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DELAY IN THE FLOW OF PLANT DEBRIS ON FLOODPLAINS OVERGROWN WITH SHRUB VEGETATION

OPÓŹNIENIA W PRZEPŁYWIE RUMOSZU ROŚLINNEGO NA OBSZARACH ZALEWOWYCH POROŚNIĘTYCH ROŚLINNOŚCIĄ KRZEWIASTĄ

Mateusz Hämmerling, Natalia Walczak, Paweł Zawadzki, Tomasz Kałuża

Poznań University of Life Sciences

Abstract. The study aims to analyze the statistical probability of the slowing down of the plant debris flow through an area rich in shrub vegetation during floods. The shrub density has a direct influence on water velocity. The study was conducted in a 2-meter section of an artificial hydraulic flume. 15 tests were made for each of the different-shaped elements. The artificial elements used were either rectangular or elliptical in shape. Tests were conducted for three different spacings of cylindrical elements imitating the shrub vegetation and for three different depths of the hydraulic flume. Analysis of the test results leads to the conclusion that an increase in the density of cylindrical elements does not always cause an increase in the flow time of plant debris. The study also shows that an increase in the water depth causes an increase in the flow time of elements imitating the thick debris, which is due to a decrease in the water flow velocity. The study also presents an analysis of the probability of plant debris being detained by the cylindrical elements imitating the shrubs. This probability was observed to be higher for rectangular than elliptical elements. It was also observed to be inversely proportional to the water depth. The obtained results indicate that the subject matter of the current study is very interesting and complex and merits further investigation.

Streszczenie. W pracy przeanalizowano statystycznie prawdopodobieństwo spowolnienia przepływu rumoszu roślinnego w czasie wezbrania przez teren porośnięty roślinnością krzewiastą. Sposób ułożenie materiału w obszarze blokującym przepływ (krzew) wpływa

Corresponding authors – Adres do korespondencji: dr inż. Mateusz Hämmerling, dr inż. Natalia Walczak, dr inż. Paweł Zawadzki, dr hab. inż. Tomasz Kałuża, Department of Hydraulic and Sanitary Engineering, Poznań University of Life Sciences, ul. Piątkowska 94A, 60-649 Poznań; e-mail: mhammer@up.poznan.pl, pzaw@up.poznan.pl, natwal@wp.pl.

bezpośrednio na wartości prędkości i oporu hydraulicznego. Doświadczenie przeprowadzono w korycie hydraulicznym, w którym na odcinku 2,0 m w 15 powtórzeniach wykonywano badania dla elementów imitujących rumosz o różnych kształtach. Obserwowano wpływ roślinności krzewiastej na warunki przepływu rumoszu grubego, modelowanego za pomocą płaskich elementów sporządzonych ze styropianu w warunkach laboratoryjnych. W badaniach imitowany rumosz przyjmował kształty prostokąta lub elipsy. Badania przeprowadzono przy trzech różnych rozstawach elementów cylindrycznych imitujący krzewy oraz dla trzech różnych napełnień koryta hydraulicznego. Analizując wyniki doświadczeń, stwierdzono, że wzrost gęstości elementów cylindrycznych imitujących krzewy nie zawsze powodował zwiększenie czasu przepływu rumoszu. Badania laboratoryjne pokazały, że wraz ze wzrostem głębokości wody w korycie zwiększał się czas przepłynięcia elementów imitujących rumosz gruby, co było spowodowane zmniejszaniem się prędkości przepływu wody w korycie. W pracy wykonano również analizę prawdopodobieństwa zatrzymania rumoszu roślinnego między cylindrycznymi elementami imitującymi krzewy. Prawdopodobieństwo zatrzymania się rumoszu jest większe dla elementów o kształcie prostokątnym niż dla elementów eliptycznych oraz maleje wraz ze wzrostem głębokości wody w korycie badawczym. Uzyskane wyniki wskazują, że podjęty problem badawczy jest bardzo interesujący i złożony, dlatego warto kontynuować prace w tym kierunku w przyszłości.

