VULNERABILITY TO FLOODS: A SIMPLIFIED MODEL FOR EXPOSED BUILDINGS

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1. Introduction

Floods in mountain areas are among the most dangerous hazards worldwide. Although most researches were focus on flood modelling, vulnerability and exposure assessment are relevant parts of the overall process toward a rational risk assessment (Fig. 1). Within this framework, the presented research focuses on the structural vulnerability of masonry buildings.

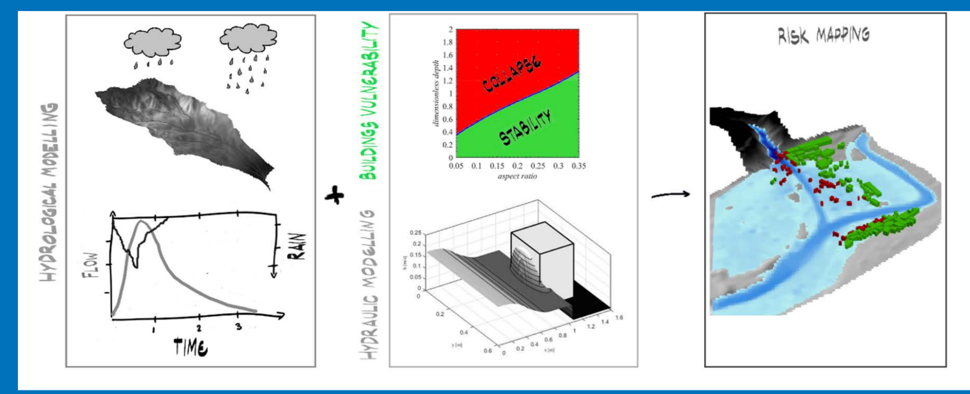

Fig. 1 – Risk assessment process with focus on the goal of this resarch

A conceptual model analyzing the stability of a wall (Fig. 3) impacted by a flow under different building configurations is provided. This scheme is conceived for application on **masonry structures with load bearing walls** within a **limited collaborative structure** that require stability analysis focused on the behavior of each **single structural element**.

Fig. 2 – View of an Alpine village

The detailed analysis of stability of a single building under the action of flood would require a specific knowledge of the building characteristics and of the mechanical properties of the materials. Since these tasks would be extremely challenging when assessing flood risk in wide areas, we propose a model for a **preliminary flood risk assessment at regional scale** where a considerable stock of exposed masonry buildings is present (e.g. Fig. 2). The application of the model allows for the identification of the highly-exposed and vulnerable buildings for possible further detailed analyses.

2. Model description

The model is developed within the **limit analysis** framework assuming:
- unlimited compressive strength and stiffness of the masonry;
- no tensile resistance of the masonry;
- no slip between masonry elements and at the foundation level;
- masonry quality that ensures a "monolithic" behavior of the wall.

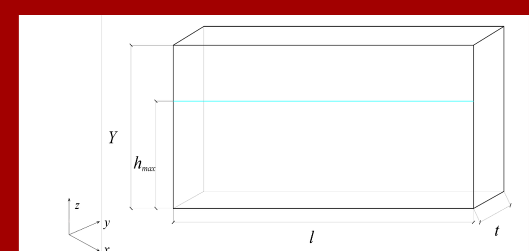

Fig. 3 – Features of the reference wall

If the force exerted by the flow exceeds the limit value, the impacted masonry wall experiences the onset of a **failure mechanism** causing the decomposition of the wall into **monolithic blocks** identified by possible **fracture lines**. The blocks rotate about the **cylindrical hinges** developing along each fracture line.

The **impact force** per unit width F(N/m) is the integral of the pressure profile on the wall. If the dynamic run-up height h_{max} (m) following the impact of the fluid on the wall is properly computed, the hydrostatic approximation provides with good approximation the peak force $F = \gamma_f \int_o^{\max(Y,h_{max})} z\,dz$, where γ_f (kg/m³) is the unit weight of the fluid, Y(m) is the height of the wall, and z(m) is the vertical coordinate.

