PULLOUT PERFORMANCE OF CHEMICAL ANCHOR BOLTS IN FIBRE CONCRETE

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Abstract

Very little independent research is available on whether adding fibres to the concrete will increase the ultimate stress of the anchor bolt pullout value. Previous investigations have focussed on the anchor and considered the anchor, in terms of dimensions and adhesive agents, but not specifically on the addition of synthetic or steel fibres to concrete. This paper addresses the practical aspect of anchor fixings and means of improving pull out performance, that will reduce the risk of failure for the designer and contractor or allow greater design loads.

This work has examined the pull out force required to cause cone shear failure to unreinforced structural concrete when resin anchor bolts were subject to an axial load. Anchor bolts were fixed in unreinforced plain and fibre concrete of different fibre dosage and type for comparisons to be made. The findings show that when compared to plain concrete increased loads can be transferred to the concrete with the use of fibre technology, when used to reinforce the concrete matrix. When the quantity of steel fibres was increased there was a corresponding increase in the pullout values of the bolts.

Bond, shear and anchorage length are well understood with rebar in concrete, however chemical anchor bolts rely heavily on manufacturers data and this study provides an independent assessment of pull out values in various fibre concrete types based upon concrete shear failure of the concrete.

Key words: Resin anchor bolts, concrete, steel and synthetic fibres, pull out.

1. Introduction

The most important point to be considered when an anchor bolt is used in concrete is its pullout strength (Soparat and Nanakor, 2008). Many engineers and researchers have

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focused on investigating pullout behaviour of anchor bolts in plain concrete while little literature exists on the behaviour of anchor bolts in fibre concrete. This work will investigate the performance of anchor bolts when fibre is included in the concrete design mix.

When suspended bolt fixings are used to support loads on concrete soffits, they rely largely on the tensile strength of the unreinforced concrete between the reinforcing bar to transmit and sustain the load. This is due to the fact that reinforced concrete has areas between the reinforcing bar that is essentially plain unreinforced concrete which has a limited capacity to transfer tensile forces.

According to Novidis, and Pantazopoulou (2008) the bond strength between bolt and concrete is mainly controlled by the surface characteristics and the rod stiffness. Failure occurs within the contact surface between the bolt and surrounding filler. It is widely known that concrete performs well under compression but has a low tensile strength. The main resistance that the anchor bolt relies upon is the concrete's tensile strength.

1.1 Fracture process zone

Figure 1, illustrates the predicted shear angle of cone pull out in plain concrete (Mosley et al, 2007), highlighting the failure plane. Braenblat (1959 and 1962) termed this plane the fracture process zone (FPZ) which is defined as the zone in which the material undergoes softening damage (tearing). The FPZ in concrete is quite small and the plastic flow is next to non existent, therefore the non linear zone is filled almost entirely with FPZ (Bažant, 2002). The tensile strength of the concrete will have the most significant effect on the pull out force required to remove an anchor bolt that has been fixed into the concrete.

