
Simplified site proof testing method for hybrid screw anchors installed in masonry

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ABSTRACT

An increasing use of hybrid anchors, combining mechanical screw anchors with epoxy, has been observed in structural applications. Site quality assurance and proof testing of post-installed anchors typically requires direct tension pull-out testing, a well-established but time-consuming procedure that often requires extensive equipment and heavy setup. While this approach is routinely applied to mechanical screw anchors, it is impractical for hybrid anchors, as tension testing requires partial withdrawal of the anchor to allow attachment to the loading device, which is not feasible once the epoxy is bonded.

This study investigates the potential of torque testing as an alternative simplified proof test method to determine the tension capacity of post-installed hybrid and mechanical anchors. A comprehensive testing program was undertaken where anchors were installed in a range of different types of masonry and concrete substrates. Two anchor types were used, hybrid and mechanical screw anchors. A total of 354 tests were performed, 174 in tension and 180 in torque, across embedment depths ranging from 25 mm to 100 mm.

Analysis of the results showed a consistent correlation between torque and tension capacities for both anchor types. Based on these results, a relationship was established and it was demonstrated that the torque test methodology provides an in-situ, quick, simple and minimally invasive proof testing method for hybrid and mechanical anchors with potential applications in seismic assessments, seismic retrofit quality assurance and structural post-earthquake inspections. These correlations were established for an Ø8 mm anchor with a specific thread geometry. An increase in capacity of hybrid anchors compared to mechanical anchors was observed, with greater improvement as the compressive strength of the substrate decreased.

1 INTRODUCTION

Mechanical and adhesive anchors are two of the most common post-installed anchor types used in the construction industry, each with its own load-transfer mechanism. Screw anchors, which belong to the mechanical category, rely on mechanical connection between threads and the substrate to transfer the loads, while adhesive anchors transfer loads through a chemical bonds. An additional anchoring solution increasingly observed in structural applications is the hybrid anchor, which combines a mechanical screw anchor and epoxy with the intent of improving performance beyond either mechanical or adhesive anchors. Hybrid anchors can be particularly useful when additional anchor capacity is required, as in the cases reported by González et al. (2018); Galvez et al. (2024).

Hybrid anchors have received limited attention in the academic literature, despite being regularly used in engineering practice and having dedicated assessment guidelines (EAD 332795-00-0601, 2020). Within these guidelines, the anchor capacity testing is performed using direct tension pull-out testing (Giresini et al., 2020; Porcarelli et al., 2021; Ramirez et al., 2023), which is a well-established method for assessing the capacity of post-installed anchors and is also standard practise for quality control proof testing (ACI 355.2-07, 2007; Alhaidary & Al-Tamimi, 2021). Such testing approach requires for part of the mechanical anchor to be left unscrewed to insert a claw into the anchor head and apply the tensile loading (see Figure 1). However, in the case of hybrid anchors the injected epoxy fixes the final position of the anchor head, making it impossible to leave part of the shaft unscrewed for proof testing. Additionally, direct tension testing is time-consuming and expensive as it often requires heavy and specialist testing equipment (see Figure 1 for example).



Figure 1: Example of tensile test setup

Given these limitations, alternative approaches have been investigated, such as non-destructive testing methods (Saleem et al., 2015). Torque testing has also been minimally explored to assess anchor capacity (ETAG 001, 2013; AC01 ICC-ES, 2020). In contrast, extensive research has been conducted on the torque method as an installation technique, focusing on the impact of the applied torque into the tensile performance (Küenzlen & Eligehausen, 2002; Liu et al., 2025).

This study therefore investigates the potential of torque testing as a suitable proof-testing method for hybrid anchors that is also applicable to mechanical screw anchors, providing an in-situ, minimally invasive, and non-destructive proof-testing method. To achieve this, an experimental programme was conducted using both mechanical screw anchors and hybrid anchors tested in both tension and torque to establish a relationship between torque capacity and tensile capacity. Anchors were installed with embedment depths ranging from 25 mm to 100 mm into Autoclaved Aerated Concrete (AAC), 1:2:9 (cement:lime:sand by

volume) lime mortar, limestone, medium-strength heritage clay brick, clay pavers, and concrete with compressive strengths of 18 MPa and 30 MPa.

