Quasi-static cyclic tests on two RC U-shaped walls under diagonal loading

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1 Introduction

This document provides additional information on the experimental tests carried out at structural testing laboratory of École Polytechnique Fédérale de Lausanne (EPFL) on two half-scale U-shaped walls: TUC and TUD (Figure A.1). The test objectives, test set-up, test specimen geometry, applied loading history and the interpretation of the test results can be found in [CB16].

This documents presents how the data is organised and how it can be reused. When using any of the data, please cite the article mentioned above as reference.

2 Instrumentation of the test units

The two test units were each instrumented with two different measurement systems: one composed of conventional measurement devices and one optical measurement system. Both measurement systems are described in the following.

The conventional measurement system was composed of the following conventional measurement devices that recorded continuously at a frequency of 1 Hz:

- load cells of the force actuators measuring the applied horizontal forces (Figure A.1)

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- load cells measuring the applied axial force (Figure A.1)
- linear variable differential transducers (LVDTs) measuring the relative horizontal displacement of the top of the wall at $h = 2.95$ m and $h = 3.35$ m (Figures A.2 and A.3)
- LVDTs measuring the vertical shortening and elongation at four outer vertical edges of the wall (Figures A.2 and A.3)
- LVDTs measuring the vertical shortening and elongation at two inner vertical edges of the wall near the flange ends

The optical measurement system Optotrack from NDI (Optotrack Certus HD [NDI09]) was composed of the following devices that recorded continuously at a frequency of 2 Hz:

- $\sim$ 500 light emitting diodes (LEDs) glued on the outer surface of the wall (Figures A.4 and A.5)
- three position sensors each comprising three digital cameras that recorded the x, y and z coordinates of the LEDs (Figure A.1)

3 Loading history

The main loading cycles were applied along the two geometric diagonals of the U-shaped section: directions E-F and H-G (Figure A.6). Cycles along the principal directions were also added at small drift levels in order to check the strength capacity of the wall in these directions. The load step numbers, their corresponding loading position and the target drifts at each load step are summarised for both test units in Figure A.7. The loading for TUD was stopped at LS80.

4 Test data

4.1 Organisation of data

The data is organised as in Figure A.8. The data was divided into two large folders: the '01_Documents_and_data' and the '02_Photos' folders. The first folder comprises a subfolder '01_Documents_and_paper' which contains all the relevant documents to understanding and reusing the experimental data. Three other subfolders were included in the first folder: a subfolder containing processed and unprocessed measurements from the conventional instruments for both test units, a subfolder containing processed and unprocessed measurements from the optical system and a subfolder containing processed and unprocessed data from the material tests. A 'Metadata_conventional_channels.xlsx' file that provides sign conventions and information on the conventional measurement instruments used was included in the conventional measurements for each test unit.

