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The original document was first made available in 2022.05.09 (version 1.0), and the last update is from: (no updates yet).

1. U-shaped Wall Test Information

Three large-scale reinforced concrete (RC) U-shaped walls are to be tested in the Institute of Mechanics, Materials and Civil Engineering (iMMC) at the Université catholique de Louvain (UCLouvain), Belgium. Two of these units (UW1 and UW2) will be used for the UCLouvain 2022 blind prediction competition. The next sections address: 2. Description of test units, 3. Material properties and casting, 4. Test setup, 5. Loading protocols, and 6. Instrumentation.

2. Description of Test Units

Three specimens will be experimentally tested under different flexure-to-torsion (M-T) ratios. The three M-T ratios are 1:0 (i.e., pure flexure), 0:1 (i.e., pure torsion), and 1:1. Importantly, for this blind prediction competition, only the results for the first two units will be considered, corresponding to the walls subjected to pure flexure and pure torsion. An axial load is also applied. The loading protocol for the first unit under pure flexure, denoted UW1, is based on a prototype 6-story wall subjected to the equivalent lateral force distribution for design of earthquake and gravity loads (Figure 1). The test specimens represent the approximate bottom 1.5 stories of the 6-story prototype structure, at half scale. Application of an overturning moment, shear force, and axial force on the top of the test specimen simulated the effects of the gravity and lateral loads acting on the upper 4.5 stories of the wall. For the second unit, denoted UW2, subjected to pure torsion, only horizontal loads (i.e., twisting) and a constant axial load will be applied.

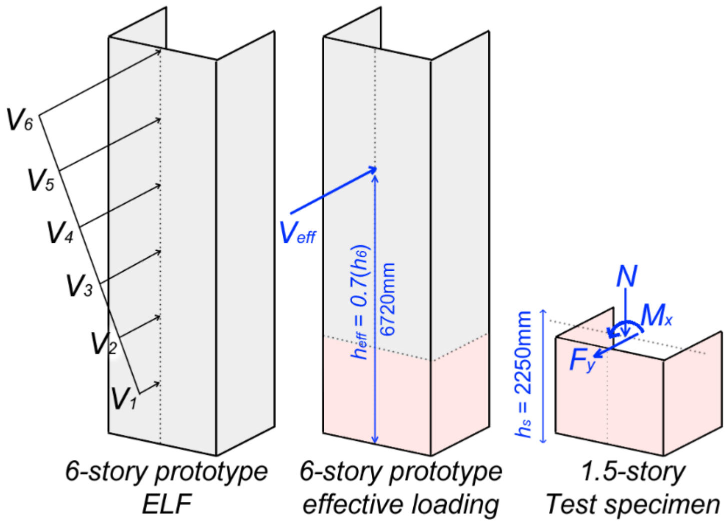

Figure 1 Six-story prototype core-wall structure (left) and the simulated test specimen UW1 (right)

The two specimens are identical in geometry and design detailing, with the cross-section of the wall and reinforcement shown in Figure 2a. The U-shaped specimens have a flange and web thickness (t_w) of 100mm, web length (L_w) of 1300mm, and flange length (L_f) of 1050mm. 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. Note also that in the flanges (near the web), two longitudinal rebars of 8mm diameter were used. Confinement reinforcement is provided in the boundary ends using 6mm bars spaced at 75mm, while the transverse (shear) reinforcement consists of 6mm bars spaced at 150mm. Figure 2b illustrates that the specimen height (h_s) to the application of the horizontal actuators is 2250mm, while the simulated effective height of the wall (h_{eff}) is 6720mm. The footing 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. For unit UW1, the size of the footing is 1400mm x 1500mm x 450mm. For unit UW2, the width of the footing was slightly increased to 1900mm x 1500mm x 450mm. The collar of the wall has a variable thickness over the flanges and in the web, increased to fasten the actuators to the wall unit. A collar was used, rather than a thick top slab, due to the warping restraints (Beyer *et al*., 2008), which are particularly important for specimen UW2 subjected to pure torsion. You will find the full set of reinforcement detailing and plan drawings of the wall units in the companion document, **Appendix A and B**.

