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Blocking Probability of Individual Logs at Racks in Rivers

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Abstract

Driftwood racks are installed in rivers to hold back arriving logs at a hydraulically acceptable place, so that the downstream reach is protected from potential flooding. The bar spacing is a central rack parameter and was considered herein with physical modelling. Single driftwood logs (uncongested arrival) were supplied serially and their blocking or passage was counted and set in relation to the relative rack bar spacing and to the approach flow conditions. The data analysis, also considering approaches published in literature, provided an empirical estimation to predict the blocking probability.

Keywords: Bar Spacing; Blocking Probability; Driftwood; Rack; River.

1. INTRODUCTION

Driftwood is a natural element of many rivers, as water and sediments are. It has an important ecological value, but might also represent a risk. If transported to narrow flow sections, it can jam and thereby alter the flow features of the river, causing flooding. Critical infrastructures in the floodplain of such a river consequently have to be protected. Racks are an efficient measure to hold back the driftwood at a non-critical section upstream of the infrastructure and remove it after a flood event.

Extensive literature is available about the design of driftwood racks in rivers. Given the wide range of driftwood characteristics as well as of the river boundary conditions, most studies report of specific cases. Studies presenting systematical variations of the dominant hydraulic parameters related to the design of driftwood racks in rivers seem rare. Hereafter, we highlight few studies with a direct link to our work.

- Godtland and Tesaker (1994) analyzed the blockage of driftwood at weirs, considering single logs as well as batches. As for the single logs, they stated that the bay width between piers (similar to a rack bar spacing) should exceed 80% of the longest log to assure the passage of most logs. Specific blocking probabilities are not discussed, nor a quantification of the effect of the bar spacing. The study of Bénet et al. (2021, 2022) supported the observations of Godtland and Tesaker (1994).
- Knauss (1995) tested different rack types in a physical model to find an optimum set-up for his considered case. The study was systematically conducted, and many practical recommendations resulted.
- Hartlieb (2015) conducted model tests on weirs and completed his results with data of Knauss (1995), among others. He concluded that the blocking probability was related to the bay width, which can be also interpreted as a rack bar spacing.
- Schalko (2018) conducted extensive model tests on driftwood racks and on bridge piers, and derived several design equations. The blocking probability resulted for individually arriving logs at bridge piers, and the backwater level rise was derived for jammed racks.
- Zenoni (2022) conducted experiments on linear racks installed transversally either perpendicular to the flow or oblique (similar to Knauss 1995), and derived the blocking probability and the tailwater level rise. The tests were done with batches of driftwood. As for the level rise, the approach of Schalko (2018) gave good results. The blocking probability depended on the relative rack bar spacing and on the approach flow conditions.

The interaction of driftwood with racks, as well as the following upstream level rise, are complex issues. The present study therefore considered a simple set-up and a focused research question. The set-up consisted of a linear rack installed transversally in a channel (Figure 1) with variable bar spacing, combined with different flow conditions. Simple wooden logs simulating trunks were supplied individually and their blockage at the rack was observed. The blocking probability was finally linked to the relative bar spacing and the flow conditions.

2. EXPERIMENTAL SETUP

Experiments were conducted in the Hydraulic Laboratory of HEIA-FR using a horizontal channel with a fixed bed of B=0.61 m width and of 4.10 m in length. The channel bottom was made of glass plates and the side walls of PVC.

The discharge was provided by the pumping system of the channel with maximum values of roughly Q=0.01 m^3/s, and measured with a magnetic-inductive flow meter (Endress+Hauser, measurement accuracy of ±0.5% FS). The flow depths were regulated independently of the discharge via a flap gate positioned at the channel end. The flap was either fully opened, so that quasi-critical flow established in the channel, or partially closed generating subcritical flow. The flow depth was measured with a point gauge (±1 mm) in the channel axis and at the two points equivalent of 1/4 of the channel width, with the rack installed (but without blocked logs) and around 0.10 m upstream of the latter. The three values were typically homogenous and thus averaged to the representative flow depth h.