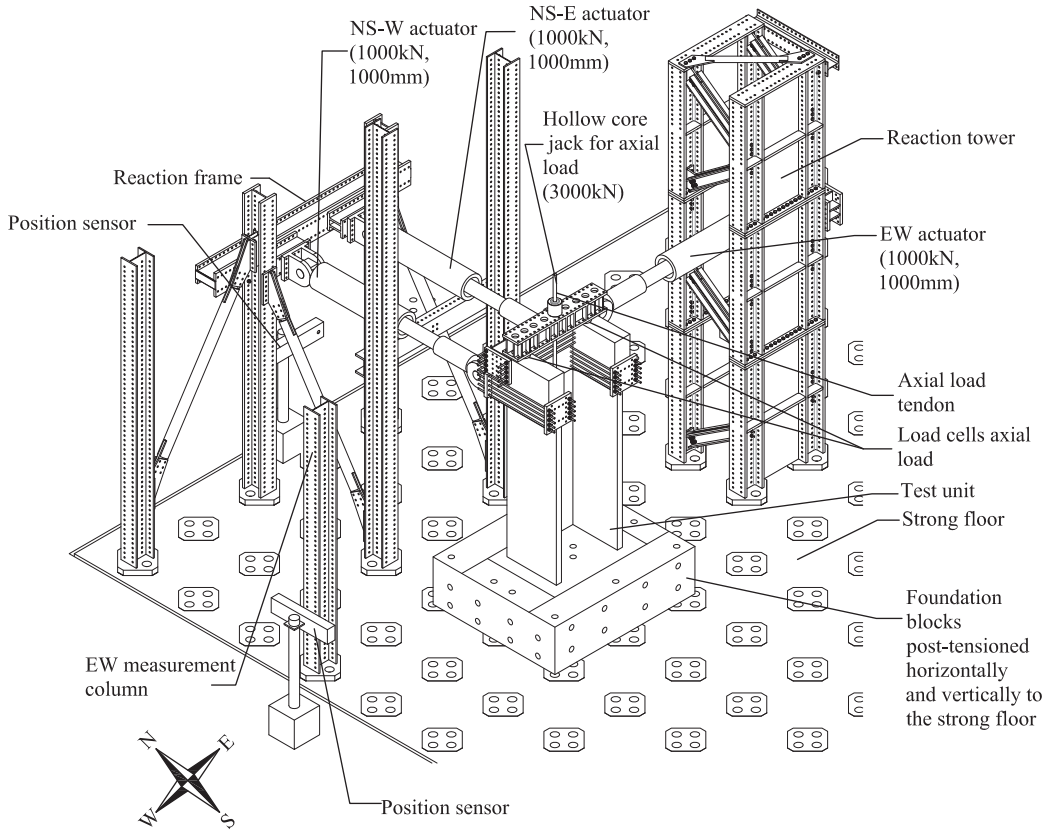

Figure A.1: Sketch of the test set-up

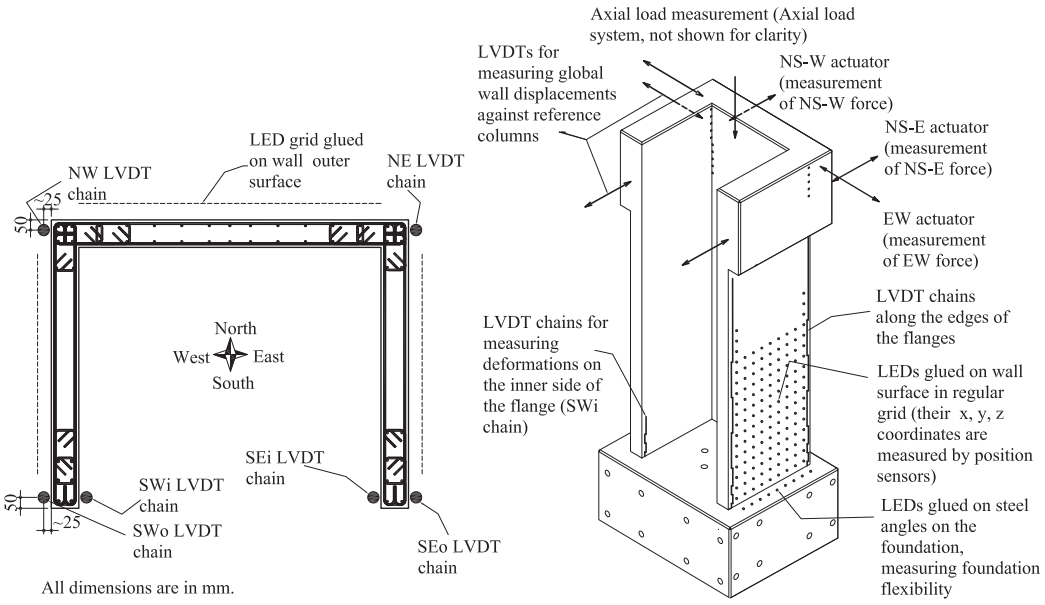

Figure A.2: Sketch of the measurement systems: top view (left) and 3D view (right)

