Cyclic test data of five URM walls at half-scale

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Summary

In addition to the test data of the full-scale unreinforced masonry (URM) walls [PB14a], also the test data obtained with the half-scale walls was made publicly available. The data has been assigned the DOI 10.5281/zenodo.12873 and can be downloaded with the following link:

https://zenodo.org/record/12873

This document describes the test program, material tests and organization of the test data. When using the data please cite as follows [PB14b]:

Petry, S and Beyer, K; Scaling unreinforced masonry for reduced-scale seismic testing. *Bulletin of Earthquake Engineering* (2014), 12(6):2557–2581, DOI: 10.1007/s10518-014-9605-1

1 Introduction

In the framework of the investigations on the scale effects [PB14b], five out the six full-scale wall test presented in [PB14a] were repeated at half-scale. The test data of the full-scale tests has been made publicly available [PB14a] and this document presents the data for the five unreinforced masonry half-scale wall tests.

The document is organized similarly to the paper on the full-scale walls [PB14a]. References to [PB14b] and [PB14a] are used to keep the length of the document to a minimum without compromising on the explanations required for reusing the data.

2 Test objectives

The objectives of repeating the test series at half-scale are outlined in detail in [PB14b] and are thus not repeated here.

3 Organization of the document

The outline of this document follows the structure of [PB14a]. Hence, first the test program, the geometry and material of the five half-scale masonry walls is described. Then specifications concerning the instrumentation and the loading protocol are given and differences to the full-scale wall tests [PB14a] highlighted.

4 Test program and test setup

The experimental campaign comprised five tests on masonry walls that all had the same dimensions (H = 1.113 m, L = 1.005 m, T = 0.10 m). The walls were named PUM1–5 and represented the test units PUP1–5 from the full-scale series [PB14a]. The moment, axial force and shear force at the top of the walls were introduced by three actuators (Fig. 1). The two vertical actuators had a force capacity of ±450 kN and a displacement capacity of ±100 mm. The horizontal actuator had a force capacity of ±100 kN and a displacement capacity of ±100 mm. The distance between the axes of the two vertical cylinders was L_{act} = 0.96 m and the distance of the horizontal cylinder to the upper edge of the wall H_{act} = 0.185 m. The vertical actuators were controlled in such a way that the axial force applied to the wall during testing remained constant. In addition, the control of the vertical actuators was coupled to the force of the horizontal actuator in such a manner that the shear span H_0 remained constant throughout the test. The axial stress N/A_{gross} and normalized shear span H_0/H were the same for the half-scale and full-scale walls [PB14b]. The applied boundary conditions are summarized in Table1. Note that also for PUM1 the boundary condition were chosen such that the shear span remained constant at H_0=0.5H, while PUP1 was tested applying a zero rotation at the top [PB14b].

For the construction of the walls the same procedure as for the full-scale walls was used [PB14a]. Photos of the construction are shown in Fig. 2. The age at testing of the individual test specimens is summarized in Table 2.

For the optical measurements, the walls were prepared similar to the full-scale walls with the difference that the distance of the LED grid was have the length. Note that due to the fine grid, the distance between the LEDs was too small to draw the cracks. Therefore, it was chosen to fix the LEDs on the other side than from which the pictures were taken.

5 Material test data

The masonry walls were constructed using a scaled brick unit which had similar properties than the hollow clay brick unit at full-scale, which was used for the construction of the full-scale walls [PB14a]. The half-scale brick is shown in Fig. 3. The brick units had dimensions of 150 x 95 x 95 mm ($L_B \times H_B \times W_B$). The geometric and mechanical properties of the units are summarized in [PB14b]. The same mortar as for the full-scale series was used (WEBER MUR MAXIT 920). Bed and head joints were fully filled and had an average thickness of 5 to 7 mm. Mortar samples were taken while constructing walls and wallettes for material tests. The

