Blind Prediction Competition
Multi-Leaf Rubble Stone Masonry Walls

Principal Investigators

EPFL EESD

Laboratory facility

GIS PLATFORM

Funding scheme

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1 Introduction

Multi-leaf rubble-stone masonry buildings are widely recognized as among the most vulnerable masonry typologies. Previous earthquakes and research have shown that the structural response of this masonry typology is influenced not only by the mechanical properties of the materials (stone and mortar) but also by the microstructure, defined by the size, shape, and spatial arrangement of individual stones. However, the role of microstructure on the mechanical behaviour of this masonry typology has yet to be systematically explored, both experimentally and numerically.

A significant limitation in current numerical modelling approaches for this type of masonry is the lack of accurate geometric representations of real walls tested in the lab that can be used as benchmarks. Recently, significant advances have been made in creating accurate digital geometrical twins of laboratory-built walls using image-based 3D reconstruction and laser scanning. Validating existing numerical models against these digital twins is now a crucial next step.

This project aims to fill this research gap by providing detailed experimental data on multi-leaf rubble stone masonry walls with systematically varied microstructure configurations, along with their exact geometrical digital twins. Seven full-scale walls have been constructed by experienced masons, each characterized by a distinct microstructure. Geometric digital twins are generated for all of them. We are organizing a blind prediction competition to facilitate comparison and improve current modelling strategies. Three of the seven constructed walls are selected for this exercise, inviting participants to submit predictions of their monotonic in-plane shear-compression responses before testing. The experimental campaign is scheduled for the beginning of May 2026 and will take place at the Structural Engineering Platform (GIS) at EPFL, Lausanne, Switzerland. If you are interested in participating in the blind prediction competition or have any questions, please do not hesitate to reach out to any of the following:

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- Prof. Katrin Beyer (katrin.beyer@epfl.ch)

2 Description of wall microstructures

Three large-scale multi-leaf rubble stone masonry walls, each characterized by a distinct microstructure, are selected for this blind prediction competition. Each wall has dimensions of 1400 mm × 1400 mm × 400 mm (height × length × width). Further details on the microstructure of each wall are provided below:

2.1 Test specimen 01

The key characteristics of the specimen are as follows:

- **Stone type:** Limestone
- **Stone dimensions:** Approximately 70–80% of stones are 20-25 cm, with the remaining stones smaller than 20 cm.
- **Mortar:** Lime-based mortar (NHL 5) with a binder-to-sand ratio of 1:3 and a water-to-binder ratio of 0.7 is used.
- **Surface finish:** One side of the wall is plastered with lime mortar (5–6 cm thick), while strips of 2–3 cm at the top and bottom are left unplastered to avoid direct load transfer to the plaster.

An overview of the specimen geometry is shown in Figure 1. The detailed geometric digital twin of this wall is available on Zenodo (https://doi.org/10.5281/zenodo.17900935).

Figure 1. Geometrical digital twin (left) and real wall (right) labelled as Test specimen 01: multi-leaf stone masonry wall built with stones of relatively larger size than specimen 03.

2.2 Test Specimen 02

The key characteristics of the specimen are as follows:

- **Stone type:** Rounded, smooth stones sourced from the river.
- **Stone dimensions:** Approximately 70–80% of the stones are 10-20 cm, while the remaining stones are larger than 20 cm.
- **Mortar:** Lime-based mortar (NHL 5) is used, with the same mix proportions as Specimen 01.
- **Surface finish:** Same as Specimen 01.

An overview of the specimen geometry is shown in Figure 2. The detailed geometric digital twin of this wall is available on Zenodo (https://doi.org/10.5281/zenodo.17900935).

Figure 2. Geometrical digital twin (left) and real wall (right) labelled as Test specimen 02: multi-leaf stone masonry wall built with smooth, rounded shape stones sourced from the river.

2.3 Test specimen 03

The key characteristics of the specimen are as follows:

- **Stone type:** Limestone
- **Brick type:** Burned solid clay brick
- **Stone dimensions:** Approximately 70–80% of the stones are 10-20 cm, while the remaining stones are larger than 20 cm.
- **Brick dimensions:** 20 x 10 x 5.2 cm
- **Mortar:** Lime-based mortar (NHL 5) is used, with the same mix proportions as Specimen 01.

- **Surface finish:** Same as Specimen 01.
- **Bricks courses:** Provided at the bottom, center, and top of the wall.

An overview of the specimen geometry is shown in Figure 3. The detailed geometric digital twin of this wall is provided separately through Zenodo (https://doi.org/10.5281/zenodo.17900935).

Figure 3. Geometrical digital twin (left) and real wall (right) labelled as Test specimen 03: multi-leaf stone masonry wall built with stones of relatively smaller size than specimen 01 and levelled with brick courses.