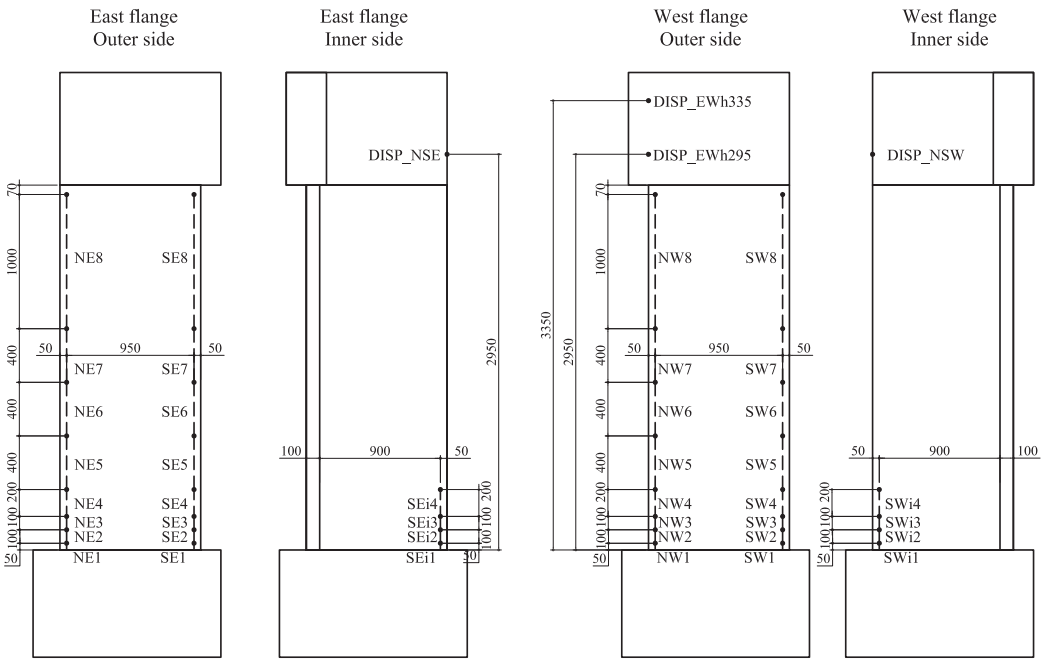

Figure A.3: TUC and TUD: Sketch of the LVDT chains mounted on the outer wall edges of the flanges and on the inner edge at the flange ends. In addition the positions of the LVDTs measuring the global wall top displacements are shown.