2 EXPERIMENTAL STUDY

A total of 354 Ø8 mm anchors were tested for comparative performance, 174 in tension and 180 in torque. Approximately 60% of the anchors were hybrid anchors and 40% mechanical screw anchors (see Table 1). The anchor pilot holes were drilled into the substrates using a rotary-only drill for mortar, brick and limestone to minimise microcracking and blowout in the substrate (Galvez et al., 2024), while hammer action drilling was used for drilling into concrete. Hybrid anchor pilot holes were also vacuum-cleaned to remove any residual dust prior to epoxy being applied. The anchors were then installed with embedment depths of 25 mm, 50 mm, 75 mm, and 100 mm. Hybrid anchors were left to cure for a minimum of 12 hours before testing (see Table 1). The two-part epoxy resin used had a compressive strength of 82 MPa and a tensile strength of 70 MPa specified by the manufacturer.

Testing was conducted on a range of materials commonly found in the built environment such as AAC, lime mortar (1:2:9 (cement:lime:sand)), limestone, heritage clay brick masonry, clay pavers, and concrete with two different compressive strengths. Between 6 and 9 tests were performed in each material. The compressive strength of tested materials is reported in Table 1.

Table 1: Material compressive strength and anchor embedment depths

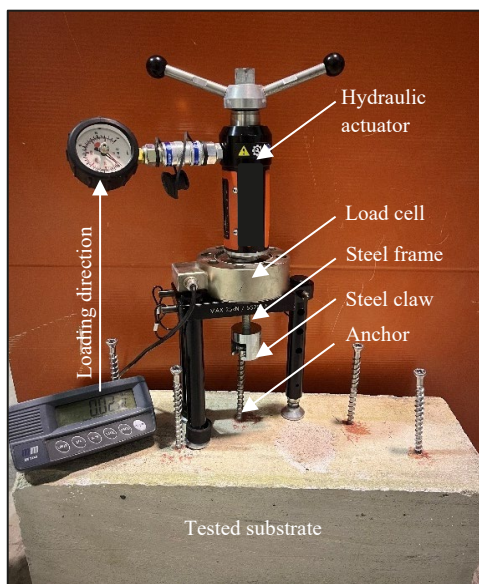
Material	Compressive Strength (CoV) [MPa]	Embedment depths [mm]
Autoclave aerated concrete (AAC)	2.5 (24%)	25, 50, 75, 100
Lime mortar (1:2:9)	4.5 (6%)	25, 50
Limestone	8.4 (31%)	25, 50, 75, 100
Clay pavers	14.2 (12%)	25
Concrete (C18)	17.7 (18%)	25, 50
Heritage clay brick	18.0 (41%)	25, 50
Concrete (C30)	29.3 (6%)	25

2.1 Testing Setup

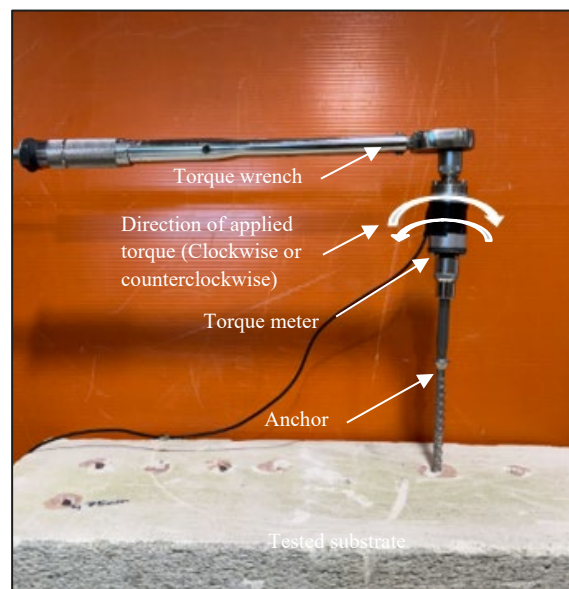
Tension pull-out tests were performed following the principles of ASTM E488-96 (2003), NZS3101.1 (2006) and EAD 332795-00-0601 (2020) using a hydraulic actuator connected to the anchor with a threaded rod and a steel claw. Anchors were monotonically pulled by progressively increasing the load until a reduction in load capacity was observed, indicating failure of the anchor. Force measurements were registered by a calibrated digital load cell (see Figure 2a). A clear span equal to three times the embedment depth was maintained between the legs of the reaction frame to prevent any interference with the failure modes, and an edge distance of 1.5 times the embedment depth was adopted.

