UNIVERSITA' DEGLI STUDI DI L'AQUILA FACOLTA' DI INGEGNERIA

D I S A T

L.I.a.m laboratorio di idraulica ambientale e marittima

“Onde di maremoto: meccanica della generazione, propagazione e interazione con le coste”

Monteluco di Roio (L’Aquila), 12 luglio 2005

Water waves generated by landslide in reservoirs: Italian events

A. Petaccia, A. Maistri

Vajont dam

Research program on landslide generated water waves

*Italian Dam Office – **RID***

*Laboratory of Environmental and Maritime Hydraulic – **LIAM**- of l'Aquila University*

The evaluation of impulsive waves originated by landslides in artificial reservoirs is of the utmost importance for dams and artificial reservoirs planning and management. In artificial basins where landslide risk exists, water level is kept below the maximum level, thus avoiding dam overtopping and the run-up on the shoreline of the potential impulse wave.

Recently, the National Dam Service (now RID Registro Italiano Dighe) funded a research program, based on experimental, numerical and mathematical studies, aimed at forecasting the main parameters related to water waves generated by landslides.
The experimental investigations carried out in LIAM laboratory led to the formulation of empirical relations on the principal features of impulse water waves propagating in a three dimensional water body . Moreover a laboratory study was used to define the impulse wave run-up on plane slope.

The results of these experiments were used to determine the principal features of subaerial landslide generated waves observed during the tragic events occurred in 1959 at the Pontesei artificial reservoir, and in 1960 and 1963 at the Vajont artificial reservoir.

3D PHYSICAL MODEL
The experimental variables

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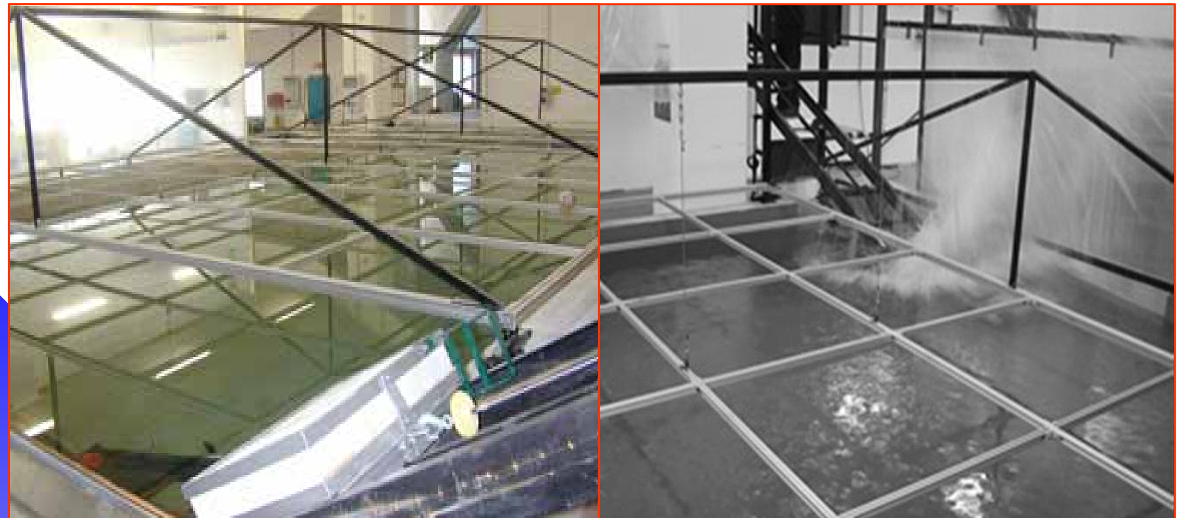
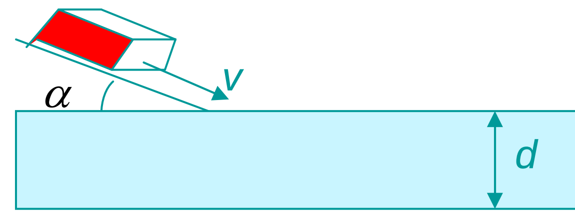
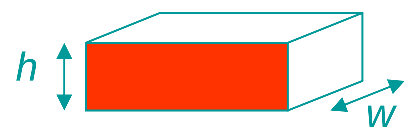


Pictures from the three dimensional physical model. On the left, solid block landslide model and wave tank. On the right, impact of the landslide model with water.