Key words: plant debris, floodplains, shrub vegetation

Słowa kluczowe: rumosz roślinny, tereny zalewowe, roślinność krzewiasta

INTRODUCTION

Resistance to flow can be due to: the structure of the river bed and the variability of cross sections and local obstacles [Wierzbicki et al. 2011]. Several natural processes together with human activity cause large quantities of organic matter to find its way into stream and river channels. The organic matter consists of fragments of plants as well as whole trees and shrubs. Due to the characteristic topographical and hydraulic conditions of the open channels in mountainous areas, this phenomenon is very well studied [Sedell et al. 1988, Gurnell et al. 1995, Radecki-Pawlik et al. 2011]. Researchers have conducted analyses of the influence of plant debris on physical characteristics of mountain rivers. They have established that the natural processes leading to the creation of plant debris are: decomposition of dead trees, avalanches, earth flows, landslides, the felling of trees by the wind, bank erosion leading to the jetting of trees and shrubs, forest management practices and the felling of trees by beavers. The dominant form of thick plant debris in the first sections of mountains springs are logs. In bigger mountain streams, where amounts of water during floods are sufficient to transport whole trees, heaps of them can be encountered alongside logs. In lower-lying sections of mountains rivers, the banks are overgrown with shrubs and deciduous trees, and the dominant form of trick plant debris there are: fragments of shrubs, trees and tree heaps [Kaczka et al. 2003]. The felled trees lying across mountain rivers form an obstacle for free water flow and the bottom sediment transport, and are called natural tree dams. Trees felled into the river can divert the main stream flow towards the opposite riverbank, causing its erosion and leading to increased windingness of the river. The presence of trees and tree heaps in the river channel causes the division of the stream and the creation of gravel outwashes, which in turn can lead to the riverbank erosion and an increase in the river width. Increased river windingness and river width and the creation of multi-stream river channel significantly influence the water flow hydraulics. The results of these changes are: an increase in the flow resistance and a decrease in the average flow velocities [Wyżga et al. 2003]. This causes the necessity of determining the influence of a given logjam on water flow conditions through an analysis of changes in the roughness coefficient of the channel in the place of the logjam. Michalec and Leksander [2011] have conducted such an analysis. They established the changes in values of the nondimensional resistance coefficient (Darcy-Weisbacha) and the roughness coefficient for the logjam on the Bukowiński Stream (km 3+500). Their analysis showed that the average water velocity through the logjam was 1,4 times bigger than the average water velocity through an unobstructed water channel.

In the case of lowland rivers, where river bottom gradients are less marked, the deposition of plant debris is much less intensive. Only in extreme cases (floods) can substantial deposits of plant debris from the river channel be expected to be set in motion. Due to a specific genesis of plant debris formation in lowland rivers, a different kind of material will shape the water flow conditions [Kałuża and Walczak 2013]. The plant debris in itself will flow freely and not block the water flow. Only when it encounters porous structures (shrubs, tree groups) will it start to deposit, which will affect the water flow conditions on floodplains [Kałuża and Radecki-Pawlik 2014].

Natural shrub vegetation can form an obstacle on floodplains in the event of a flood [Kubrak et al. 2013]. The dense shrub structure together with the accumulated organic matter block water flow. The various shapes and sizes of the organic matter and its distribution affect water velocity and resistance.

The plant debris can be divided into small debris (grass, leaves) and thick debris, which comprises:

- long elements – in which one dimension is substantially bigger than the other two (branch fragments),
- flat elements – in which one dimension is substantially smaller than the other two (bark fragments).

Due to differences in shapes and sizes of the debris and its orientation, local water velocities and flow resistance values vary.

The study analyzed the influence of vegetation density on flow conditions of the thick debris, modeled with flat elements made of foamed polysterene.

MATERIALS AND METHODS

The research was conducted on a physical model in the water research laboratory of the Department of Hydraulic and Sanitary Engineering University of Life Sciences in Poznań.

The model used was a hydraulic flume which was rectangular in section, 10 m long and 0.46 m wide. Water level elevation was determined with the use of a water level range.

The water flow discharge was $0.06\ m^3 \cdot s^{-1}$ and the flow velocities ranged between $0.45\ m \cdot s^{-1}$ (for water depth 0.276 m) and $0.91\ m \cdot s^{-1}$ (for water depth 0.136 m). On the basis of measurements of the shrub vegetation conducted during fieldwork [Walczak et al. 2013], the cylindrical diameter of 0.003 m was adopted for the elements imitating the shrub vegetation. The height of the elements varied depending on the water depth. The assumptions was that 75% of the elements' height should be under water. 3 different spacings of shrub vegetation were employed depending on the size of the plant debris. The maximum spacing between cylindrical elements imitating the shrub vegetation was: 0.08 m for 12 elements, 0.05 m for 17 elements and 0.03 m for 28 elements. The density of cylindrical elements was: 12.77 elements · m^{-2} for the maximum spacing, 18.08 elements · m^{-2} for the medium spacing and 29.78 elements · m^{-2} for the smallest spacing.

