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TESTS ON SPECIAL ANCHORS FOR MASONRY INFILLS WITH SPECIAL OPPORTUNITY FOR SEISMIC RETROFITTING

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Abstract

Reinforced concrete frame structures are treated as moment resisting frames, with different design options. The bearing capacity of such frames can be significantly increased by masonry infill walls that act as shear walls.

The greatest supporting effect of the wall on the frame is expected in in-plane (IP) direction. The IP loads are introduced into the wall as compressive forces, whereas the Out-of-plane (OoP) loads generate shear forces at the joints between the frame and infill. IP loads can be transferred very well through mortared joints, while additional securing is recommended for OoP direction. Particularly in case of earthquakes, infills must withstand OoP loads to prevent failure, which can endanger people and block escape routes. It should also be possible to quickly refurbish the structure so that it can withstand subsequent impacts.

A good opportunity to improve the OoP performance is to place special ties in the joints between the frame and infill. The action on these ties can be determined from the load carrying capacity and deformation behaviour of the frame structure or by calculation according to EN 1998 or similar.

As the intended anchors are to connect a concrete element to a masonry wall, a system is proposed that consists of an anchor channel cast in concrete into which special masonry anchors engage. This system has the advantage that it is easy to install and can be reinstalled very simply in the event of renovation or damage. This fastening system can also be post-installed in the event of seismic retrofitting.

These fixings have a decisive influence on the interaction between the RC frame and the infill and require a proper design, best to be achieved by tests in different scales.

In this paper, the technical background is explained, and the various experimental results are illustrated and compared.

Keywords: Seismic repair, masonry infill, special fixings, non structural elements.

1. Introduction

Reinforced Concrete (RC) frames with masonry infill walls are widely utilized as an external wall construction system. Under seismic loading, these structures are subjected to forces in both the in-plane (IP) and out-of-plane (OoP) directions. In the IP direction, the masonry infill—if not physically separated from the RC frame—enhances its load-bearing capacity, allowing it to be treated as a structural component. In contrast, OoP forces induce shear stresses at the interface, with the infill often behaving as a non-structural element.

The distinction between structural and non-structural members, as well as corresponding design standards, is critical and has been extensively discussed in the literature (e.g., [1]). Failure of the masonry infill during seismic events, such as falling bricks, poses significant risks to life safety and evacuation. Additionally, such failures adversely affect the IP load-bearing capacity of the structure, increasing deformation demands.

Enhancing the interaction between the RC frame and the infill can mitigate these risks. The incorporation of wall anchors at the frame-infill interface has been shown to improve the overall performance, reducing the likelihood of interface failures and ensuring effective load transfer under varying load directions.

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Traditional unreinforced mortar joints often fail to accommodate large relative displacements induced by seismic loads, necessitating the development of robust anchoring systems. The primary forces on these anchors stem from the relative deformations between the RC frame and the masonry infill, making analytical predictions challenging. Experimental testing provides a more reliable means of evaluating these systems.

This paper explores the behavior of masonry infills in RC frames with specialized anchoring systems, with an emphasis on their performance under IP and OoP seismic loads. The tests are carried out at different scales. This method proved to be particularly effective for obtaining reliable results in a reasonable amount of time and effort [2]. Micro- and macro-scale tests evaluate the effectiveness of these anchors acc. to [3] in improving structural resilience.

2. Micro-scale tests on wall anchors

2.1.Scope

Seismic events often cause RC frame systems with masonry infill walls to fail in the OoP direction due to separation at the mortar joint between the frame and the infill. To improve joint performance, wall ties can be incorporated. This study evaluates the load-bearing behavior of these ties.

2.2.Anchor system for pre-installation

The anchor system analysed here consists of flat anchors placed in the infill wall and a cast-in anchor channel to transfer the connection load into the concrete frame.

The anchor channels consist of a C-shaped channel profile fitted with head bolts. These anchor channels are designed to be inserted into the formwork and cast into the concrete.

Once the concrete frame has been constructed, the infill is masoned in place, with the flat anchors interlocking with the rail profiles to ensure a firm connection between the infill and the concrete, see Figure 1.

Figure 1. a) cast-in anchor channel; b) flat anchor interlocking with the channel.

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Figure 2. a) tested wall anchors; b) anchors installed in the joint of a brick pair.