A driftwood rack was installed across the channel at 1.20 m upstream of its end. The rack axis was perpendicular to the channel axis. The rack bars were fixed on a beam above the channel and consisted of vertical cylinders with 0.009 m in diameter. Their axial bar spacing was systematically varied as b=0.05, 0.10, 0.15, 0.20, 0.30, and 0.40 m. A symmetrical arrangement of the bars relative to the channel axis was installed (Figure 1). For the subsequent analysis, the rack bar spacing b was set in relation to the wood log length L, resulting in the relative bar spacing b/L.

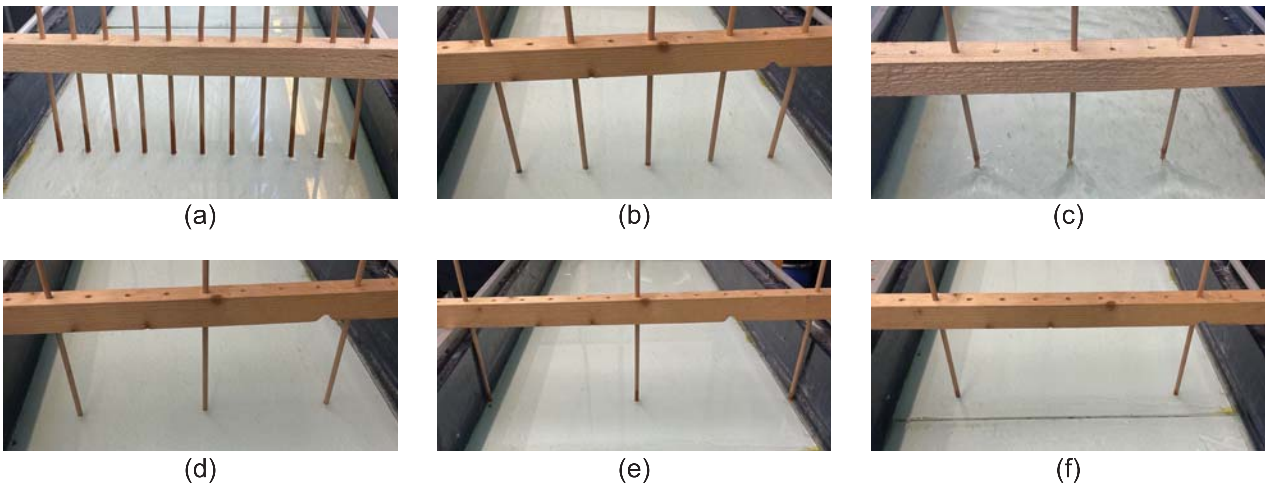


Figure 1. Channel with rack having a variable relative bar spacing b/L= (a) 0.25, (b) 0.50, (c) 0.75, (d) 1.00, (e) 1.50, and (f) 2.00.

Cylindrical wood logs with a rough surface were used to represent the driftwood. They were all L=0.20 m long and had a diameter of D=0.01 m. Per test, a total of N=50 of these logs was supplied serially at the channel begin, but at an arbitrary lateral position and with an arbitrary orientation. A blocked log was removed before the subsequent log was supplied. Sufficient time was provided before deciding if a log was blocked or passed. The number T of blocked logs was counted to define the blocking probability P as

$$P = \frac{T}{N} \quad [1]$$

Furlan (2019) stated that the number of test repetitions for a similar set-up as we use is correlated with the reliability of the observation. For instance, a confidence interval of 10% is predicted for 30 repetitions. With N=50 repetitions (log insertions) per tests, we should subsequently achieve a blocking probability accuracy below 10%. Our observation indicated a bit a higher fluctuation, for instance during the tests 6 to 8, which were conducted under identical conditions. The value P varied between 0.54 and 0.78 (Table 1).