Two different **static schemes** and **failure mechanisms** are addressed, depending on the efficiency of the constraint provided by the cross-walls, the floor, and the foundation to the reference wall.

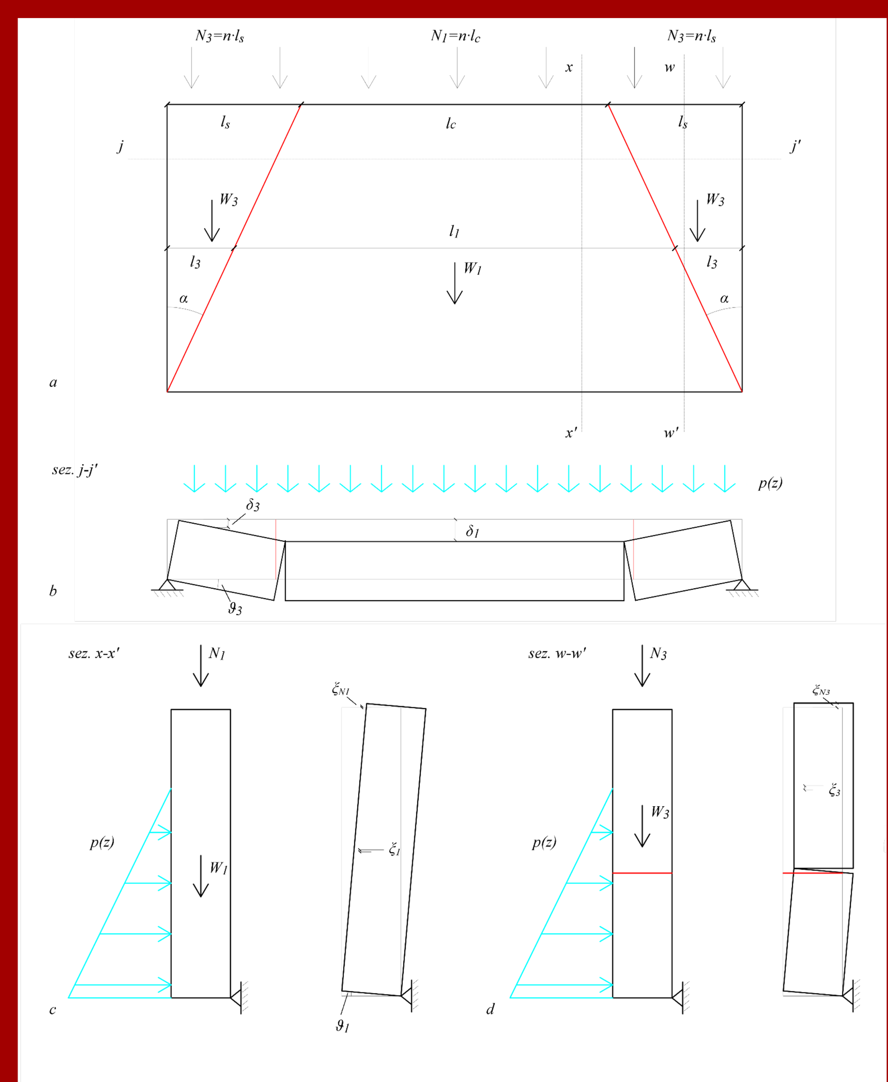

Fig. 4 - 3-edges support: wall simply supported on the *cross-walls* and at the *foundation* level. Front view (a), plan cross section (b) and vertical cross sections (c, d) .