Micro-scale tests were conducted on individual anchors to determine their horizontal shear capacity, as per EN 846-7 [4], Figure 2. Ten masonry units, each comprising two perforated NF-standard bricks (EN 1998-2 [5]) joined by M2.5 mortar, were constructed. The anchors were embedded in the mortar joints, and the specimens were tested nine days later.

The test load was applied via shear forces on the bricks while the anchoring concrete block remained fixed. Shear forces were induced using a tension rod, as illustrated in Figure 3.

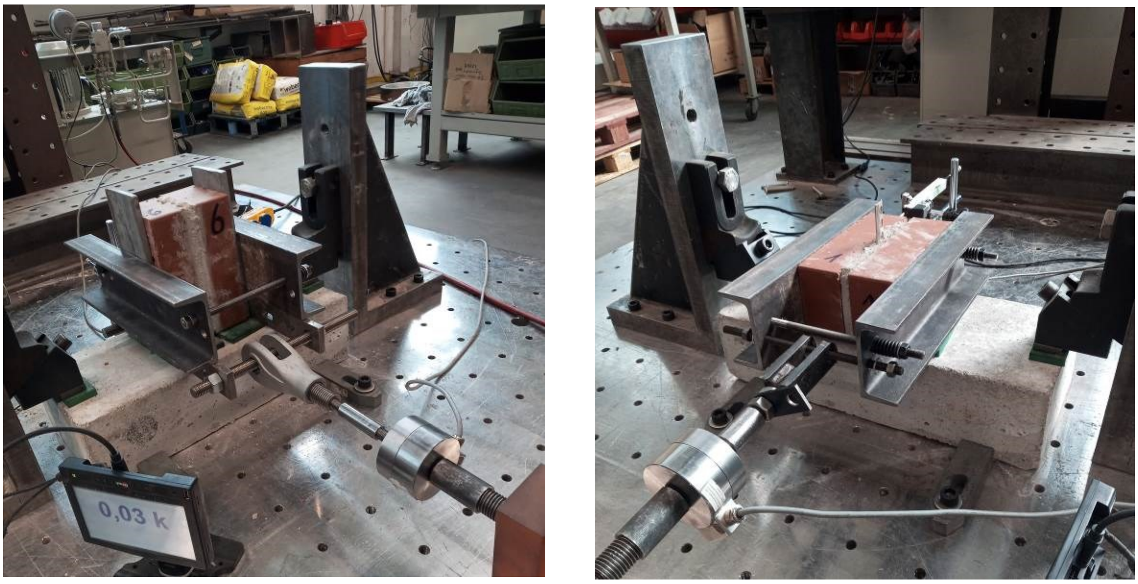

Figure 3. a and b. Test setup for testing the horizontal shear capacity of wall ties in micro scale, a: longitudinal direction of bricks, b: transverse direction of bricks.

For anchors embedded transversely, the mean maximum shear load reached approximately 2900 N, with deflections ranging between 1.50 mm and 3.77 mm. Failure predominantly occurred within the mortar joint.

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2.3. Anchor system for post installation

The fastening system is also suitable for structures that were not fitted directly with the rail system during construction. For subsequent fastening, the rails can be fixed to the concrete using dowels, see Figure 4. As before, the flat anchors are hooked into the rails during the masonry of the infill.

Figure 4. a) post installed anchor channel; b) flat anchor interlocking with the channel.

The resulting gap between the infill and the concrete frame should be grouted.

In contrast to the anchor channels set in concrete, the channel profile cannot transfer the shear force into the concrete with its flanks, but is subjected to bending in the transverse direction.

Appropriate tests - as previously carried out - provide information about the final resistance. These tests could not be carried out by the time this paper was finalised, but the results will be available by the time of the conference.

However, it is to be expected that the final resistances will be similar to those of the concreted-in system, as it is known from preliminary tests that the rails can absorb a higher load and that the failure occurs again in the mortar joint of the bricks.

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3. Macro-scale Tests

3.1. Specimens

The macro-scale specimens replicated a segment of a seven-story RC building at a 1:2.5 scale, see [6] among others. This typical RC frame structure included two-way slabs and unreinforced masonry infill walls, as shown in Figure 5.