A total of 40 tests were conducted. The relative rack bar spacing b/L and the flow conditions, expressed with de Froude number F, were systematically varied. The tested parameter range is given in Table 1, including minima and maxima. The Froude number F based on the flow velocity from the Continuity equation $U=Q/Bh$ and was defined for the rectangular channel as

$$\mathrm{F} = \frac{U}{\sqrt{gh}} \tag{2}$$

Model effects were addressed via flow velocity measurements upstream of the rack (Zenoni 2022). A typical and transversally quite symmetrical profile was detected, so that the approach flow conditions seem adequate. The behavior of the trunks when approaching the rack did further not outline any anomalies. Scale effects are possible, since the logs used herein have a particular size, stiffness, density and surface roughness, which may differ from prototype observations. This is, however, for all driftwood-related studies the case. Furthermore, the small flow depths and discharges used herein might promote the effect of viscosity. This study has thus a preliminary character.

Table 1. Test program.

Test Nr	*b* [m]	*b*/*L* [-]	F [-]	*T* [-]	*P* [-]
1	0.05	0.25	0.85	40	0.80
2	0.05	0.25	0.58	34	0.68
3	0.05	0.25	0.68	37	0.74
4	0.05	0.25	0.69	36	0.72
5	0.05	0.25	0.71	28	0.56
6	0.05	0.25	0.22	27	0.54
7	0.05	0.25	0.22	39	0.78
8	0.05	0.25	0.22	37	0.74
9	0.05	0.25	0.33	30	0.60
10	0.05	0.25	0.36	35	0.70
11	0.10	0.50	1.17	19	0.38
12	0.10	0.50	1.22	22	0.44
13	0.10	0.50	1.14	18	0.36
14	0.10	0.50	0.23	38	0.76
15	0.10	0.50	0.33	30	0.60
16	0.10	0.50	0.37	26	0.52
17	0.10	0.50	0.11	31	0.62
18	0.10	0.50	0.18	33	0.66
19	0.10	0.50	0.23	21	0.42
20	0.15	0.75	1.18	8	0.16
21	0.15	0.75	1.17	6	0.12
22	0.15	0.75	1.16	3	0.06
23	0.15	0.75	0.23	17	0.34
24	0.15	0.75	0.33	14	0.28
25	0.15	0.75	0.39	11	0.22
26	0.20	1.00	1.18	0	0.00
27	0.20	1.00	1.15	2	0.04
28	0.20	1.00	1.16	4	0.08
29	0.20	1.00	0.23	3	0.06
30	0.20	1.00	0.31	4	0.08
31	0.20	1.00	0.39	3	0.06
32	0.30	1.50	1.14	1	0.02
33	0.30	1.50	1.15	0	0.00
34	0.30	1.50	1.22	1	0.02
35	0.30	1.50	0.23	1	0.02
36	0.30	1.50	0.33	1	0.02
37	0.30	1.50	0.39	4	0.08
38	0.40	2.00	1.21	0	0.00
39	0.40	2.00	1.17	0	0.00
40	0.40	2.00	1.22	0	0.00
Minimum		0.25	0.11		0.00
Maximum		2.00	1.22		0.80

3. BLOCKING PROBABILITY

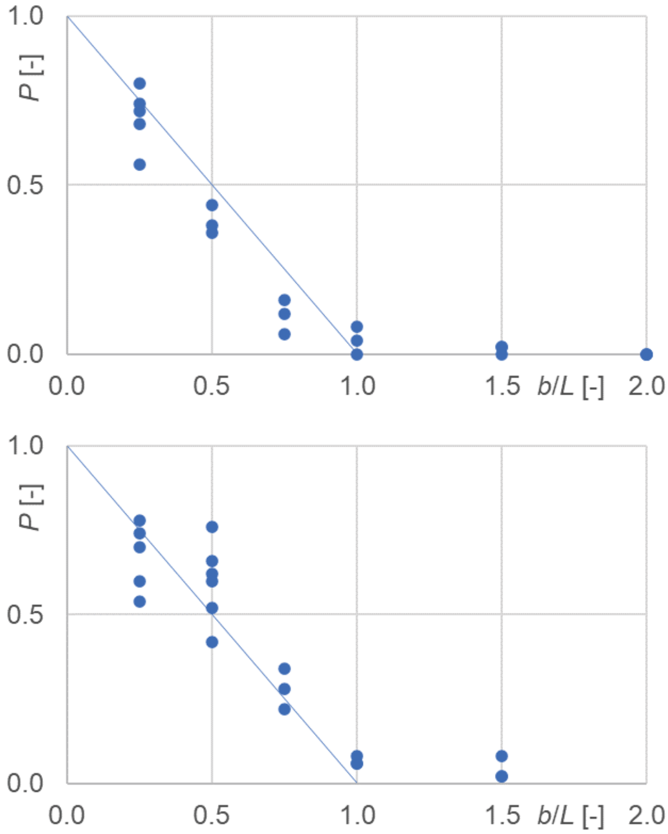
As literature indicates, the blocking probability of a single log depends on various parameters. As key parameters, however, were the rack bar spacing (Godtland and Tesaker 1994) and the approach flow conditions (Schalko 2018) identified. The present study consequently focused on these two effects, as the test program in Table 1 shows. The data analysis was therefore done separately for both: the effect of the (1) relative bar spacing is shown per flow regime, and (2) approach flow condition effect is derived per relative bar spacing. The combination of both effects finally allowed to give an empirical equation for the blocking probability.