The experimental parameters



Landslide width **w** (m)
Landslide height ***h*** *(m)*
Impact velocity ***v*** *(m/sec)*
Landslide surface inclination ***α*** *(°)*
Distance from impact point ***r*** *(m)*
Angle from velocity vector ***Φ*** (°)
Local water depth ***d*** *(m)*



The landslides were modelled as solid blocks with zero porosity

Ranges of non dimensional parameters of the performed experiment

h/d	w/d	$v/\sqrt{(gd)}$	α	θ	r/d
0.11÷0.45	0.75÷3.00	0.99 ÷ 2.22	16° ÷ 26°	0° ÷ 90°	1.31÷15.12

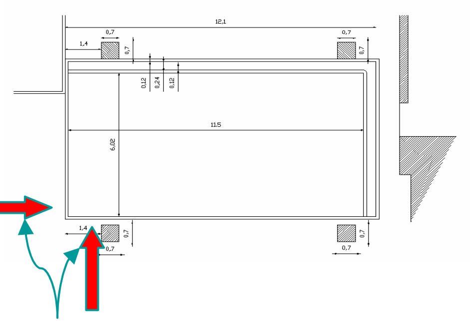
3D PHYSICAL MODEL Experimental formulation

Size basin

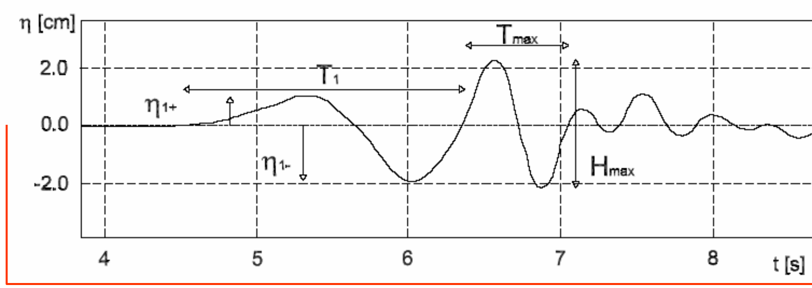
Lenght = 11.50 m

Width = 6.00 m

Depht = 0.80 m



Impact direction landslide



Maximum generated wave height

$$\left(\frac{H_{max}}{d}\right)^{*} = 0.12 \cdot \left(\frac{r}{d}\right)^{-0.4} \cdot \left(\frac{w}{d}\right)^{0.79} \cdot \left(\frac{h}{d}\right)^{0.5} \cdot \left(v/\sqrt{gd}\right)^{0.17} \cdot e^{0.6\cdot\cos\theta - 0.8\cdot\sin\alpha}$$

Wave period of maximum wave height

$$T_{max}\sqrt{g/d} = 2.5\left(\frac{h}{d}\right)^{0.1}\left(\frac{v}{\sqrt{gd}}\right)^{0.29}\left(\frac{r}{d}\right)^{0.18} e^{0.22\sin(\alpha)}$$

Wave height and period of the first water wave

$$H_1/d = 0.2(r/d)^{-0.8}(w/d)^{1.17}(h/d)^{0.88} \cdot \left(v/\sqrt{gd}\right)^{0.22} e^{1.32\cos\theta - 1.12\sin\alpha}$$

$$T_1\sqrt{\frac{g}{d}} = 6.9\left(\frac{r}{d}\right)^{0.16}\left(\frac{w}{d}\right)^{0.16}\left(\frac{h}{d}\right)^{0.16} e^{0.23\cos\theta}$$

