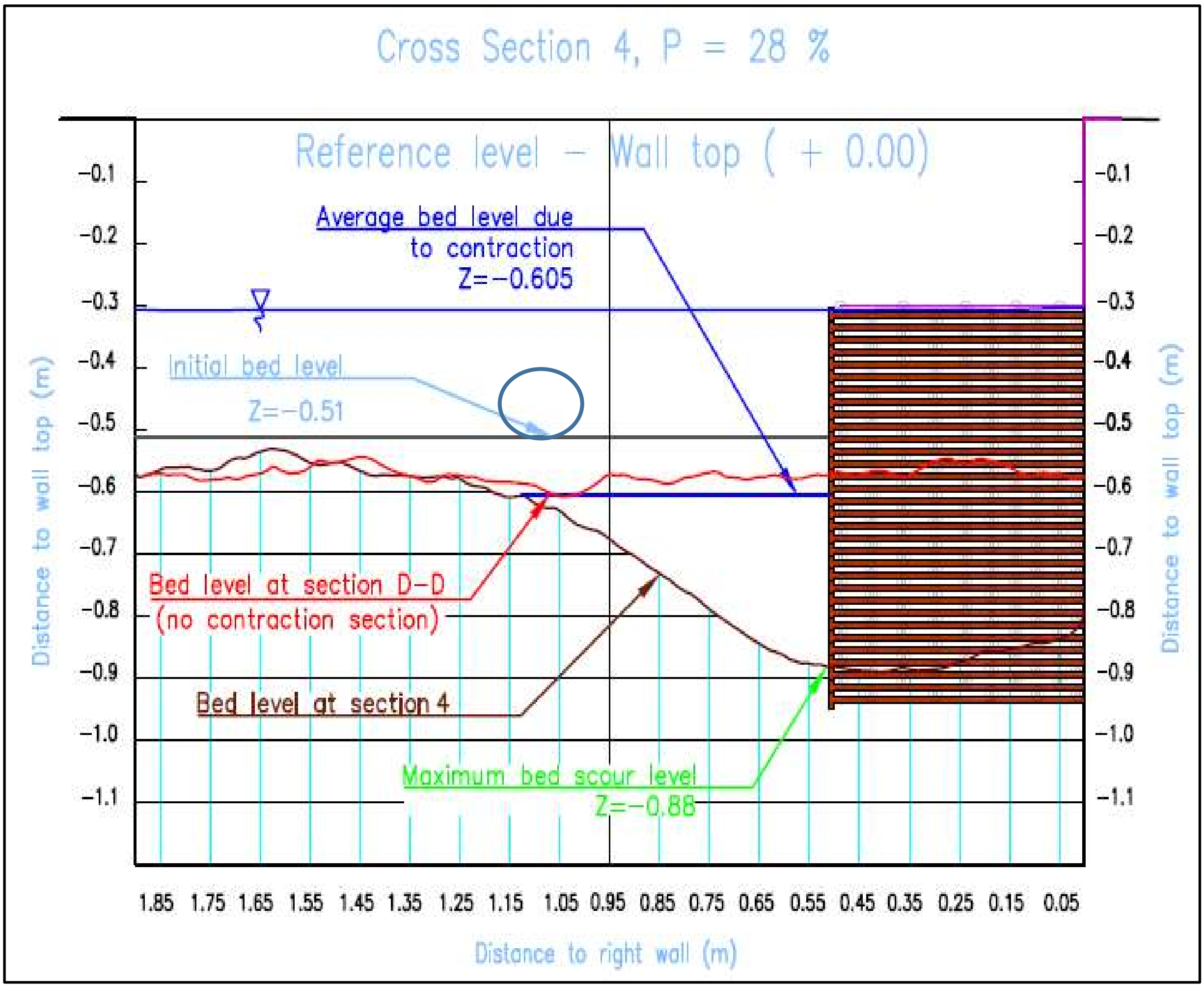

Figure 13. Cross section in the reach where the scaled down groyne was installed. Notice the change in bed profile slope

Table 1. Dimensionless parameters considered in this study (Huaraca, 2019).

