**NOTE: This document will be updated regularly with respect to its initial version, as more information becomes available or to include possible adjustments. To facilitate the identification of the updated parts in this document, please search for instances of the word "UPDATED". After each of such instances, in between parenthesis, the date of the corresponding update is indicated.**

**VERSION 1.1: 2023.09.27**

**PREVIOUS VERSIONS: 2023.07.24 (Version 1.0)**

## 1. Introduction

Two large-scale reinforced concrete (RC) U-shaped walls will be tested using the main shake table of the National Laboratory for Civil Engineering (LNEC), Portugal. This experimental program is primarily funded by ERIES (Engineering Research Infrastructures for European Synergies) Transnational Access program. The project is called "ALL4wALL – Smart ALLoys for WALLs: towards durable structures with long service lives and minimal seismic residual displacements". The user group of the ERIES – ALL4wALL is composed of seven institutions: Université catholique de Louvain (UCLouvain), ENPC ParisTech, ISAE-Supméca - Institut supérieur de mécanique de Paris, University of Liège, University of Ljubljana, University of Pavia, and York University (Canada).

The dynamic tests of the ERIES-ALL4wALL represent a continuation of an experimental program previously conducted at UCLouvain, Belgium, which involved quasi-static tests on two RC U-shaped core walls subjected to axial-flexural and axial-torsional loading; more information on these tests can be found in Hoult *et al*. (2023b). The ERIES-ALL4wALL 2023 Blind Prediction Competition, organised mainly by UCLouvain with the support of LNEC, focuses on the response prediction of the first of the two wall specimens. The details of the test specimen, the setup, and the material properties are given below.

A technical session in the WCEE2024, "CMS-1: RC structural walls: advances and future challenges for design, modelling, testing, and construction", and the winners of each category (see document "Rules.pdf") will have the opportunity to participate and present their modelling technique (in person if they are attending the conference, online if they are not).

## 2. Description of the U-shaped Wall Test Specimen

The first wall unit, denoted UWS1, is illustrated in Figure 1a and comprises a foundation, two intermediate slabs (with an opening in the centre, corresponding to the interior perimeter of the wall cross-section), and a top collar (i.e., increased thickness at the head of the wall). This test unit represents a half-scaled core wall and, as shown in Figure 1b, has the same cross-section and reinforcement detailing[1] as previous test units UW1 and UW2 (Hoult *et al*., 2023b). The U-shaped specimen has a wall thickness ($t_w$) of 100mm, web length ($L_w$) of 1300mm, and flange length ($L_f$) of 1050mm. Figure 1b also shows the definition of the wall segments used in this research investigation, i.e. "Flange one", "Web", and "Flange two". Lumped longitudinal reinforcement, consisting of 12mm diameter ($d_{bl}$) bars, is used in the boundary ends, while distributed $d_{bl}$=6mm bars are used in the web. Confinement reinforcement is provided in the boundary ends using 6mm bars spaced at 50mm, while the transverse (shear) reinforcement consists of 6mm bars spaced at 100mm. The foundation and the collar of the wall are detailed with a high volume of reinforcement using 20mm and 12mm diameter bars, respectively, such that they effectively remain elastic during testing and provide a large stiffness. The size of the foundation is 2100mm x 2100mm x 500mm. The top collar corresponds to an increased wall thickness at the wall head, which is required to support the top masses. An open collar was used, rather than a continuous thick top slab spanning over the flanges, due to warping restraint considerations (Beyer *et al*., 2008). The participants can find the full set of reinforcement detailing and plan drawings of the wall units in the companion document, "Appendix A – Plans and detailing".

[1] Note that the confinement ties are spaced at 50 mm for UWS1, whereas for the previous quasi-static reverse-cyclically tested units UW1 and UW2 they were spaced at 75 mm.

## 3. Material Properties

### 3a. Steel reinforcement properties

As per the requirements of Eurocode 8 (Eurocode, 2004) to ensure ductility and energy dissipation, Class C steel was used for the longitudinal and transverse reinforcing bars in the wall. Class C reinforcement was also used for the other reinforcement in the foundation and collar of the wall. The salient mechanical properties of the Class C longitudinal reinforcing steel, obtained from tensile tests, are given in Table 1: $f_y$ and $f_u$ are the yield and ultimate stress; $\varepsilon_{sy}$, $\varepsilon_{sh}$, $\varepsilon_{su}$ are the strain values corresponding to yield, strain hardening, and ultimate stress, respectively; and $E_s$ is the Young's modulus. The mechanical properties of the transverse reinforcing steel (e.g., shear reinforcement and confinement) will be provided at a later date. For preliminary modelling purposes, the mechanical properties of the 6 mm transverse reinforcement can be taken as similar to those given in Table 1.