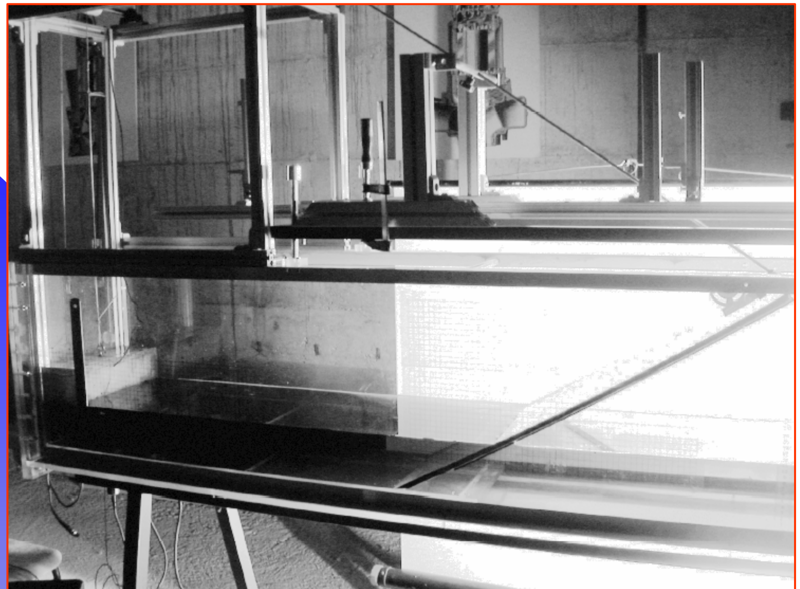
Crest and trough of the first water wave

$$\eta_{1+}/d = 0.069(r/d)^{-0.82}(w/d)^{1.28}(h/d)^{0.97} \cdot \left(v/\sqrt{gd}\right)^{0.2} e^{1.55\cos\theta - 1.4\sin\alpha}$$

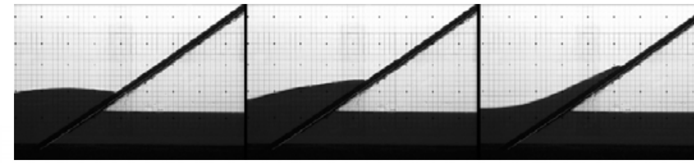
$$\eta_{1-}/d = -0.12(r/d)^{-0.82}(w/d)^{1.11}(h/d)^{0.84} \cdot \left(v/\sqrt{gd}\right)^{0.24} e^{1.21\cos\theta - \sin\alpha}$$

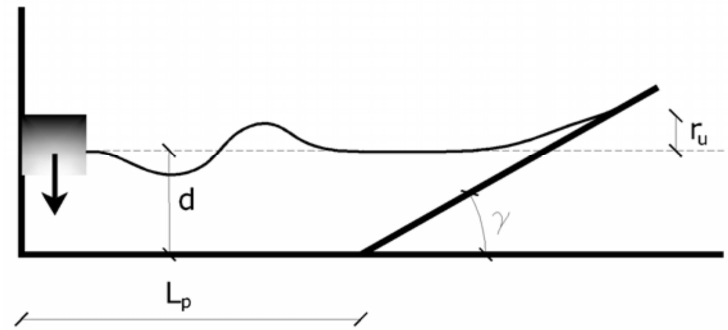
2D PHYSICAL MODEL
Experimental formulation

Wave flume



Images from one of the performed experiments on the run-up of landslide generated water waves





Sketch of the physical model used to study the run-up of landslide generated water waves on plane slopes

Experimental ranges of the considerate non dimensional variables.