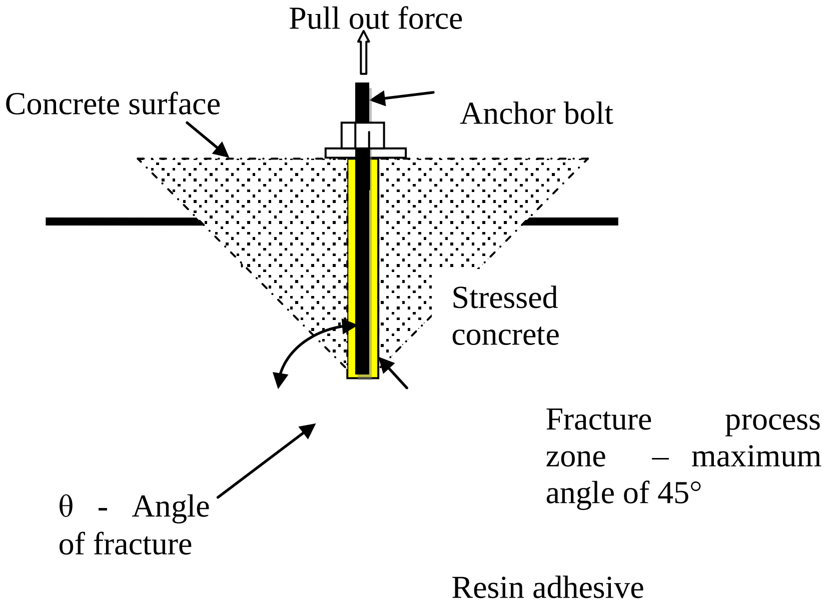

Figure 1 – Predicted angle of shear

The situation shown in Figure 2, shows a reinforcing bar lying within the tensile stress zone, the additional reinforcement resists pullout by providing a key between the stress zone and the unstressed concrete. Ultimate failure only occurs here once the bar has sheared away from the concrete in which it is embedded (Mosley et al. 2007).

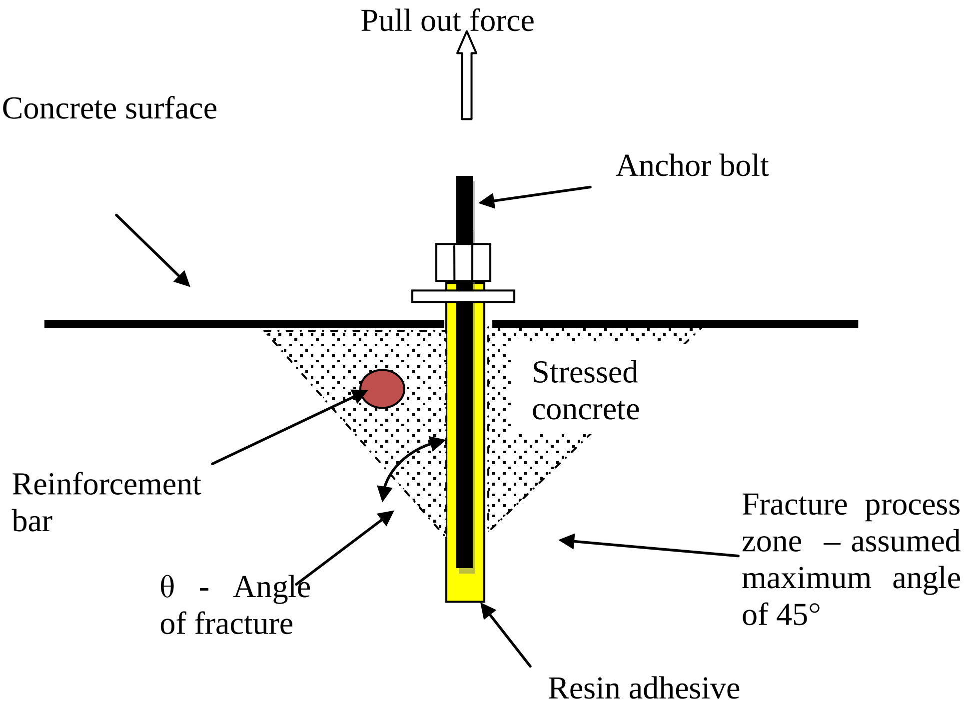

Fig 2. The force interaction of anchor bolts in reinforced concrete

According to Bentur, and Mindess (2006, p.255) "steel fibres aligned in the direction of the tensile stress may bring about very large increases in direct tensile strength, as high as 133% for 5% by volume of smooth, straight steel fibres". This suggests that steel fibres added to concrete may interact with the anchor bolt to improve the resistance of shear/tensile forces from an applied axial load. Previous work by Richardson (2010) has also considered the performance of polypropylene fibre/concrete mixes and the intention of this paper is to address the interaction of both steel and polypropylene fibre concretes when loads are applied to an anchor bolts, embedded in these mediums.

