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Anchors Post-installed in High Strength Concrete

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Abstract: Nowadays, the great constructions of Colombia and the world, especially road infrastructure, have encouraged the use of high strength concrete. The use of post-installed anchors has also grown simultaneously in all concrete structures. Therefore, an experimental procedure was developed in this investigation to assess post-installed anchor systems based on tensile tests with high strength concrete specimens. The evaluation considers the analysis of the tensile tests results of test specimens with an anchoring system for three lengths (6, 9 and 12 times the diameter of the rod) with two rod diameters (3/8" and 5/8") in two grades of high strength concrete (5000 Psi and 6000 Psi) to determine the effective length and system load. The analysis carried out on the experimental test is to correlate the result of the maximum strength of steel reinforcement used (fy = 4200 Psi) with the variable post-installed anchoring systems. The results obtained are the percentage of system strength depending on anchor length and the effective length that ensures the steel creep and the correlations between the percentage of effective strength achieved for each anchorage length and the use of high strength concrete. With the above parameters, the contribution of high strength concrete to the efficiency of the post-installed anchorage systems was analyzed.

Key words: post-installed anchor; high strength concrete

1. Introduction

With all the construction boom, we must not lose sight of the fact that nowadays the demands of road infrastructure structures are making the use of high strength concrete more and more frequent. Bridges with high mechanical demands, pavements with early service ages, structures with increasingly slender geometries, prestressed or post-tensioned elements in road infrastructure structures, ports with structures subject to severe exposure conditions, such as aggressive marine environments, are some of the road infrastructure works that have encouraged the use of high strength concrete. However, research into the use of post-installed epoxy anchors in concrete with these requirements has not been further developed.

In all sectors of road infrastructure construction, reuse of existing engineering or continuation of existing concrete constructions is carried out, resulting in construction joints, expansion, repair, reinforcement, redesign, or segmented construction, such as bridges, due to construction process reasons. This is why the use of post-installed anchors between existing and new structures is undeniable to ensure that they behave properly (adhesion, load transfer or guarantee monolithic structures). Among these anchors, the most commonly used is the epoxy anchor.

Therefore, the objective of the research is to evaluate the effective length and strength of post-installed epoxy anchors for two diameters of rebar in specimens of two grades of high-strength concrete by direct tensile tests.

2. Previous Research

In recent years, numerous studies have been conducted to investigate the performance of adhesive anchors (post-installed anchors), in particular, the effects of embedding length (anchor length), type of anchoring agent used (bonding agent), borehole diameter, rebar diameter, edge distance and spacing of anchors in a concrete surface.

There are full pullout tests performed by Shah et al. [1] on steel bars anchored at two different embedding lengths (anchorage length), using materials from two different manufacturers. Obata et al. [2] have developed studies of free edge effects on the tensile strength of anchorage systems, both experimentally and analytically [3].

The behavior of natural stone [4] and masonry [5] post-installed anchors has also been investigated. At the same time, some studies have investigated the behavior of adhesive anchors (post-installed anchors) under external loading. The tensile behavior of post-installed epoxy anchors embedded in low-strength concrete has also been studied [6], as well as the shear behavior of epoxy resin anchors embedded in low strength concrete [7]. Kwon et al [8] have studied the behavior of post-installed shear connectors under static and fatigue loads. Failure modes have also been reported, with a comprehensive description of loading rate effects as a function of anchor support behavior [9]. Several failure modes [9, 10] have been proposed in the literature to determine the load failure of adhesive anchors (post-installed anchors) in concrete. In most cases, these modes are related to specific products and the diameter of the test bars to be used is usually less than 40 mm. The pullout strength for large diameter post-installed anchors embedded in concrete foundations was investigated [11]. It was also found that ACI 318 has a very overconservative approach to the tensile capacity of post-installed anchors when considering low-strength concrete. Moreover, it has congregated the greatest amount of information for investigations of post-installed anchor systems through the state-of-the-art report on anchors in concrete [12].

The research developed, although it has not used high-strength concrete, has managed to characterize some of the mechanical properties, classify types of anchors, develop testing methodologies, and even recommend installation processes [13]. As a synthesis of all the above, the state of the art of the variables involved in a post-installed anchorage system is consulted and integrated in order to parameterize the variables to be taken into account in this study, without stopping in numerical simulation studies and shear or chemical behavior of the post-installed anchorage system and others not mentioned.

3. Experimental Procedure

3.1 Manufacture of high-strength concrete

This project uses two types of concrete strength defined as f'c1 and f'c2. A total of 60 specimens were produced, 30 of each strength corresponding to the sample size, with an additional six specimens for contingency purposes. The recommendations for the construction of high strength concretes were taken, according to the catalogs of special concrete discovered in the construction of high-strength concrete [14, 15]. According to the above, it was decided to use conventional Portland cement, verify the dosages to achieve high-strength concrete and define a water-cement A/C ratio that guarantees a high-strength concrete [16]. Therefore, it was found that to obtain strengths higher than 34 MPa, water-cement ratios lower than 0.45 are required [17]. In practice, these A/C ratios are somewhat complicated to obtain, therefore, the use of a water reducer was necessary to achieve the specified ratios [18].