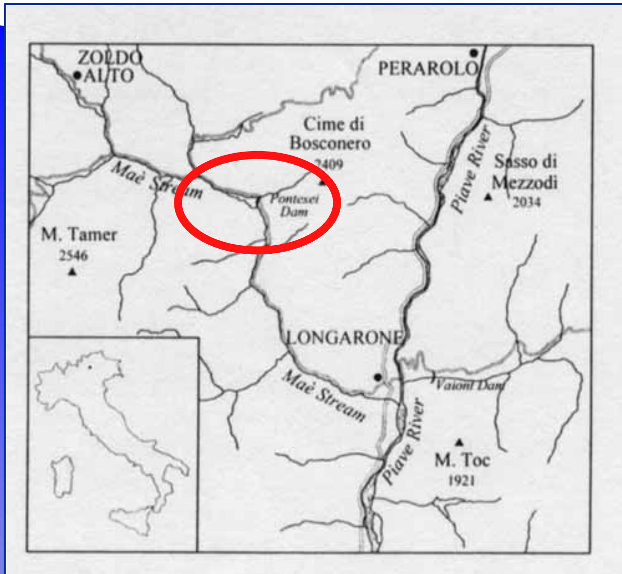
H/d	$T\sqrt{(g/d)}$	γ
0.18 ÷0.70	7.45 ÷ 15.60	19° ÷ 84°

Wave runup on the sloped plane (runup r_u)

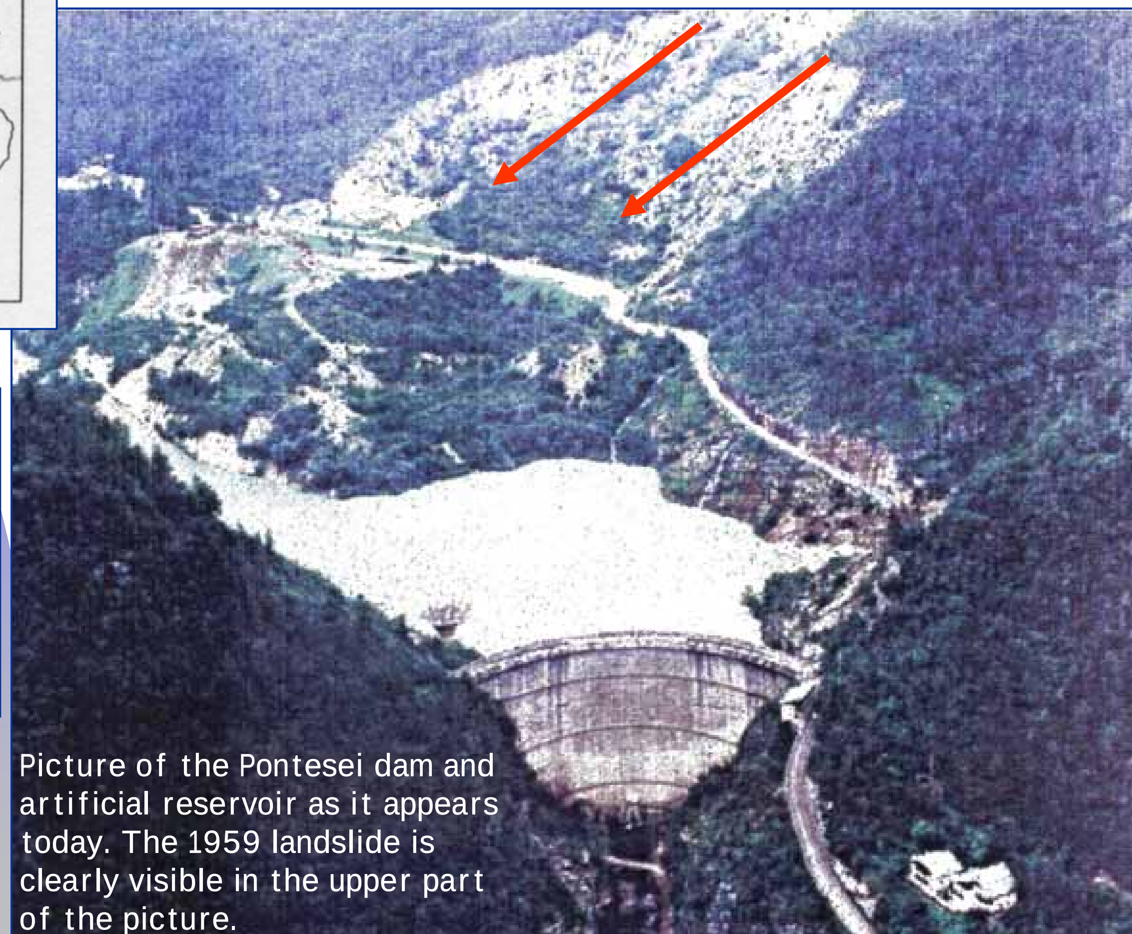
$$r_u/d = 1.37(H/d)^{1.51}\left(T\sqrt{g/d}\right)^{0.47}(\sin\gamma)^{0.26}$$