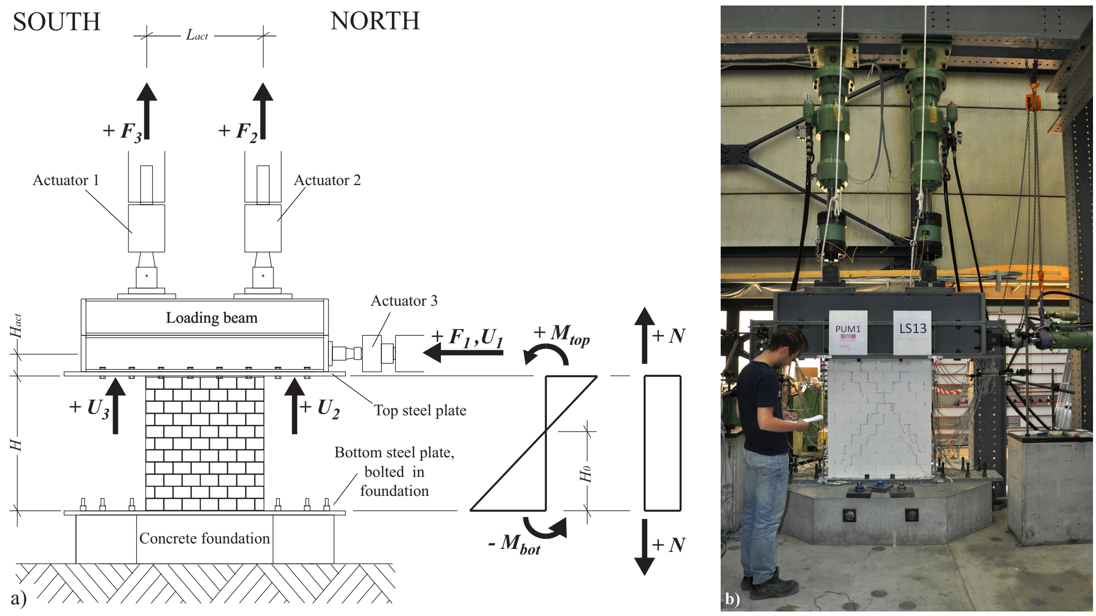

Figure 1 (a) Test setup with sign conventions after processing of the data and (b) photo showing the test setup of the half-scale wall tests with the three actuators

Figure 2 Steel plates with layer of quartz sand and test units during construction

mortar samples were tested when testing the corresponding walls and wallettes. The mortar properties for all types of specimens are summarized in Table 3.

To determine the material properties of the masonry, the same three types of standard masonry material tests were conducted as for the full-scale wall tests [PB14a]: (1) the compression strength, elasticity modulus and Poisson's ratio were determined with compression tests (WUM1–5) on masonry wallettes [CEN02], (2) the peak shear strength and residual shear strength of the mortar brick interface were determined with shear tests (TUM1–10) on masonry triplets [CEN07] and (3) the diagonal tensile strength was determined with diagonal compression tests (QUM1–5) on square masonry wallettes [RIL91]. Figures 4 to 6 show for each material test a photo of a specimen and the test results. The mean masonry properties and coefficients of variation are summarized in Table 3 of [PB14b]. The data obtained from material tests are provided together with the data of the half-scale wall tests (see Section 8).

Note that the LVDTs indicated in Fig.4c of [PB14a] were only used for the first five triplet tests (TUM1–5), while for the test units TUM6–10 only the forces were recorded. Out of the

Table 1 Test program

Specimen	Axial force N	Axial stress ratio σ_0/f_u	Shear span H_0	Eq. for control of vertical actuators
PUM1	-105 kN	0.18	$0.5H$	Actuator 2 & 3: $F_{2,3} = \frac{N}{2} \pm c \cdot F_1$
PUM2	-105 kN	0.18	$0.75H$	
PUM3	-105 kN	0.18	$1.5H$	
PUM4	-155 kN	0.26	$1.5H$	
PUM5	-55 kN	0.09	$0.75H$	

H	Height of the wall
H_0	Shear span
$F_{2,3}$	Forces of the two vertical actuators after processing
F_1	Force of the horizontal actuator after processing
c	Constant describing the dependency between $F_{2,3}$ and F_1 which determines the moment profile. The value of this constant depends on H_0 and the geometry of the test setup.

Table 2 Age at testing of the specimens for the compression tests (WUM), for the diagonal compression tests (QUM), for the shear tests (TUM) and for the five quasi-static cyclic wall tests (PUM1–5)

	WUM	QUM	TUM	PUM1	PUM2	PUM3	PUM4	PUM5	
Age at testing	154	50	50	60	70	88	98	112	days

ten triplet units, two units (TUM5 and TUM8) provided unreasonable results (the axial stress which we applied was too high and the bricks fractured before sliding in the joints could occur). These two units were omitted when computing residual and peak strength and are not shown in Fig. 5b.

6 Instrumentation

The test units (PUM1–5) were instrumented with 42 conventional channels, which were recorded at a frequency of 1 Hz. Next to global quantities (forces applied by actuators, horizontal displacements of top beam) some local deformations were measured with LVDTs and

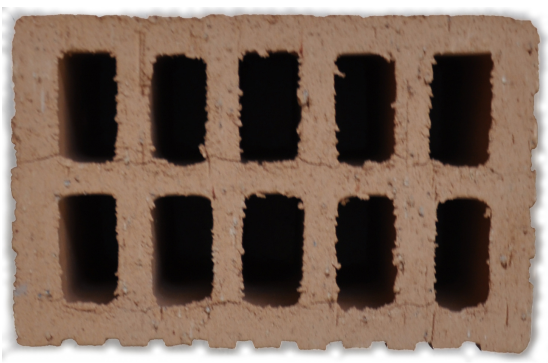

Figure 3 Investigated clay brick at half-scale

Table 3 Mortar properties corresponding to the mortar used for the construction of the specimens for the compression tests (WUM), for the diagonal compression tests (QUM), for the shear tests (TUM) and for the six quasi-static cyclic wall tests (PUM1–5)