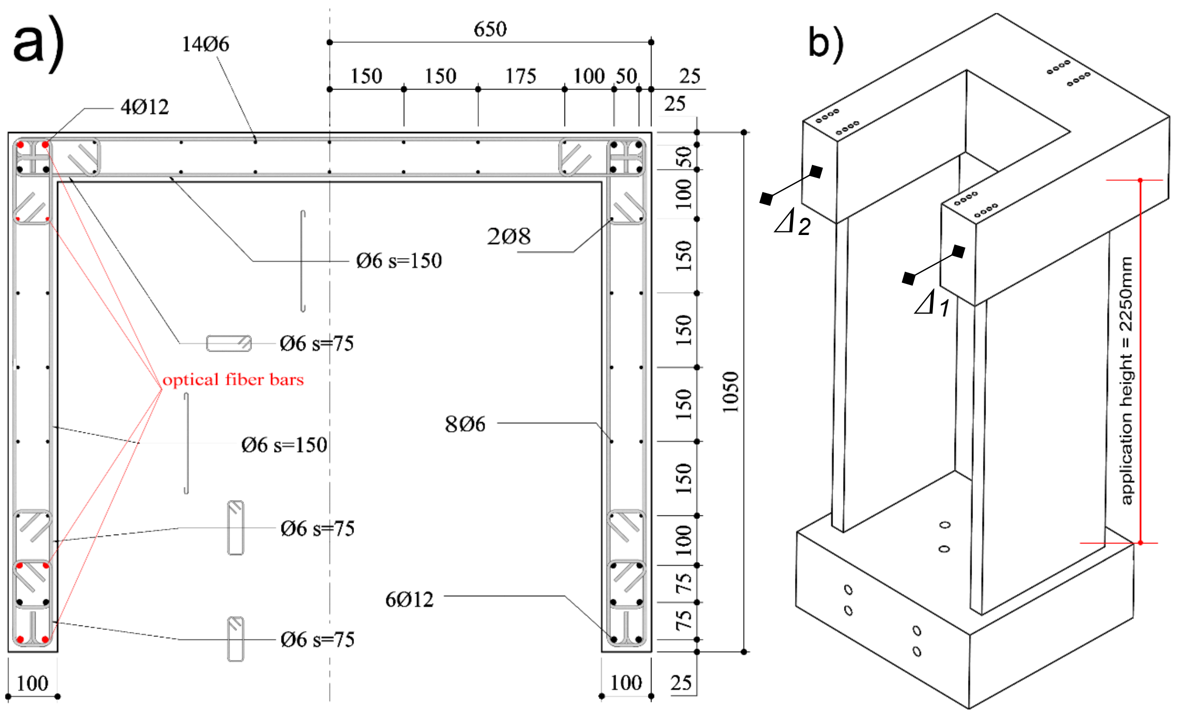

Figure 2 Test units UW1 and UW2: (a) cross-section and reinforcement layout (dimensions in mm) and (b) elevation view

3. Material Properties and Casting

3a. Steel reinforcement properties and rebar cage

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 B reinforcement was used for the other reinforcement in the foundation and collar of the wall. The salient mechanical properties of the Class C reinforcing steel, as obtained from tensions tests, are given in Table 1: f_y and f_u are the yield and ultimate stress; ε_{sy}, ε_{sh}, ε_{su} are the strain values corresponding to yield, strain hardening, and ultimate strain (respectively); and E_s is the Young's modulus.

Table 1 Mechanical properties of the Class C reinforcement

d_{bl}	f_y	f_u	ε_{sy}	ε_{sh}	ε_{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

The rebar cages are assembled in a precast production factory. Although a maximum guidance and control is envisaged, it may not be possible to guarantee in absolute detail the respect of the construction plans. Some of the features that are judged potentially more relevant to the response of the walls are reported below, to the best of the organizers' observations, judging from photos taken immediately prior to the casting. Firstly, it should be noted that the units are cast with its longitudinal axis in the horizontal position, with the flanges positioned vertically and the web on the top (i.e., in the position ⊓).