Application of forecasting formulation

Pontesei reservoir
March 22nd, 1959 event
(Southern Alps)



H dam (D.M. 24.03.82)	93,00 m
Storage capacity before the landslide event	$9.09 \cdot 10^{6}$ mc
Storage capacity after the landslide event	$5.8 \cdot 10^{6}$ mc



Picture of the Pontesei dam and artificial reservoir as it appears today. The 1959 landslide is clearly visible in the upper part of the picture.

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Pontesei reservoir
March 22nd, 1959 event

On March the 22nd 1959, an impulsive wave was generated by the falling of a rotational slide which mobilised about 4.5-5.0 million m^3 of debris. The basin contained about 6.10 million m^3 of water A man, who was riding along the street on opposite side of the basin, was killed by the run-up of impulse water wave. The 1959 event didn't cause damages to the dam, but reduced the storage capacity of about the 50%.

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Pontesei reservoir March 22nd, 1959 event

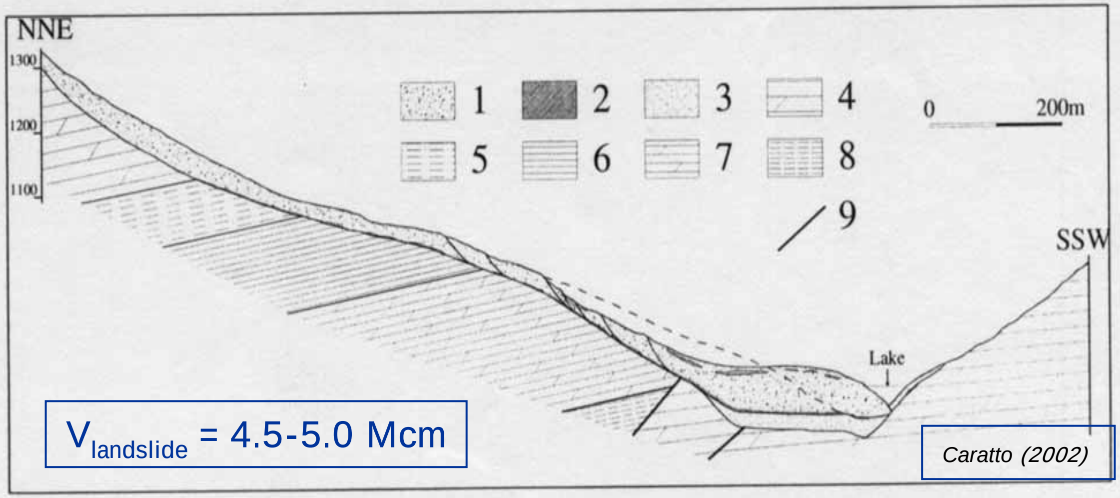
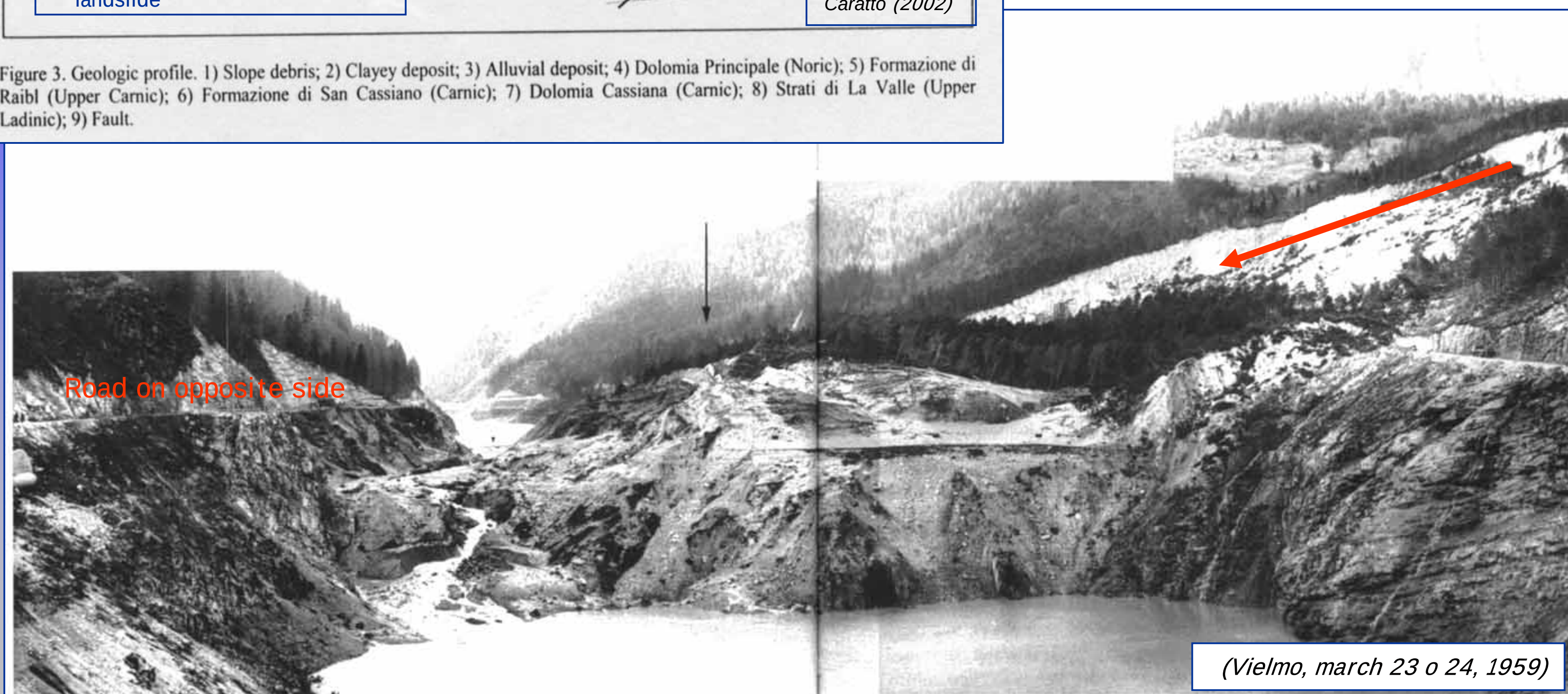