		WUM	QUM	TUM	PUM1	PUM2	PUM3	PUM4	PUM5	
Compression strength $f_{M,c}$	Mean	14.0	13.7	13.0	9.27	11.3	12.3	9.45	11.9	MPa
	Std. dev.	5	9	6	8	10	9	7	18	%
Flexural tensile strength $f_{M,ft}$	Mean	3.57	3.36	3.23	2.89	3.55	3.40	3.01	3.79	MPa
	Std. dev.	19	7	19	8	13	12	12	15	%

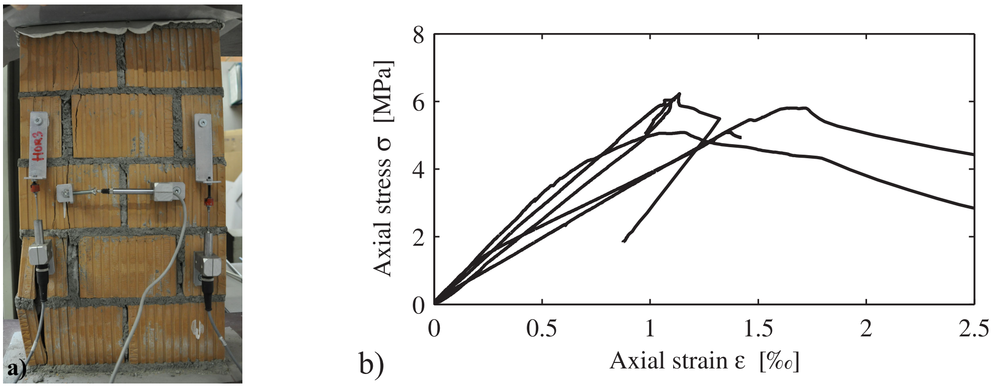

Figure 4 (a) Specimen for the compression tests with mounted measurement devices and (b) stress-strain relationships

omega gauges. The locations of the conventional instruments are indicated in Fig. 7. The base lengths for the instruments measuring local deformations are summarized in Table 4. Note that due to the small width of the half-scale walls, the horizontal strains at the narrow sides were not measured and therefore the channels 30–32 and 40–42 are empty. The sign convention for the actuator forces and displacements of the top beam are shown in Fig. 1. The exact position of the instruments U3, V3, U2 and V2 (Fig. 7) varied slightly between walls and the horizontal distance from the instrument to the outer edge of the wall is specified in Table 5.

The optical measurements were performed with the commercially available system Optotrak from NDI (Optotrak Certus HD [NDI11]). The photogrammetric system works with one position sensors consisting of three digital cameras (see Fig. 8a), which measured the 3D-coordinates of the LEDs (see Fig. 8b) glued onto the test unit, foundation and loading beam. The LEDs were glued onto the wall in the same way as for the full-scale walls [PB14a]. During each measurement frame all LEDs illuminate one after each other and the positioning sensors recorded the x-, y- and z-coordinates of each LED with a measurement frequency of 4 Hz.

The measurement systems used for the optical and conventional measurements worked independently from each other and were synchronized after the test during the post-processing phase with the help of a self-written Matlab script. For more details on this procedure please refer to [PB14a].

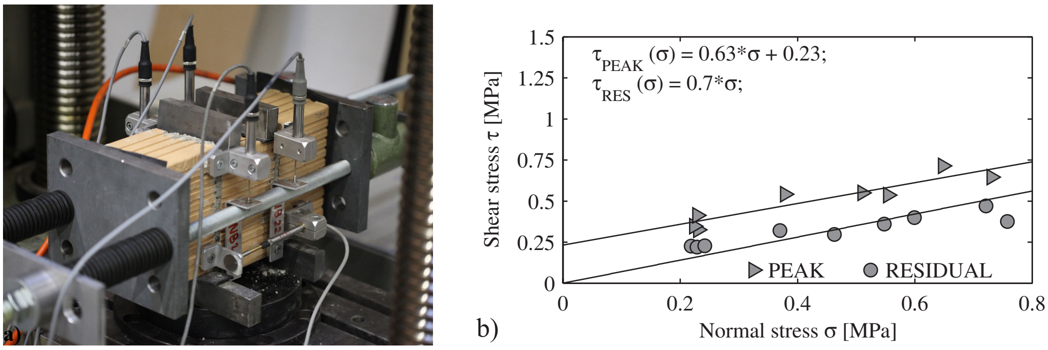

Figure 5 (a) Test setup for the shear tests with specimen and (b) applied normal stress versus resulting peak and residual shear strength of the mortar brick interface