To the knowledge of the authors, there are no standards for performing torque testing to predict tension capacity as part of site testing procedures. The closest guidance is provided by AC01 ICC-ES (2020) and

Annex A of ETAG 001 (2013), which suggest optional verification procedures for determining the prestress forces into an anchor when a setting torque is prescribed by the manufacturer. The procedures and principles outlined in these documents formed a starting point to develop the testing methodology adopted in this study. The torque was applied to the anchors using a manual torque wrench and was progressively increased until a reduction in load capacity was observed, indicating failure of the anchor. The data was continuously recorded with a digital torquemeter attached to the torque wrench (see Figure 2b). Mechanical screw anchors were installed until the tip of the anchor reached the base of the drilled hole and were then torqued in the clockwise direction. The applied rotation causes crushing of the substrate material between the threads, which determines the failure resistance. In contrast, in the case of the hybrid anchors containing epoxy the counterclockwise direction (unwinding) was chosen and maintained throughout the tests.



(a) Tension



(b) Torque

Figure 2: Test setups

3 RESULTS

A summary of the experimental results is shown in Table 2, with the ultimate capacities of the tension and torque tests for both mechanical screw and hybrid anchors, including the corresponding coefficient of variation (CoV), embedment depths and the substrate material. The three governing failure modes observed in tension testing were cone failure, splitting of the substrate and a combination of cone and pull-out failure (see Figure 3a,b,c). The three predominant failure modes in torque testing were: (i) steel shank failure of the anchor, (ii) bond failure of hybrid anchors, characterised by the failure of the bond between the epoxy and the surrounding substrate material, and (iii) thread bearing failure, in which the threads of the mechanical screw anchors bear against the substrate and crush the material in the pilot hole between the threads (see Figure 3d,e,f). The results of torque and tension tests for both anchor types were plotted in Figure 4, where the trendlines were fitted to describe the relationship between tension and torque testing. The results indicate a positive linear correlation between the tension and torque capacities for both hybrid ($Tension = (Torque - 14.5)/3.6$ with an $R^2 = 0.89$) and mechanical anchors ($Tension = (Torque - 5.7)/7.9$ with an $R^2 = 0.86$).

Table 2: Results of tension and torque testing

Material	Embedment [mm]	Average max Tension force [kN] (CoV)		Average max Torque force [Nm] (CoV)	
		Hybrid	Mechanical	Hybrid	Mechanical
Autoclave aerated concrete (AAC)	25	1.2 (21%)	0.4 (11%)	12.5 (10%)	6.2 (11%)
	50	2.9 (1%)	1.4 (16%)	25.3 (7%)	11.5 (11%)
	75	4.4 (7%)	-	36.9 (3%)	-
	100	6.8 (4%)	3.1 (3%)	48.5 (5%)	18.1 (14%)
Lime mortar (1:2:9)	25	2.0 (7%)	0.8 (17%)	21.2 (12%)	15.8 (22%)
	50	7.5 (6%)	-	43.4 (5%)	-
Limestone	25	2.3 (22%)	1.3 (19%)	14.5 (34%)	21.3 (10%)
	50	6.0 (6%)	2.9 (10%)	33.1 (20%)	41.9 (15%)
	75	11.0 (6%)	-	54.4 (10%)	-
	100	14.5 (7%)	9.4 (9%)	70.8 (21%)	71.8 (5%)
Clay pavers	25	8.7 (6%)	3.1 (18%)	35.4 (30%)	42.5 (15%)
Heritage clay brick	25	4.0 (28%)	2.3 (11%)	30.4 (13%)	21.6 (25%)
	50	9.8 (49%)	6.4 (26%)	50.4 (32%)	56.4 (35%)
Concrete (C18)	25	8.4 (12%)	4.8 (19%)	45.4 (34%)	73.2 (8%)
	50	24.5 (11%)	-	77.6 (10%)	-
Concrete (C30)	25	10.9 (18%)	6.5 (15%)	47.7 (32%)	77.1 (8%)



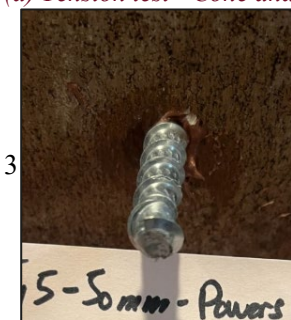
(a) Tension test - Cone and pull-out failure



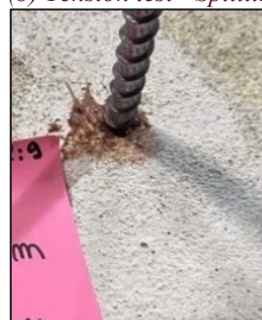
(b) Tension test - Splitting of specimen



(c) Tension test - Cone failure



(d) Torque test - Steel failure



(e) Torque test - Bond failure



(f) Torque test - Threads bearing failure

Figure 3: Failure modes

The compressive strength of heritage clay bricks varied significantly from brick to brick (see CoV in Table 1), consequently, each pair of tension and torque tests were conducted on a single brick and presented as individual data points rather than an average across multiple bricks for the comparative plot in Figure 4. Torque test that resulted in steel shank failure (average torque of 75 Nm with CoV of 10%) were excluded from the correlation analysis, as these results do not reflect the performance of the substrate material or the epoxy bond. This exclusion effectively limits the correlation to tension capacities of up to 10 kN for mechanical screw anchors and 15 kN for hybrid anchors. In addition, torque tests of mechanical screw anchors installed in substrates with large aggregates, such as concrete, resulted in high readings likely due to the anchor thread engaging directly with high strength stone aggregates within the pilot hole. These results were therefore also removed from the correlation.