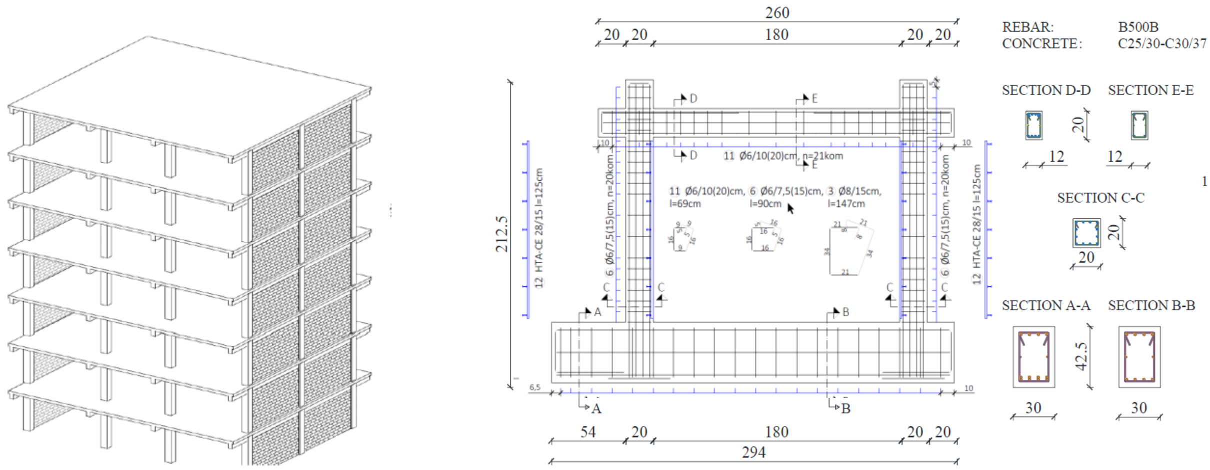
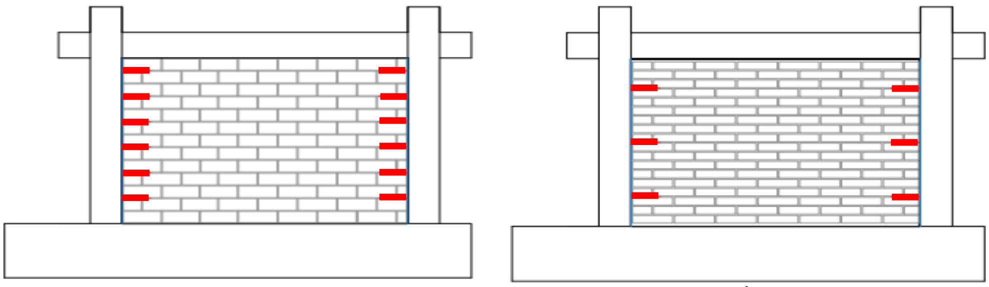


Figure 5. a and b, Representative Building with RC frames, and test frame used for macro scale tests.

Cast-in anchor channels were embedded within the RC columns, allowing anchors to interlock with the masonry joints, see Figure 6.

Figure 6. a and b, Positioning of wall tie anchors: a: clay blocks and b: clay brick masonry

The anchors are distributed like shown in Figure 7, as a result of a pre-calculation, assuming a maximum capacity of 1,5 kN in shear direction (i.e. OoP).



a b

Figure 7. a and b, Distribution of the anchors over the sides of the infill: a: clay blocks and b: clay brick masonry.

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4. Test Setup

The test configuration and procedure followed those described in [7], with the key distinction being the inclusion of wall anchors in the present study. Previous tests omitted such reinforcement at the frame-infill interface. Consequently, the current investigation emphasizes the impact of these ties, particularly on the performance of the connection between the concrete frame and the masonry infill.

4.1. Test Procedure

Out-of-Plane (OoP) Tests

Cyclic quasi-static shear tests were conducted on specimens with cavity walls constructed from hollow clay blocks and solid brick masonry. Each specimen was oriented such that the dotted side faced the ARAMIS optical sensor, enabling precise 3D strain measurement. The specimens were secured with brackets fixed to rails embedded in the reactive floor, while the tops of the columns were left free (see Figure 8).

The load was applied at the intersection of the column centerlines and the top beam using hydraulic jacks, each operated manually through independent hydraulic units. The tests were performed in a single cyclic direction.