**Table 1 Mechanical properties of the Class C reinforcement used in the wall units**

| $d_{bl}$ | $f_y$ | $f_u$ | $\varepsilon_{sy}$ | $\varepsilon_{sh}$ | $\varepsilon_{su}$ | $E_s$ |
|---|---|---|---|---|---|---|
| [mm] | [MPa] | [MPa] | [mm/mm] | [mm/mm] | [mm/mm] | [GPa] |
| 6 | 550 | 676 | 0.0027 | 0.010 | 0.095 | 207 |
| 8 | 538 | 664 | 0.0027 | 0.024 | 0.120 | 196 |
| 12 | 580 | 690 | 0.0029 | 0.021 | 0.101 | 199 |

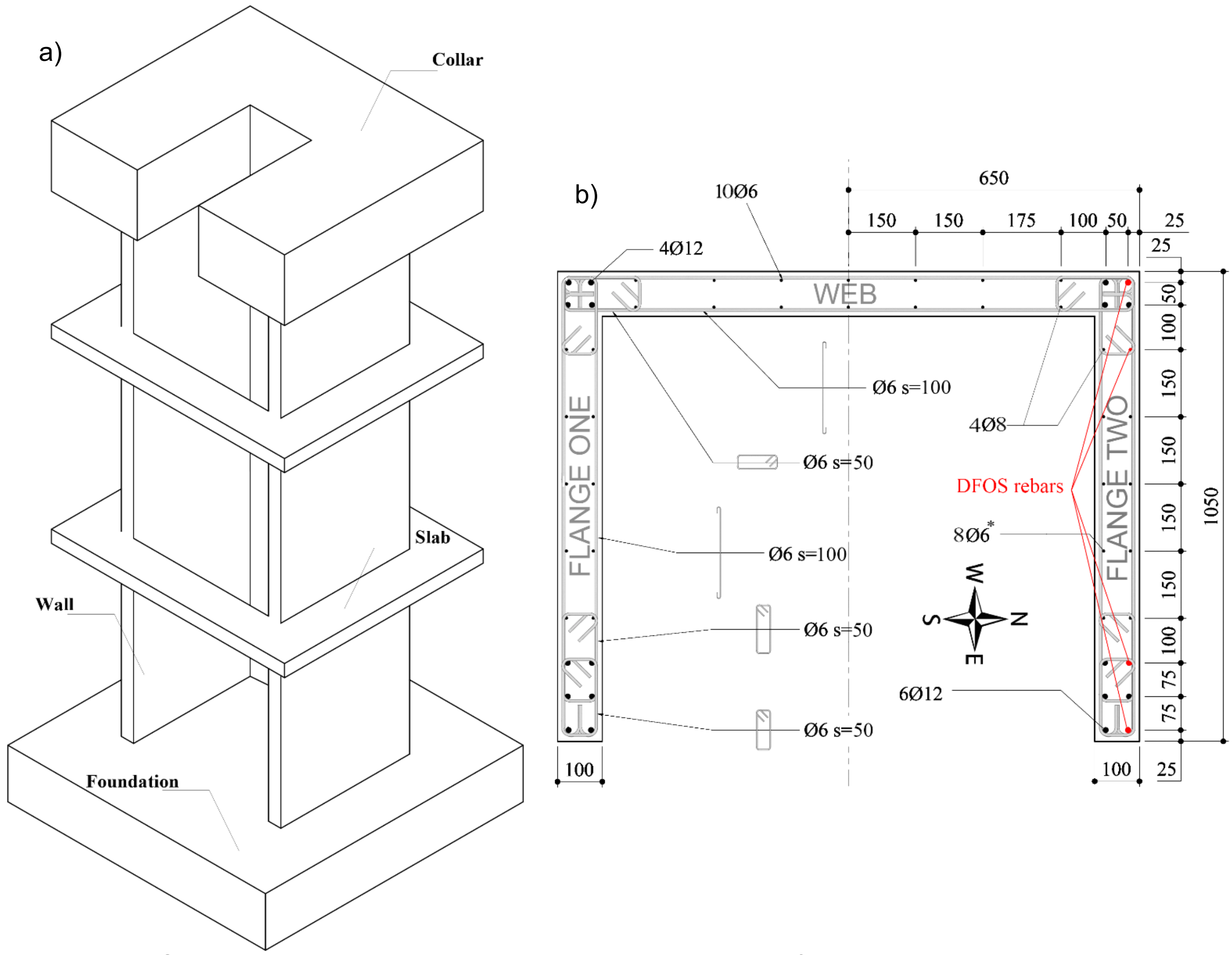


**Figure 1 Unit UWS1 (a) three-dimensional elevation view and (b) cross-section and reinforcement detailing; the proposed instrumented steel reinforcing bars with distributed fibre-optic sensors are denoted "DFOS rebars"**

### 3b. Concrete properties

At the time of writing (version 1.0 of this document), the concrete properties have yet to be tested. A 30 MPa, 28-day strength ($f'_c$) is warranted. Future versions of this document will be updated with the concrete properties as soon as the cylinder tests are performed, allowing for the participants to adjust their models before final submission.

## 4. Test Setup

The wall unit will be tested on the large shake table at LNEC. The maximum horizontal actuators' capacity in the east-west (EW) and north-south (NS) directions are 700 kN and 500 kN, respectively. The orientation of the wall with respect to these cardinal directions is shown in Figure 1b. The maximum displacement and velocity of the table in either direction is ± 200 mm and ± 600 mm/s, respectively. The maximum payload of the shake table is approximately 40 ton.

Large masses are needed to attain the flexural force capacity of the scaled units. Therefore, several 1.13 ton and 0.59 ton mass blocks are connected to the collar (head) of the wall. As depicted in Figure 2, these mass blocks are 840 mm x 840 mm in cross-section, and 250 mm or 130 mm thick for the 1.13 ton and 0.59 ton, respectively. Each block has four connection points in a square grid of 500 mm as depicted in Figure 2. A total of 20 (i.e., 4 x 5) 1.13 ton mass blocks are placed atop of the collar of the wall unit. Furthermore, four 0.59 