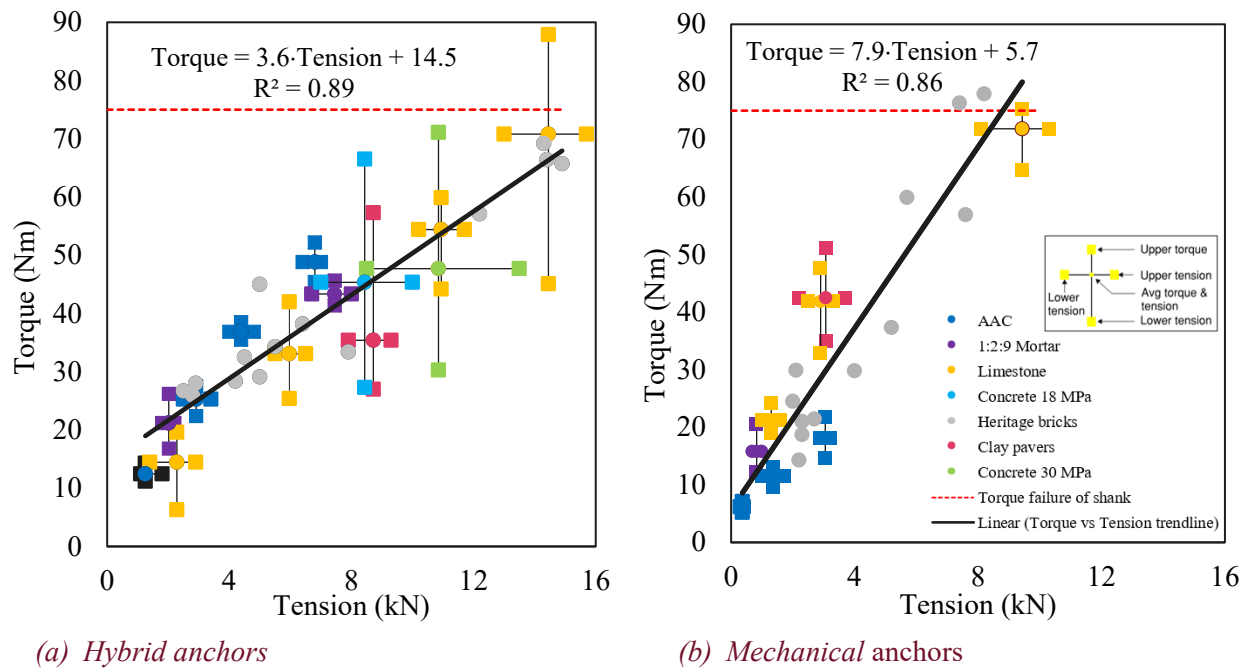


Figure 4. Torque vs tension capacities showing data spread with upper and lower values of individual tests

The results for hybrid anchors tension capacity were found to be an average of 2.0 higher than those for mechanical screw anchors, with a maximum increment of 3.4 and a minimum of 1.5 (see Figure 5). These results were analysed as a function of substrate compressive strength (σ_c) using the ratio between hybrid (N_h) and mechanical screw (N_m) anchor capacities as a measure of performance improvement. The trend indicates that a power-law increment of the performance ratio with decreasing σ_c with no significant influence of embedment depth across the tested range. The power-law relationship obtained (see Figure 5) allows to estimate the tensile capacity of a hybrid anchor based on the σ_c of the substrate and tensile pull-out capacity of the mechanical screw anchor installed in the same substrate, expressed as $N_h = \frac{3 N_m}{\sigma_c^{0.2}}$. These findings indicate that hybrid anchors are particularly well suited for low strength substrates, where increased capacity per anchor is required.

Both hybrid and mechanical anchor tests performed in clay pavers used the same type of units. However, the mechanical screw anchors were tested without drying the pavers after open-air storage, resulting in a higher moisture content and, consequently, lower expected substrate strength. This difference does not affect the trendlines presented in Figure 4, as torque and tension tests were conducted under the same conditions for each anchor type. However, it does influence the comparison presented in Figure 5. Therefore, the clay paver results were excluded from the analysis.