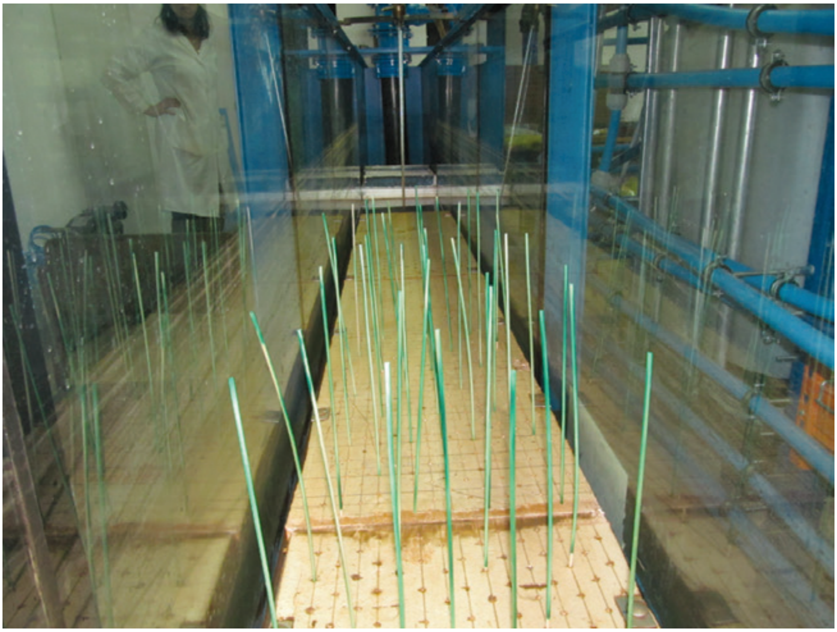

Fig. 1. Elements imitating shrub vegetation
Ryc. 1. Elementy imitujące roślinność krzewiastą

The density of the cylindrical elements imitating the shrub vegetation can also be expressed by its porosity.

The porosity of shrub elements is presented as pore volume to water volume ratio [Dziubiński and Prywer 2009]:

$$\varepsilon = \frac{V_w}{V} = 1 - \frac{V_p}{V} \tag{1}$$

where:

V_p – volume of the shrub elements,
V_w – water volume,
V – control volume.

In the case of a hydraulic flume of given geometrical dimensions, in which vegetation is modeled by cylindrical elements, the volumetric porosity can be calculated with the equation:

$$\varepsilon = 1 - \frac{n\pi d^2}{bhL} \tag{2}$$

where:
- n – number of the shrubs elements,
- d – diameter of the shrubs elements,
- b – width of the research model,
- h – water level in the hydraulic flume,
- L – section length.

The volumetric porosity ε signifies the volume taken up by water in its control volume. Another indicator of porosity is surface porosity established for a given cross section with the equation:

$$\varepsilon_a = \frac{A_w}{A} = \frac{A - A_w}{A} = 1 - \frac{A_p}{A} \tag{3}$$

where:
- A_p – the surface of shrub elements,
- A – the cross section,
- A_w – the water surface

For different cross sections the value ε_a can change. However, the average surface porosity coefficient equals the volumetric porosity coefficient $(\varepsilon_a)_{śr} = \varepsilon$ [Grabarczyk 2010].

It was assumed that elements of plant debris obstruct the free water flow by being stopped on plant elements. During in situ measurements it was observed that in natural environment plant debris is also made up of volumetric elements such as bark, branch and bough fragments. On the basis of these observations rectangular (P) and elliptical (E) elements were adopted for the study. The shapes and sizes of these elements were determined as a result of the comparison of shapes of natural and artificial elements, their length being the decisive value (fig. 2).

The comparison of natural and artificial elements (tab. 1) indicates that the adoption of the shapes of the elements (rectangle and ellipse) used in the study is justified. Artificial to natural element length ratio is between 73% and 89%.

The type of elements imitating the natural plant debris used in the study depended on the shrub density in the hydraulic flume. Along with the increase is the shrub density, the number of elements used in the experiments decreased because bigger elements imitating the plant debris were not able to flow through the area of immense density. Water depth in the flume also affected the number of experiments. At smaller depths, the water velocity was so high that the elements imitating the plant debris damaged the shrub elements by braking them. In this case, further research was pointless.

Fig. 2. Collation of natural and artificial elements of plant debris
Ryc. 2. Zestawienie elementów naturalnych i sztucznych rumoszu roślinnego

Table 1. Collation of natural and artificial plant debris sizes
Tabela 1. Zestawienie naturalnych i zastępczych wielkości geometrycznych rumoszu roślinnego

Shape Kształt		Natural plant debris sizes m Rozmiary naturalnego rumoszu m			Artificial plant debris sizes m Rozmiary zastępczego rumoszu m			Artificial length / natural length Długość zastępcza / długość naturalna
		length długość	width szerokość	thickness grubość	length długość	width szerokość	thickness grubość	%
Rectangle Prostokąt	1 P	0.12	0.050	0.005	0.087	0.087	0.03	73
Ellipse Elipsa	1 E	0.10	0.045	0.010	0.075	0.075	0.03	75
Rectangle Prostokąt	2 P	0.2	0.05	0.019	0.177	0.087	0.03	89
Ellipse Elipsa	2 E	0.2	0.04	0.177	0.177	0.087	0.03	89

RESULTS AND DISCUSSION

Analysing the flow resistance values it was assumed that the time needed by an element of thick debris to flow freely through a specified section does not depend on its shape but solely on the water flow velocity and obstacles: the volume and density of the shrub vegetation.