2. Materials

2.1 Concrete

The characteristic design strength of the structural concrete used in this study was C 45 which was used to replicate a structural concrete grade that would be used on site. Hilti recommend a concrete strength of C25 to C60 with the HVU anchors as used in this test. The mix design per m^3 was CEM 11 cement 420kg, <4mm sand 940kg, < 20mm coarse aggregate 1040kg, with a water/cement ratio of 0.5.

2.2 Fibres

2.2.1 Polypropylene fibres

Propex (2010) Enduro 600 macro-synthetic fibres were selected for this research due to their ability to carry post-crack loads (Richardson et al., 2010 and Richardson 2005). The Enduro 600 is a 50mm polypropylene/polyethylene, macro-synthetic fibre with surface indentations and a cross section of 1.0 mm x 0.6mm were used at a dosage rate 5 kg/m^3. The manufacturer's recommended dosage range lies between 5 to 9 kg/m^3, and the fibres have a specific gravity of 0.91 with a melt point of 164 degrees °C.

2.2.2 Steel fibres

The steel fibres used in this research had physical dimensions of 50mm long by 1mm diameter with tensile strength of 1050 Mpa with offset ends in order to enhance the pullout strength (see Figure 3). The recommended dosage rates of 20 kg/m^3, 40 kg/m^3 and 60 kg/m^3 were used (SI Concrete Systems 2003).

Fig 3. Steel fibres (SI Concrete systems 2003)

2.3 Chemical anchor bolts

The Hilti M10, HAS:E anchor bolt was used in this research. The bolt, as shown in Figure 4, is of strength class 5.8 (500 Mpa ultimate tensile strength) with an ultimate design pull out resistance of 34.5 kN when used in C 40 concrete (Hilti, 2010). The embedded bolt length adopted was 90 mm and the bolt was of diameter 10 mm A 12mm drill hole was used, permitting 1 mm either side of the bolt for installations with granular resin glue.

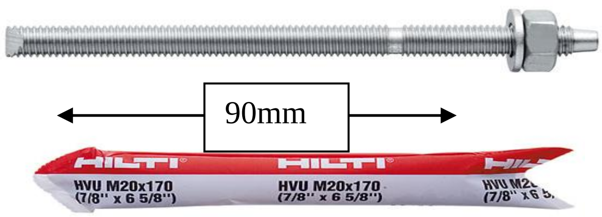

Fig. 4. Zinc coated high tensile steel anchor bolt and fixing resin (Hilti 2010)

The anchor bolts were fixed with a urethane methacrylate resin, inorganic filler dibenzoyle peroxide, phlegmatized methacrylic acid, monoester with propane-1,2-diol Xi; R <10% and dibenzoyl peroxide <2%. A setting tool was used with a hammer drill to drive the bolt into the pre mixed chemical sleeve holding the resin, which was placed in the pre drilled hole.

3. Methodology

3.1 Slab and cube manufacture

The slab thickness and bolt spacing was designed to ensure that a FPZ was able to form, thus assessing the concrete performance as opposed to the bond between the resin and the anchor. Eligehausen and Ozbolt (2010) examined fastener design using fracture mechanics and they state that, "concrete normally fails by cone shaped concrete breakout". The assumption was made that the resin would provide an effective bond for the full depth of the drilled hole and that a forty five degree shear plane would be reasonable (Mosley et al, 2007).