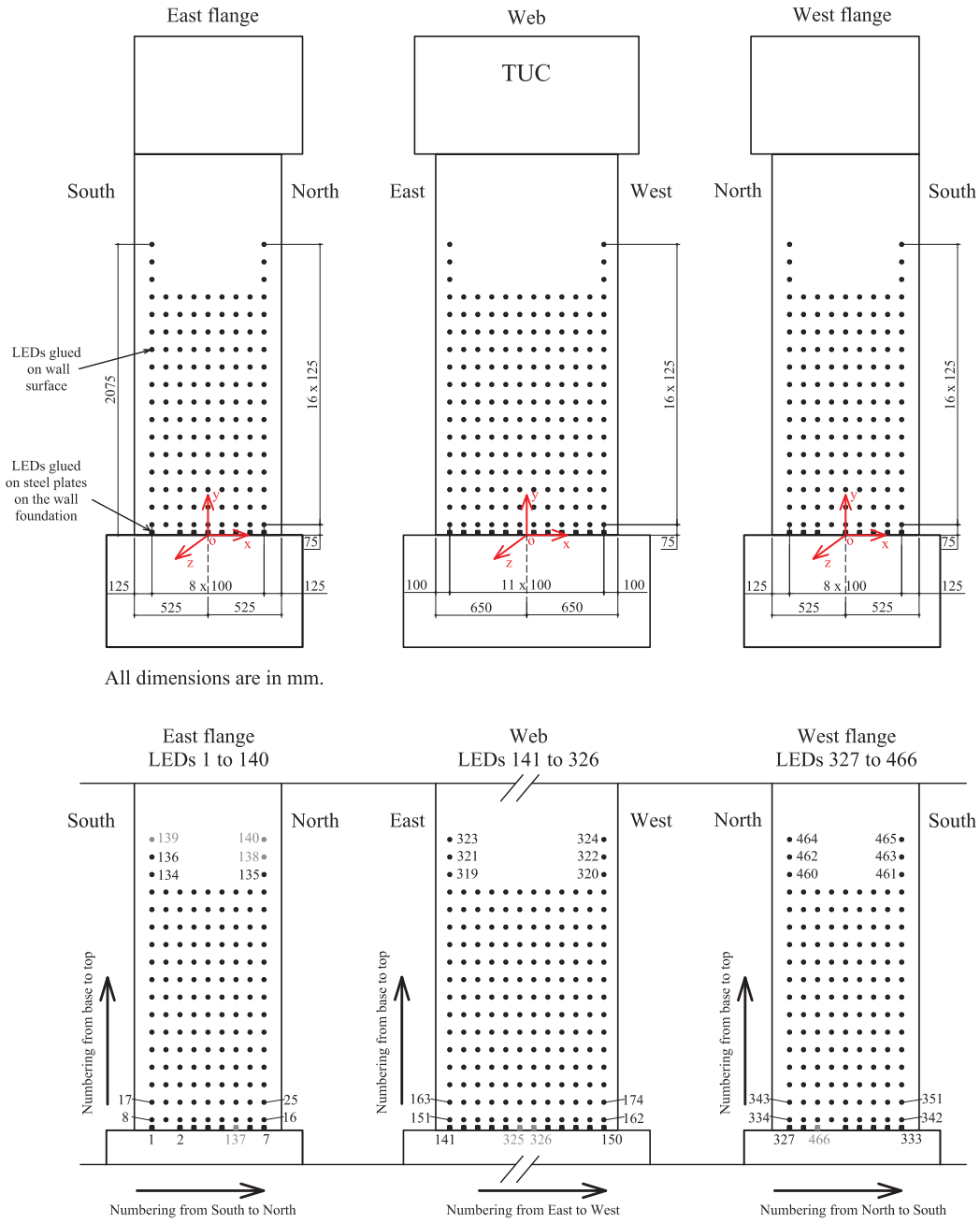

Figure A.4: TUC: Sketch of the positions of the LEDs glued on the outer faces of the wall, the local coordinate axes with respect to which the processed optical data is given and the numbering of the LEDs after data post-processing. Grey colour marks LEDs that are obsolete, i.e., that were not visible to the position sensors during testing.

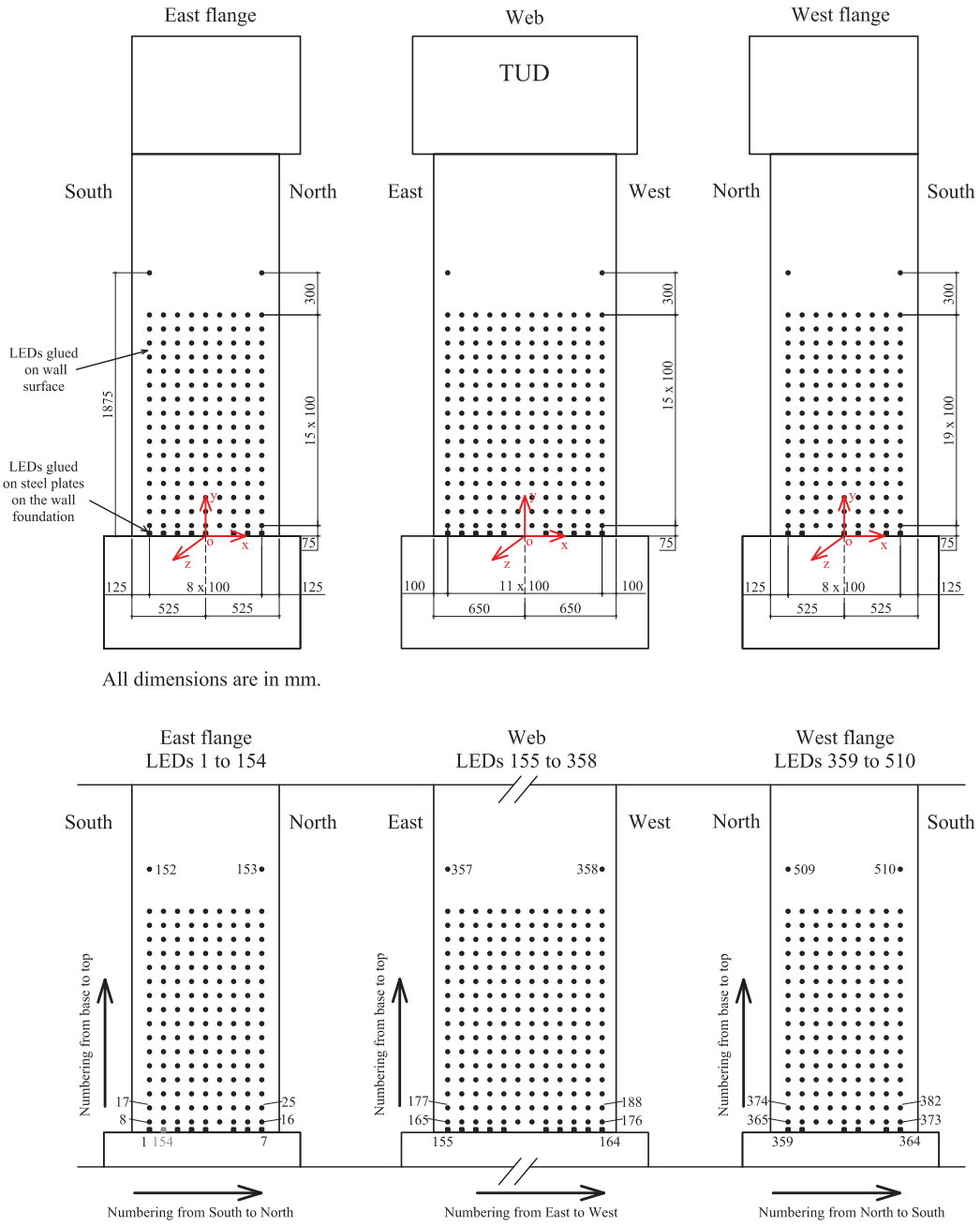

Figure A.5: TUD: Sketch of the positions of the LEDs glued on the outer faces of the wall, the local coordinate axes with respect to which the processed optical data is given and the numbering of the LEDs after data post-processing. Grey colour marks LEDs that are obsolete, i.e., that were not visible to the position sensors during testing.