3 Material properties

The mechanical properties of limestone are obtained from the literature [1]. The mechanical properties of the lime-based mortar used for construction and plastering are determined experimentally. Mortar prisms of dimensions 160 × 40 × 40 mm were cast and tested following EN 1015-11 [2]. Flexural strength is determined by three-point bending tests, after which compressive strength tests are conducted on the halves obtained from the flexural tests. The preliminary results of these material tests are summarized in Tables 1 and 2. The mechanical properties of the mortar used in each wall will be shared later, as these will be tested closer to the date of the wall test.

Additionally, participants will later receive data from simple compression tests on wallets measuring 900 mm × 900 mm × 400 mm, constructed with the same materials and similar microstructures. The compressive strength reported in the literature for the rubble stone masonry typology (without brick courses) is 0.67 MPa, with a coefficient of variation of 23% [3].

Table 1. Preliminary mechanical properties of mortar.

Mortar type	Compressive strength [MPa]	Flexural strength [MPa]	Young's modulus [MPa]
Construction mortar	3.11 ± 0.26 (8%, 6, 90)	0.79 ± 0.29 (36%, 3, 90)	301 ± 60 (20%, 6, 90)
Plaster mortar	1.52 ± 0.16 (10%, 6, 30)	0.67 ± 0.01 (2%, 3, 30)	157 ± 51 (33%, 6, 30)

***Notation:** mean ± standard deviation (CoV: Coefficient of Variation, number of samples, age of mortar in days at time of testing).*
***Note*:** Young's modulus of mortar samples is computed as the slope between 1/3 and 2/3 of the compressive strength.*

Table 2. Mechanical properties of stones.

Mortar type	Compressive strength [MPa]	Young's modulus [GPa]
Limestone	116.1 ± 13 (11%, 4)	27 ± 3 (11%, 4)
River stones*	-	-
Bricks*	-	-

Notation: *mean ± standard deviation (CoV: Coefficient of Variation, number of samples).*
Note: *Information on the mechanical properties of river stones and bricks will be shared in the coming days.*

4 Testing scheme and instrumentation

Figure 4 depicts a schematic diagram of the shear-compression test setup. For more details on the experimental setup, please refer to Oreb et al. [4]. We will test all three walls in monotonic in-plane shear-compression loading under double-bending boundary conditions. The test setup consists of:

- Two vertical servo-hydraulic actuators for force-controlled loading, each with a capacity of ±1000 kN.
- One horizontal servo-hydraulic actuator for displacement-controlled loading, with a displacement capacity of ±500 mm.

The test will be conducted in two phases:

- Phase 1 – Pre-compression: An axial pre-compression load of 50 kN will be applied.
- Phase 2 – Shear-compression: A horizontal displacement will be imposed at a rate of 0.01 mm/sec. The test will continue until axial load failure, defined as the point at which the wall can no longer sustain the constant axial load.

The response of the test specimens will be recorded using two types of measurement systems: (a) traditional hard-wired instruments for force and displacement measurements and (b) an optical system employing digital image correlation (DIC) to capture the 3D displacement field on both sides of the wall. The hard-wired system will include 11 linear variable differential transformers (LVDTs, 'lv'), string potentiometers (STPs, 'stp'), and inclinometers to monitor global and local movements of the wall, foundation, and loading beam. LVDTs will measure foundation sliding and rocking as well as horizontal and vertical displacements, while inclinometers and potentiometers will track rotation and vertical elongation of the loading beam. The optical system will consist of stereo camera pairs on both sides of the wall. For the digital image correlation measurements, we will follow the procedures suggested by the International Digital Image Correlation Society [5]. The 3D displacement fields will be processed using commercial DIC software, providing full-field measurements for post-test analysis.

Note that the exact instrumentation plan is still under discussion, and information may be updated in the future.

