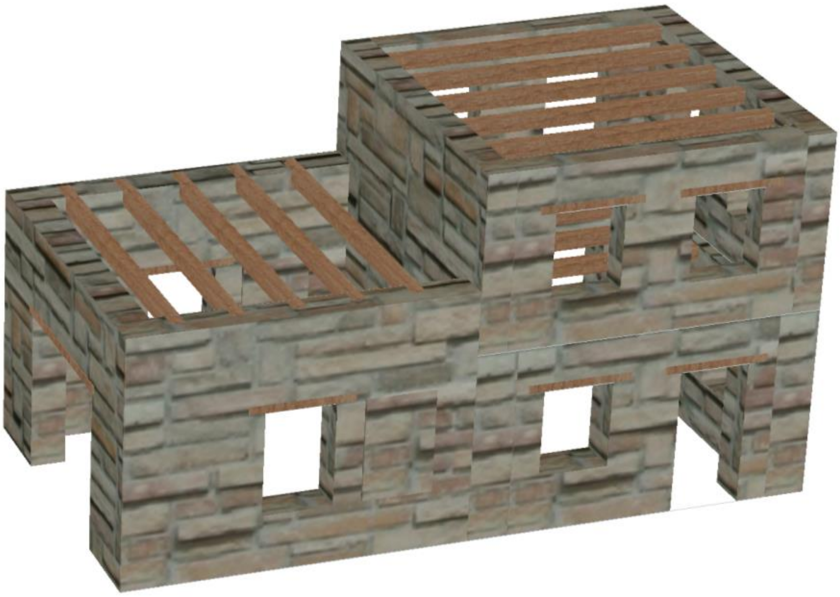
SERA Project: Adjacent Interacting Masonry Structures

Blind prediction competition



Principal Investigators

Laboratory facility

Funding scheme

SERA H2020-INFRAIA-2016-2017, Transnational access to research infrastructure

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1 Introduction

In many historical centres in Europe, stone masonry buildings are part of building aggregates, which developed when the layout of the city or village was densified. In these aggregates, adjacent buildings share structural walls to support floors and roofs. Meanwhile, the masonry walls of the façades of adjacent buildings are often connected by dry joints since adjacent buildings were constructed at different times. Observations after for the 2016 earthquakes in Central Italy showed that the dry joints between the building units were often the first elements to be damaged. As a result, the joints opened up leading to pounding between the building units and a complicated interaction at floor and roof beam supports.

The analysis of such building aggregates is very challenging and modelling guidelines missing. Advances in the development of analysis methods have been impeded by the lack of experimental data on the seismic response of such aggregates. The objective of this project is to provide such experimental data by testing an aggregate of two buildings under two components of horizontal excitation. One building is a two storey building, the other a one storey building. The buildings share one common wall while the façade walls are connected by dry joints. The floors are at different heights leading to a complex dynamic response of this smallest possible building aggregate.

To compare and advance the modelling approaches a blind prediction competition is organised. This document provides all required information. The test is planned for end of November 2019 and will be carried out at the LNEC facility in Lisbon, Portugal, under the lead of Prof. António Correia, Prof. Paulo Candeias and Prof. Alfredo Campos Costa. If interested in taking part in the blind prediction competition or in case of any questions, please contact any of the following:

- Prof. Katrin Beyer (katrin.beyer@epfl.ch), Igor Tomić (igor.tomic@epfl.ch)
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- Prof. Matthew DeJong (dejong@berkeley.edu)
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2 Specimen geometry and mass

The test specimen consists of two units: Unit 1 is a one storey building and Unit 2 a two storey building. The shared wall belongs to Unit 2.

The key parameters of the specimen are:

- Half scale prototype;
- 2 units: Unit 2 consists of two floors and Unit 1 of one floor;
- 1.5 tonnes of additional masses per floor of Unit 2, evenly distributed;
- No connection between the units; the two units will be built so that the connection is a dry connection (i.e., at a given height, first unit 2 and then unit 1 will be constructed);
- Double leaf stone masonry – Unit 1 wall thickness 30cm and unit 2 thickness 35 cm and 25cm of the first and the second floor, respectively;
- Decreased spandrel thickness;
- Timber diaphragms with different orientation;
- Steel angles placed to anchor beams into walls are not activated and are not expected to influence the behaviour of the test buildings. They are placed as precaution for later phases of the test.

The following figures give an overview of the specimen geometry. The detailed specimen geometry in form of final construction plans is provided in the attachment (see Section 8).