ton mass blocks are also placed atop of the collar (see Figure 2). The above means that the applied total mass above the collar is 24.96 ton. In conjunction with the mass of the collar of the wall unit of 3.27 ton, the total mass at the top of the wall is 28.23 ton – this is the mass that will be used to calculate the approximate in-plane force using an accelerometer (see Section 5 and Figure 3b). M30 threaded bars will be used to fasten the foundation of the unit to the shake table and also the applied mass on the top collar and to the sides of the wall. The M30 bars in the foundation will be prestressed to a minimum force of 250 kN, where the position of the 16 anchor points can be observed in the plan drawings (see "Appendix A – Plans and detailing.pdf"). The exact locations of the top masses' connection points to the wall collar, through 40 mm diameter PVC pipes placed vertically along the thickness of the collar, are shown in Plan 6 of the drawings (see "Appendix A – Plans and detailing.pdf").

An important information for the structural response is also depicted in Figure 2b, namely the position of the "Centre of Mass" – which corresponds to the centre of mass of the U-shaped wall unit above the foundation (i.e., including both flanges, the web, and the collar), and the position of the "Centre of Applied Mass" – which corresponds to the centre of mass of the 24 mass blocks (20x of 1.13 ton, 4x of 0.59 ton, as mentioned) applied above the collar. The centre of the applied mass (from the blocks) is calculated to be approximately 540 mm from the flange boundary ends, whereas the centre of mass from the wall unit is calculated to be approximately 516 mm. The reader is invited to consult the publication by Hoult *et al.* (2023b), where the axial load was also applied with an eccentricity.

Another important information concerns the cardinal directions (i.e., north-south, east-west) given in Figure 1b, which correspond to the cardinal directions of the LNEC testing facility and shake table. The positive conventions are taken from north to south to and from west to east.