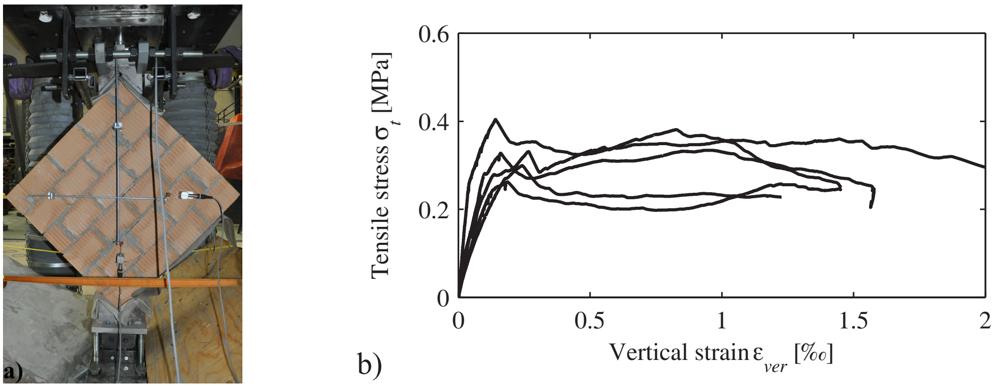

Figure 6 (a) Specimen for the diagonal compression tests with typical stair stepped crack along mortar joints and (b) stress-strain relationships

7 Testing procedure

All tests were performed applying the same procedure as for the full-scale walls [PB14a]. The displacement amplitudes of the half-cycles corresponded to the following drift levels: 0.025%, 0.05%, 0.1%, 0.15%, 0.2%, 0.3%, 0.4%, 0.6%, 0.8% and 1.0%. Note that the cycles with amplitudes of 0.15% and 0.25% were not included in the loading history applied to PUM1, but added from PUM2 onwards. This corresponds to the load histories applied to the full-scale walls.

8 Test data

8.1 Organization of data

The data can be downloaded as one zip file from www.zenodo.org using the DOI xxxx (7 files of 0.26–1.33 GB). The platform ZENODO (www.zenodo.org) was developed under the European FP7 project (http://www.openaire.eu/) and is hosted by the research facility CERN which operates a Large Hadron Collider.

Upon unzipping, the folder structure unfolds as follows (Fig. 9): The data is organized first by specimen (PUM1–5 for the five walls, QUM for the diagonal compression tests, TUM for the triplet tests and WUM for the compression tests). For each wall specimen there are three subfolders ("photos", "unprocessed_data" and "processed_data") and for each type of material

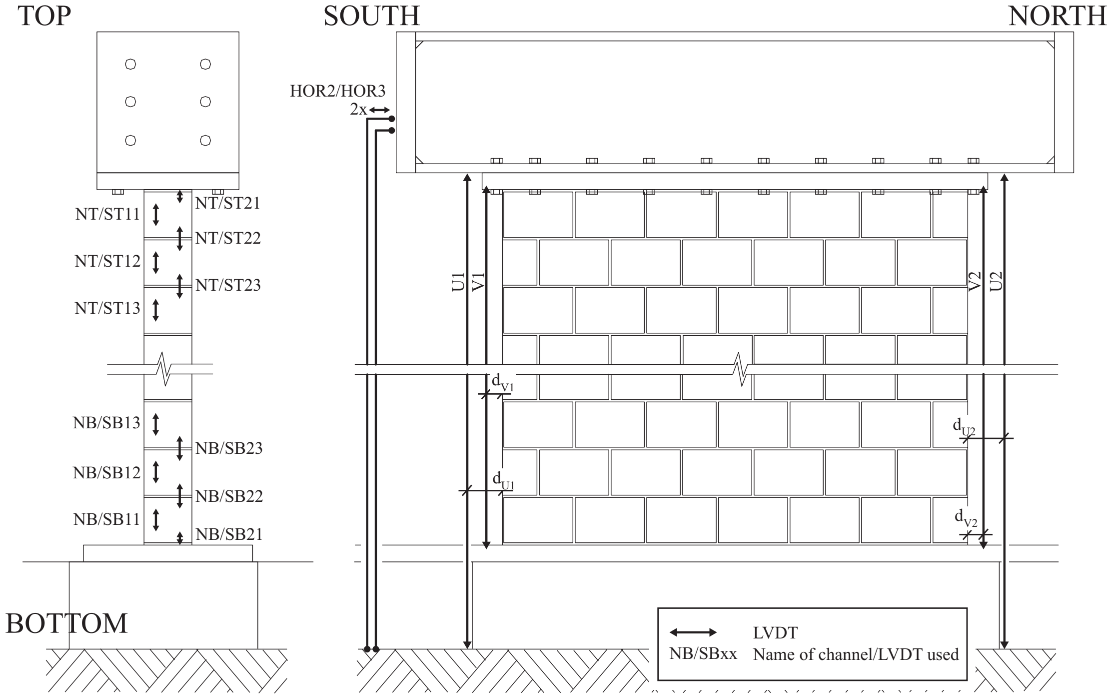

Figure 7 Location of the conventional measurement devices

tests two subfolders ("unprocessed_data" and "processed_data"). The following sections outline the organization of the data within the individual folders and the processing applied to the data. Each wall folder contains one file "Metadata_conventional_channels.xls" which contains information on all instruments used (type of instrument, producer, measurement range, measurement unit, base length for displacement measurements, sign convention).