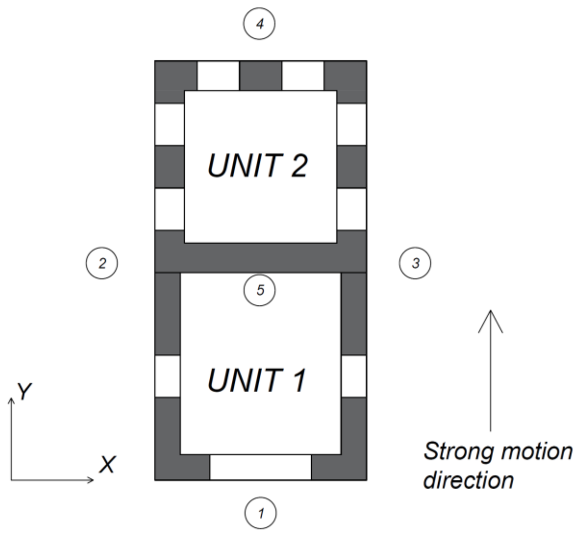
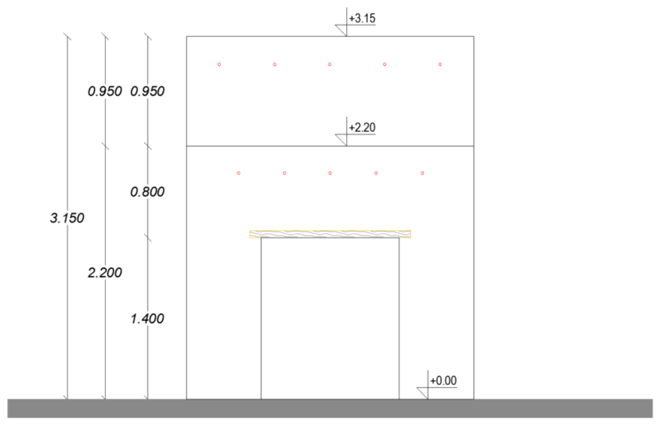
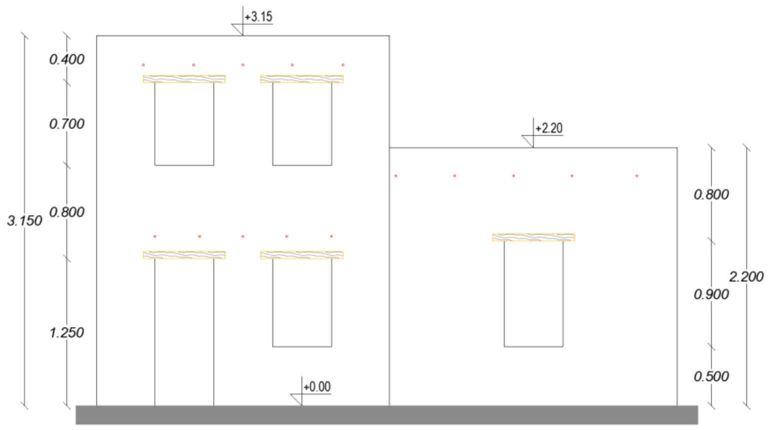


Figure 1. Unit orientation. The numbers in circles indicate the façade number. The facades are plotted in the following figures.