Permeability (%)	**y_s/y**	**Fr**	**L/y**	**K_1**	**K_2**
51.0	1.049	0.187	1.79	1	1
45.5	0.977	0.171	1.72	1	1
42.5	1.024	0.182	1.76	1	1
36.0	0.977	0.173	1.69	1	1
28.0	0.961	0.171	1.67	1	1

]

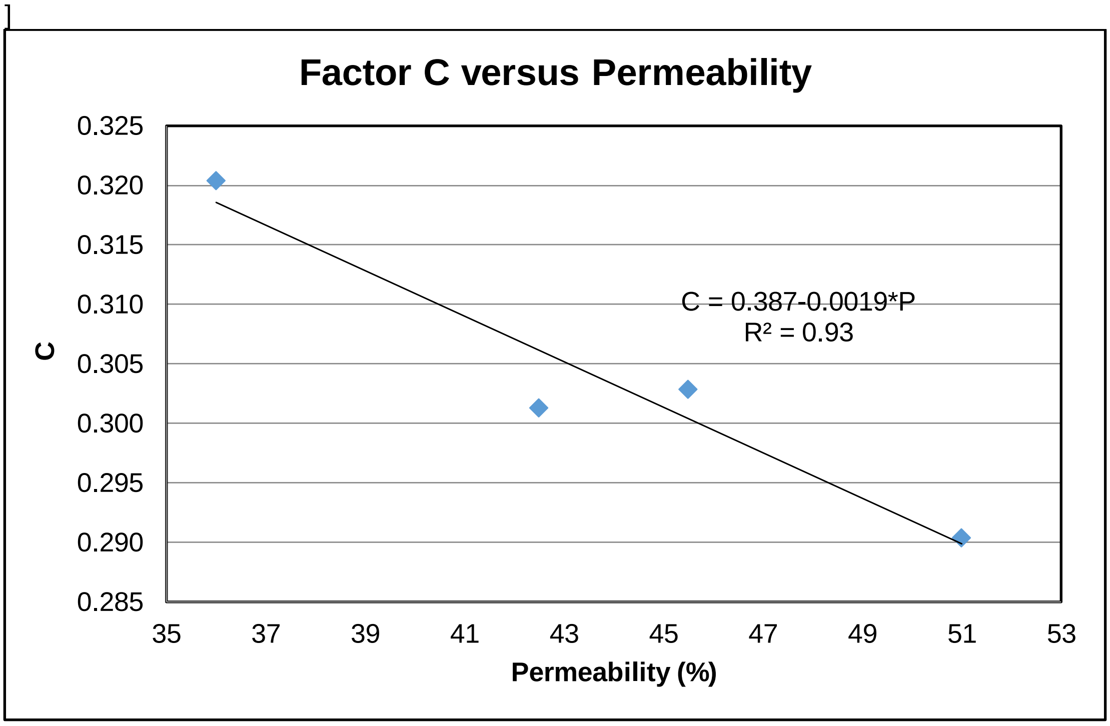

Figure 14. Factor C as a function of permeability. P is given in percentage.

5 CONCLUSIONS AND RECOMMENDATIONS

An experimental program was conducted to study the influence of permeability on local scour of ELJ groynes. A dimensionless factor, C, representing the influence of groyne permeability on a modified Froelich´s formula for calculating maximum local scour in an ELJ groyne, was obtained.

Average value of C is approximately 0.3. However, it appears to be a linear correlation between C and groyne permeability, P, for the kind of structure tested in this experimental program when permeability ranges between 36 and 51 %. It was shown that maximum velocities near the groyne tip (at point 4F) diminish as permeability increases. Greater permeability diminishes the intensity of the flow near the groyne's head by allowing partial passage of flow through the ELJ groyne's interstices, thus weakening the vortex around the structure and the scour potential. Results from this limited experimental program show that optimal permeability ranges from 42.5 % and 51 % because local scour and maximum velocities are the lowest of all tests. Velocities do not appear to diminish further when permeability exceeds 45.5 %. Furthermore, greater permeabilities may affect the stability of the structure.

This result can be applied for this type of structure as other configurations may alter flow patterns around the structure and, therefore, alter the depth of scour. Further tests should be conducted to confirm the relation between C and P using other kinds of ELJs.

The structure's stability should be taken into account when determining the final structure's permeability. Other considerations, that are not examined in detail in this paper, indicate that a permeability of 37 % could be adequate for this type of erosion control measure. This permeability may not be uniform throughout the structure. It is rather the average of permeabilities of three different segments in which permeability is lower near the groyne's tip.

ACKNOWLEDGEMENTS

The first author received formative research fund FIC-F-7-2016 from the Office of the Research Provost of Universidad Nacional de Ingenieria to finance the experimental phase of his professional thesis. In addition, this study was part of contract Nº 358-PNICP-PIAP-2014, signed between the National University of Engineering (UNI) and the National Innovation Program for Competitiveness and Productivity of the Ministry of Production (INNOVATE PERU). The authors also would like to thank Jhon Bautista, Martin Cieza, Alfredo Jacay, Mishel Reyes, Jhostyn Nina and Walter Chuan, research interns who participated in the preparation and data collection of the tests. Mr Hugo Saca built the ELJ groynes that were used in the tests and set up the bed prior to the tests. Messrs. German Quinte and Israel Chuquimajo helped repair and provide maintenance to the electromechanical equipment.