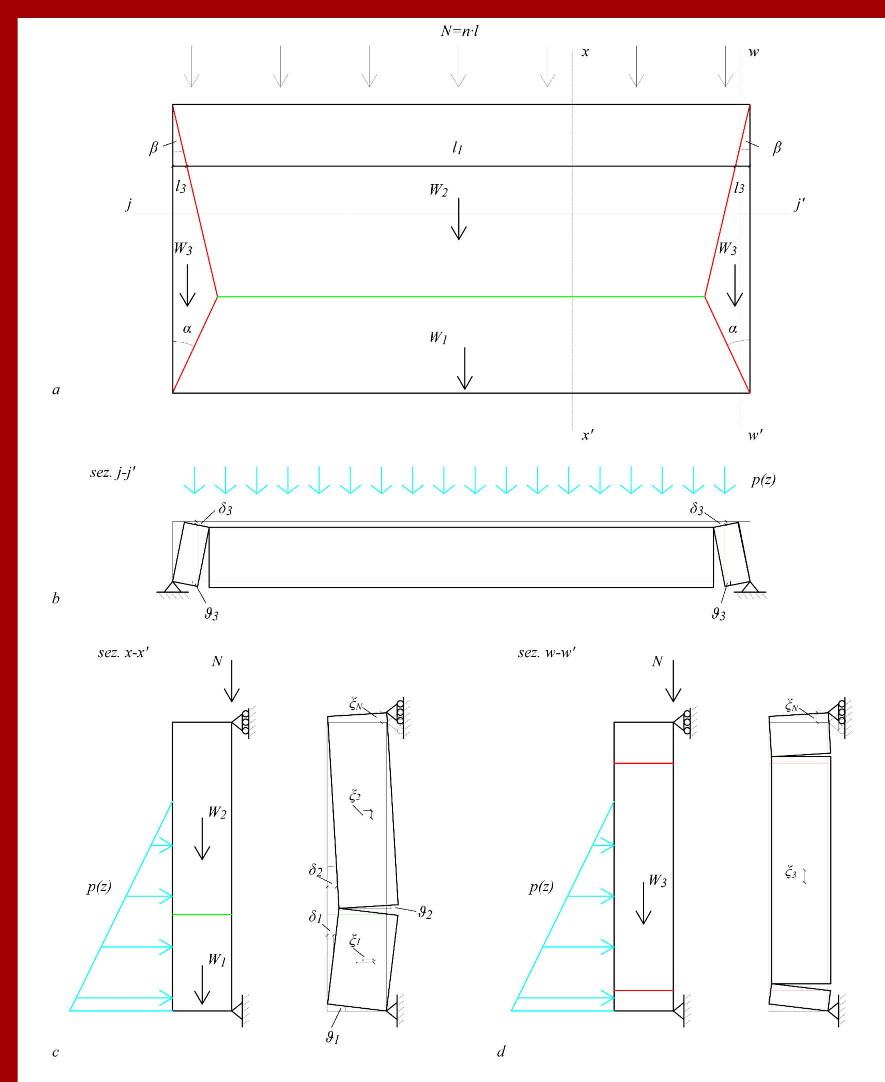

Fig. 5 - 4-edges support: wall simply supported on the *cross-walls*, at the *top*, and *foundation* levels. Front view (a), plan cross section (b) and vertical cross sections (c, d) .

3. Resulting thresholds

The resulting vulnerability thresholds were computed numerically by solving the equations of the virtual work principle. The conditions of incipient instability, i.e. the onset of the failure mechanism, is achieved when the absolute value of the work done by the stabilizing actions (self weight and vertical loads, L^+) equals the absolute value of the work done by the overturning actions (impact force, L^-). The results obtained by the two schemes can be rewritten in dimensionless form:

$$\frac{L^+}{L^-} = f(g, \rho_m, l, t, n, h_{max}, \rho_f, \alpha)$$

where g (m/s²) is the gravity acceleration, ρ_m (kg/m³) is the density of the masonry, l (m) is the width of the wall, t (m) is the thickness of the wall, Y (m) is the height of the wall, n (-) is the vertical load per unit width at the top of the wall, h_{max} (m) is the run-up height, ρ_f(kg/m³) is the fluid density and α(°) is the inclination of the lateral hinges. Applying the Buckingham theorem and assuming as fundamental quantities g, ρ_m e Y it is possible to obtain 6 dimensionless groups:

$X_1 = \frac{l}{Y}$	*Wall aspect ratio*	$X_4 = \frac{h_{max}}{Y}$	*Fraction of wall impacted by the flow*
$X_2 = \frac{t}{Y}$	*Slenderness of the wall*	$X_5 = \frac{\rho_f}{\rho_m}$	*Ratio between fluid and masonry density*
$X_3 = \frac{n}{g\rho_m Yt}$	*Load per unit width at the top as a fraction of the wall weight*	$X_6 = \alpha$	*Fracture line inclination*

Tab. 1. Dimensionless groups

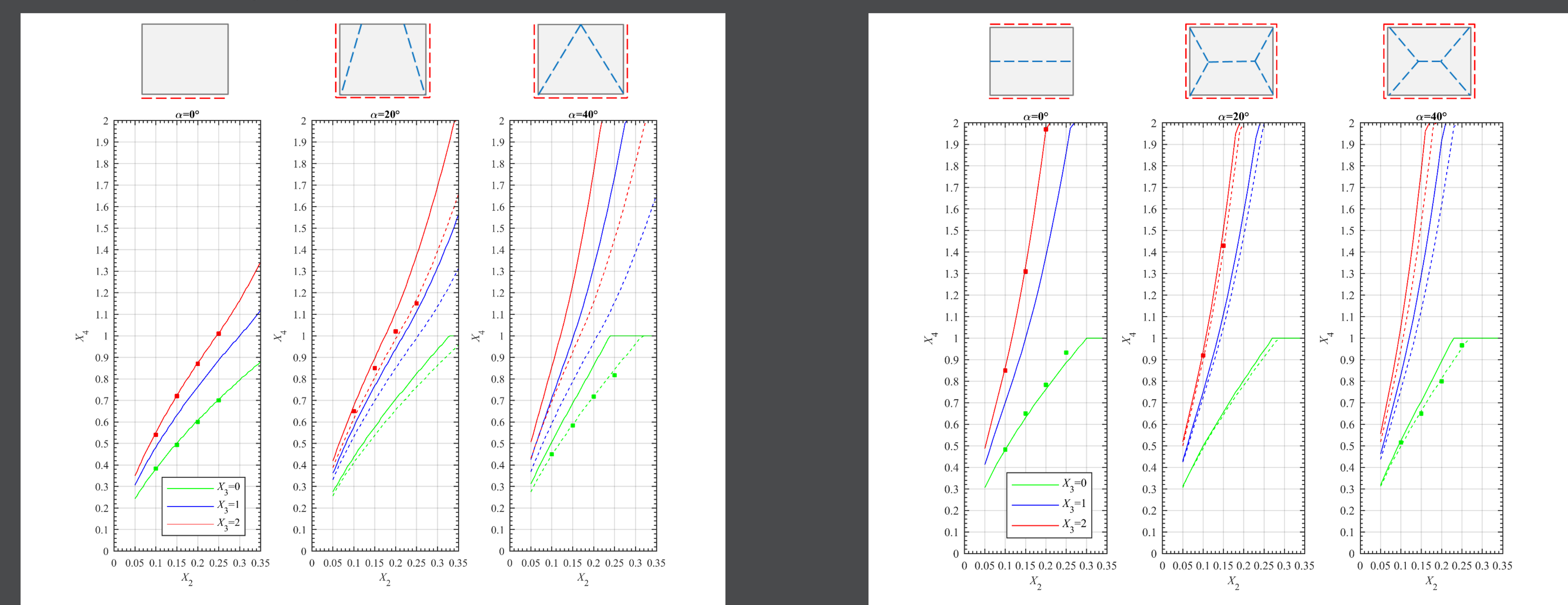

Fig. 6 - Vulnerability thresholds for the 3-edges (LEFT) and 4-edges (RIGHT)support schemes as a function of the slenderness of the wall (X_2). The solid line plots are computed for X_1=1 and the hatched lines for X_1=2. Note: α=0° refers to wall sides unrestrained. The solid dots represent the results of the FEM model mentioned in Section (4). Thresholds computed assuming ρ_f=1000 kg/m³ and ρ_m= 1800 kg/m³ (X_5=0.56).