However the angle of shear will vary depending upon the effects of the fibres in the concrete. Five 600mm x 600mm x 150 mm slabs were cast. The assumptions made in the determination of the slab sizing were tested using finite element analysis to ensure a degree of accuracy. This simulation supported the theoretical fracture angle assumed and displayed the potential stress patterns stress patterns assumed between the initial loading and final failure. Figure 5 shows the stress patterns at 0.02877 seconds after loading and confirms the theoretical assumptions made in section 1.1

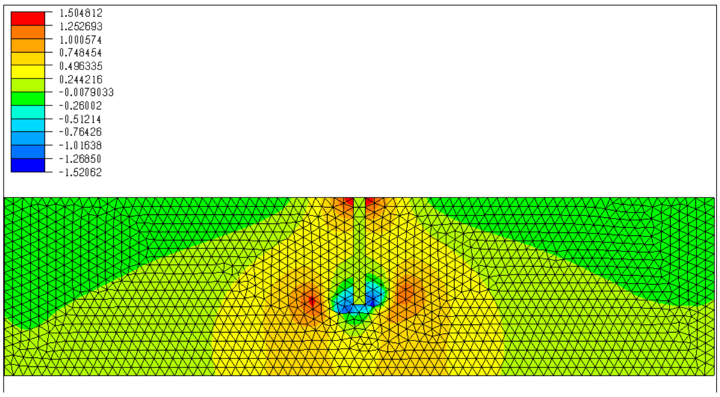

Fig. 5 Stress patterns and crack propagation at 0.02877 seconds

One slab was formed from plain concrete, three slabs were manufactured with steel fibres included and one slab was cast using the plain concrete mix with a synthetic fibre addition . The concrete was batched individually and three control 150 mm cubes were taken from each batch to assess the consistency of the concrete used. The concrete slabs were covered and allowed to cure for 28 days before they were prepared for the anchor pullout test.

After curing, the bolt holes were drilled and vacumed to ensure that the holes were free of any debris. Figure 6 illustrates the positions of the drill Two opposing bolts were selected for the test to avoid over stressing the test slab and the remaining two bolts were fixed for use in case one of the original selection failed prematurely. Once all the anchor bolts were set in place, the slabs were left for 24 hours in a warm laboratory to allow the resin enough time to cure and achieve the ultimate design strength.

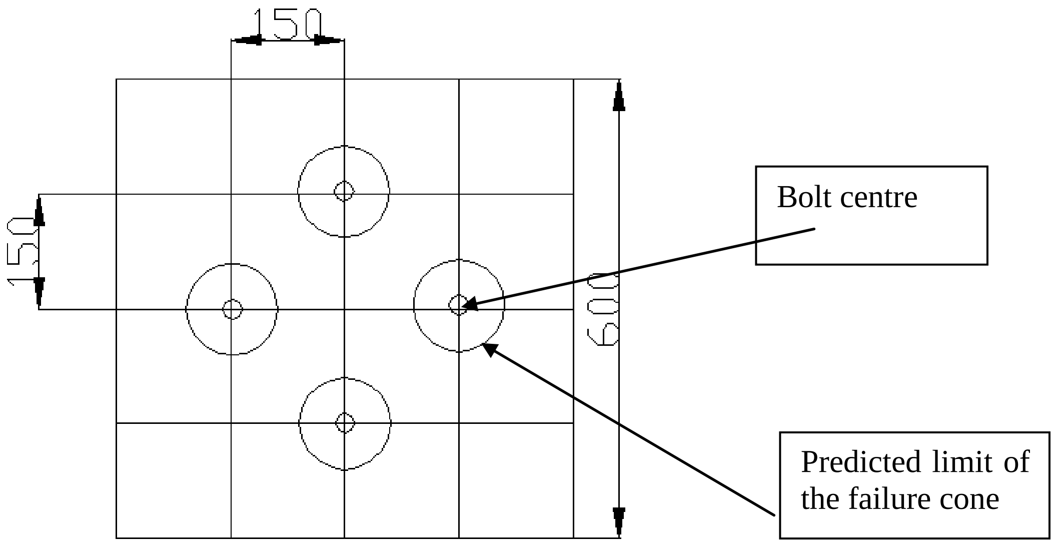

Fig. 6: Plan diagram of anchor bolt positions and concrete slab dimensions (mm)

4. Results

The concrete was batched with a slump between 80 to 100 mm and a recorded a mean density of 2332 kg/m^3, showing a standard deviation of 28.03 kg/m^3. After 28 days of curing the concrete cubes were loaded at a rate of 6.8 kN/sec and were compression tested to BS EN 12390-3: 2002. Table 1 shows the compressive strength of the control cubes taken from the slab batching material. All cubes displayed normal failure modes. The different batches were very similar to one another with low standard deviation values. It was noted that the addition of fibres made no significant change in compressive strength and the failure values were within normal batching tolerances.