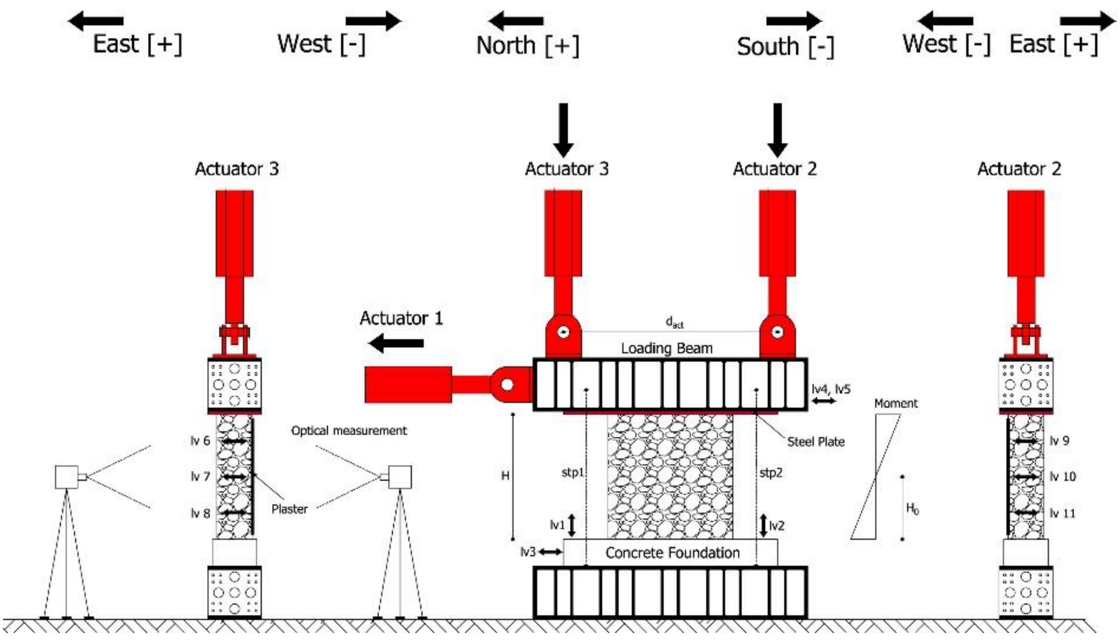

Figure 4. Scheme of shear-compression test setup and instrumentation. The image is adapted from Oreb et al. [4]***.***

5 Information to be reported for the blind prediction

For the blind prediction competition, participants shall submit two types of information:

1) Description of the methodology used for the prediction. We accept submissions using either numerical or analytical methods, or a combination of those.
2) The predicted response for each provided wall microstructure.

5.1 Description of the methodology used for the prediction

Participants shall describe their methodology. The required information includes:

- General description of the model, including the modelling framework (e.g., finite element, discrete element, homogenized continuum),
- Details on the modelling of stone units and mortar, covering:
    - How units and joints are represented (e.g., continuum, block-based, interface models),
    - The constitutive laws and material properties assigned,
    - Any assumptions or simplifications made.
- In case no numerical modelling approach is used, please provide information about the analytical methodology.

Forms for describing the model and observed values are available for download (see Section 6).

5.2 Quantities to be reported for the blind prediction competition

Participants shall report the following predicted quantities for each wall microstructure:

- Horizontal load–drift response in .csv format
- Peak horizontal force V_p
- Effective stiffness, defined as the secant stiffness at 70% of V_p
- Ultimate drift, defined as the drift corresponding to a 20% reduction of the peak horizontal strength
- Drift at collapse, defined as the drift corresponding to a 50% reduction of the peak horizontal strength, or the point at which the wall can no longer sustain the constant vertical axial load, whichever occurs first.
- Measurement of the maximum opening/separation between the wall leaf and its location at the ultimate drift state (drift at 20% reduction in peak strength).
- Failure mode and crack pattern

Participants are free to choose to provide **deterministic** or **probabilistic results**, or **both**. The probabilistic results should be provided as

upper and lower bounds for each of the requested quantities.

5.3 Methodology for evaluating the response

5.3.1. Deterministic approach

For submitted predictions with single values for each quantity q^i, the score will be computed for each quantity as:

$$S^i = 1 - \min\left(\left|\frac{q^i_{pred} - q^i_{exp}}{q^i_{exp}}\right|, 1\right)$$

where q^i_{pred} and q^i_{exp} are the predicted and experimental results, respectively, for the quantity q^i.

The total score will be computed by considering the same weight for all requested quantities.

$$Total\ Score = \sum_{i=1}^{7} S^i$$

5.3.2. Probabilistic approach

When providing probabilistic predictions, participants should briefly outline the methodology and assumptions used to derive the range of reported values and (optionally) the confidence interval they correspond to.

The procedure for evaluating probabilistic predictions is the following. For each quantity q^i, if the experimental value falls within the predicted closed range, the score will be:

$$S^i = 1.2 - \max\left(\min\left(\frac{\Delta q^i_{pred}}{q^i_{exp}}, 1.2\right), 0.2\right)$$

Where Δq_{pred} is the difference between the upper and lower bounds and q_{exp} is the experimental result for the specific quantity q. If the experimental value falls outside the predicted closed range, a score equal to zero will be assigned for the specific quantity. The total score will be computed by considering the same weight for all requested quantities.

$$Total\ Score = \sum_{i=1}^{7} S^i$$

6 Material for download

The following material can be downloaded in zip files from the following Zenodo repository: (https://doi.org/10.5281/zenodo.17900935).

1. Geometrical digital twins of the walls.
2. Preliminary mechanical properties of mortar, stones, and brick units.
3. Forms and report template to be completed for blind prediction competition.

7 Outlook

In a second phase, participants in the blind prediction competition may be invited to perform a post-diction. The decision on whether to carry out the post-diction will be made after the completion of the experimental tests.

8 Acknowledgements

The experimental tests are funded by the Swiss National Science Foundation (SNSF) through the grant agreement No. 200021_219862 (Behaviour of multi-leaf stone masonry walls under in-plane shear-compression loading). This opportunity is gratefully acknowledged.

9 References

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