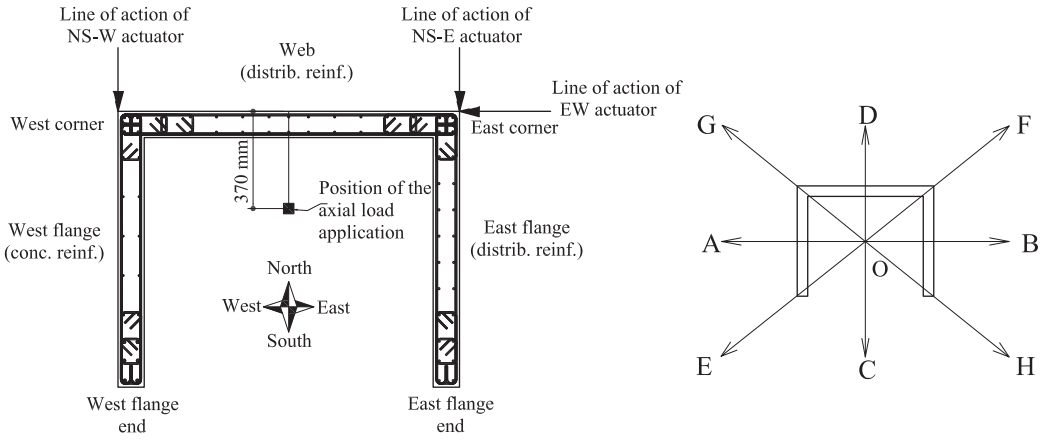

Figure A.6: Naming of wall parts, cardinal orientation and loading positions

4.2 Unprocessed data

The unprocessed data contains the original files as recorded by the measurement systems during the testing of the walls. The type of files recorded will depend on the type of measurement systems used.

4.2.1 Conventional measurement data

The conventional measurements were recorded using the CATMAN software [HBM00]. This software outputs ascii files that contain the unmodified measurements as recorded by the system. A channel is assigned to each instrument of the system. The type of recorded measurements and the corresponding channel names are listed below:

- Measurement of forces and displacements of the horizontal actuators: ACTU_FORCE_EW, ACTU_FORCE_NSW, ACTU_FORCE_NSE, ACTU_DISP_EW, ACTU_DISP_NSW and ACTU_DISP_NSE
- Measurement of the applied axial forces from the two load cells placed between the top steel beam and the wall collar: F_AX_W, F_AX_E (TUC) or measurements of axial force load cell placed on the pre-stressed axial tendon: F_AX_1 and of pressure applied in the hollow core jack: PRESS_AX (TUD)
- Measurements of relative horizontal displacements at the top of the wall using LVDTs: DISP_EWh295, DISP_EWh335, DISP_NSW, DISP_NSE
- Measurements of shortening and elongation of the wall edges using six LVDT chains: SWi1 to SWi4, SW1 to SW8, NW1 to NW8, NE1 to NE8, SE1 to SE8 and SEi1 to SEi4