Unit UW1

- Construction workers forgot to include cover spacers, and therefore it is feared that the rebar cage can move during concrete pouring. It is more likely that this will be an issue for the south region of the flanges, which are subjected to larger hydrostatic pressure, than for the web, which is on top during casting, and overall more "restrained" due to the rest of the cage. In particular, the south outermost regions of the West flange may be more prone to move as the construction workers were advised to minimize contacts with the rebars where the optical fibres were glued. A couple of photos also appear to point to a slight reduction of the distance along the thickness between the centers of the longitudinal rebars in these same regions of the flanges (i.e., instead of the theoretical distance of 56 mm, maybe 10 mm less?). The above observations will be confirmed or disproved (and reported here as an update) after the wall test, which is expected to show the interior of the cage at the bottom south outermost regions (boundary elements) of the flanges. The stirrups and confinement reinforcement do not seem to have been bent with high quality (e.g., the angles at the corners are too rounded), it remains to be seen if this will play a role on the response.

Unit UW2

- Construction workers were now instructed to included cover spacers, and therefore it is more likely that the rebar cage will not move during concrete pouring, namely the flanges. The photos are not sufficiently clear to understand whether the distance along the thickness between the centers of the longitudinal rebars in the boundary element regions of the flanges was again reduced (which appeared to have occurred in UW1). The confinement reinforcement was carefully prepared at the LEMSC laboratory and delivered to the construction factory, and therefore this point should not be a reason of potential concern as it was for UW1. Again, the above observations will be confirmed or disproved (and reported here as an update) after the wall test.

3b. Concrete properties and casting

At the time of writing of the original version of this document, the concrete properties at the day of the test have yet to be determined. A 30 MPa, 28-day cylinder design strength (f'_c) is warranted. To achieve it, and in view of the impossibility of the precast construction factory to change its high cement quality, and to use vibrating engines, an air-entrained (5-6%) self-consolidating concrete was employed. This is likely to reduce the density of the concrete from its usual value, which is reported below. This document will be updated with the concrete properties as the testing of the cylinders and cubes progress.

<u>Unit UW1</u>

- Day 7: Cube concrete strength: 15.0 MPa; concrete density: ≈2200 kg/m^3.
- Day 19: Cube concrete strength: 28.1 MPa

<u>Unit UW2</u>

- (not yet available)

4. Test Setup

In total, five actuators are used to simulate the behaviour of the half-scale, 6-story RC core wall. Figure 3 illustrates the laboratory setup used to test the wall specimens. It is worth noting that a 3D pdf is available in the companion documents (see **Appendix C**). The three vertical actuators are used to apply the overturning moment, simulating a wall with a larger shear span, as well as the axial load. A constant axial load ratio (*ALR*) of 5% is used throughout testing for both units. The applied axial force (*N*) can be calculated using Equation 1. One-third of the axial force (i.e., *N*/3) will be applied by each of the vertical actuators on the wall.

$$ALR = \frac{N}{f_c' A_g} \quad (1)$$

where A_g is the gross cross-sectional area of the wall (=320,000mm^2), and f_c' is the concrete strength at the day of testing.

Two horizontal actuators apply the shear force for specimen UW1 and the rotation (i.e., torque) for specimen UW2. As depicted in Figure 3, the horizontal actuators are connected to a steel beam, which is subsequently connected to the collar of the wall. The lever arm distance between the application points of the two horizontal actuators is 2400mm.

The unit foundation was fixed to the strong floor using a series of post-tensioned, threaded rods. Two additional foundation blocks on either side of the test unit were also used to restrain the wall from sliding and twisting at its base (Figure 3), connected to the foundation of the wall through four post-tensioned threaded rods. Finally, the foundation blocks were also fixed to the strong floor, again through post-tensioned threaded rods.