Throughout the testing process, crack propagation was marked on the white surface of the specimens until ultimate failure occurred. For safety reasons, crack recording was halted during the final stages of the tests and resumed after specimen unloading to document the residual damage.

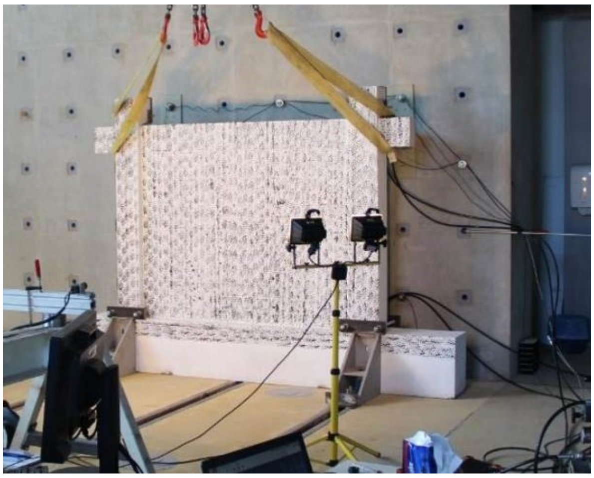

Figure 8. Test setup OoP.

The load was applied incrementally as a quasi-static pulsating cyclic force, with each step executed twice and increasing by 10 kN per increment. Loading continued until the RC frame began yielding, as shown in Figure 9. All deformations were recorded using the ARAMIS optical system. The specimens endured jack displacements up to 140 mm, corresponding to an inter-story drift ratio of approximately 10%. Throughout the tests, the specimens remained stable, and no significant operational issues arose.

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a b c

Figure 9. a, b and c: Load and deflection OoP, a: begin of test, b: medium load level with first cracks in the concrete, c: yielding of the frame.

In-Plane (IP) Tests

The IP tests were conducted on the same infill specimens (hollow clay and solid brick masonry), oriented with the dotted side facing ARAMIS for 3D strain tracking. The specimens were mounted within a reactive frame secured to a reactive slab and wall (see Figure 10). A specialized hood with roller supports was installed atop the columns to allow IP translations.

Vertical gravitational loads of 365 kN were applied to each column using a hydraulic press, maintained manually throughout the tests. This vertical force was combined with lateral loads applied at the ends of the top beam via hydraulic jacks, inducing alternating compression and unloading in the two columns.

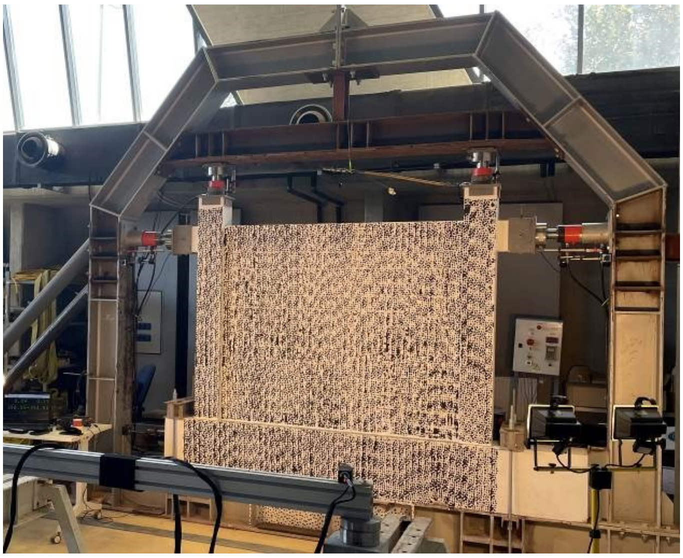

Figure 10. Test setup IP.

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Push-Out Tests

Following each OoP test, push-out tests were performed to evaluate the residual shear capacity of the wall anchors. Load distribution was achieved through steel beams to concentrate forces on the joint interface.

5. Test Results

5.1. Out-of-Plane Tests

The OoP tests aimed to demonstrate the anchoring system's ability to restrain the infill wall under OoP loading while maintaining neutral or positive effects on IP load performance.