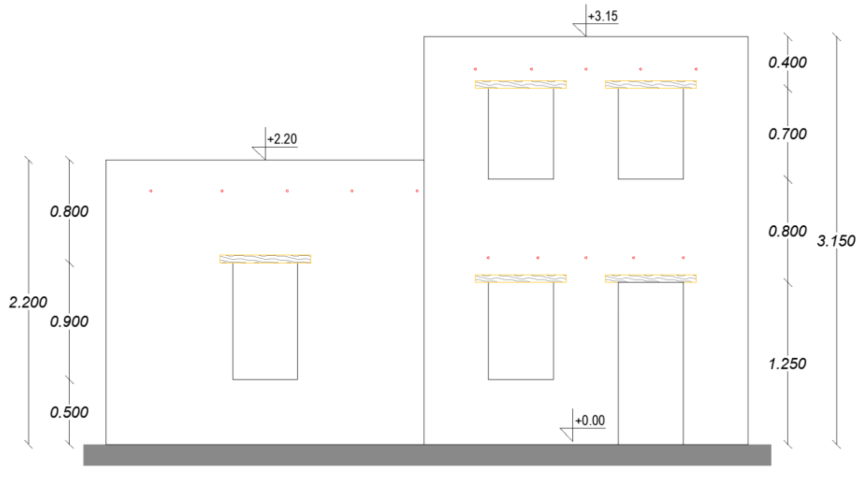
Facade 1

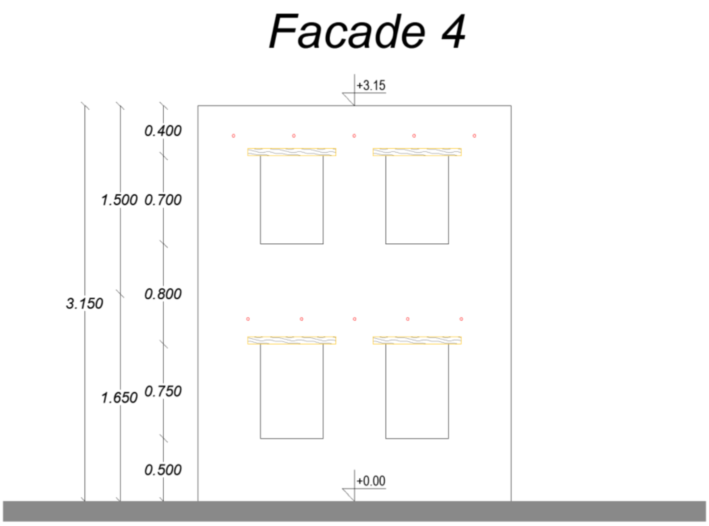


Facade 2



Facade 3





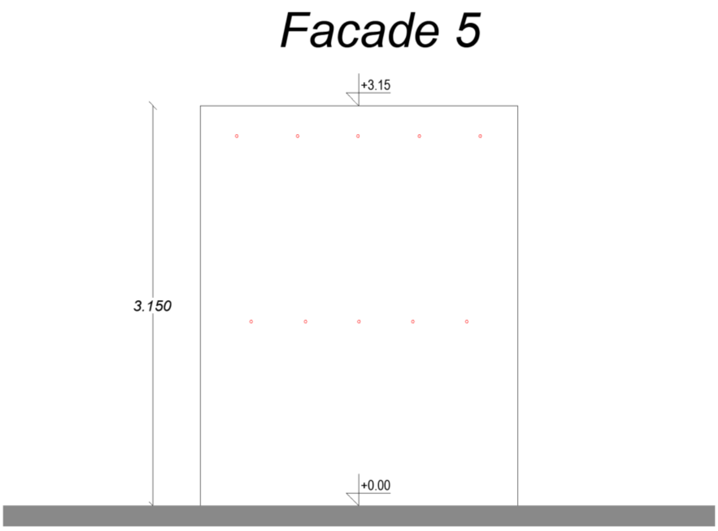


Figure 2. Geometry of the facades. All dimensions are in metres.

Table 1. Summary of masses

Specimen mass	
Walls of Unit 1	7194 kg
Floors of Unit 1	278 kg
Total Unit 1	**7472 kg**
Walls of Unit 2	12408 kg
Floors of Unit 2	562 kg
Additional masses of Unit 2	3000 kg
Total Unit 2	**15970 kg**
Steel foundation	7000 kg
Concrete slab on top of steel foundation	11000 kg
TOTAL	**41 442 kg**

3 Material properties

The material for the construction of the stone masonry walls will be - as much as possible - the same as the one used for a shake table test conducted at the Eucentre (Guerrini et al., 2019; Senaldi et al., 2019). The shake table test conducted at the Eucentre was also conducted at half-scale.

Material properties reported here were derived by Guerrini et al. (2017) and Senaldi et al. (2019) as part of experimental campaign conducted prior to the shake table test performed at the Eucentre. This experimental campaign comprised shear-compression tests and material tests for mortar, stones and masonry. The results of the material tests are summarised in Table 2, Table 3 and Table 4.

Additionally, participants are provided with data from cyclic shear compression test on masonry wallets of the same material and typology. The results of these tests are provided in electronic format and can be used by the participants to calibrate their models.

Table 2. Mortar properties (Guerrini et al., 2017)

Mortar properties	Average	C.o.V. [%]
Mortar compressive strength, f_m [MPa]	1.75	28
Mortar tensile strength, $f_{m,t}$ [MPa]	0.60	23
Mortar Young's modulus, E_m [MPa]	243	35

Table 3. Stone properties (Guerrini et al., 2017)

Stone properties	Average	C.o.V. [%]
Credaro Berrettino stone compressive strength, f_b [MPa]	144	-
Credaro Berrettino stone tensile strength, f_{bt} [MPa]	19	-

Table 4. Masonry properties (Guerrini et al., 2017)