8.2 Photos

In addition to the data from conventional and optical measurements, photos are used to document the damage to the walls. Photos were taken at each load step, i.e. at peak displacements. These photos are labeled with "LSxx.JPG" where xx stands for the load step. To document the residual damage at zero horizontal force when passing from one load step to the other, the loading was shortly stopped for PUM1–5 when reaching $F_1 \approx 0$ kN. The photo at $F_1 \approx 0$ kN between load steps xx and xx+1 is labeled "LSxx_to_LSxx+1.JPG".

At each load step, the cracks were traced using blue and red pens in order to render the cracks visible on photos. Cracks that were noticed for the first time at load steps in the positive loading direction (LS2, LS4, ...) were marked with a blue line and cracks that were noticed for the first time at load steps in the negative direction (LS3, LS5, ...) were marked in red. Cracks that appeared in the base joint during transportation or while fixing the bottom steel plate to the concrete foundation are marked in black and are annotated with 0. Such cracks appeared for all walls but they remained limited to hairline cracks extending only over a small part of the wall length.

Table 4 Base length for the local measurement devices(Fig. 7)

Channel name	Channel number	Unit	PUM1	PUM2	PUM3	PUM4	PUM5
NB11	13	mm	51	45	48	51	50
NB12	14	mm	50	47	48	52	51
NB13	15	mm	41	48	47	48	50
NB21	16	mm	28	26	30	16	30
NB22	17	mm	56	63	53	55	53
NB23	18	mm	55	53	57	53	53
SB11	19	mm	44	53	46	52	50
SB12	20	mm	45	50	47	50	55
SB13	21	mm	50	50	48	47	50
SB21	22	mm	35	28	30	21	31
SB22	23	mm	59	63	58	55	49
SB23	24	mm	53	56	49	50	54
NT11	25	mm	49	50	49	51	51
NT12	26	mm	50	49	50	49	53
NT13	27	mm	49	47	51	49	54
NT21	28	mm	40	54	35	32	38
NT22	29	mm	52	51	50	51	50
NT23	30	mm	51	49	51	51	50
ST11	34	mm	46	48	47	51	50
ST12	35	mm	51	40	48	50	52
ST13	36	mm	46	44	43	53	50
ST21	37	mm	34	58	35	25	40
ST22	38	mm	52	53	52	50	49
ST23	39	mm	50	51	51	50	48

8.3 Unprocessed data

The unprocessed data contains the original files recorded during the testing of the walls. The folder ”unprocessed_data” contains two subfolders ”conventional” and ”optical”.

8.3.1 Conventional measurement data

The conventional measurements were recorded using the system ”CATMAN” [HBM00] and the files contain the unmodified output files of this system. They comprise the actuator forces (F_1, F_2 and F_3), the voltage channel ”NDI-channel” (see Section ”Instrumentation”), the measurement from the internal displacement transducer of actuator 3 (U3), the measurements from the external displacement transducers (U1, U2, HOR2, HOR3, V2 and V3) and the local displacement measurements at the corners of the wall (NB11 to ST33). The voltage channel ”NDI-channel” was exported from the NDI system and indicated when the optical measurement system was recording. The conventional measurement system was always started before and stopped after the optical measurement system and this voltage signal was therefore used to synchronize the two measurement systems. The folder ”conventional” stores the following types of files, which are all ascii-files: The files containing the measurement during loading are labeled ”LSxx_to_LSxx+1.asc”. While holding the position at one load step, the data was written to a file labeled ”LSxx.asc”. When loading was interrupted during

Table 5 Distances defining the location of the conventional measurement devices U2, U3, V2 and V3 (Fig. 7)

Distance	Channel number	Unit	PUM1	PUM2	PUM3	PUM4	PUM5
d_{U1}	5	mm	10	495	495	485	510
d_{U2}	7	mm	10	405	395	385	400
d_{V1}	9	mm	500	15	-15	50	40
d_{V2}	10	mm	500	27	45	55	70