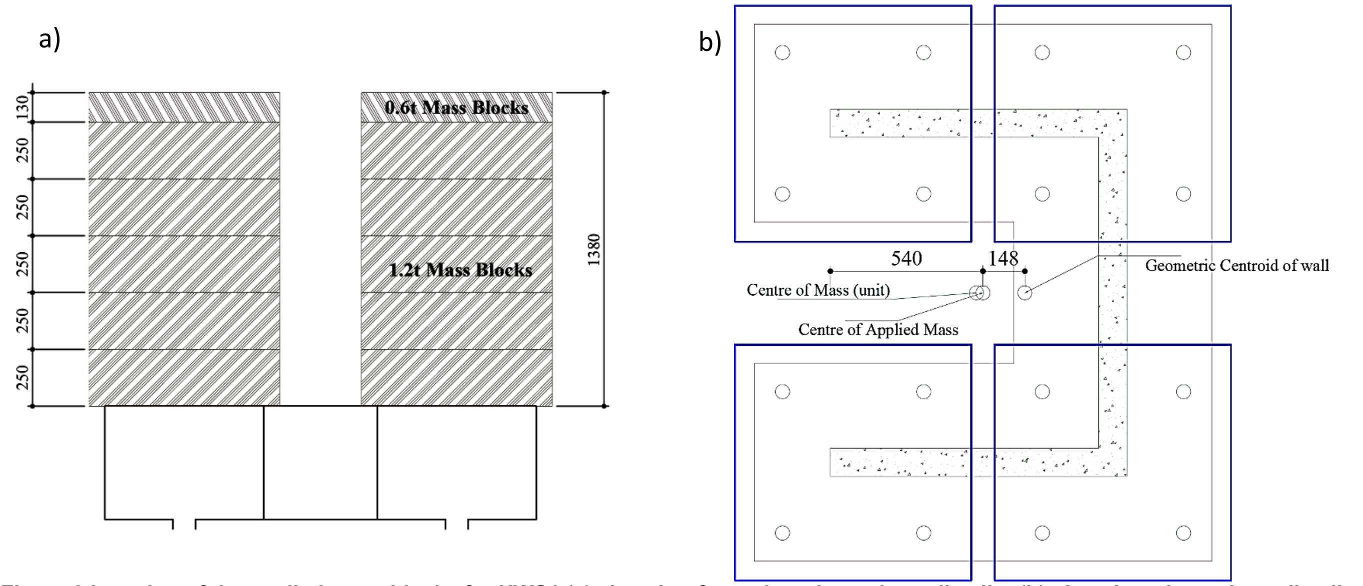


**Figure 2 Location of the applied mass blocks for UWS1 (a) elevation-front view above the wall collar (b) plan view above the wall collar with the 4 regions in blue indicating the mass blocks**

## 5. Instrumentation

An extensive amount of different instrumentation will be used to measure salient engineering parameters throughout testing of the walls. For sake of brevity, most of the instrumentation is not reported here. Instead, only the instrumentation used to measure the engineering parameters required for the blind prediction is mentioned. The absolute displacement of the wall in the east-west direction (see Figure 1b for cardinal directions) will be measured using potentiometers (also known as string pots). Two string pots (SP) will measure the east-west displacement at the ends of the flanges of the collar at a height of 4290 mm from the foundation, as illustrated in Figure 3a. SP1 and SP2 (Figure 3a) will also be used to measure the torsional rotation (with a lever arm of 1.2 m). It is worth mentioning that another potentiometer will be used to measure the east-west displacement of the table, such that an absolute measurement of the wall can be calculated. Figure 3b illustrates the location of the accelerometer (i.e., ACC1, at a height of 4290 mm) used to measure the acceleration along both horizontal directions. This acceleration will be used to calculate the approximate in-plane, east-west lateral inertial force using the applied mass of 28.23 ton. Note that this value for the mass includes an approximation for the mass of the collar of the wall.