Masonry properties	Average	C.o.V. [%]
Density of masonry, ρ [kg/m^3]	1980	5
Masonry compressive strength, f [MPa]	1.30	2.6
Masonry tensile strength, f_t [MPa]	0.17	7.3
Masonry cohesion, f_{v0} [MPa]	0.233	7.3
Masonry Poisson's modulus, ν [-]	0.14	56
Masonry Young's modulus in compression, E [MPa]	3462	12
Masonry shear modulus, G [MPa]	1524†	17
Masonry shear modulus, G [MPa]	1898‡	58
†*from vertical compression tests* ‡*from diagonal compression tests*		

4 Earthquake records

The specimen will be tested under one and two components of horizontal excitation (see following section). The shake table test will be conducted using the two horizontal components of the Albatros station from the Montenegro 1979 (Luzzi, Puglia, Russo, 2016).

Two sets of records are provided (see Section 8):

1) The original records as downloaded from the ESM database;
2) The scaled records that will be used for the shake table test.

4.1 Original records as downloaded from the ESM database

The first two records are the two horizontal components of the earthquake as downloaded from the database. The E-W component and the N-S component of the original records have PGAs of 0.21g and 0.18g, respectively. The original .rar file as downloaded from the ESM database is provided. Note that in these files the acceleration is provided in cm/s^2. Original .rar file contains multiple files, of which the key ones are the following:

- EU.ULA..HNE.D.19790415.061941.C.ACC.ASC – Horizontal component in the east - west direction [cm/s^2];
- EU.ULA..HNN.D.19790415.061941.C.ACC.ASC – Horizontal component in the north - south direction [cm/s^2].

4.2 Records scaled and adapted for the shake table test:

The records to be used for the shake table test have derived from the original records as follows:

- For the test, which is conducted at half-scale, the time axis of the record will be shortened by a factor of sqrt(2). The original time step of the records is 0.005s. For the testing of the scaled structure, the time step will be reduced to 0.005/sqrt(2)=0.003536s.
- The acceleration components have been scaled individually to match the PGA limit of the shake table of 0.875g in the longitudinal direction (y-direction) and of 0.625g in the transverse direction (x-direction).
- Transverse direction component has been changed from north - south to south - north orientation to be applied in the positive x-direction;
- Acceleration in these files is provided in m/s^2.

The scaled records have the following filenames:

- Montenegro_Albatros_EW_100p_shake_table.txt (applied in the positive y-direction, see Figure 1);
- Montenegro_Albatros_SN_100p_shake_table.txt (applied in the positive x-direction, see Figure 1).

5 Testing sequence

The maximum PGA that the shake table can apply for a specimen weight of 40 t is 0.875g in the y-direction (longitudinal) and 0.625g in x-direction (transversal, for the axis orientation see Figure 1).

At the moment, it is foreseen to reach this limit through in four steps, applying the ground motion at 25%, 50%, 75% and 100% of the ground motion given in the files Montenegro_Albatros_EW(SN)_100p_shake_table.txt. At each level, three tests will be conducted (always in the same order):

- Firstly, a uni-directional test in the y-direction will be conducted (Substep I);

- Secondly, a uni-directional test in the x-direction will be conducted (Substep II);
- Thirdly, a bi-directional test in the x- and y-direction will be conducted (Substep III).

The given limit will be reached through four steps as described in Table 5.

Note that the exact testing sequence is still under discussion and the information might be updated in the future.

Table 5. Testing sequence

Level of shaking	Substep I	Substep II	Substep III
25% shake table capacity PGA 0.219/0.156g y/x-dir	y-direction	x-direction	Both directions
50% shake table capacity PGA 0.438/0.313g y/x-dir	y-direction	x-direction	Both directions
75% shake table capacity PGA 0.656/0.469g y/x-dir	y-direction	x-direction	Both directions
100% shake table capacity PGA 0.875/0.625g y/x-dir	y-direction	x-direction	Both directions

6 Instrumentation

The behaviour of the test specimen will be recorded using the accelerometers and displacement transducers, possibly also an optical measurement system.

Experimental base shear values in x- and y-direction (BS_x and BS_y) will be given by assigning masses to each of the accelerometer.

$$\boldsymbol{BS_x = \sum_{i=1}^{N} a_i^x m_i} \qquad (1)$$

$$\boldsymbol{BS_y = \sum_{i=1}^{N} a_i^y m_i} \qquad (2)$$

Where a_i^x, a_i^y stands for acceleration measured at accelerometer i in the x- and y-direction and m_i stands for the portion of the mass assigned to the same accelerometer.

Exact equations with individual masses will be reported in the later version of the document.