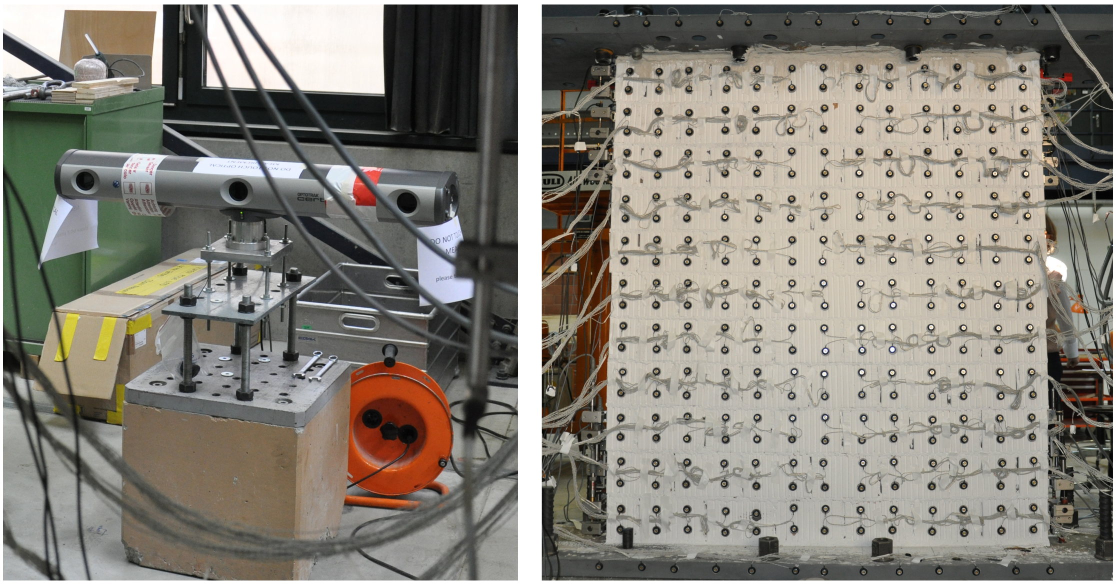

Figure 8 Measurement device used for the optical measurement system: (a) position sensors consisting of three cameras and (b) LEDs glued onto the back side of the masonry wall

the night, the files labeled "LSxx_to_unload.asc" and "Restart_to_LSxx+1.asc" contain the corresponding half loadstep with the unloading/reloading part.

8.3.2 Optical measurement data

The folder "optical" contains the output of the NDI measurement system. For each recording sequence a separate folder was created which stores the NDI-specific file formats (raw data and sensor settings) and the measurement data exported to Excel. The folders are named "LSxx_to_LSxx+1" for measurements when loading from one load step to the next and "LSxx" for measurements at one load step. For the latter, the data was recorded for 90 to 120 seconds. The Excel-files carry the same names as the folders plus the suffix "_001_3d.xls": "LSxx_to_LSxx+1_001_3d.xls" and "LSxx_001_3d_xls".

Each Excel-file contains three header lines which indicate the number of frames included in this file, the recording frequency in Hz (4 Hz for PUM1–5) and the units of the coordinate measurements (mm). After one blank line, the actual measurement data is organized in columns. The first column stores an index starting always from 1. The second and following columns give the coordinate measurements of the LEDs. Always three columns store the x-, y-, and z-coordinate measurements of one LED. The labels of these columns are for LED number 1 Marker_1x, Marker_1y, Marker_1z. At this stage the LED numbers are random (see also App A). If the LED-coordinates could not be measured because the LED was not visible for the position sensor, the columns corresponding to this LED do not contain any entries. Note that for the small-scale walls the LEDs were glued at the back side of the LEDs. Therefore the coordinate system is rotated with respect to the one from the full-scale series and the sign of the x-axes is inverted (see 10).

8.4 Processed data

The processing of the data is done in analogy to the full-scale series [PB14a]. Thus, for each test, the data acquired during loading is appended to one continuous vector of 10000–15000 data points. The data recorded at a load step was averaged and hence, condensed to one single measurement point. A second file contains these measurement points for all load steps (22