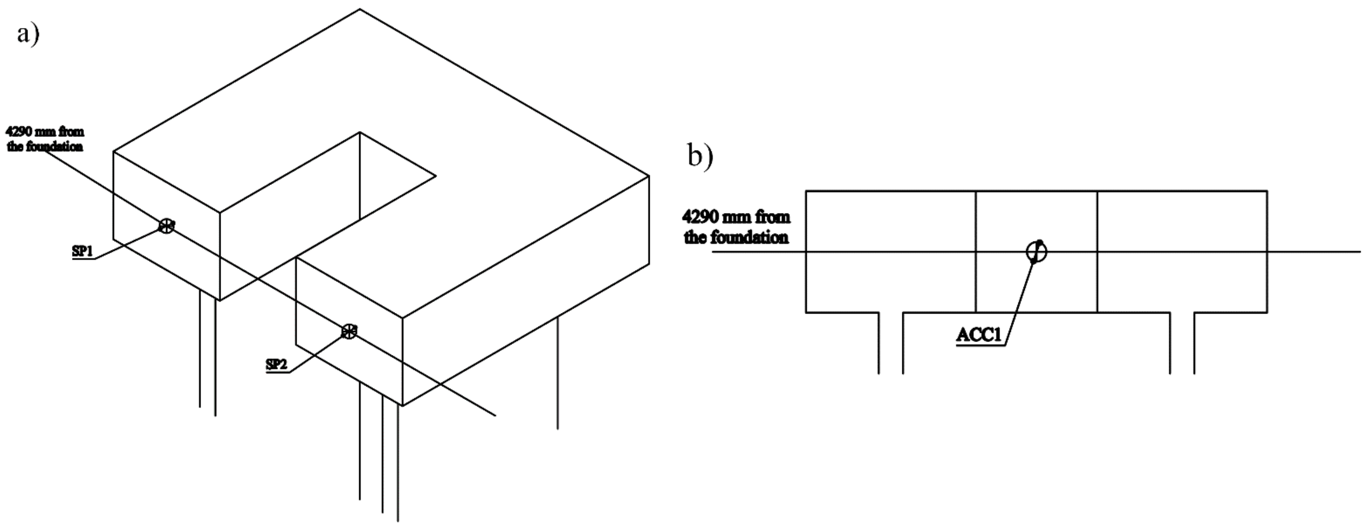


**Figure 3 Instrumentation attached to the collar at a height of 4290 mm from the foundation used for some of the blind prediction measurements (a) potentiometers, or string pots (SP) locations at the flanges ends of the collar, and (b) accelerometer (ACC1) on the inside of the web-collar**

Distributed fibre-optic sensors (DFOS) will be used to measure high-resolution longitudinal strains in selected steel reinforcing bars. The location of the four longitudinal bars that will be instrumented with this technology is indicated in Figure 1b. The same technology was used successfully to measure high-resolution strains of the rebars in the quasi-static tests conducted at UCLouvain in 2022 – see Hoult *et al*. (2023a) for more information. Subsequently, the same technology and methods will be employed for the proposed dynamic tests.

## 6. Loading Procedures

**-- UPDATED, start of modifications (VERSION 1.1: 2023.09.27) --**

### 6a. Ground Motions

The 2016 Central Italy earthquake sequence caused significant damage and loss of life (Sextos et al., 2018), representing the largest Italian seismic sequence densely observed with modern geodetic measurements (Cheloni et al., 2017), see Figure 4. The moment magnitude $M_w$ 6.5 event was the largest of the three main events that occurred on 30 October 2016. The earthquake sequence forced people to evacuate and abandon several villages, which miraculously resulted in no loss of life from this one particular earthquake in the sequence (Sextos et al., 2018; Stewart et al., 2018). The normal faulting (Cheloni et al., 2017) $M_w$ 6.5 event ruptured a 15 km-long section of the fault (Stewart et al., 2018) at a shallow depth of 3–7 km (Cheloni et al., 2017). A reconnaissance of damaged structures close to the epicenter of the events revealed that buildings with most damage were 2 to 3 stories (Sextos et al., 2018), although this was largely related to unreinforced masonry structures. The two primary contributors of the damage patterns observed were found to be the local site effects (i.e., amplification of the seismic waves) and the high-frequency content of the ground motions (Sextos et al., 2018).

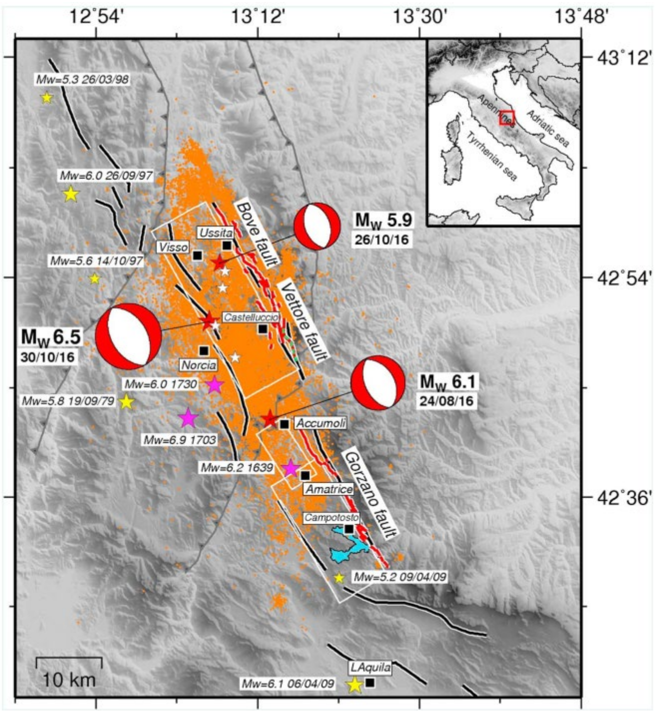


**Figure 4 Seismotectonic framework of the 2016 Central Italy earthquake sequence, adopted from Cheloni *et al.* (2017)**

