FLUME EXPERIMENTS OF LOG INCIPIENT MOTION IN RIVERS

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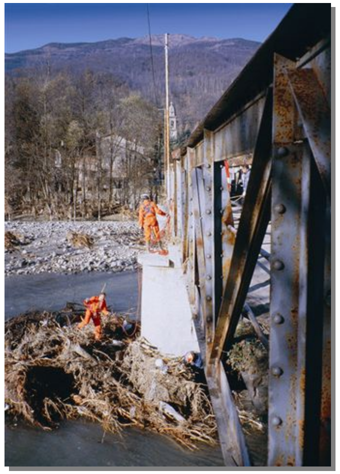
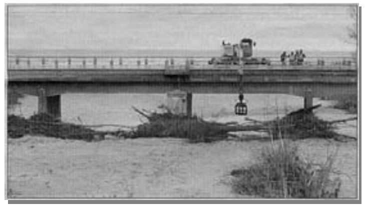
A) MOTIVATIONS OF THE RESEARCH

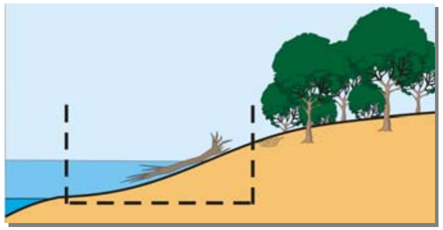
In natural rivers the transport phenomena of floating debris involve a large number of problems that are relevant to both environmental and technical aspects. A large part of the research developed has been motivated by linkages between fish habitat and geomorphological processes and forms influenced by large woody debris [Gippel et al., Reg. Rivers Res. Manage., 1996]. On the other hand, drifts reduce the capacity of bridge openings, contribute to scour around piers and abutements, and increase lateral forces on bridges.





Among woody debris, key pieces are individual logs with rootwads that are less likely to move than other wood pieces during a bankfull flow. They play a relevant role in snags amassing because key pieces constitute the first step of the woody accumulation process [Diehl, USGS-FHWA, 1997].

B) THE ANALYZED CASE

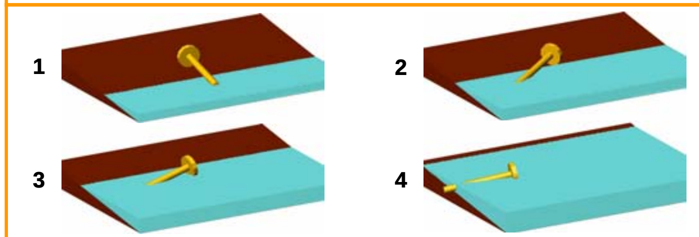


We consider a single log (a key piece) fallen into a fluvial bank owing to natural mortality, windthrow, bank undercutting, fire, or slope failures from adjacent forest stands. Wood input to streams occurs during flood events when the level rises, and the buoyancy and water velocity overcome the resistance due to the log weight and friction forces. Models of wood entrainment in rives were considered by Braudrick & Grant [WRR, 2000] and Bocchiola et al. [AWR, 2006]. The present work differs from analyses reported in the literature for the following two reasons: i) the log is assumed fallen on a sloping bank transversal to the main flow direction, and ii) all the logs experimentally investigated, with the exception of a single comparison case, are characterized by the presence of rootwads. The combined effects due to i) and ii) contribute to a more realistic description of the phenomenon and have a manifest effect in the key piece incipient movement. Wood entrainment is schematized in the flume considering only the river portion delimited by the dashed rectangle, i.e., by neglecting transversal flow exchange between the channel and the bank [e.g. Wormeaton, 1996].

C) LABORATORY FACILITIES AND EXPERIMENT DESCRIPTION

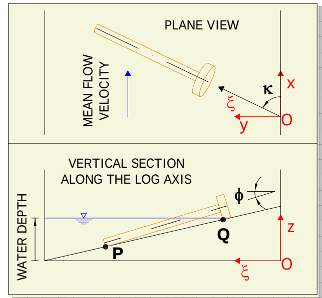
The experiments were carried out in a closed circuit flume 5.5 m long and 0.30 m wide. A 3 m long portion of the flume bed was reshaped with transversally tilted wood planks fixed on a proper framework to obtain a slope S_t=11-12% transversal to the main flow direction. The inlet of reshaped section was rounded to reduce the flow disturbance in the transition from the rectangular section of flume. The surface roughness of wood planks was artificially increased by gluing a thin layer of sand with a negligible scatter in the particle-size distribution, so that the d_{50}=1,2 mm value can be assumed as the bottom roughness, ensuring turbulence conditions for the flow (u^*>70). Three different longitudinal slope S_o (0%, 2% and 3,5%) were considered to reproduce different hydrodynamic conditions in the central part of the reshaped section where the incipient motion of logs was simulated. Here both the water and the bottom levels were measured in three different positions along four transversal sections of canal at each fixed discharge considered. The levels were surveyed to the nearest tenth of millimetres using a point gauge and the discharge was measured by an electromagnetic flow meter. This allows the interpolation of steady state stage area–discharge relationships and the accurate description of the bottom geometry adopted in the interpretation of experiments. The key pieces were simulated by wood cylinder ended with an octagon (to take into account the rootwad) of different lengths and thicknesses. Each single log was initially placed transversal to the mean flow direction. Then, water depth and velocity were gradually increased by augmenting the discharge via a slow sequence of small increments, so reproducing a sequence of steady flow states in the flume. The video recording of the experiment and the joint continuous discharge measurement permit the identification of the log position and hydrodynamic conditions (via the stage–discharge and area–discharge relationships) at the threshold of motion.