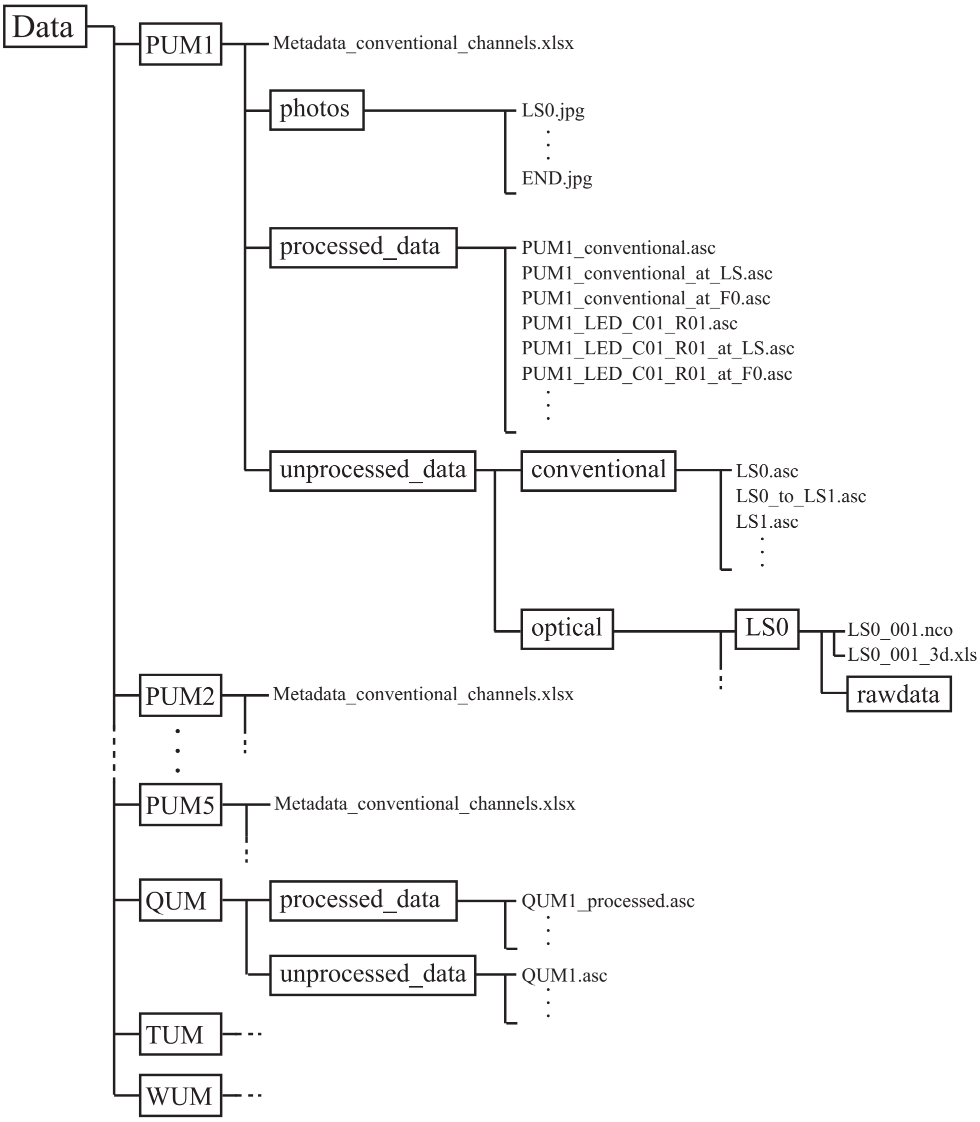

Figure 9 Organization of the data for the half-scale test series

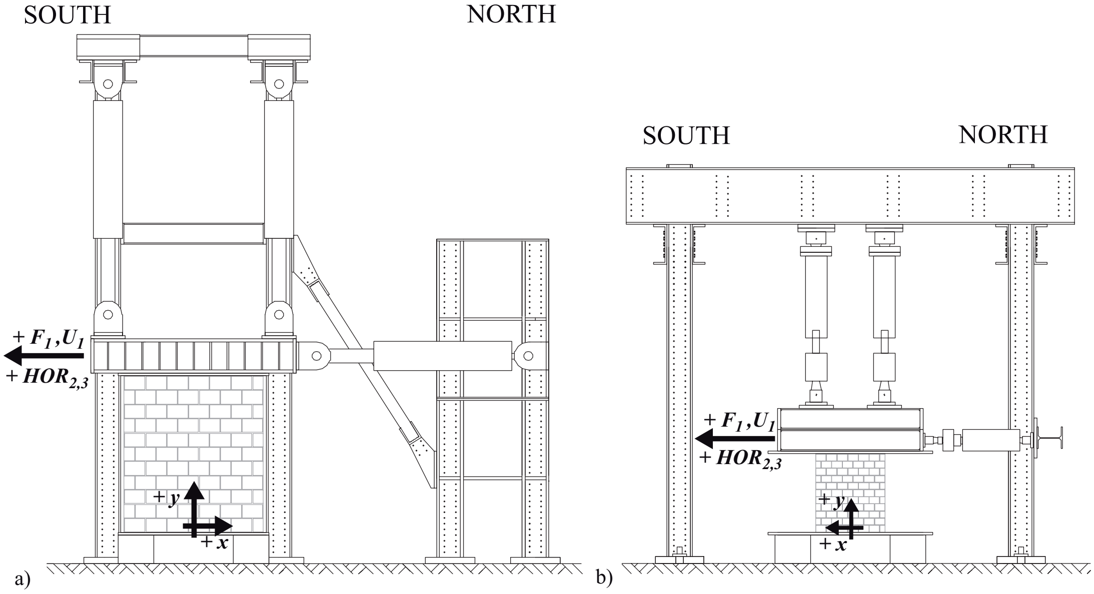

Figure 10 Sign convention and coordinates orientation for (a) the full-scale wall tests (PUP1–6) and (b) the half-scale wall tests (PUM1–5)

to 48 data points, depending on the number of loadsteps until failure). In addition, the data recorded at $F_1 \approx 0$ kN between two successive load steps was identified and also condensed to one point. This data describes the residual deformations for zero horizontal force and is contained in a third file. The suffix of each file ("_at_LS", "_at_F0" or none for the loading phase from peak to peak) indicates the type of file (see Fig. 9).