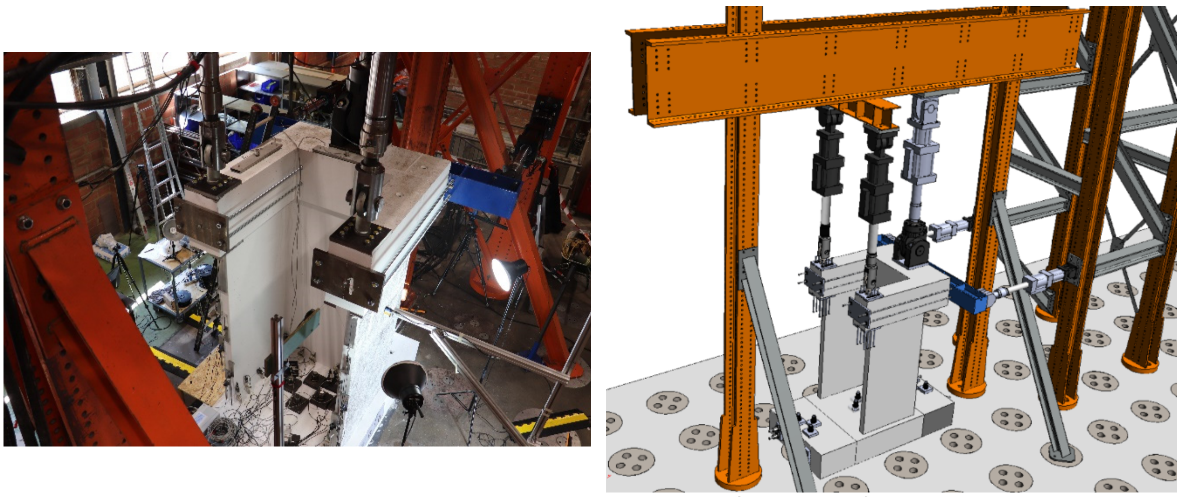

Figure 3 Test setup in the laboratory (see Appendix C document for 3D PDF)

5. Loading Protocols

In the following sections, the loading protocols for the two units, UW1 and UW2, are provided with reference to the positions given in Figure 4b.

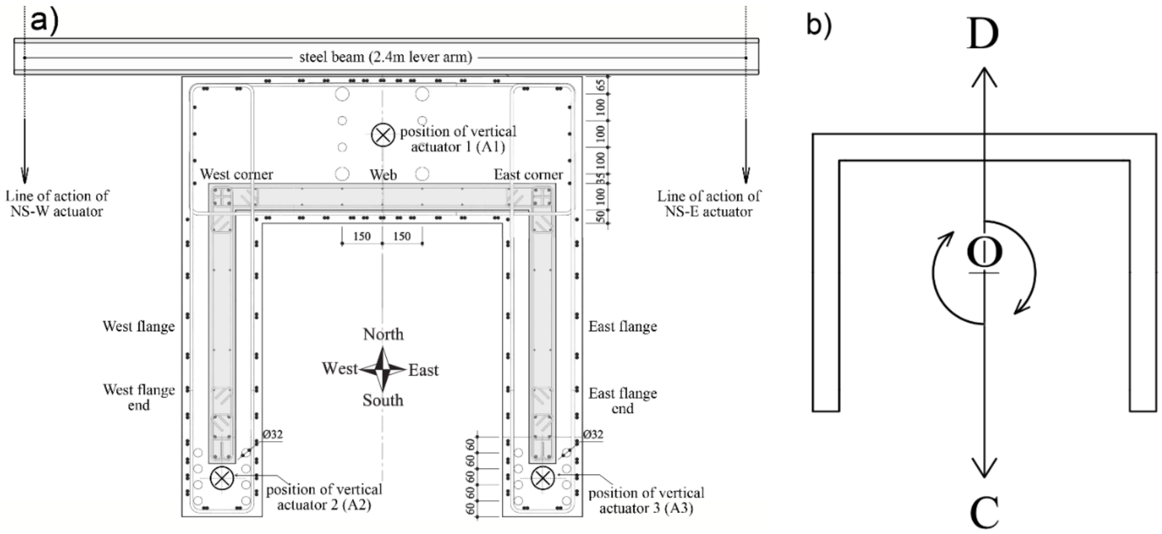

Figure 4 (a) application points of the five actuators with indication of the cardinal points (b) loading positions of the wall. Unit UW1 is largely subjected to flexural loading to positions C and D, whereas unit UW2 is subjected to torsion at position O (blue arrows)

5a. Specimen UW1, Pure Flexure

The displacement-controlled reverse-cyclic quasi-static loading protocol in Figure 5 will be used to test specimen UW1 under pure flexure. The incremental loading parameter was chosen to be the imposed in-plane drift ($d=\Delta/h_s$, where Δ is the imposed displacement and the specimen height h_s is 2250mm, as mentioned above). The flexural loading history to positions C and D (see Figure 4b) for UW1 is described below:

- Between 0.0% and 1.0% drift: one-cycle at each drift level, increments of 0.1% drift
- For drifts larger than 1.0%: two-cycles at each drift level, increments of 0.5% drift

The overturning moment (M_x), imposed by the vertical actuators can be calculated as:

$$M_x = F_y(h_{eff} - h_s) \quad \textbf{2}$$

where F_y is the total shear force imposed on the wall by the two horizontal actuators (see also Figure 1).