Viewing time periods in which water t_w or plant debris t_e cover a flume section, one can estimate the probability that the plant debris will flow unobstructed with the equation:

$$p = \frac{t_w}{t_e} \tag{4}$$

It can be also assumed that in the case of plant debris being obstructed in its flow by shrub elements, $t_e \approx \infty$, and $p = 0$. The probability of unobstructed plant debris flow can be calculated with the equation:

$$p' = 1 - p = 1 - \frac{t_w}{t_e} \tag{5}$$

For the purposes of further analyses, research results obtained for 1 P and 1 E (the smallest elements) were used. The research produced results for all the different shrub element spacings and water depths. Table 2 shows the average of 15 flow times for each element together with their standard deviations. The relative value of variable dispersion (coefficient of the variation of standard deviation, v) was established, which is a ratio of the standard deviation and of the arithmetic mean of that variable expressed in percentages. The coefficient of variation defines the relative dispersion value and facilitates the comparison of the variation of flow times through the same elements at different element densities. Table 2 shows the smallest scatter of results for 1 P element at the maximum density (18.08 elem. $\cdot$ m^{-2}) and the biggest scatter of results for element 2 E at the smallest density.

The results show that the bigger the water depth in the hydraulic flume the longer the flow time of plant debris. It can be expected that a higher plant debris density will increase the flow time of plant debris. This assumption turned out to be true for plant density of 12.77 elements $\cdot$ m^{-2} and 29.78 elements $\cdot$ m^{-2}. For plant density of 18.08 elements $\cdot$ m^{-2}, however, an increase trend was observed. These results were replicated for all element shapes and water depths in the hydraulic flume.

Figure 3 shows average flow times of 1 P element observed in a 2 – meter section of the flume for different shrub densities. The three colours seen in the graph denote the three shrub densities: continuous (green) – 12.77 elements $\cdot$ m^{-2}, intermittent (yellow) – 18.08 elements $\cdot$ m^{-2}, punctate (red) – 29.78 elements $\cdot$ m^{-2}. The diagram shows that the bigger the water depth the slower the flow time of the plant debris. Flow times for the different shrub densities partially overlap.

Figure 3 shows: the average values and standard deviations. Figure 3 shows that the bigger the water depth, the longer the flow time of the rectangular element. These flow times for all shrub densities partially overlap. The biggest average flow time values were obtained for the density of 29.78 elements · m^{-2}. For all density variants, a linear dependence of flow time to flow depth (flow velocity) was obtained. The correlation coefficient for all the densities was R = 0,99.

Table 2. Collation of the average flow times for 1 P, 1 E and 2 P, 2 E elements at different shrub densities
Tabela 2. Zestawienie uśrednionych czasów przepłynięcia elementów 1P i 1E oraz 2 P i 2 E dla różnych gęstości

Element type Rodzaj elementu	Water depth Głębokość	Shrub element density Gęstość elementów krzewiastych								
		12.77 elem. · m^{-2}			18.08 elem. · m^{-2}			29.78 elem. · m^{-2}		
		t	$\pm s_t$	v	t	$\pm s_t$	v	t	$\pm s_t$	v
	m	s	s	–	s	s	–	s	s	–
1 P	0.136	3.29	0.63	0.19	2.98	0.32	0.11	4.08	0.43	0.11
	0.216	5.26	0.75	0.14	4.39	0.39	0.09	6.24	0.66	0.11
	0.276	6.28	0.8	0.13	5.94	0.56	0.09	7.49	0.83	0.11
1 E	0.136	3.00	0.38	0.13	2.75	0.25	0.09	4.03	0.93	0.23
	0.216	4.89	1.03	0.21	4.34	0.42	0.10	5.22	0.56	0.11
	0.276	5.35	0.91	0.17	5.79	1.15	0.20	6.72	0.48	0.07
2 P	0.136	4.14	0.96	0.23	4.27	0.395	0.09	–	–	
	0.216	5.86	1.01	0.17	6.18	1.189	0.19	–	–	
	0.276	8.4	1.87	0.22	8.09	1.112	0.14	–	–	
2 E	0.136	3.53	0.64	0.18	3.34	0.655	0.20	–	–	
	0.216	6.54	1.98	0.30	5.31	0.890	0.17	–	–	
	0.276	7.25	2.07	0.29	8.86	1.785	0.20	–	–	

Figure 4 shows the dependence of average flow times of 2 P element on water depths. Due to the size of the element imitating the plant debris, it was impossible to conduct an analysis at maximum density. For the densities of 12.77 elements · m^{-2} and 18.08 elements · m^{-2}, flow times of 2 P element increase together with the increases of water depth. A directly proportional dependence was observed irrespective of the plant element densities. As the water depth was increased (and for a constant flow it means a decrease in velocity), so did the flow time of elements imitating the plant debris. The dependence was directly proportional. The correleation coefficient for the density of 12.77 elements · m^{-2} was R = 0.98; for 18.08 elements · m^{-2} R = 0.99. Research also included measurements of flow times of the 1 E and 2 E element at different water depths in the flume. Figure 5 shows the 1 E element flow time to water depth ratio.