Figure 3. Geologic profile. 1) Slope debris; 2) Clayey deposit; 3) Alluvial deposit; 4) Dolomia Principale (Noric); 5) Formazione di Raibl (Upper Carnic); 6) Formazione di San Cassiano (Carnic); 7) Dolomia Cassiana (Carnic); 8) Strati di La Valle (Upper Ladinic); 9) Fault.



(Vielmo, march 23 o 24, 1959)

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Parameters introduced in the experimental formulation

Landslide width (w)	[m]	400.0
Landslide height (h)	[m]	47.0
Impact velocity (v)	[m/sec]	0.4-0.8
Local water depth (d)	[m]	47.0
Angle from velocity vector (θ)	[°]	0.00
Landslide surface inclination (α)	[°]	5-10
Distance from impact point (r)	[m]	175.0
Runup slope inclination (γ)	[°]	40

h/d	w/d	$v/\sqrt{(gd)}$	α	θ	r/d
0.11÷0.45 **1.0**	0.75÷3.00 **8.51**	0.99 ÷ 2.22 **0.019 ÷ 0.037**	16° ÷ 26° **5° ÷ 10°**	0° ÷ 90° **0°**	1.31÷15.12 **3.72**

Landslide non dimensional parameters

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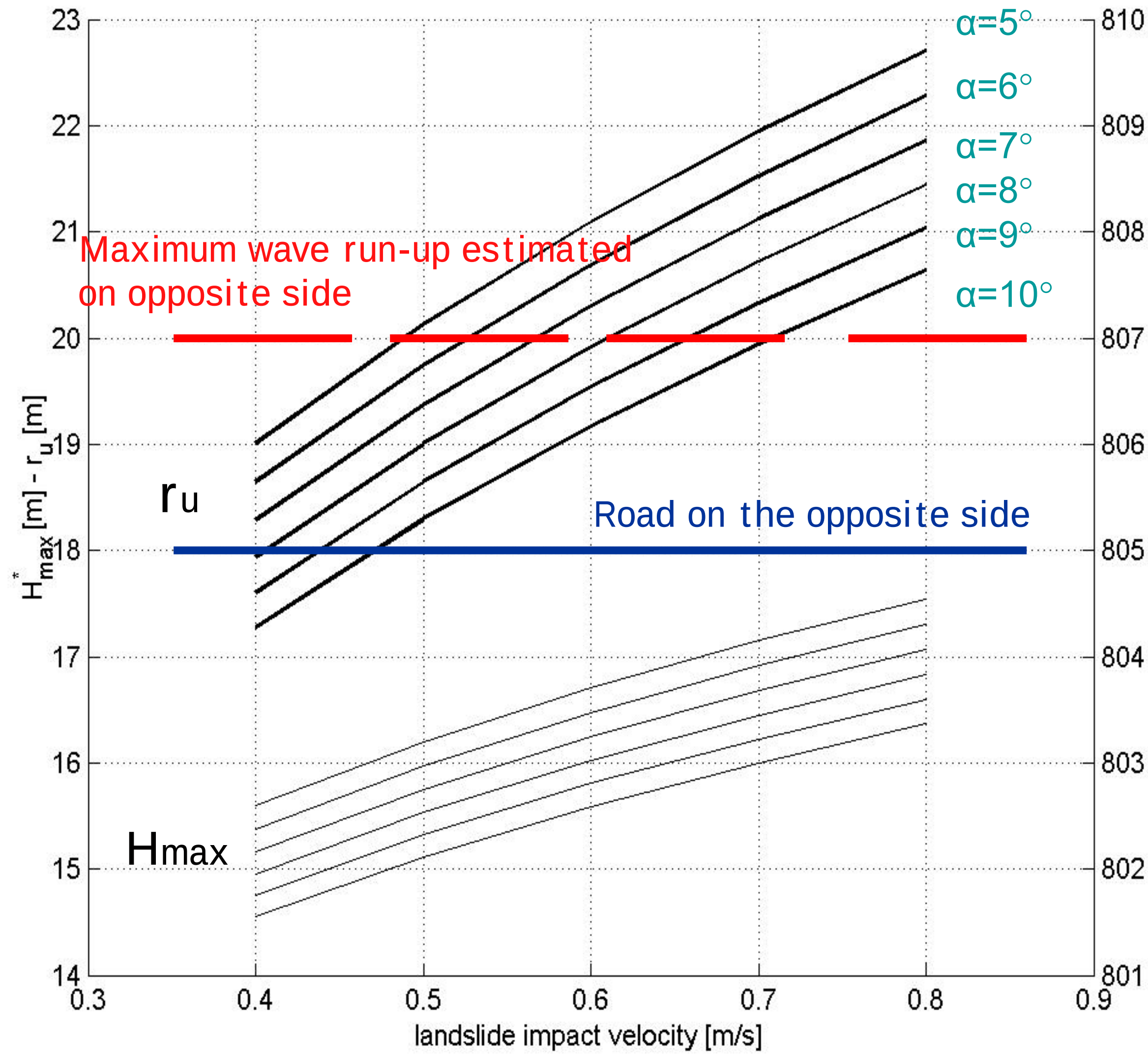
Application of forecasting formulation