REFERENCES

Abbe, T.B., Brooks, A.P., Montgomery, D.R. (2003) Wood in river rehabilitation and management. In: Gregory, S.V., Boyer, K.L., Gurnell, A.M. (Eds.), The ecology and management of wood inworld rivers. American Fisheries Society, Symposium, vol. 37. Bethesda, Maryland, pp. 367-389.

Bautista, Jhon Alex (2018) Eficiencia De Un Sistema De Espigones Permeables Fabricados Con Troncos De Árboles En La Retención De Sedimentos En Ríos Amazónicos. Professional Title Thesis (In Spanish). School of Hydraulic Engineering. Universidad Nacional de Cajamarca. Cajamarca, Peru.

Bautista, J.A.; Kuroiwa, J.M; Huaman, J.F; and Castro, L.F (2019) Influence of Permeability on Sediment Trapping Efficiency in an ELJ Groyne Field. Proceedings of the World Water Resources and Environment Congress 2019. Pittsburgh, VA. American Society of Civil Engineers.

Bakker, W. T.; Hulsbergen, C. H.; Roelse, P.; Smit, C.; Svasek, J. N. (1985). Permeable Groynes: experiments and practice in the Netherlands. Coastal engineering Proceedings, 19, 2026-2041.

Brooks, A. P. (2006). Design guideline for the reintroduction of wood into Australian streams. Camberra: Land & Water Australia.

Brown, S. A. (1985). Design of spur-type streambank. Stabilization structures Final Report, "FHWA/RD-84-101". Washington D.C.: US Department of Transportation. Federal Highway Administration.

Cherry, J., Beschta, R.L. (1989). Coarse woody debris and channel morphology: A flume study. Water Resour. Res., 25, 1031-1036.

Chuan, W; Kuroiwa, J.M; Castro, L.F. and Vasquez, L. (2019) Transport and Trapping of Woody Debris in A River Meander Protected with ELJ Groynes. E-proceedings of the 38th IAHR World Congress. September 1-6, 2019, Panama City, Panama.

Froehlich, D. C. (1989). Abutment Scour Prediction. Annual Transportation Board Meeting, Washington, D.C.

Gallisdorfer, M. S.; Bennett, S. J.; Atkinson, J. F.; Ghaneeizad, S. M.; Brooks, A. P.; Simon, A.; Langendoen, E. J. (2014). Physical-scale model designs for engineered log jams in rivers. Journal of Hydro Environment Research, 8, 115-128.

Herrera Environmental Consultants (2006). Application of Engineered Logjams - Conceptual Design Guidelines. Scottish Environmental Protection Agency. Scotland, UK

House, R. A. & Boehne, P. L. (1985). Evaluation of instream enhancement structures for spawning and rearing in a coastal Oregon stream. North American Journal of Fisheries Management, 5, 283-295.

Huaraca, Jean Deivi (2019) Estudio Experimental De La Influencia De La Permeabilidad En La Erosión Local De Espigones De Troncos De Árboles. Professional Title Thesis (in Spanish). School of Civil Engineering. Universidad Nacional de Ingenieria. Lima, Peru.

Julien, P. Y. (2002). River mechanics. New York: Cambridge University Press.

Mahmoud M. M.; Ahmed H. S.; Abd El Raheem G.A.; Ali N. A. and Tominaga A. (2012) Flow analysis around Groyne with different Permeability in compound channel Floodplains. Flow analysis around groyne with different permeability in compound channel floodplains. Journal of Engineering Sciences, 41, 302-320.

Richardson, E.V., Simons, D.B. & Lagasse, P.F. (2001) *River Engineering for Highway Encroachments – Highways in The River Environment*, US Department of Transportation, Federal Highway Administration. Publication No. FHWA NHI 01-004 (Hydraulic Design Series Number 6).

Svoboda, C. D. & Russel, K. (2011) Large wood structures for scour development and habitat. World Environmental and Water Resources Congress: Bearing Knowledge for Sustainability. ASCE, 2572-2581.

Wallerstein, N.P., Alonso, C.V., Bennett, S.J., Thorne, C.R. (2001) Distorted Froude scaled flume analysis of large woody debris. Earth Surf. Processes Landforms, 26, 1265-1283.