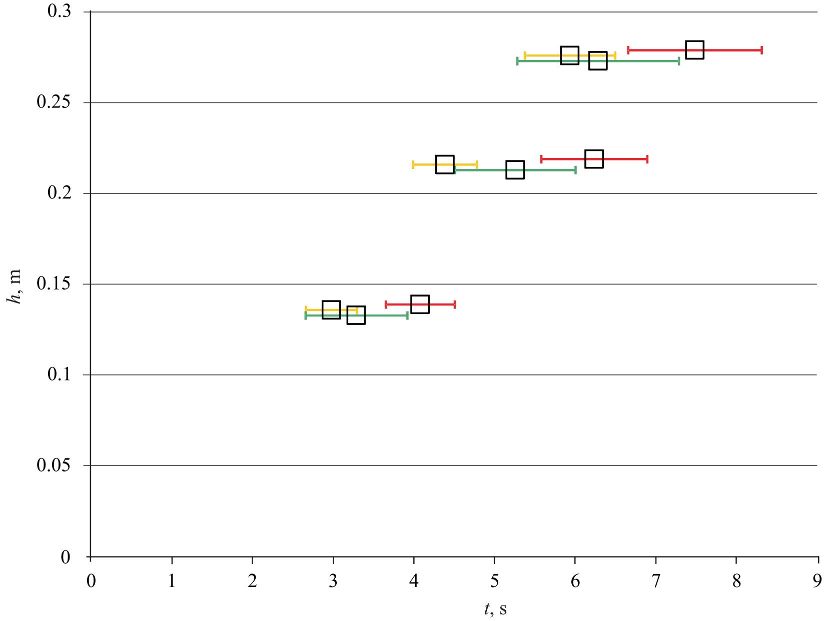

Fig. 3. Dependence of average flow times of the 1 P element on water depths
Ryc. 3. Zmiany uśrednionych czasów przepłynięcia elementu 1 P w zależności od głębokości wody

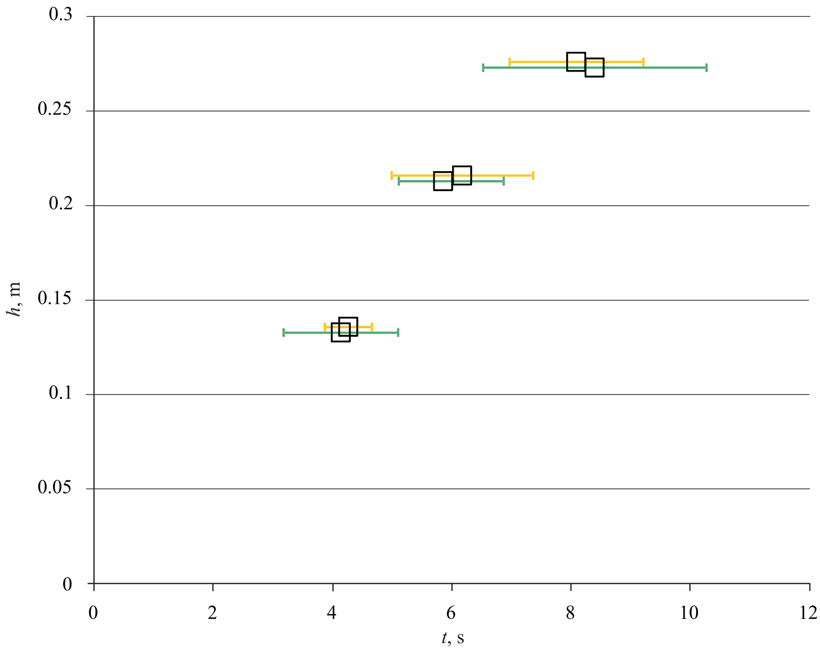

Fig. 4. Dependence of average flow times of 2 P element on water depths
Ryc. 4. Zmiany uśrednionych czasów przepłynięcia elementu 2 P w zależności od głębokości wody