Tab. 1: Compressive strength of control cubes (C45 design mix)

Slab/fibre type/dose	**Mean stress at failure N/mm²**	**Standard Deviation δ**
Plain	45.3	0.471
Steel fibre 20 kg	45	1.69
Steel fibre 40 kg	48	1.63
Steel fibre 60 kg	47.3	2.05
Synthetic Type 2	46.6	0.94

The hydraulic pull out testing apparatus under load; is shown testing an anchor bolt (Figure 7).

Fig. 7: Anchor pullout apparatus

The anchor pull out apparatus was a hand operated hydraulic pump that recorded the pull out force (kN) directly onto a dial gauge. When the force was applied to the bolt, even cracking occurred around the bolt until the concrete sheared off into a cone shaped failure mode (Figure 8). Figure 8 also illustrates the cone concrete brekout highlighted by Eligehausen and Ozbolt (2010).

Fig. 8: Pull out failure

Table 2 shows the ultimate pull out values of the bolts and the cone diameter of concrete broken out upon failure. The fracture stress in the fracture process zone, reduces due to the inclusion of fibres which lowers the angle of shear (θ) from the bolt tip to the concrete surface. The minimum and maximum angle of shear (θ) for the plain concrete was 35° and the angle of shear (θ) for the 40 kg fibre concrete was 48°. The use of fibres dispersed the forces in the fracture process zone thus enabling a larger area of concrete to resist the pull out force when compared to plain concrete, resulting in higher pull out values.

Tab. 2: Pull out values related to breakout cone size

Slab type	**Pull out force kN**	**Cone diameter mm**	**Mean pullout value kN**
Plain	35	130	
Plain	35	120	35
Steel fibre 20kg	37	170	
Steel fibre 20kg	37	150	37
Steel fibre 40kg	38	200	
Steel fibre 40kg	38	200	38
Steel fibre 60kg	40	200	
Steel fibre 60kg	38	190	39
Synthetic Type 2	40	160	
Synthetic Type 2	37	160	38.5

The FPZ does not proceed simultaneiously over the concrete cone created by the pull out force, but it propagates from a single point (Bažant, 2002). Figure 9 shows an increase in pull out diameter where fibres are used when compared to plain concrete. The cone diameter mirrors the pull out values as shown in Figure 10.

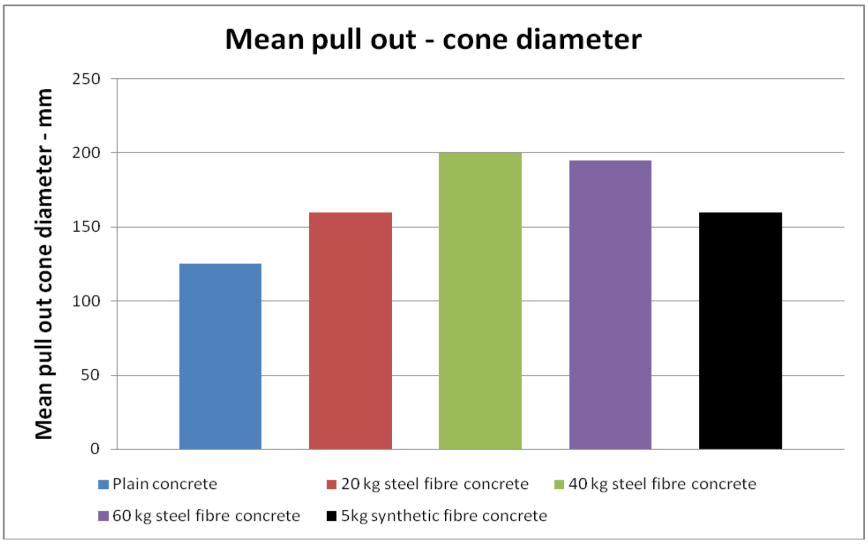

Fig. 9: Pull out cone diameter (mm)