LS number	Loading position	Target drift @h=2.95 m [%]
LS0	zero measurement	0
LS1	axial load	0
LS2	C (NS)	-0.1
LS3	D (NS)	0.1
LS4	O	0
LS5	A (EW)	-0.1
LS6	B (EW)	0.1
LS7	O	0
LS8	C (NS)	-0.2
LS9	D (NS)	0.2
LS10	O	0
LS11	A (EW)	-0.2
LS12	B (EW)	0.2
LS13	O	0
LS14	E (Diag1)	-0.2
LS15	F (Diag1)	0.2
LS16	O	0
LS17	H (Diag2)	0.2
LS18	G (Diag2)	-0.2
LS19	O	0
LS20	E (Diag1)	-0.3
LS21	F (Diag1)	0.3
LS22	O	0
LS23	H (Diag2)	0.3
LS24	G (Diag2)	-0.3
LS25	O	0
LS26	C (NS)	-0.3
LS27	D (NS)	0.3
LS28	O	0
LS29	A (EW)	-0.3
LS30	B (EW)	0.3
LS31	O	0
LS32	E (Diag1)	-0.4
LS33	F (Diag1)	0.4
LS34	O	0
LS35	H (Diag2)	0.4
LS36	G (Diag2)	-0.4
LS37	O	0
LS38	C (NS)	-0.4
LS39	D (NS)	0.4
LS40	O	0
LS41	A (EW)	-0.4
LS42	B (EW)	0.4
LS43	O	0
LS44	E (Diag1)	-0.6
LS45	F (Diag1)	0.6
LS46	O	0
LS47	H (Diag2)	0.6
LS48	G (Diag2)	-0.6
LS49	O	0
LS50	C (NS)	-0.6
LS51	D (NS)	0.6
LS52	O	0
LS53	A (EW)	-0.6
LS54	B (EW)	0.6
LS55	O	0
LS56	C (NS)	-0.8
LS57	D (NS)	0.8
LS58	C (NS)	-0.8
LS59	D (NS)	0.8
LS60	O	0
LS61	A (EW)	-0.8
LS62	B (EW)	0.8
LS63	A (EW)	-0.8
LS64	B (EW)	0.8

LS number	Loading position	Target drift @h=2.95 m [%]
LS65	O	0
LS66	E (Diag1)	-1
LS67	F (Diag1)	1
LS68	E (Diag1)	-1
LS69	F (Diag1)	1
LS70	0	0
LS71	H (Diag2)	1
LS72	G (Diag2)	-1
LS73	H (Diag2)	1
LS74	G (Diag2)	-1
LS75	O	0
LS76	H (Diag2)	1.5
LS77	G (Diag2)	-1.5
LS78	H (Diag2)	1.5
LS79	G (Diag2)	-1.5
LS80	O	0
LS81	E (Diag1)	-1.5
LS82	F (Diag1)	1.5
LS83	E (Diag1)	-1.5
LS84	F (Diag1)	1.5
LS85	O	0
LS86	E (Diag1)	-2
LS87	F (Diag1)	2
LS88	E (Diag1)	-2
LS89	F (Diag1)	2
LS90	O	0
LS91	H (Diag2)	2
LS92	G (Diag2)	-2
LS93	H (Diag2)	2
LS94	G (Diag2)	-2
LS95	O	0
LS96	H (Diag2)	2.5
LS97	G (Diag2)	-2.5
LS98	O	0
LS99	E (Diag1)	-2.5
LS100	F (Diag1)	2.5
LS101	O	0
LS102	E (Diag1)	
LS103	O	0
LS104	H (Diag2)	
LS105	O	0

failure of TUC for the two diagonal directions

failure of TUD

Figure A.7: Load step number, corresponding loading position and target drifts. The last loadstep for TUD is LS80.