Pontesei reservoir
March 22nd, 1959 event



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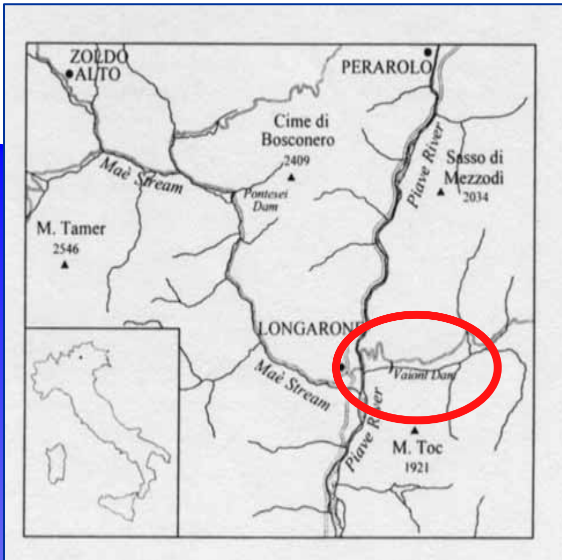
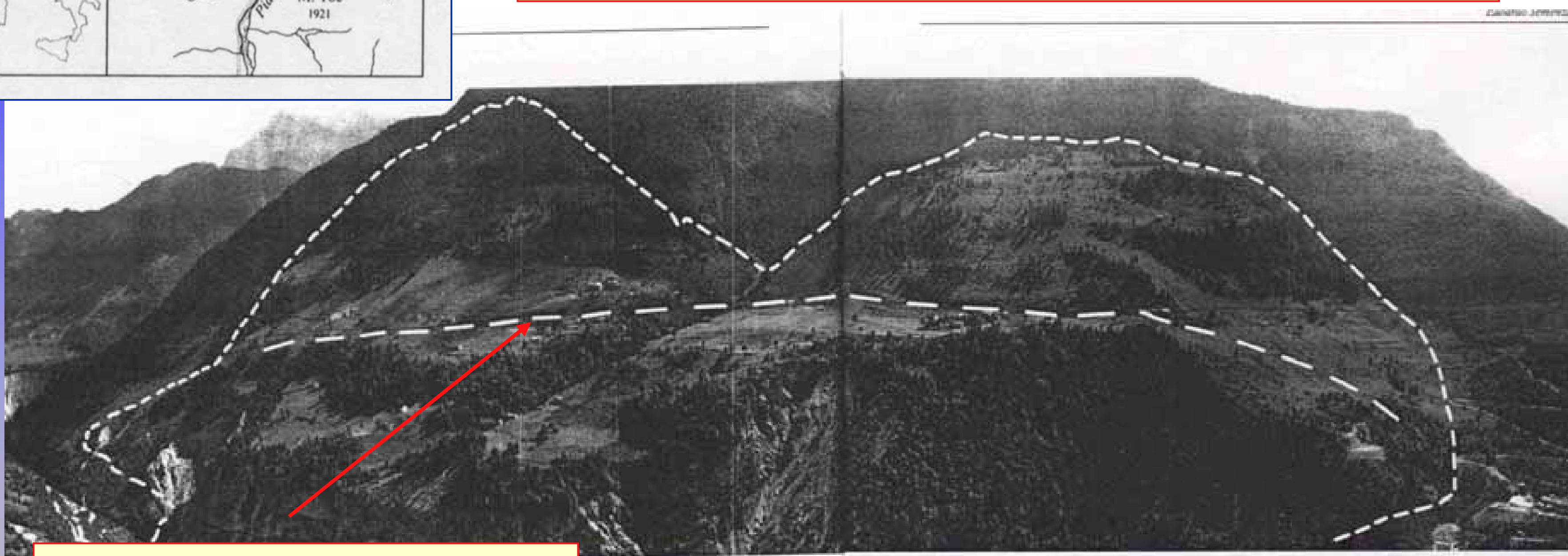
Vajont reservoir
Left slope of the valley (Toc mountain)



Picture of the Toc mountain, reporting the first hypothesis about dimension and shape of the landslide mechanism interesting the Vajont reservoir



First hypothesis of paleo-slide (1959)

E. Semenza, 1959

The construction of the artificial reservoir in the Vajont valley triggered the instability of the slopes, and two rock landslides which fell into the water on November 4th, 1960 and on October 9th 1963.

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