Figure 10 shows the mean pull out values and the change in values, when compared to the plain concrete slab. The following increase in pull out force was recorded, 5.7% for 20 kg, 8.6% for 40 kg, 11.4% for 60 kg steel wire fibres and 10% for synthetic Type 2 fibres. The manufacturers pull out design strength for C 45 concrete was 34.5 kN and 35 kN was recorded from this test. The increased pull out values for the fibre concrete is due to the fibre inclusion in concrete providing an enhanced tensile strength.

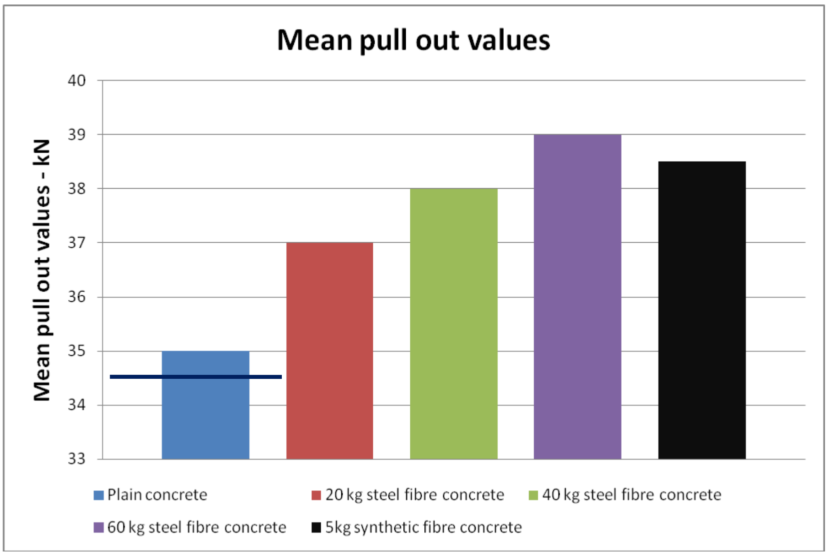

Figure 10: Mean bolt pull out values (kN)

When the slabs with steel fibres were tested, at the point of failure the concrete would fail explosively. This did not happen in the slab with the synthetic fibres, instead the cone produced, stayed intact. Type 2 synthetic fibres provided an alternative to steel fibres as they performed well against the plain concrete.

Following the pull out test the concrete was removed from the embedded section of the bolt and it was found that an uneven spread of the granular resin was observed towards the bottom of the bolt for each concrete type used. To avoid this situation a fluid resin should be used instead of a granular resin.

5. Conclusion

The anchor bolts performed beyond their design strength values and the pull out performance was enhanced with fibre additions in all cases. An increase in fibre dose produced an increase in pull out values. The use of synthetic fibres may provide a designer with an alternative to steel when fibres are used in concrete, within a corrosive environment. An additional benefit of synthetic fibre inclusion in concrete, is the ease of drilling for anchor bolts when compared to steel fibre concrete.

6. Further work

The bolt pull out test was valid for a static load applied to an embedded bolt fixing in plain unreinforced concrete. Modifying the concrete with the inclusion of fibres is thought to have improved the ductility of this quasibrittle material by increasing the area under a load/displacement curve due to strain softening following the initial fracture and further testing could easily be executed to support this opinion.

Further investigation on the pull out performance of the reinforcing bar at various depths of cover and at variable proximity to the bolt is envisaged. The effect of fibres with regard to bolts positioned close to a free edge, will be examined to see if minimum edge distances can be reduced. A dynamic loading test of various short durations to replicate impact loading will expand the work presented in this paper.

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