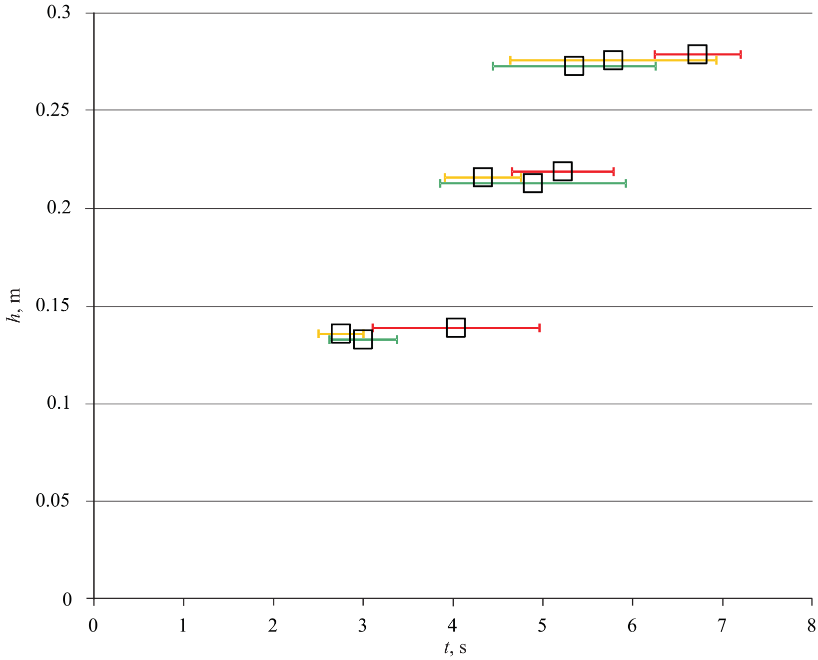

Fig. 5. Dependence of average flow times of the 1 E element on water depths
Ryc. 5. Zmiany uśrednionych czasów przepłynięcia elementu 1 E w zależności od głębokości wody

For the density of 29.78 elements · m^{-2}, the longest average flow times (4.03–6.72s) were obtained. As was the case with the smallest rectangular element, for all the variants of density a linear dependence was observed of time to flow depth, where the correlation coefficient was in the range of 0.97–0.99.

Analyzing the dependence shown in Figure 6, it can be noted that for the smallest water depth equal to 0.14 m, deviation of flow time for element 2 E was the smallest. With increasing water depth was observed to rise time deviation. The correlation coefficient for the density of 12.77 elements · m^{-2} was $R = 0.96$; for 18.08 elements · m^{-2} $R = 0.97$. Unfortunately, failed to carry out research at the highest density of shrubby elements despite the elliptical shape of the plant debris.

Research demonstrated an obvious dependence of plant debris flow times on average water flow times. As the flow velocity increases, the flow time decreases, chich can be seen in Figure 7 for 1 P elements. The points indicating flow times arranged in relationship exponential trend line of a significant correlation coefficient. The highest coefficient was obtained for water flow velocities in a flume without any blocking elements ($R = 1.0$). For all the other dependencies, the correlation coefficient is approximately $R = 0.99$.

Figure 7 also shows that as the number of elements imitating the shrub vegetation increases, so does the flow time for 1 P element.

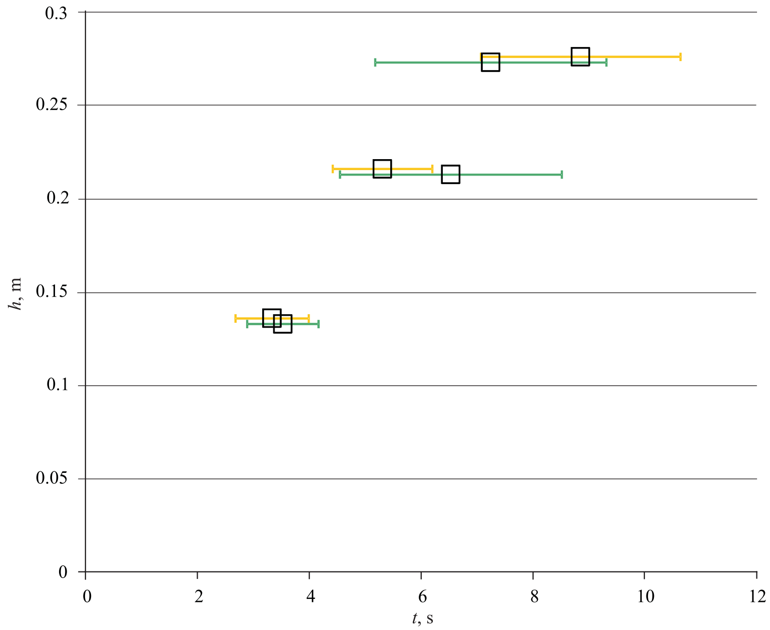

Fig. 6. Dependence of average flow times of the 2 E element on water depths
Ryc. 6. Zmiany uśrednionych czasów przepłynięcia elementu 2 E w zależności od głębokości wody

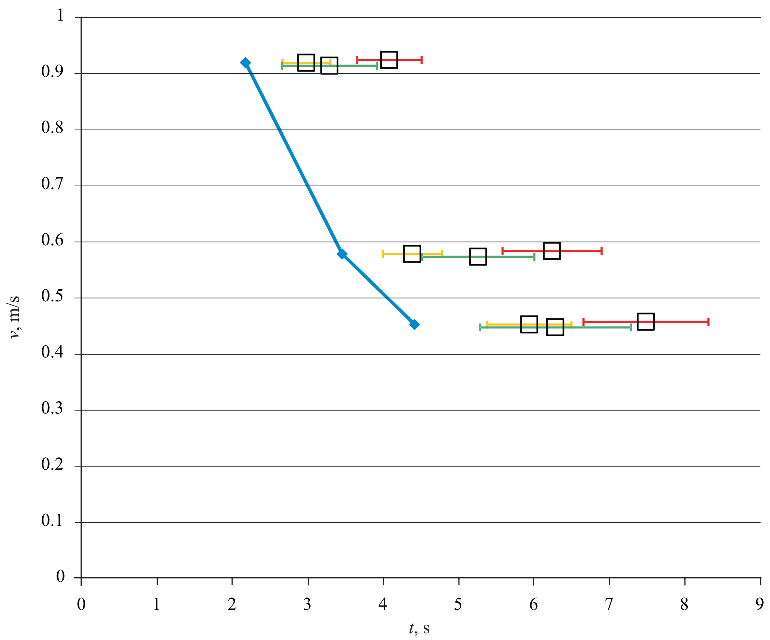

Fig. 7. Average 1 P flow times to flow velocities ratio
Ryc. 7. Uśrednione czasy przepływu elementu 1P w zależności od prędkości