The wall will be first loaded to the North (towards position D), such that the web of the wall is in compression (i.e., flange boundary ends in tension). The wall will be tested until failure occurs, defined as the displacement corresponding to a post-peak drop from the maximum strength of the unit in each direction (C and D) of at least 20%, in the envelope curve.

As indicated in Figure 5, small twists will be applied to unit UW1 at salient drift levels and at positions C, D, and O. This was also practiced in previous U-shaped wall tests (see Beyer *et al.*, 2008; Hoult & Beyer, 2020; Hoult & Beyer, 2021; Hoult *et al.*, 2020) to provide information on the degradation of torsional stiffness. The applied twist is small enough to ensure that it does not contribute or influence the overall flexural behaviour and corresponding failure mode observed. A small force of 10kN in each actuator with opposite signs, corresponding to a maximum torque (10kN x 2.4m) of 24kNm, will be applied to the wall at the following drift levels: 0%, 0.5%, 1.0%, 1.5%, and 2.0%. The latter assumes that failure of the wall will not occur before 2.0%; if failure is attained after 2.0%, no further twists will be applied not to influence the response of the wall in flexure. Each twist will be applied in both directions (i.e., clockwise, and counterclockwise) and then returned to the original values prior to the twist. During each applied twist, the vertical actuator forces will be kept with their values before twisting. More information on the loading protocol and the forces/displacements used can be found in the LoadingProtocolUW1.xlsx document.

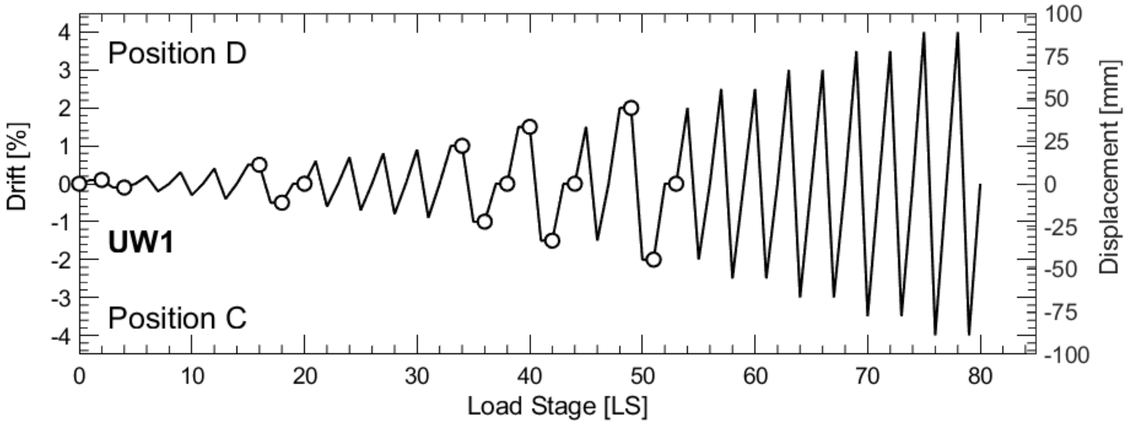

Figure 5 Loading protocol for specimen UW1, under pure flexure. The circles indicate the load stages (LS) where the small twists, to determine the torsional stiffness, will be applied to the wall.