3.1 Effect of the relative rack bar spacing

The effect of the relative rack bar spacing b/L on the blocking probability P is shown in Figure 2.

First, only data with a fully opened flap gate are considered. These tests were close to undulating flow conditions with $0.68 \leq F \leq 1.22$. Then, as visible in Figure 2a, the probability P depended quasi linearly of b/L within $0 \leq b/L \leq 1$. The related function might be given as $P=(1-b/L)$ for that range (trend line in the figure). Hartlieb (2015) mentioned a similar relation of (L/b–0.96) for groups of homogeneous logs. Larger relative bar spacings ($b/L>1$) let pass (almost) all logs, so that $P\approx 0$. This observation agrees well with the statement of Godtland and Tesaker (1994) but is now, however, based on a much broader data base. Our observation supports the statement that almost all individually arriving logs passed a rack if the relative bar spacing was above $b/L>0.8$.

Second, the data with clearly subcritical flow conditions are considered (Figure 2b, $0.11 \leq F \leq 0.54$). The before discussed observations are still applicable, but the data scatter slightly larger.



(a)

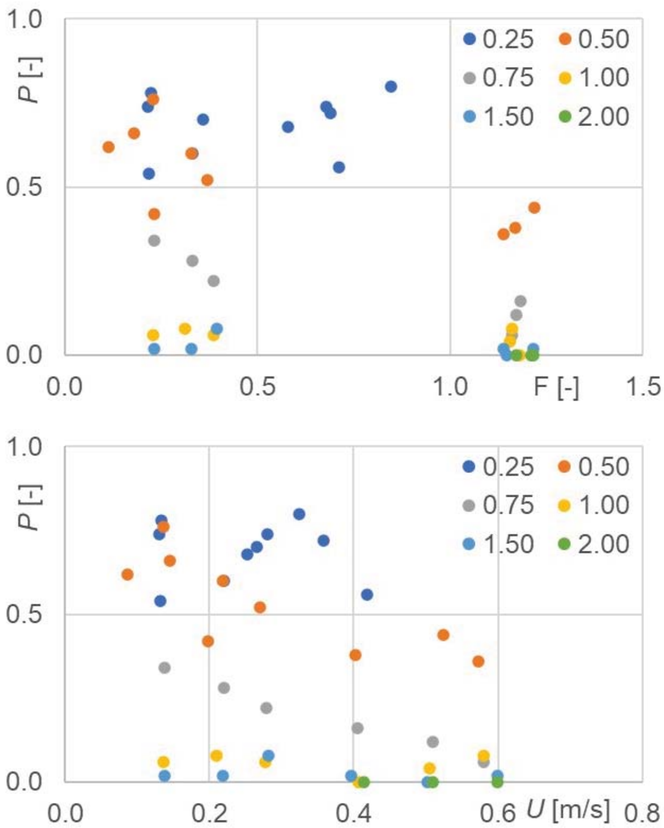
(b)

Figure 2. Blocking probability P versus relative rack bar spacing b/L for approximately (a) critical flow ($0.68 \leq F \leq 1.22$), and (b) subcritical flow ($0.11 \leq F \leq 0.54$).

