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DYNAMIC PRESSURE ON CHECK-DAM DUE TO DEBRIS-FLOW COLLISION

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ABSTRACT

Debris and mud flows collision on structures originates dynamic pressure, whose knowledge is obviously essential in rationally designing transversal protection structures (e.g., check dams). This problem appears to be nowadays of definite relevance, being the effects of debris and mud flows devastating.

Experimental data have been herein arranged by taking advantage of the *impact coefficient*, defined as the ratio between maximum flow deceleration to gravity acceleration. This coefficient turned out to be convenient in concisely labelling the dynamic behaviour of debris and mud flows. The impact coefficient is presented as a function of debris velocity and run-up height of the jet. The time the maximum deceleration occurs has been inferred by computing the temporal evolution of the maximum force acting on the wall.

INTRODUCTORY REMARKS.

Mud and debris flow can be defined as the flow of a mixture of heterogeneous material, composed of water, lime and solid particles (gravel, sand), having specific rheological properties. One of the distinctive and impressive peculiarities of debris flow is the observed capability in carrying downstream blocks of rocks, floating over the debris toe. The maximum transversal dimension of the boulders can be as large as four meters. Debris flow manages to propagate downstream for distance as long as many kilometers and the toe of debris flow can build velocity as high as 20 m/s . The effects of debris flow can be devastating, claiming casualties and massive material damages all over the World.

In order to control the downstream propagation of debris flow and to exert a retaining action of boulders, a number of different kinds of transversal protection structures (e.g. check dams) have been conceived. Hydraulic performance of structures can be accurately verified by physical modelling (Armanini and Trivellato,1990). Due to inertial effects, mud and debris flow collision on structures does originate dynamic pressure, whose knowledge is obviously essential in designing the structure.

The review of current literature does not give much assistance in collecting useful results, since any so far proposed approach (Lichtenhan, 1973; Aulizky, 1990) is unsatisfactory under some respects. Particularly, unsteadiness of phenomenon is not taken into account properly (Armanini and Scotton,1992). Check-dams designing is currently performed in Europe via a semi-empirical method after the recommendation of some European Public Authorities.

The present paper aims at attaining to a comprehensive understanding of debris flow collision in order to carry out a more rationally based design of hydraulic structures.

THEORETICAL APPROACH.

The unsteady problem of collision is governed by Euler non-linear equations along with kinematic condition on the free surface, whose evolution is clearly not known a priori. The analytical solution of the problem, whether accessible, would be of remarkable complexity.

As for the numerical solution , it was obtained by mapping the flow field domain in case of hydrodynamic pressure due to a horizontal seismic movement

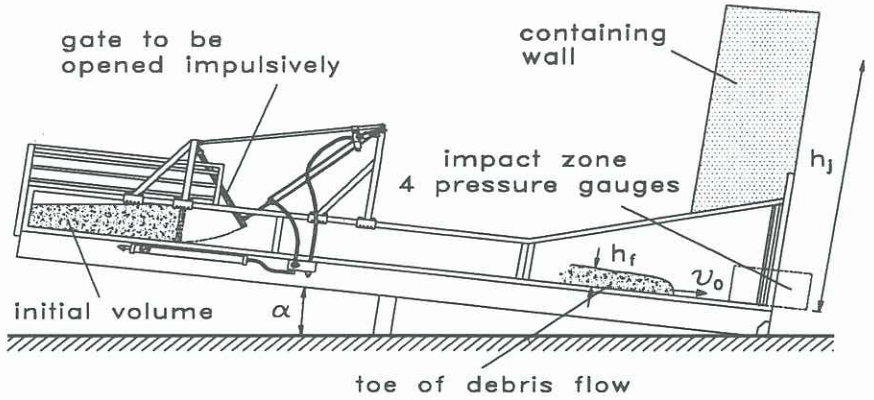

Figure 1: EXPERIMENTAL APPARATUS AND NOTATION.

of a dam (Chen,1994). The numerical solution is successful when the acceleration experienced by the wall (or, in other words, the deceleration experienced by the flow) does not exceed the range tested in the numerical experiments (namely $0.5g$) , which is less than it tipically occurs in debris flow collision. Moreover, the numerical solution cannot be thought of general value and its implementation in different domains is rather demanding. Hence a more practical and accessible interpretation of experimental data is needed.