5b. Specimen UW2, Pure Torque

The displacement-controlled reverse-cyclic quasi-static loading protocol in Figure 6 will be used to test specimen UW2 under pure torsion. The incremental loading parameter was chosen to be the imposed wall rotation at the top (θ). The experimentally derived rotation (θ_{exp}) is explained in the next section. It is worth emphasising that the rotation is derived from displacements by the wall, not from the stroke displacements of the actuators connected to the rigid beam (see Figure 5a). The loading history for UW2 is described below:

- Between rotations of 0 mrad* and 20 mrad: one-cycle at each rotation level, increments of 2.5 mrad
- Between rotation of 20 mrad and 30 mrad: two-cycles at each rotation level, increments of 5.0 mrad
- For rotations larger than 30 mrad: two-cycles at each rotation level, increments of 10 mrad

*mrad = milliradian =radians x10^3

As indicated in Figure 6, a small flexural push will be applied to unit UW2 at salient rotation levels and at position O, as well as the positive and negative (i.e., the clockwise and counterclockwise, respectively) twist positions. The applied push is small enough to ensure that it does not contribute or influence the overall torsional behaviour and corresponding failure mode observed. The first series of pushes will be force-controlled with a total of 20kN in each direction (i.e., positions D and C, Figure 4b). The other series of pushes, for rotations equal to or greater than 10 mrad, will be displacement controlled. A push will be applied to the wall at the following rotation levels: 0 mrad, 10 mrad, 20 mrad, 30 mrad. It is assumed that the failure of the wall will not occur before a rotation of 30 mrad; if failure is attained after 30 mrad, no further push will be applied not to influence the response of the wall in torsion. Each push will be applied in both directions (i.e., positions D and C, Figure 4b) and returned to the original position of the wall prior to the push. During each applied twist, the vertical actuator forces will be kept with their values before twisting, which (for this wall) is equivalent to the applied axial loads. More information on the loading protocol and the forces/displacements used can be found in the LoadingProtocolUW2.xlsx document.

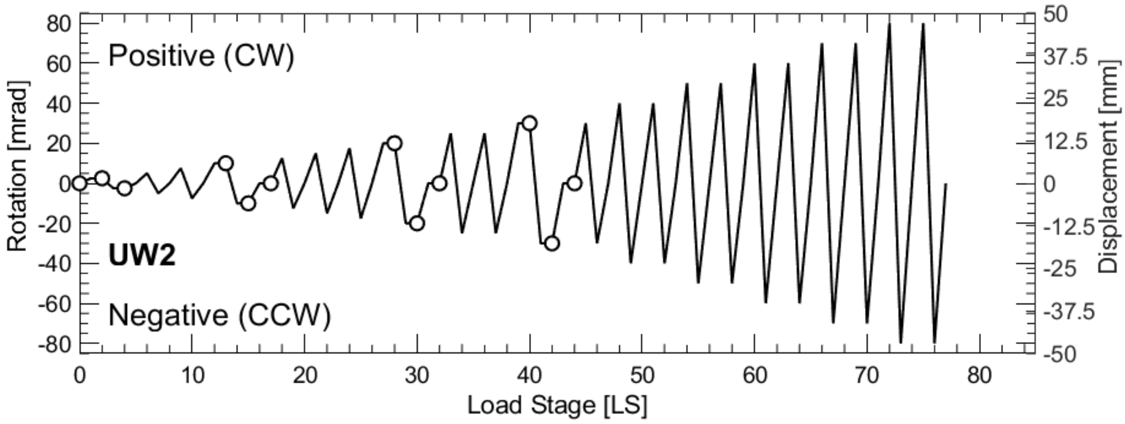

Figure 6 Loading protocol for specimen UW2, under pure torsion. The circles indicate the load stages (LS) where the small push, to determine the translational stiffness, will be applied to the wall.

6. Instrumentation

6a. Conventional Instrumentation

The top displacements of the two wall flanges, Δ_1 and Δ_2, will be measured along the North-South direction by a pair of potentiometers (i.e., string pots), each connected to the South extremity of the top wall collar. These string pots are connected at the same height of the imposed horizontal loads (=2250mm) from the wall base, and are represented in Figure 2b. For the specimen UW1, the imposed displacement Δ corresponds to the average of the two string pots, Δ_1 and Δ_2. For specimen UW2, the rotation of the wall will be calculated as such:

$$\theta_{exp} \approx \frac{\Delta_1 - \Delta_2}{1.2} \qquad (3)$$

where Δ_1 and Δ_2 (in mm) correspond to the displacement recorded by string pot 1 and 2 respectively, and 1.2 on the denominator is the lever arm distance (in m) between the two flanges (center-to-center); the resulting θ_{exp} is in milliradian.