Displacement measurements from ARAMIS revealed minimal relative deformation at the column-infill joints (Figure 11). Crack patterns on the tension side (Figure 12) exhibited pronounced horizontal fractures in both concrete and masonry, with negligible vertical cracking, particularly in the joint areas. This suggests that the anchors effectively absorbed loads and maintained structural integrity.

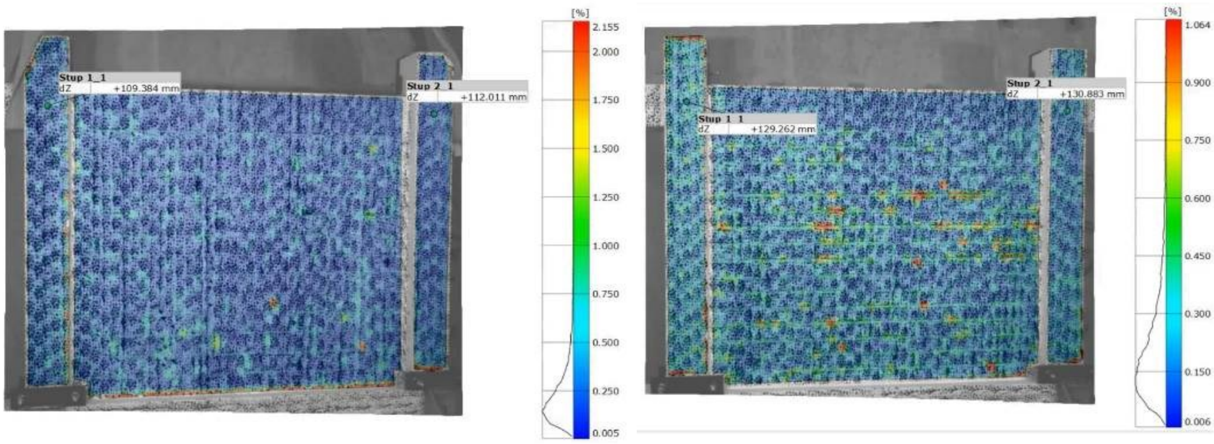

Figure 11. Displacements after OoP tests, a: block masonry, b: brick masonry.

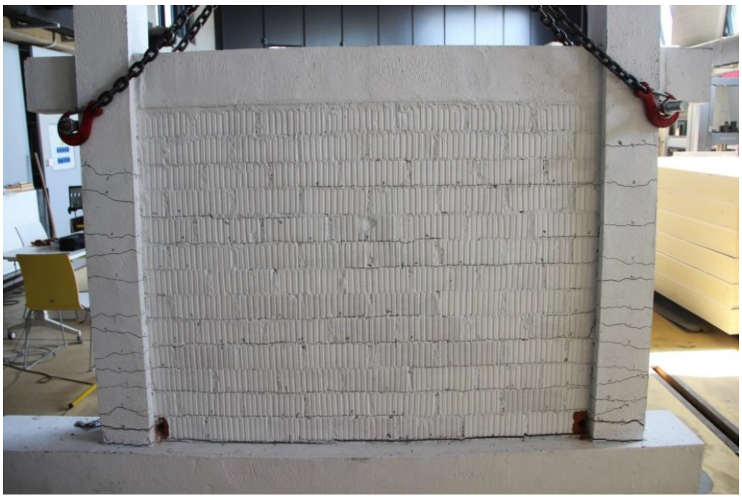

Figure 12. Crack pattern OoP.

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5.2. In-Plane Tests

The IP tests exhibited typical load transfer behavior, with compression forces acting on the infill joints at the applied load side. Shear deformation induced horizontal cracking within the masonry joints, consistent with standard unreinforced masonry failure modes. Figure 13 illustrates displacement profiles, while Figure 14 highlights final crack patterns.