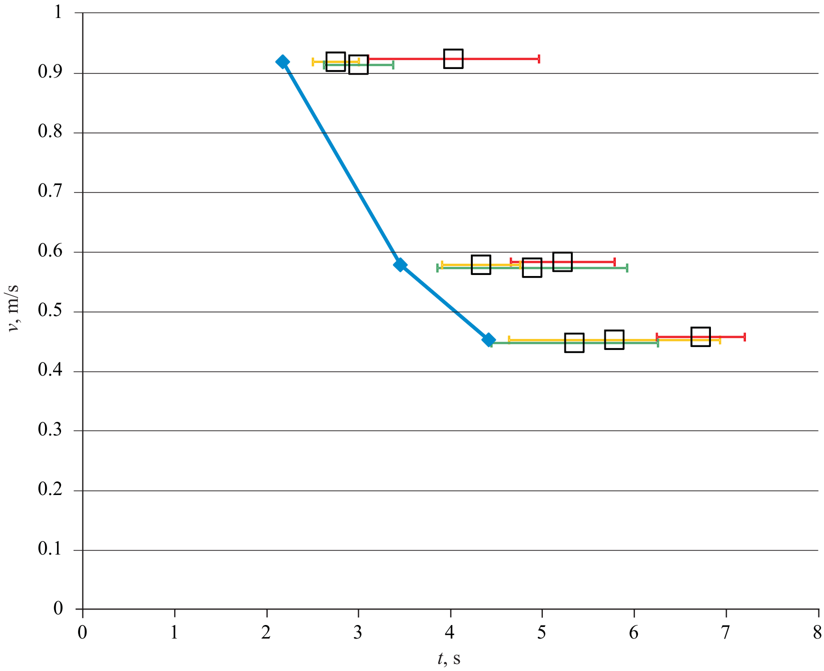

Fig. 8. Average 1 E element flow times to flow velocities ratio
Ryc. 8. Uśrednione czasy przepływu elementu 1 E w zależności od prędkości

Analysis of the water flow time to 1 E element flow velocity dependence leads to the conclusion that for all densities, the longer the time, the shorter the flow velocity (fig. 8).

The variables marked on Figure 8 were analyzed in terms of compatibility of matching trend line (exponential, linear). The highest compatibility was observed for exponential line, for chich the correlation coefficient *R* was 0.98–1.00.

Table 3 shows parameters for the cylindrical elements imitating the shrub vegetation (volume and porosity) and for the hydraulic flow (velocity and discharge). The values are given for different depths and all the densities.

In order to establish the influence of shrub porosity on hydraulic parameters, an analysis of hydraulic radiuses with porosity (equation 2) and without porosity (the classic approach) (equation 3) was made. Its results are presented in table 3.

Additionally, an analysis was made of the probability of unobstructed plant debris flow through shrub elements. Table 4 shows the probability of plant debris detention by low shrubbery (equation 5) for 1 P and 1 E elements, and 2 P and 2 E elements.

Table 3. Collation of parameters for cylindrical elements imitating the shrub vegetation
Tabela 3. Zestawienie parametrów cylindrycznych elementów imitujących roślinność krzewiastą

h	*V*	—		1 – ε	*U*	*Q*
m	m^3	elem. · m^{-2}	m^3	–	m · s^{-1}	$m^3 \cdot s^{-1}$
0.136	0.13056	12.77	$2.1 \cdot 10^{-5}$	$1.6 \cdot 10^{-4}$	0.919	0.060
		18.08	$2.9 \cdot 10^{-5}$	$2.2 \cdot 10^{-4}$		
		29.78	$4.8 \cdot 10^{-5}$	$3.7 \cdot 10^{-4}$		
0.216	0.20736	12.77	$8.6 \cdot 10^{-10}$	$4.13 \cdot 10^{-9}$	0.579	0.060
		18.08	$1.2 \cdot 10^{-9}$	$5.9 \cdot 1\ 0^{-9}$		
		29.78	$2 \cdot 10^{-9}$	$9.6 \cdot 10^{-9}$		
0.276	0.26496	12.77	$1.9 \cdot 10^{-185}$	$7.2 \cdot 10^{-18}$	0.453	0.060
		18.08	$2.7 \cdot 10^{-18}$	$1.0 \cdot 10^{-17}$		
		29.78	$4.5 \cdot 10^{-18}$	$1.7 \cdot 10^{-17}$		