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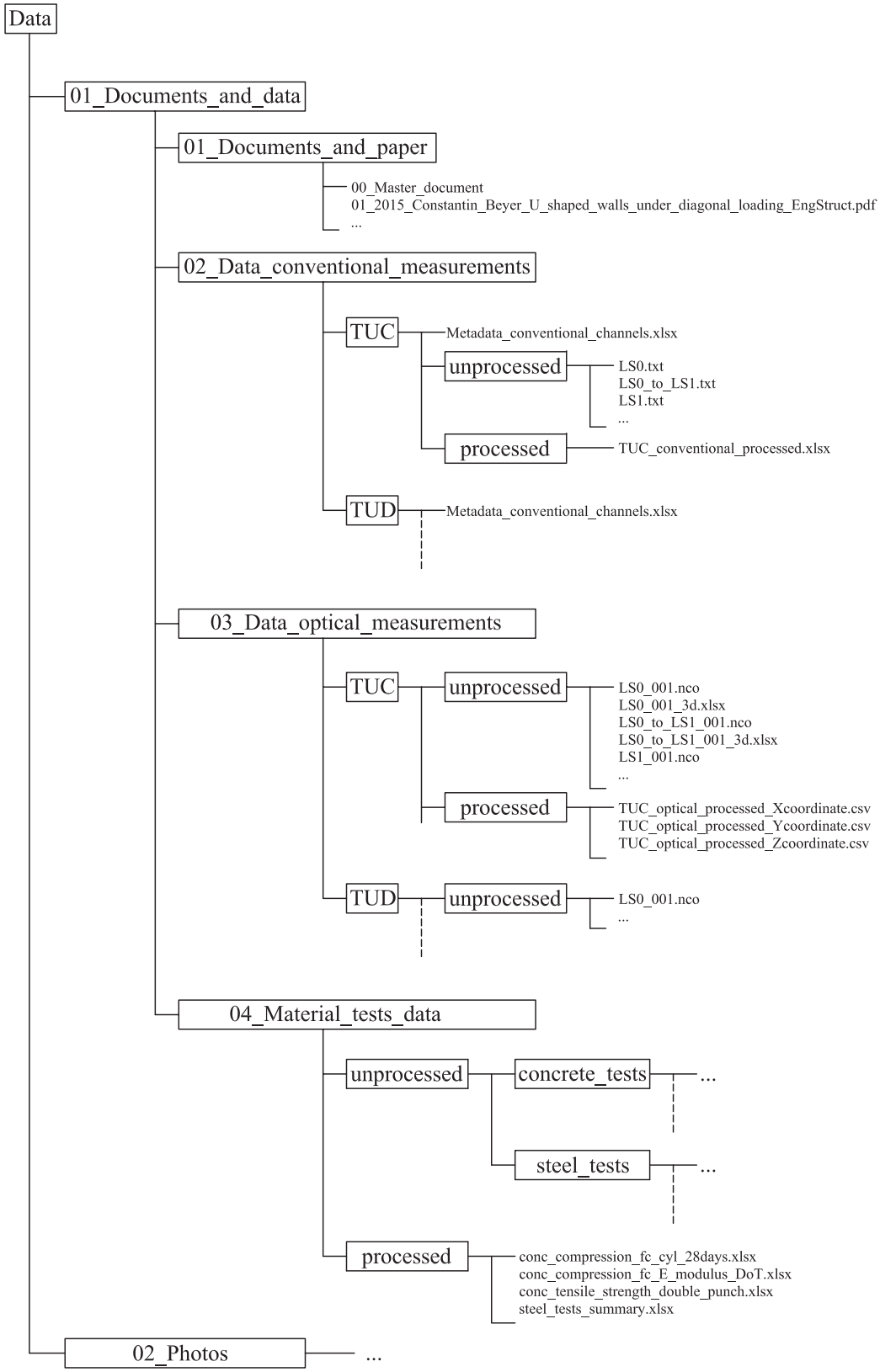

Figure A.8: Sketch of the data organisation.

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- Voltage measurement exported from the NDI system to indicate when the optical system was recording: LED. The conventional system recording was always started before and stopped after the NDI recording. This voltage measurement was used to synchronise the conventional and the optical measurement system.
- Additional measurements to check the safety of the test set-up during loading. One LVDT fixed below the strong floor of the testing laboratory to record the vertical displacement of the strong floor during loading: DISP_SLAB. Inclinometers fixed on the wall collar and on the top steel beam and measuring their inclination with respect to the wall vertical axis during loading: INCLIN_WALL, INCLIN_BEAM (only for TUC).

The files are labelled as 'LSxx_to_LSxx+1.txt' to indicate measurement during loading from one load step to the next and 'LSxx.txt' to indicate measurement at load step (i.e., while holding the wall position at the target displacement).

4.2.2 Optical measurement data

The data recorded from the NDI measurement system was placed in the subfolder named '03_Data_optical_measurements'. For each separate recording the NDI system exports the measurement data to an Excel file. In addition an ascii file with extension 'nco' is created carrying data on the settings of the NDI system. The files are named 'LSxx_to_LSxx+1_001' for measurements when loading from one load step to the next and 'LSxx' for measurements while holding the position at one load step. The Excel files are named as the 'nco' files are, plus the suffix '_3d.xls': 'LSxx_to_LSxx+1_001_3d.xls' and 'LSxx_001_3d_xls'.

Each Excel file has three header lines. These lines indicate the number of frames included in the file (i.e., number of measurements values for one coordinate of a LED), the recording frequency in Hz (2 Hz for both TUC and TUD) and the units of the coordinate measurements (mm). A blank line follows the header lines, then comes the actual measurement data that is organised in columns. The first column stores the frame index that always starts from one. From the second column on, the coordinate measurements of the LEDs follow. These measurement are organised by LED number and by x, y and z coordinate. For example the second, third and fourth column which correspond to LED number 1 are labelled Marker_1x, Marker_1y and Marker_1z respectively. In the unprocessed data, the numbering of the LEDs is random. If a LED was not visible to the position sensors during loading, the columns corresponding to this LED are blank.