One possibility of theoretical approach is offered by the resemblance that can subsist between debris flow collision and hydrodynamic pressure on dams due to a horizontal seismic movement: for the latter phenomenon, massive literature results are already available that could be extended to the former. As it is known (see, for instance, Shul'man,1987), the problem is reduced to the solution of the Laplacian operator written in terms of the velocity potential. Boundary conditions have been already discussed elsewhere (Scotton and Trivellato,1995). Of particular interest here is the displacement of the upstream face of the structure; the wall acceleration, a_d, can be supposed to be : $a_d(t) = a_o \sin(\omega t)$, where a_o is the initial acceleration ; $\omega = 2\pi/T$; T is the earthquake period ; t is the temporal abscissa.

At the time $t_M = T/4$, the pressure can reach its maximum value. The pressure due to debris flow collision can be basically thought of as that due to the displacement experienced by the structure in the first quarter of a period of a fictitious sinusoidal earthquake (the interest being in fact only in predicting the maximum value of the deceleration and, as a consequence, the maximum value of dynamic pressure) and not in studying the whole temporal evolution of the pressure on the wall.

According to the seismic model, the relevant scales are : the time scale t_M , (i.e., the time the maximum deceleration occurs) ; and the length scale h_f , (i.e., the undisturbed height of debris flow) . However, h_f was shown not to be a proper length scale (Scotton and Trivellato,1995), due to the hypothesis of tiny displacements of free surface which the seismic model is based on. The above hypothesis can in no way be met by actual debris flow collision, so the length scale has been redefined as h_j, i.e. the maximum run-up height of the jet after collision. The latter scale has an intrinsic meaning of unsteadiness.

Among the notable results of seismic theory, it is to be cited the role played by the wall inclination with respect to the line normal to the bottom, the maximum values of pressure occurring when the wall inclination is upstream. Thus it can be deduced a wall inclined downstream ought to be preferred as far as the reduction of dynamic pressure is concerned.

EXPERIMENTAL STUDY.

The full description of the experimental apparatus is reported in Scotton (1995). It basically consists of a tilted flume of rectangular section (6 m long, 0.5 m wide), at the end of which a perspex wall was placed and always kept normal to the flume's bottom (Fig.1). The flume was adjustable in slope and bottom roughness could be varied. The wall was instrumented by 4 pressure transducer gauges, that were accommodated any 2 cm along the vertical symmetry axis of the test wall, starting 0.5 cm above the bottom floor. Each transducer was set up at a 250 Hz frequency response, that turned out to be a by far convenient frequency to measure the temporal evolution of pressure at impinging time. At the very beginning of the flume, a reservoir was installed and filled either with clear water or with a mixture of water and sediment (simulated by suitable plastic materials). Initial volume and concentration of mixture were both varied.

The experimental procedure consisted in releasing impulsively the mixture in the reservoir and in mea-