Table 4. Collation of unobstructed plant debris flow at different depths
Tabela 4. Zestawienie prawdopodobieństwa przepłynięcia rumoszu przy różnych głębokościach

		1 P		1 E	
h, m	t_w, s	t_e, s	*p*'	t_e, s	*p*'
0.136	2.176	3.45	0.37	3.26	0.33
0.216	3.456	5.30	0.35	4.82	0.28
0.276	4.416	6.57	0.33	5.95	0.26
		2 P		2 E	
v, m · s^{-1}	t_w, s	t_e, s	*p*'	t_e, s	*p*'
0.919	2.176	4.21	0.48	3.43	0.37
0.579	3.456	6.02	0.43	5.92	0.42
0.453	4.416	8.25	0.46	8.05	0.45

SUMMARY

Analysis of research results of the influence of the density of structure vertical cylinder on the slowing down of the flow time of elements imitating the shrub vegetation through floodplains overgrown with shrub vegetation leads to the following conclusions:

1. The shape of the elements imitating the plant debris is not a crucial factor influencing their flow times. However, it was observed that streamlined (elliptical) 1 E elements flow faster than rectangular 1 P elements. The differences in flow times were observed for smaller densities of plant elements 12.7 elements · m^{-2} and for bigger water depth (0.276 m). For all research results, a linear dependence of flow time on flow depth (flow velocity) was obtained, and the correlation coefficient was $R = 0{,}99$.

2. Research demonstrated an obvious dependence of plant element flow times on average water flow times. As the flow velocities of 1 P elements increase, their flow times decrease.
3. The probability of detention of an individual 1 P, 1 E or 2 E element is inversely proportional to water depth.
4. The obtained results demonstrate the significance of the problem of flat plant debris elements flow through shrub vegetation. The research proved the random character of the phenomenon, which, however, is determined by the density of twigs, the size and density of plant elements and the flow velocity. The obtained results lead to the conclusion that further research is needed to better understand the phenomenon.

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REFERENCES

Dziubiński M., Prywer J., 2009. Mechanika płynów dwufazowych. WNT Warszawa.
Grabarczyk Cz., 2010. Hydromechanika filtrowania wody. WNT Warszawa.
Gurnell A.M., Gregory K.J., Petts G.E., 1995. The role of coarse woody Derbis in forest aquatic habitats: implications for management. Aquatic Conserv. 5, 143–166.
Kaczka R., Wyżga B., Zawiejska J., 2003. Gruby rumosz drzewny jako cenny składnik górskich systemów fluwialnych. [W:] J. Lach (red.). Dynamika zmian środowiska geograficznego pod wpływem antropopresji. Akademia Pedagogiczna Kraków, 118–125.
Kałuża T., Walczak N., 2013. Hydrauliczne i hydrologiczne aspekt powodzi w 2010 roku w zlewniach Wisły i Odry. Bogucki Wydawnictwo Naukowe Poznań.
Kałuża T., Radecki-Pawlik A., 2014. Określenie wpływu grubego i drobnego rumoszu roślinnego na hydrodynamikę koryt rzecznych. Acta Sci. Pol., Formatio Circumiectus 13(1), 5–14.
Kubrak J., Żelazo J., Kozioł A., Kubrak E., Wasilewicz M., 2013. Analiza wpływu roślinności na przepustowość obwałowanego odcinka koryta Wisły. Gosp. Wodna 5, 188–194.
Michalec B., Leksander B., 2011. Określenie bezwymiarowego współczynnika oporów i współczynnika szorstkości w przekroju zatoru z grubego rumoszu drzewnego. Infrastr. Ekol. Ter. Wiej. 10, 121–130.
Radecki-Pawlik A., Wieczorek M., Plesiński K., 2011. Zróżnicowanie parametrów hydrodynamicznych cieku w miejscu zdeponowania grubego rumoszu drzewnego, Acta Sci. Pol., Formatio Circumiectus 10(2), 35–46.
Sedell J.R., Bisson P.A., Swanson E.J., Gregory S.V., 1988. What we know about large trees that fali into streams and rivers. [W:] C. Maser, R.F. Tarrant, J.M. Trappe, J.F. Franklin (red.). From the Forest to the Sea: a Strory of Fallen Trees. SDA Forest Serv. Techn. Rep. 229, 47–81.
Walczak N., Walczak Z., Hämmerling M., Przedwojski B., 2013. Analytical Model for Vertical Velocity Distribution and Hydraulic Roughness at the Flow Through River Bed and Valley with Vegetation. Rocz. Ochr. Środ. 15, 405–419.
Wierzbicki M., Hämmerling M., Przedwojski B., 2011. Wpływ budowy progów stabilizujących na kształtowanie się układu zwierciadła wody i dna poniżej zbiornika Jeziorsko. Gosp. Wodna 6, 239–243.
Wyżga B., Zawiejska J., Kaczka R., 2003. Znaczenie rumoszu drzewnego w ciekach górskich. Aura 11, 18–20.

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