D) KEY PIECE ENTRAINMENT SEQUENCE



1: initial position; **2**: the log rotates around the rootwad; **3**: the log reduces its inclination respect to the mean flow direction; **4**: the log starts to move and is dragged out by the flow (almost aligned with mean flow direction).

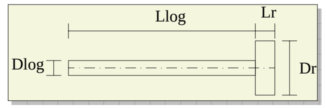
E) CONCEPTUAL MODEL AND EXPERIMENT ANALYSIS



A conceptual model, based on the 3-D stationary equilibrium of gravity, buoyancy, friction and hydrodynamic forces acting on a rigid body, was developed to allow the interpretation of scale flume model experiments. Starting from an initial low level, at each computational step the depth and velocity of water increase following a prescribed law and the vertical reactions acting on the support points P and Q are calculated as well as the friction forces. If the friction force in P is less than the hydrodynamic forces parallel to the support plane, the log rotates around Q and finds a new equilibrium by varying both the angles κ and ϕ until also in Q the friction results smaller than the hydrodynamic force (threshold of motion). Dry and wetted logs were considered, and the friction factor was set as the mean of (scattered) measured values. The model was then used to back-calculate the theoretical drag coefficients C_D by matching conditions at incipient motion measured in the flume experiments.

Log #	L_{log}	D_{log}	L_r	D_r
1	15.0	1.5	0.5	5.0
2	12.0	1.2	1.0	5.0
3	12.0	1.2	1.5	2.4
4	12.0	1.2	1.5	4.0
5	10.0	1.5	1.0	4.0
6	15.0	1.2	1.0	3.0
7	12.0	1.5	1.0	1.5

(measure in cm)



Our conceptual model does not consider the rotation of log on its own axis, and for this reason the key piece rootwad was shaped with an octagon. Nevertheless this happens in some cases with higher S_o slope and the resulting C_D were discarded. From the two sets of experimental runs reported in the follows one can observe that key piece threshold of motion is characterized by: i) κ=0° for low velocity (S_o=0%) when the buoyancy force prevails on P (for the wetted density also not illustrated here); ii) κ=10° -15° for higher velocity (S_o=3.5%) when the log does not float on P. Moreover the stability increases for higher D_r/L_{log} ratios corresponding to higher friction factors.

run & log #	density (kg/m³)	S_o (%)	friction factor	water depth (cm)	flow velocity (m/s)	κ (deg)	C_D
2.0-1	605	0.0	1.35	5.04	0.34	0°	0.37
2.0-2	597	0.0	1.55	4.75	0.32	0°	1.60
2.0-3	820	0.0	1.09	4.05	0.26	0°	0.99
2.0-4	827	0.0	1.35	4.78	0.32	0°	1.79
2.0-5	582	0.0	1.39	4.43	0.29	0°	1.13
2.0-6	858	0.0	1.13	4.33	0.28	0°	1.16
2.0-7	865	0.0	0.59	3.57	0.23	0°	2.65
7.0-1	744	3.5	1.35	1.8	0.59	87°	(*)
7.0-2	752	3.5	1.55	3.7	0.88	16°	1.29
7.0-3	950	3.5	1.09	4.8	1.01	20°	(*)
7.0-4	933	3.5	1.35	3.7	0.87	11°	1.60
7.0-5	722	3.5	1.39	3.5	0.85	15°	1.41
7.0-6	1090	3.5	1.13	4.7	1.00	9°	0.55
7.0-7	1080	3.5	0.59	4.0	0.92	15°	(*)

(*) the log rotates on its own axis

The obtained C_D values agree with results in literature [e.g. Manga & Kirchner, WRR 2000], but they must be considered as realizations of a stochastic process, being affected by uncertainties related to the friction factors and the hydrodynamic schematization, that considers only mean water levels and velocities. The validated model will be useful to define threshold statistics of motion for different log geometries and hydrodynamic conditions.