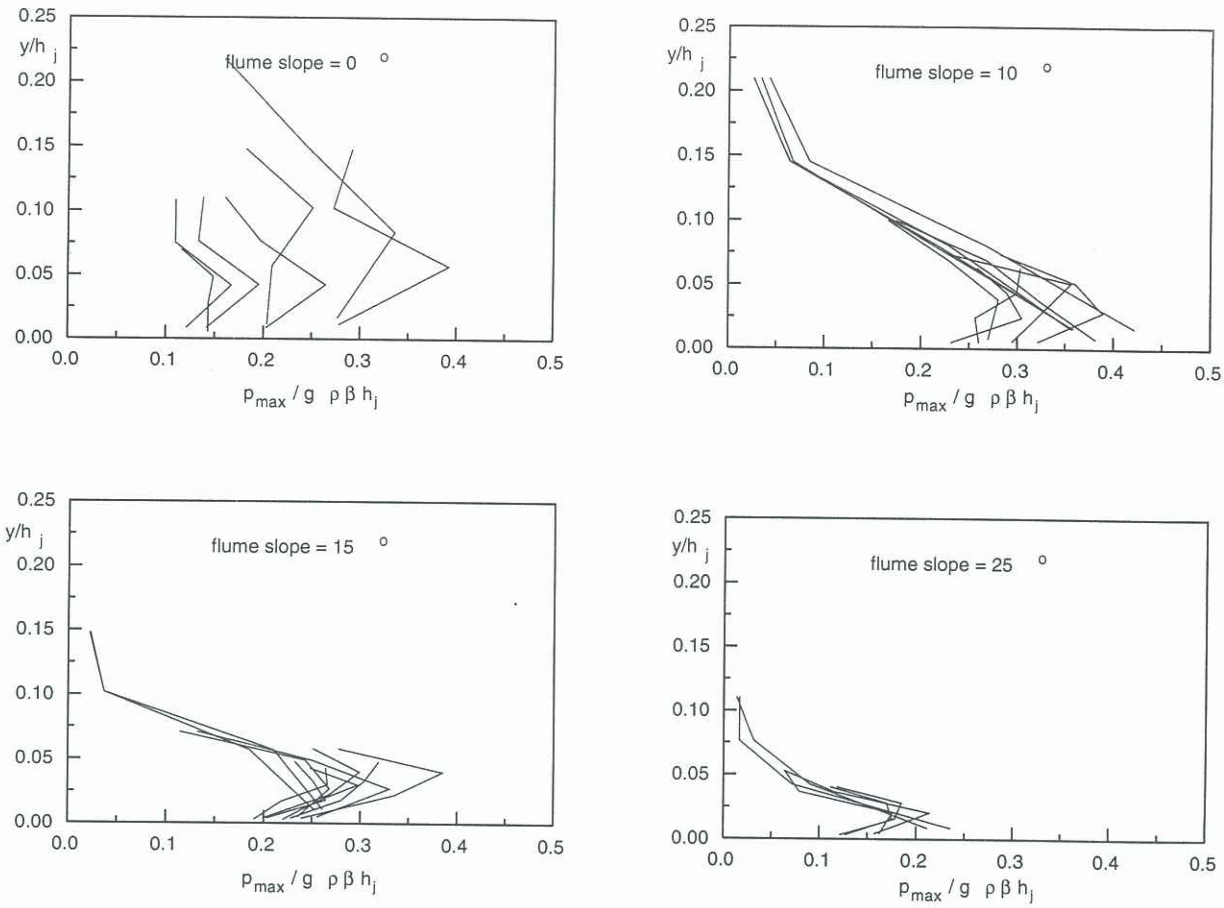

Figure 2: DYNAMIC PRESSURE DISTRIBUTIONS ON THE WALL.

suring the pressure evolution on the test wall after collision. The maximum run-up height, h_j, was measured by high speed video camera frames (accuracy: $\pm 3\ cm$), along with toe velocity, v_o (accuracy: $\pm 4\%$).

The estimate of t_M (i.e., the time the maximum deceleration occurs), is of most interest to calculate the impact coefficient (to be presented in what follows). Unfortunately, the evaluation of t_M is far from being an easy task due to the complex fluidodynamics of impact phenomenon: in fact, important secondary circulations are generated due both to the presence of lateral walls and to the impact of toe. Also, air entrainment was observed to occur before and after impinging when $Fr_f > 5$ (Trivellato,1993).

Due to the above phenomena, temporal evolution of wall pressure is characterized by strong pulsations. So, in spite of the great effort in performing accurate experiments, a poor repetitivity was detected in test experiments: in fact, the difference in pressure measurements among experiments sharing identical initial conditions could be as high as a disappointing $5\% \div 15\%$. Poor repetitivity was caused by the ever changing evolution of debris toe, that is intrinsically 3-D; thus the modes of impact do differ in each experiment and the measurement of t_M was neither easy nor univocal. The criterion presently adopted was to compute the total force acting on the test wall by means of the 4 available pressure gauges.

The total force diagram puts in evidence the t_M , to be seen now as the time the total force attains its maximum. However, the above criterion cannot still be sufficient in every instances , particularly when the flume slope is zero, when several maxima occur within a short period of time (Scotton and Trivellato,1995). In the latter instances, it is suggested t_M should be chosen when one of the maxima of the total force is in phase with the pressure maximum of the gauge whose elevation is nearest to the debris depth.

Only clear water experiments with smooth bottom floor are reported herein : a follow-up paper will be focusing on results pertaining to heterogeneous mixture, rough bottom and new procedure of measuring.

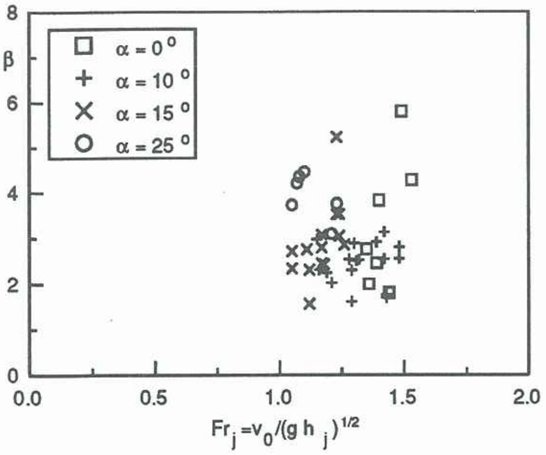

Figure 3: IMPACT COEFFICIENT.