6b. Digital Image Correlation

A speckle pattern for digital image correlation (DIC) measurements is applied on two outside surfaces of the wall (web and East flange) covering the full height of the wall from the base up to 2 meters high. The speckle pattern is applied by randomly painting a pattern to produce black dots with an approximate diameter between 3-5 mm. Two sets of two-camera systems are used, depicted in Figure 7, each set capturing the three-dimensional displacement field of the surfaces of the wall. The cameras recorded black and white photographs to decrease file size and simultaneously have an increased capacity for sensor dimensions, resulting in high resolution images. The images will be processed using Instra4D (V4.6) from Dantec Dynamics, where the displacement and strain fields for the perimeter of the wall (i.e., web and east flange) are computed. The speckle pattern on the East flange and web of unit UW1 is shown in Figure 8.

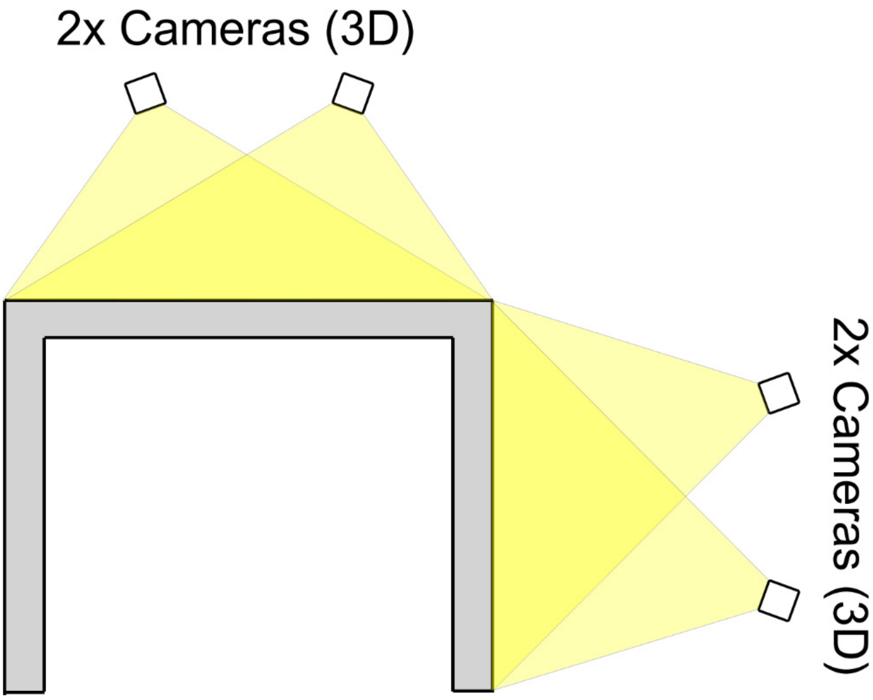

Figure 7 Setup and locations of the cameras for digital image correlation techniques

Figure 8 Speckle pattern on the East flange and Web of UW1 at LS0 (i.e., prior to loading)

6c. Optical Fibers

State-of-the-art high-definition fibre optic sensing is used to accurately determine the strains of some of the reinforcing bars (Figure 9). A LUNA optical distributed sensor interrogator 4-channel ODiSI 6000 Series system is used to compile the data. High resolution (≈0.65mm) measurements of strain along the sensor fiber are recorded throughout the testing of unit UW1 and UW2 at an acquisition frequency of ≈3 Hz. Importantly, eight longitudinal reinforcing bars, as indicated in Figure 2a, had optical fibers glued to derive the strain profiles up the height of the wall. A current limitation of this technology, in practice, appears to be a maximum allowable strain of 1.0−1.5% being recorded by the system. Thus, while the strains from the fiber optics will be recorded through the entire test, resolution will be likely lost in the plastic regions of the wall with strains greater than 1.0%. The fiber used was polyimide coated sensing fiber housed in polytetrafluoroethylene tubing. After some initial trials, a general-purpose adhesive ("Loctite 401", cyanoacrylate technology) was used to glue the fiber to the bar, along within a previously cut 1mm slit. An epoxy ("ESK-50") was used to provide a coating of protection between the glued fiber and the concrete.

Figure 9 Close-up of the 12mm reinforcing bar with optical fiber attached

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