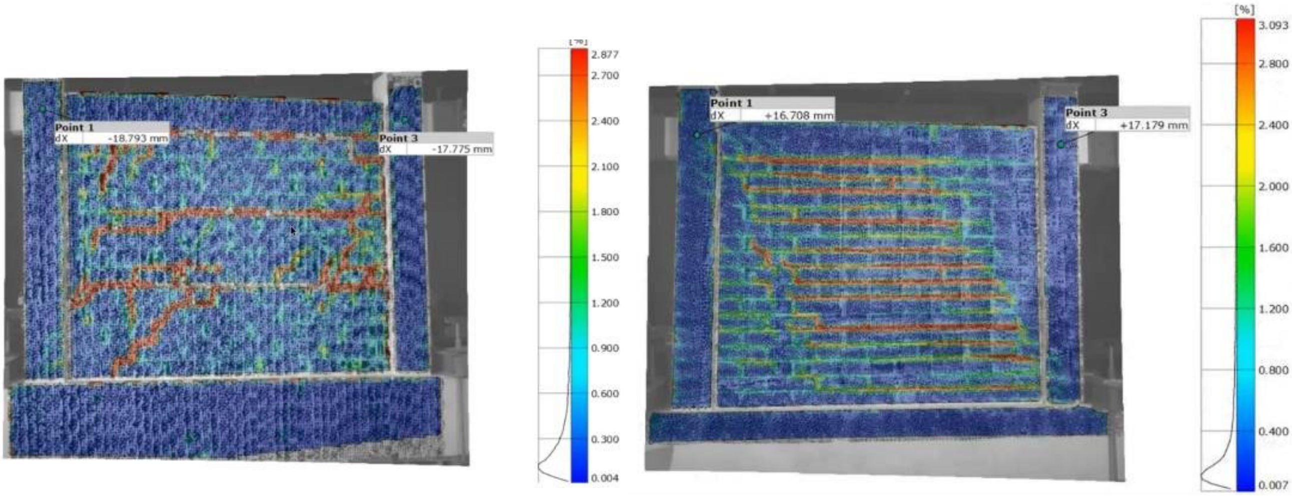

Figure 13. Displacements after IP tests, a: block masonry, b: brick masonry.

Also in these tests, no relative displacements could be observed in the vertical joints between concrete and masonry. Figure 14 shows the final crack pattern with typical IP (shear) cracks occurring on masonry infills.

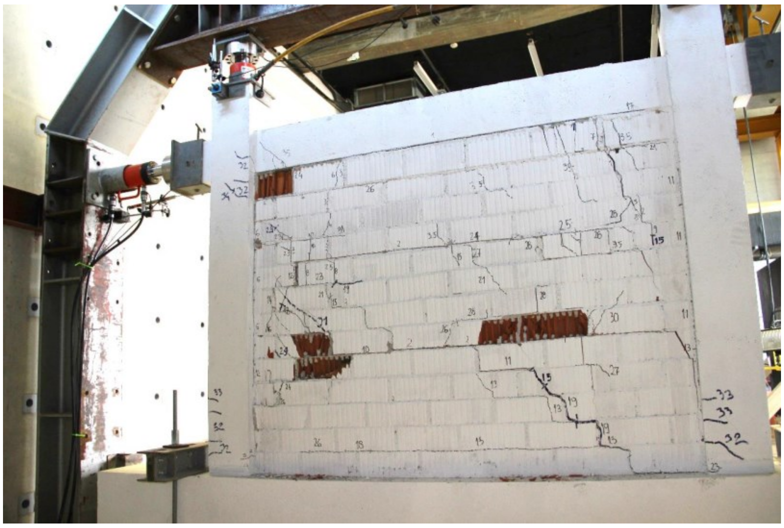

Figure 14. Final crack pattern, IP tests.

Finally, the joints were opened for anchor inspection. It could be observed that neither the anchors nor the channel section in the columns showed significant cracking or deformation during all IP tests.

No relative displacements were observed in the vertical joints between the RC frame and masonry. Post-test inspection revealed no damage to either the anchors or channel sections in the columns (Figure 15).

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Figure 15. Final inspection of the anchors after removing bricks.

5.3. Push out tests.

After each OoP test, a push test was performed on each specimen. These tests were intended to test whether the previous loading has an influence on the horizontal shear capacity of the anchors, the focus here being on the reinforced joint and not on the infill itself. Therefore - instead of the in this case usual airbag test, in which the load is applied to the masonry via inflatable cushions - the load was applied linearly near the joints, see Figure 16. The load was applied with a hydraulic jack, distributed through steel beams so that it was introduced linearly near the column/masonry joint. As before, in the IP and OoP tests no influence of cracking on the vertical joint was observed, the push tests also showed no reduction in the shear strength of the anchors.