RESULTS.

Comprimibility effects of water can be ignored since debris flow velocities are tipically nearly three orders of magnitude less than sound celerity in water; also, resonance conditions in the wall are far from being expected, due to the non-periodic nature of the involved vibrations. An *impact coefficient*, β , (acting like a fictitious seismic coefficient) is introduced as the ratio between the maximum flow deceleration (v_o/t_M) to gravity acceleration:

$$\beta = \frac{v_o/t_M}{g}$$

Hence any debris flow collision can be conveniently labelled by only one coefficient, which ranged between 0.5 through 6 in present laboratory tests. Fig. 2 presents the experimental results obtained for $0^o, 10^o, 15^o, 25^o$ flume slopes, supposedly the most representative. For brevity's sake, results pertaining to $5^o, 20^o$ slopes are not reported here (however, they are available by the Authors). In fig. 2, ρ is the density of mixture, g is the gravity acceleration, y is the co-ordinate running along the wall and normal to the flume bottom floor, positive upward.

Data scattering comes as a consequence of the actual collision, that is intrinsically a 3-D phenomenon. It is believed a 2-D impact (only achievable in theory) is capable to originate higher pressure values than in the 3-D case. Fig. 3 presents the impact coefficient.

CONCLUSIONS.

From a practical point of view, the first step is the evaluation of debris flow velocity, v_o , and of debris flow depth, h_f ; both quantities can be either estimated according to designing criteria or calculated via a propagation model for debris flow. The second step is the evaluation of the run-up height by fig. 4 (R_{h_f} is the hydraulic radius based on h_f) ; the evaluation of the impact coefficient derives from fig. 3 and the dynamic pressure distribution is eventually known by fig. 2.

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REFERENCES.

Armanini, A., and Scotton, P., 1992, "Experimental analysis on dynamic impact of debris flow on structure", *Proceedings, 6th Interpraevent Conference*, Vol. 6, Bern.

Armanini, A., and Trivellato, F., 1990, "Physical modelling of debris flow", *Proceedings, 22th National Congress of Hydraulics and Hydraulics Structures*, Cosenza, Italy (in Italian) .

Aulitzky, H., 1990, "Vorläufige Studienblätter zu der Vorlesung Wildbach n. Lawinenverbanng, Sommersen", Einverlag des Inst. für Bodenkultur, BI, Nr. 2.6/12a, 2.6/31, Wien (in German) .

Chen, B.F., 1994, "Nonlinear hydrodynamic pressures by earthquakes on dam faces with arbitrary reservoir shapes", *Journal of Hydraulics Research*, vol. 32, n. 3.

Daido, A., 1993, "Impact force of mud-debris flows on structures", *Proceedings, 25° IAHR Congress*, B-6-5, Tokyo.

Lichtenhahn, C., 1973, "Die Berechnung von Sperren in Beton und Eisenbeton", Kolloquium on Torrent Dams, ODC 384.3, Mitteilungen der Forstlichen Bundes Versuchsaustalt, 102, Wien (in German).

Scotton, P., 1995, "Dynamic impact of debris flow : experimental study", Technical Report, IDR2, Dept. of Civ. and Envir. Engnr., University of Trento, Italy.

Scotton, P., and Trivellato, F., 1995, "Vulnerability of check-dams", *Proceedings, 7th Congress on Seismic Engineering*, Siena, Italy (in Italian).

Shul'man, S.G., 1987, *Seismic pressure of water on hydraulic structures*, Russian Translations Series, n. 48, Balkema, Rotterdam, 1987.

Trivellato, F., 1993, "Ski jump aerators in partially filled conduits", *Proceedings, International Conference in Hydrosciences*, Washington D.C., USA.

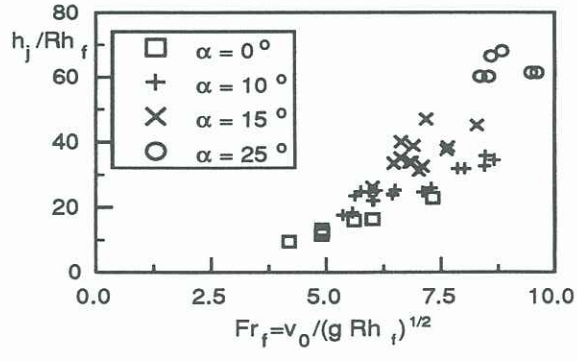

Figure 4: RUN-UP HEIGHT.