8.4.1 Processing of the conventional measurement data

With the exception of the channels containing the forces F_1, F_2 and F_3, the signal coming from the NDI measurement and the time, all channels were shifted to zero in such a way that the displacement at LS0 corresponds to zero. In the setup of the small scale series, the actuators 1–3 were numbered in the inverse direction than for the full-scale series. In order to make comparison easier, the order the force channels in the small-scale series were changed thus that F_1 represents the force in the horizontal actuator and F_2 and F_3 the force in the vertical actuator at the North and the South respectively (see numeration of actuators after processing in Fig. 1). After that, the sign of the force of the horizontal actuator, F_1, the displacement measurements V1 and V2 and the deformation measurements NB11 to ST33 were inverted in order to match the sign convention described in "Metadata_conventional_channels.xls". In addition, the conventional data was carefully processed to remove any bias or data that is not linked to the actual behavior of the test data (e.g. offsets because conventional instruments were moved during testing). This process involved certain judgment; in case of doubt the data was not modified.

The self-weight of the loading beam (8.8 kN) was added to the axial load applied at the top of the walls; the weight of the horizontal actuator was negligible. Thus, the force applied by the two vertical actuators F_2 and F_3 was adjusted as follows:

$$F_{2,3} = F_{2,3} - \frac{8.8\text{kN}}{2} \tag{1}$$

Table 6 Computed channels

Channel number	Channel name	Unit	Shortcut	Formulae/Explanation	Sign convention
44	Average HOR	mm	-	$\frac{(\text{HOR2+HOR3})}{2}$	+ = towards South - = towards North
46	Normal force	kN	N	$F_2 + F_3$	+ = pulling to top - = pushing to bottom
47	Top moment	kNm	M_{top}	$(F_2 - F_3) \cdot \frac{L_{act}}{2} + F_1 \cdot H_{act}$	See Fig. 1a of [PB14a]
48	Bottom moment	kNm	M_{bot}	$(F_2 - F_3) \cdot \frac{L_{act}}{2} + F_1 \cdot (H + H_{act})$	See Fig. 1a of [PB14a]
49	Shear span	m	H_0	$\frac{M_{bot}}{M_{bot} - M_{top}} \cdot H$	-
50	Rotation from U2 and U3	mm/m	-	$\frac{(\text{U2+U3})}{d_{U2} + d_{U3} + L}$	+ = counter clockwise - = clockwise
51	Rotation from V2 and V3	mm/m	-	$\frac{(\text{V2+V3})}{d_{V2} + d_{V3} + L}$	+ = counter clockwise - = clockwise
53	Disp at top plate	mm	-	Average displacement obtained from LEDs glued onto the top steel plate	+ = towards South - = towards North
54	Missing disp	mm	-	Displacement obtained from CH44, where measurement from LEDs is missing	+ = towards South - = towards North
55	Disp at top plate	mm	-	Displacement obtained from CH53 and CH54	+ = towards South - = towards North
56	Drift	%	-	$\frac{\text{CH55}}{\text{MarkersPosition}}$	+ = towards South - = towards North

In addition to the recorded channels, a set of computed channels was added to the processed data. The objective of these computed channels is to allow the user to quickly plot fundamental graphs such as the shear force-average drift hysteresis of the wall. Table 6 defines these computed channels: CH53 was obtained by averaging the displacement from all LEDs glued onto the top steel plate. CH54 contains entries only when the optical measurements were missing, hence, when CH53 indicates a NaN-value (NaN=Not a Number). In this case, CH44 is taken as replacement and shifted in such a way as to remove any offsets between CH53 and CH54. The final displacement of the top plate of the wall is channel CH55, which assembles channels CH53 and CH54. CH56 stores the average drift which was obtained by dividing the displacement of the top plate (CH55) by the average height of the wall as obtained from LS0 measurements.

8.4.2 Processing of the optical measurement data

To remove any inherent noise, the optical measurement data was smoothed over a range of 50 data points using the Matlab-function ”smooth” [Mat10]. The coordinate system was then rotated and shifted to align the axes with the xy-axes as indicated in Fig. 10b. Finally, the data was synchronized with the processed conventional measurements. In order to have the same number of entries for the conventional and optical measurements, the measurement frequency of the optical measurements was reduced leading to 150–500 data points between peak displacements. LEDs that fell off during testing were identified and the corresponding entries were replaced by NaN-entries. NaN-entries were also assigned when LED-coordinates were not recorded. Finally, the LEDs were renumbered indicating the position of the LED by a row and a column number. The coordinate histories of each LED are stored in an ascii-file with three columns for the x-, y-, and z-coordinate.

The files are named ”LED_Rxx_Cyy.asc”, where xx corresponds to the row number and yy to the column number.

8.5 Data for material tests (QUM, TUM and WUM)

Data from the material tests was processed similar to the conventional data from the wall tests. Hence, all channels were set to zero at zero load and any bias or data that is not linked to the actual behavior of the test data was eliminated (e.g. offsets because conventional instruments were moved during testing).

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