3.2 Effect of the approach flow conditions

Several studies indicate that the approach flow conditions affect the blocking probability of individually arriving logs on racks or bridge piers. These conditions are characterized by the approach flow velocity U or the approach flow Froude number F (Equation 2). Both effects are illustrated in Figure 3 showing P versus F or U, for each of the tested *b*/*L*. As visible per *b*/*L*, the value of *P* generally slightly reduces with increasing F or *U*. Hartlieb (2015) also stated that large F and *U* tend to reduce *P* if only few logs arrive at the rack.

The effect of F and of some normalizations of *U* were analyzed. For the latter, the terms U_c/U, $U^2/2gH$, $U^2/2gL$, and H_W/H were tested, with U_c as critical flow velocity, *H* as specific energy head (without blocked log), and H_W as specific energy head with a blocked log. The best determination was finally achieved with the term including the log length *L*. This term was also used by Schalko (2018) to describe the blocking probability of a single log on a bridge pier, supporting the validity of the term.



(a)
(b)

Figure 3. Blocking probability *P* versus (a) Froude number F, and (b) flow velocity *U*, both without blocked log and for 0.25≤*b*/*L*≤2.

3.3 Combined effects

Combining the two identified terms to describe the effects of the relative rack bar spacing and of the approach flow velocity on the blocking probability resulted finally in Equation (3). The latter writes

$$P = 0.42\left(1-\frac{b}{L}\right)\left(\frac{U^2}{2gL}\right)^{-0.2} \qquad [3]$$

The two constants 0.42 and –0.2 were optimized to achieve a coefficient of determination of R^2=0.97 between the measured values *P* and those predicted by Equation (3). Both are shown in Figure 4, including the ±20% range as dashed lines. Almost all points fall within these boundaries. The validity of Equation (3) includes 0.25≤*b*/*L*≤1 and 0.11≤F≤1.22 (Table 1).

According to Godtland and Tesaker (1994), “large” relative rack bar spacings of *b*/*L*>0.8 (or 1 following our observations) let pass almost all individually arriving trunks. For such “partial” racks installed in rivers, the blocking probability becomes roughly

$$P \leq 0.1 \qquad [4]$$

Figure 2 supports this observation.

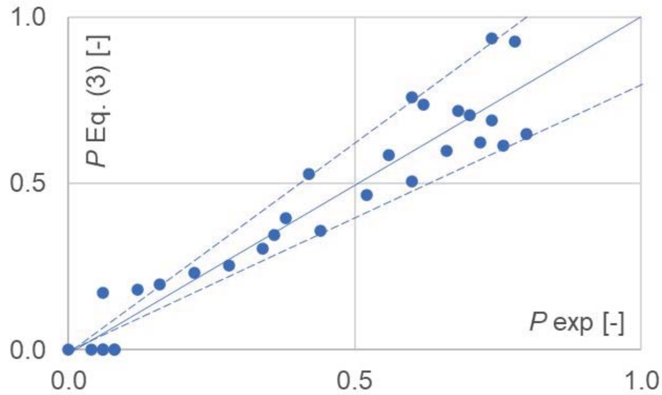


Figure 4. Blocking probability *P* as measured in the channel (exp) and predicted by Equation (3).

4. CONCLUSIONS

Physical model tests with individually suppled wooden logs were conducted, facing a rack installed transversally in a channel (Figure 1). The approach flow conditions as well as the relative rack bar spacing were systematically varied. The blockage or passage of the logs was observed and a blocking probability derived. The latter depended linearly of the rack bar spacing and slightly on the flow conditions (within the tested hydraulic parameters and boundary conditions, Table 1), as summarized in Equation 3.

Isolated (uncongested) arriving logs seem rare in rivers during critical flood events. Batches of driftwood appear more frequently and behave potentially differently at racks in terms of the blocking probability. Nevertheless, the observations of Zenoni (2022) showed that the relative rack bar spacing remains import, whereas the effect of F becomes more important, as Hartlieb (2015) stated.

5. ACKNOWLEDGEMENTS

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