The seismometer station MZ04 was one of many that captured the $M_w$ 6.5 event of October 30 2016. The MZ04 recording station was located at a close Joyner-Boore distance ($R_{jb}$) of 6.4 km, with an epicentral distance of 23 km. The station is situated on site class C with an estimated shear wave velocity of the upper 30 m ($V_{s30}$) measured to be 355 m/s. The 5% damped pseudo spectral acceleration (*PSa*) response captured by MZ04 in the east-west and north-south directions (HNE and HNN, respectively) is given in Figure 5a. The peak ground acceleration (PGA) in these two directions is approximately 0.645g and 0.808g, respectively

The proposed dynamic tests of unit UWS1 will comprise eight different levels of ground motions (GM1 – GM8), if structural failure is not judged imminent and for safety reasons the next runs with higher scale factors are cancelled. Each ground motion level corresponds to a different scale combination of the HNE and HNN of the $M_w$ 6.5 event recorded on October 30 2016 by MZ04. The HNN ground motions will be used in the east-west (EW) shake table direction, and the HNE will be used in the north-south (NS) direction. The positive direction of the ground motion corresponds to the positive direction of the shake table as defined above (i.e., from north to south and from west to east).

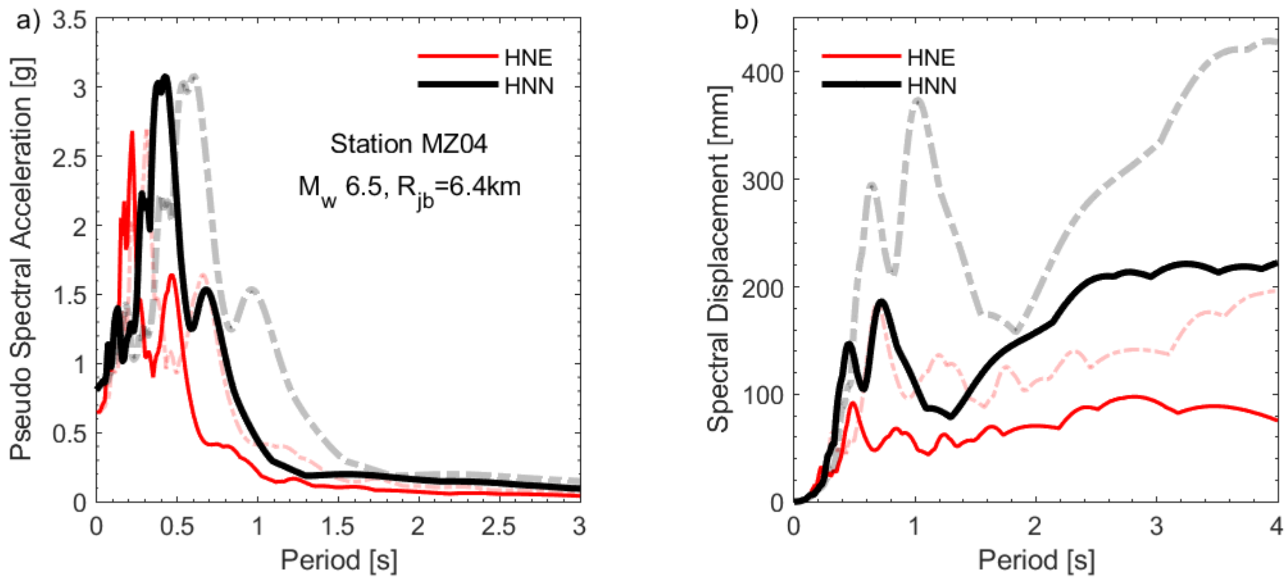


**Figure 5 $M_w$ 6.5 event from the 2016 Central Italy earthquake sequence on 30 October (a) 5% damped pseudo spectral acceleration (b) 5% damped pseudo spectral displacement. The transparent and dashed-lines represent the original (uncorrected) response captured by MZ04 using a time-step interval of 0.005s, whereas the opaque lines represent the corrected response using scaled time-step.**

The different scaling and combinations used for each GM level (i.e., GM1 to GM8) are given below in Table 2. A test run, GM0, corresponding to only 10% of the east-west ground motion, will also be firstly conducted.