Combination of large number of displacement transducers and optical measurement system will enable precise observation of both in-plane and out-of-plane displacements.

7 Quantities to be reported for the blind prediction test

For the blind prediction competition, two types of information is sought:

1) Description of the model used for the prediction;
2) Prediction of the values to be reported for each of the twelve runs outlined in Table 5 (also incomplete sets, e.g. only for the 100% shake table capacity, can be submitted).

7.1 Description of the model used for the prediction

The following information on the model is sought:

- General description of the model;
- Description of how the interface between the units was modelled;
- Description of the applied damping model and the damping values used;
- Description of the floor model and the connection between floor and walls
- Description of the how the wall-to-wall connections within each unit were modelled;
- Any specific property of the model which could be of interest.

Forms for the description of the model and observed values are provided for download (see Section 8).

7.2 Quantities to be reported for the blind prediction competition

The **time histories** and **maximum values** of the following 12 quantities are to be reported for each of the 12 runs in the provided Excel file (for each run one sheet + one sheet for maximum values):

- Selected roof node displacements (6 quantities: Rd1-Rd6); (see Figure 3);
- Interface opening between the units (4 quantities: Id1-Id4); (see Figure 3);
- Base shear (2 quantities, in x- and y-direction).

For the roof node displacements and the base shear, the axis system and its sign convention shown in Figure 3 should be used. The interface opening should be computed as displacement of Unit 2 – displacement of Unit 1. A positive value for Id1 and Id3 should therefore represent an opening of the interface in y-direction. A positive value for Id2 and Id4 should represent the situation where the x-displacement of Unit 2 (at the interface) is larger than the x-displacement of Unit 1. The interface opening will be measured at the roof level of Unit 1, i.e., 2.2 m above the foundation.

Additionally, after each of the four levels of shaking in the adjoined form the participants should describe the expected damage with regard to the in-plane and out-of-plane damage to elements and any damage to the interface between the two units. It is suggested that the expected damage pattern is reported by sketching the damage pattern on the provided sketches of the façades.

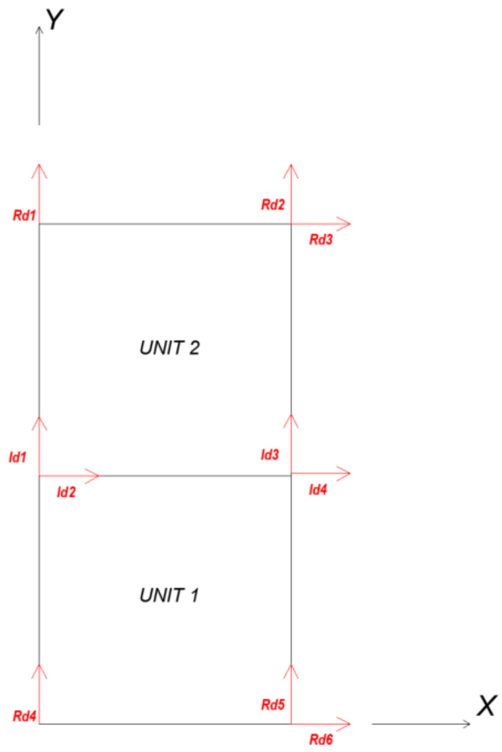


Figure 3. Quantities to be reported

8 Material for download

The following material can be downloaded in one zip-file from the following Zenodo repository:

1. Construction drawings;
2. Results of shear-compression tests ;
3. Earthquake records;
4. Forms and tables to be completed for blind prediction competition.

9 Outlook

In a second phase, the participants of the blind prediction might be invited to do a post-diction using as input updated information on the actually applied table motions, the testing sequence and material properties. The decision whether a post-diction will be carried out will be taken after the test.

10 References

Guerrini, G., Senaldi, I., Graziotti, F., Magenes, G., Beyer, K., Penna, A., 2019. Shake-Table Test of a Strengthened Stone Masonry Building Aggregate with Flexible Diaphragms. International Journal of Architectural Heritage 1–20. https://doi.org/10.1080/15583058.2019.1635661

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Luzi, L., Puglia, R., Russo, E., & Orfeus, W. G., 2016. Engineering strong motion database, version 1.0. Istituto Nazionale di Geofisica e Vulcanologia, Observatories & Research Facilities for European Seismology. doi, 10.

Senaldi, I.E., Guerrini, G., Comini, P., Graziotti, F., Penna, A., Beyer, K., Magenes, G., 2019. Experimental seismic performance of a half-scale stone masonry building aggregate. Bulletin of Earthquake Engineering. https://doi.org/10.1007/s10518-019-00631-2