4.2.3 Measurement irregularities

Several measurement irregularities occurred during the testing of TUC and TUD. These irregularities are listed below:

- During the testing of TUC, due to a malfunction of the actuator system, loading from position H to G (LS35 to LS36) was done in steps and data files were stitched together for post-processing. In addition, when reaching LS36 one of the three actuators continued to load slightly above the target drift but at a high speed. It applied a small torsion on the wall but no important additional cracks were observed after this.
- For both TUC and TUD, the LEDs glued on the foundation originally followed a regular grid consistent with the grid of the LEDs on the wall surface. However several LEDs on the foundation were removed prior to commencing the tests as their visibility to the position sensors was obstructed by the pre-tensioning bar ends and plates. Additional LEDs were not visible during the entire testing procedure but were left in place and marked as obsolete.

4.3 Processed data

Both the conventional and the optical measurement data were processed in order to reduce the amount of data and to make it easy to use. The processing consisted of: synchronising the optical and the conventional measurement data, removing any bias in the measurements not related to the actual wall behaviour (e.g., accidental touching of measurement instruments or LEDs that had fallen off but were still recording) and organising the data in one set of measurements during loading between load steps. The measurements during loading (i.e., files of type LSxx_to_LSxx+1) were assembled together resulting in one single continuous vector of 57110 data points for TUC and 19146 data points for TUD.

4.3.1 Conventional measurement data

The measurements of the conventional instruments have been offset so that the deformations and displacements at initial load step LS0 are zero. The measurements of the actuator forces, time channel and voltage channel were not offset.

The signs of some of the top displacement measurements and actuator forces were inverted so that they match the sign convention for the wall as described in 'Metadata_conventional_channels.xlsx'. In addition, the processed top displacements were modified to remove the contribution of the foundation flexibility (foundation uplift and sliding with respect to the strong floor) recorded by means of the LEDs glued on the steel plates on the foundation.

4.3.2 Optical measurement data

Several processing steps were performed for the optical measurement data:

- The data was smoothed over a range of 20 data points in order to remove measurement noise. Smoothing was done using the Matlab function 'smooth' [Mat10].

- For each flange and the web, the coordinate system was rotated and shifted so that it is aligned with the local xyz coordinate system of each wall part, i.e., web or flanges. For any of the three wall parts, the local x axis is always aligned with the length of the wall part, the local y axis is aligned with the wall height and local z axis is perpendicular on the wall surface and oriented from the wall towards the position sensor (Figures A.4 and A.5). The origin of the local coordinate system is always: at mid-length of each wall part (x axis), at the base of the wall specimen (y axis) and at the outer wall surface (z axis).
- The optical measurement data was synchronised with the processed conventional measurement data. In order to have the same number of measurement values for both systems, the measurement frequency of the optical system (2 Hz) was reduced to the frequency of the conventional system (1 Hz).
- LEDs that fell off during testing were identified and the corresponding entries were replaced by NaN (Not a Number) entries.
- LEDs were renumbered starting from the base of the East flange, from left to right on the outer wall surface. Obsolete LEDs, i.e., LEDs that were not visible during testing are numbered at the end for each wall part and are shown in grey in Figures A.4 and A.5.

The processed optical measurements for all LEDs are stored in three separate csv files, one for each x, y and z coordinate. The three files are named: 'TUC_optical_processed_Xcoordinate.csv', 'TUC_optical_processed_Ycoordinate.csv' and 'TUC_optical_processed_Zcoordinate.csv', for the case of TUC and similarly for TUD. The processed x, y and z coordinates are expressed with respect to the local axes of each of the wall parts (Figures A.4 and A.5).

4.4 Photos

All the photos documenting the construction, test set-up and the damage during testing of the two specimens were saved in the second main folder '02_Photos'. The photos documenting the damage of the walls were taken at load steps while holding the wall position at the target peak displacement. These photos are found in the '02_TUC_testing' and '04_TUD_testing' and are organised in folders 'LSxx' created for each load step numbered xx. Each 'LSxx' folder contains global photos of the wall specimen taken from the front (view of the inner wall faces), back (view perpendicular on the web), and the two sides (views perpendicular on the two flanges). These global photos are saved in 'Overview' subfolder. In addition, when damage became significant detailed photos at the damage locations were taken. These are photos were saved in the subfolder 'Detailed'.

At each load step, the cracks were traced using blue, red, black and green pens in order to render the cracks visible on photos. Each color corresponded to different loading positions: red - positions A and F, blue - positions B and and E, black - positions C and H, green - positions D and G (see also Figure A.6).

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