One complete file is provided to all participants, corresponding to the "corrected" (i.e., time step scaled due to similitude laws) of the full scale (i.e., 100%) ground motions of HNN and HNE captured by MZ04 (in units of g). This involved downloading the original processed file from the Engineering Strong Motion (ESM) database and processing further: the ground motions were scaled in time by $1/\sqrt{2}$ (see the next section on Similitude Laws), resampled to 200 Hz (dt = 0.005s), cropped to a total duration of 30 seconds, low-pass filtered at 40 Hz, integrated twice in the frequency domain, and a cosine tape window was used to assure initial and final displacements were zero. The HNN and HNE directions have been renamed EW and NS for consistency with the shake table directions and conventions. The input ground motion file, containing both accelerations and displacements, can be now found on the website:

"3A.MZ04.Joint_Scaled_200Hz_Target30s_Final.txt".

Due to the interaction between the shake table and the specimen, the input acceleration-time histories effectively applied will deviate from the herein provided ones. The effectively applied input acceleration-time histories will be provided to all the participants after the tests have been performed, which will allow them to adjust their predictions before the final submission.

**-- UPDATED, end of modifications (VERSION 1.1: 2023.09.27) --**

**Table 2 Scale factors (in percent) used for the ground motions captured by MZ04 of the Mw 6.5 Central Italy earthquake event on October 30 2016.**

| | Scale [%] | |
|---|---|---|
| | HNN (east-west on shake table) | HNE (north-south on shake table) |
| GM0 | 10 | 0 |
| GM1 | 25 | 0 |
| GM2 | 25 | 25 |
| GM3 | 50 | 0 |
| GM4 | 50 | 50 |
| GM5 | 75 | 0 |
| GM6 | 75 | 75 |
| GM7 | 100 | 0 |
| GM8 | 100 | 100 |

### 6b. Similitude Laws

As explained in Pinho (2000), to reproduce the true dynamic response of a prototype core wall structure requires accurate simulation of the geometry, initial and boundary conditions, stress-strain relationship of the materials, and mass and gravity forces. The latter of these poses a challenging problem, where the simulation of the mass and gravity forces are closely linked to the similitude law adopted. As such, the Cauchy-Froude law must be respected in the dynamic testing of scaled models (Pinho, 2000). Assuming that the materials are the same for the full-scale prototype and half-scale model (i.e., $E_p$ / $E_m$ = 1), the scale factors using the Cauchy-Froude similitude laws are attained. It is worth noting that, because the density ($\rho$) becomes inversely proportional to the geometric scale factor ($\lambda$ = 2 in this case), it is not uncommon for the scale of the specific mass to be considered independently of the geometric scale. The total applied mass used for these tests is 24.96 ton, which, in conjunction with the self-weight of the unit (estimated at 12.95 ton, assuming a reinforced concrete density of 2500 kg/m$^3$), is below the maximum payload of the shake table, of 40 ton. Importantly, these similitude laws and the corresponding scaling factor/s were applied to the ground motions in Section 6a, which essentially shifts the spectral acceleration response.

**Table 3 Scale factors using the Cauchy-Froude Similitude Laws**

| Parameter | Symbol | Scale Factor |
|---|---|---|
| Length | L | $L_p$ / $L_m$ = λ |
| Modulus of Elasticity | E | $E_p$ / $E_m$ = 1 |
| Specific Mass | ρ | $\lambda^{-1}$ |
| Area | A | $\lambda^2$ |
| Volume | V | $\lambda^3$ |
| Mass | m | $\lambda^2$ |
| Displacement | d | λ |
| Velocity | v | $\lambda^{1/2}$ |
| Acceleration | a | 1 |
| Weight | W | $\lambda^2$ |
| Force | F | $\lambda^2$ |
| Moment | M | $\lambda^3$ |
| Stress | σ | 1 |
| Strain | ε | 1 |
| Time | t | $\lambda^{1/2}$ |
| Frequency | f | $\lambda^{-1/2}$ |

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