4. Discussion

A **Finite Element Model** (FEM) of the wall under different loads and constraints configurations was set-up in Abaqus to **validate the conceptual thresholds** and to assess the **influence of the simplifying assumption**. The resulting minimum heights h_{max} causing failure (solid dots in Fig. 7) show **good agreement** with the thresholds of the conceptual simplified model. A sensitivity analysis was carried out to further highlight the influence of the mechanical parameters related to masonry stiffness and strength. The parameter that mainly affects the results is the **tensile strength** of the masonry. The increase or decrease of the tensile strength lead to the increase or decrease of h_{max}, respectively. The amount of changing is bounded by **10%**. The model is less sensitive to the variation of the other parameters.

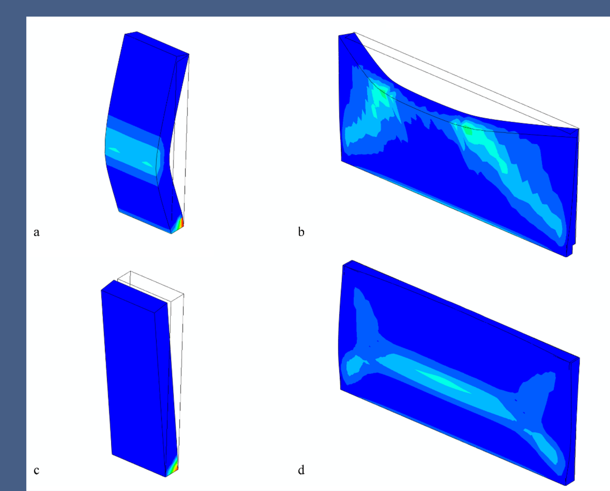

Fig. 7 – Deflected shape of the model at failure and location of the tensile plastic strains (X_3=0). a) wall with fixed base and pin-connections at the top; b) wall with fixed base and pin-connections at the sides; c) wall with fixed base only; d) wall with fixed base and pin-connections at the other sides.

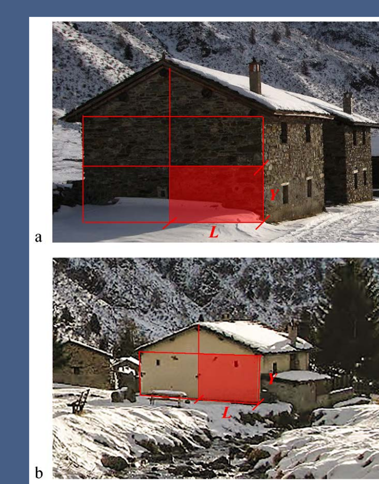

Fig. 8 – Examples of traditional masonry buildings. The red shadings show the elementary wall units considered for the simplified analysis summarized in Tab. 2.

Figure	Scheme	X_1	X_2	X_3	X_4	X_5	X_6
8.a	4 edges	1.6	0.22	1÷1.4	***1.8÷2***	0.56	30°
8.b	3 edges	1.2	0.15	1÷1.2	***0.75÷0.85***	0.56	20°÷30°

Tab. 2. Results of the application of the model to the buildings in Fig. 8.

An **example of application** of the model is given with reference to the buildings in Fig. 8. The most exposed faces of both buildings are free of relevant openings and the cross-walls can guarantee support since no relevant openings are located near the edges. The results are summarized in Tab. 2.

Additional FEM analyses will be considered for future activities to test the representativeness of the simplified models in the case of presence of openings such as **doors and windows** and to explore the behavior of the **overall building**. Moreover, the possibility to define **other types of limit states** and the evaluation of the **economic implications** of structural flood damages could be further investigated.