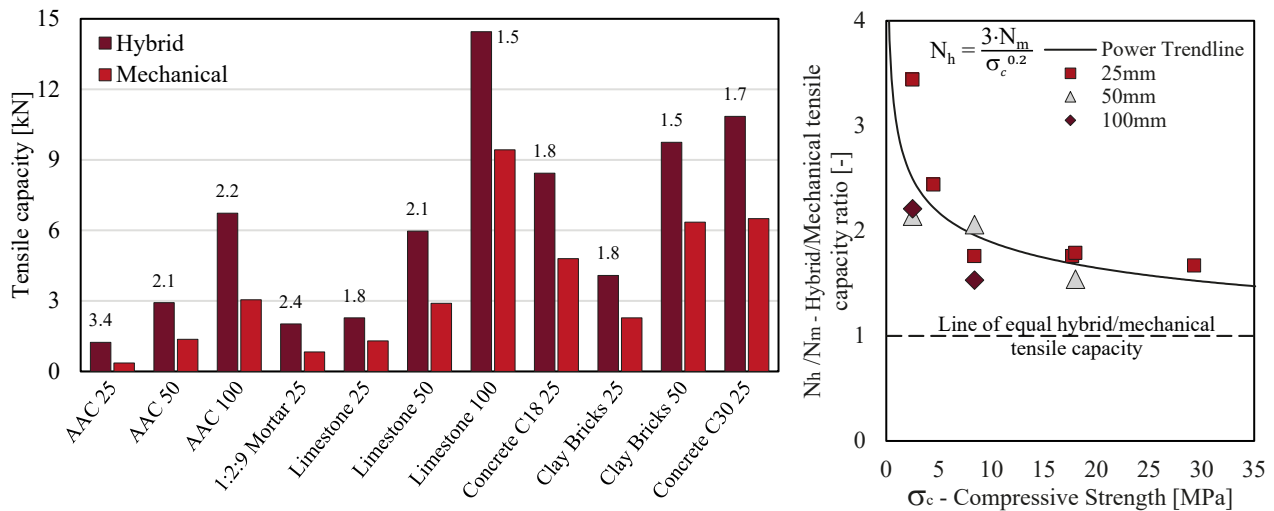


Figure 5. Tensile strength of hybrid and mechanical anchors in different material. Increment of hybrid anchors relative to mechanical anchors indicated. Embedment depth included after the material name.

4 CONCLUSIONS

This study investigated the use of torque testing as a fast and cost-effective proof testing method for hybrid adhesive-screw and mechanical anchors to verify their on-site tension capacity. The conclusions drawn herein are limited to the use of Ø8 mm anchors with a specific thread geometry.

A total of 354 anchor tests were conducted to establish the correlation between tensile and torque capacities for both hybrid and mechanical anchors, situating the results within the context of the currently dominant direct tension testing. A strong positive linear correlation was obtained for both mechanical screw anchors ($\text{Tension} = (\text{Torque} - 5.7)/7.9$) and hybrid anchors ($\text{Tension} = (\text{Torque} - 14.5)/3.6$) installed in masonry and concrete substrates, with embedment depths ranging from 25 mm to 100 mm. The derived relationships showed high coefficients of determination ($R^2 = 0.86$ for mechanical screw anchors and $R^2 = 0.89$ for hybrid anchors). The applicability of the reported torque to tension capacity correlations are limited by the use of mechanical screw anchors in concrete with small aggregate sizes, due to high aggregates resulting in high unreliable results. The correlations are also limited by the shank steel failure capacity in torque testing, which resulted in 14 kN for hybrid anchors and 8 kN for mechanical screw anchors. Within these limits, torque testing proved to be a reliable and minimally invasive in-situ proof-testing method that avoids several of the drawbacks associated of direct pull-out tension testing.

Hybrid anchors exhibited an improvement in tension capacity with relation to mechanical screw anchors that followed a power-law relationship, with the relationship increasing as the compressive strength of the substrate decreased. From such relationship it was possible to estimate the tensile capacity of hybrid anchors (N_h) using the compressive strength of the substrate material (σ_c) and the tensile capacity of a mechanical anchor (N_m) installed in such material based on the following relationship $N_h = \frac{3 \cdot N_m}{\sigma_c^{0.2}}$. This observation indicates that hybrid anchors provide a particularly effective solution for low-strength materials where increased capacity per anchor is required.

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