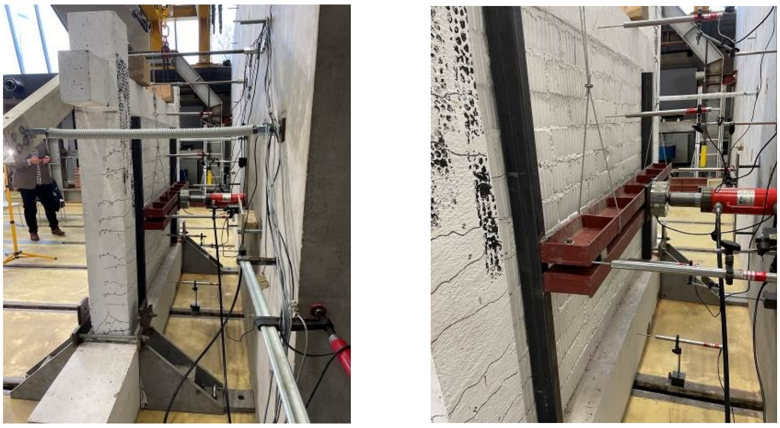

Figure 16. Test setup Push Out.

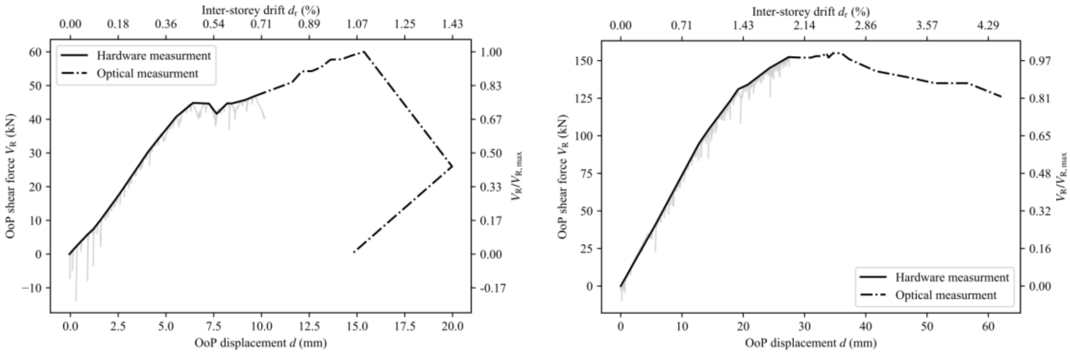

Figure 17. Final load/displacements at Push-Out test.

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6. Summary

This study presents experimental evaluations of masonry infills secured with specialized anchors within RC frames, focusing on seismic load resistance. Tests were performed on masonry infills, placed in reinforced concrete frames, where the joints are secured by flat wall ties to improve the seismic resistance of such a construction. A description of the displacement tests in the IP and OoP directions is presented. For the IP and OoP tests, two sets of specimens with identical RC frames and different infills were used, one consisting of hollow blocks and the other of solid brick masonry.

In a first step, the fixing system, consisting of a channels profile and the flat anchors, were tested in accordance with EN 845 [3] and EN 846 [4] in order to determine the characteristic horizontal shear strength in the longitudinal and transverse directions in so-called micro tests. A distinction was made in these tests between cast-in channels and post-installed channels.

Large tests in a macro scale were carried out on reinforced concrete frames fitted with masonry infills, anchored to the concrete columns with ties. To ensure anchoring, cast-in anchor channels were installed in the concrete columns of the frame, in which the anchors were interlocked and embedded in the masonry joints.

Key findings include:

1. **Micro-scale tests** demonstrated the anchors' substantial horizontal shear capacity.
2. **Macro-scale OoP tests** showed that the anchors maintained the stability of the joint, with no or minimal relative deformation observed.
3. **Post-OoP push-out tests** confirmed that anchors retained full shear capacity, ensuring the system's resilience.

The results emphasise the usefulness of such anchoring systems when using RC frame infill assemblies in cohesive composite structures. It does not necessarily make a difference whether the infill participates in the load-bearing effect of the frame structure, as a shearwall and thus represents a structural element, or whether it is a partition wall without load-bearing effect, i.e. a non-structural element. The anchor system shown - consisting of a rail attached to the concrete and flat anchors that interlock with this rail - can be installed both during the construction of the concrete structure (cast-in) and subsequently (post-installed), e.g. as part of seismic retrofitting.

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