On the other hand, the compressive strength was measured at seven days to verify the expected strength projection at 28 days, and after the curing period, the compressive strength of six specimens (three specimens of each strength) was measured at 28 days in the universal machine of the Pedagogical and Technological University of Colombia, using the NTC 673 standard for compressive strength test of concrete cylinders, which verified that the concrete strengths are as expected for the development of the research [19].

The 28-day strength of each working strength was predicted using the projection of the 7-day test results. As a result, the f'c1 strength was 34.38 MPa (5000 Psi) and the f'c2 strength was 42.11 MPa (6000 Psi).

3.2 Post-installed anchors assembly process

The assembly procedure of the post-installed anchorage systems was taken and adapted from the research project entitled "Study of the tensile strength in post-installed structural anchors with epoxy adhesive" [20], which was conducted within the framework of this research project. In addition, the factors that influence the system [21] were taken into account, as well as the recommendations of the elements that affect the tensile strength of the system [22]. The anchorage systems were carried out according to the following experimental design.

Reinforcing bars of 3/8" (9.5 mm) and 5/8" (15.9 mm) were used. Drilling diameter was performed using 1/2" diameter drill bits for 3/8" anchor and 3/4" diameter drill bits for 5/8" anchor; that is, 1/8" in addition to the rebar diameter. The drill lengths used were 6, 9 and 12 times the rebar diameter. Therefore, the drilling lengths were for the 3/8" (9.5 mm) rebar: 6 times = 57 mm; 9 times = 85 mm and 12 times = 114 mm, and for the 5/8" (15.9 mm) rebar: 6 times = 95.4 mm; 9 times = 143 mm and 12 times = 190.8 mm. The anchorage systems were installed in f'c1 (5000 Psi) and f'c2 (6000 Psi) concretes. The above corresponds to a 3 × 2 × 2 factorial experimental design with four replicates, i.e. 3 drilling lengths, 2 rod diameters, in 2 concrete grades with 4 replicates of each combination, for a total of 48 specimens. The assembly of the anchorage systems with the main variables for the assembly was carried out as shown in Fig. 1.

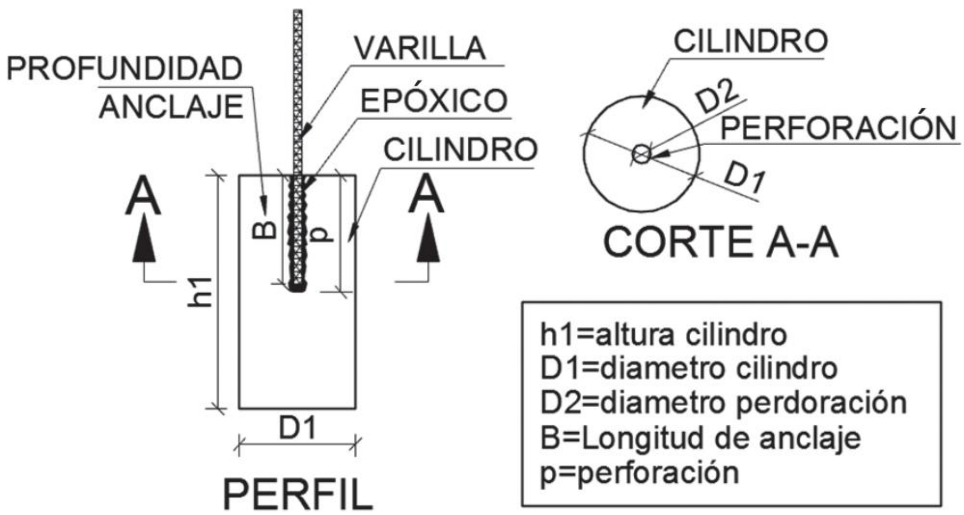


Figure 1. Post-installed anchorage system. Source: own elaboration.

Subsequently, the installation of the reinforcing bars with epoxy adhesive was carried out (as shown in Fig. 1), for which the manufacturer's recommendations [23] were taken into account to ensure the performance requirements of structural adhesives [24].

After the anchorage system specimens were assembled, tensile strength tests were performed. The pure tensile strength tests on the structural anchorage systems were performed on the universal machine of the soils and materials laboratory of the Pedagogical and Technological University of Colombia (UPTC).

For the assembly, a steel coupling adjusted to the universal machine of laboratory was fabricated, which has a circular hole in the geometric center with a diameter of 0.12 m to generate a free area for the development of the system failure. A typical tensile test was performed at a loading rate of 1 MPa/s, and all 48 specimens failed. Therefore, a graph of the load (kN) and elongation (mm) of each specimen was obtained, which is the characteristic of this experiment. This program was executed on the basis of ICONTEC (1995). The installation diagram is shown in Fig. 2.

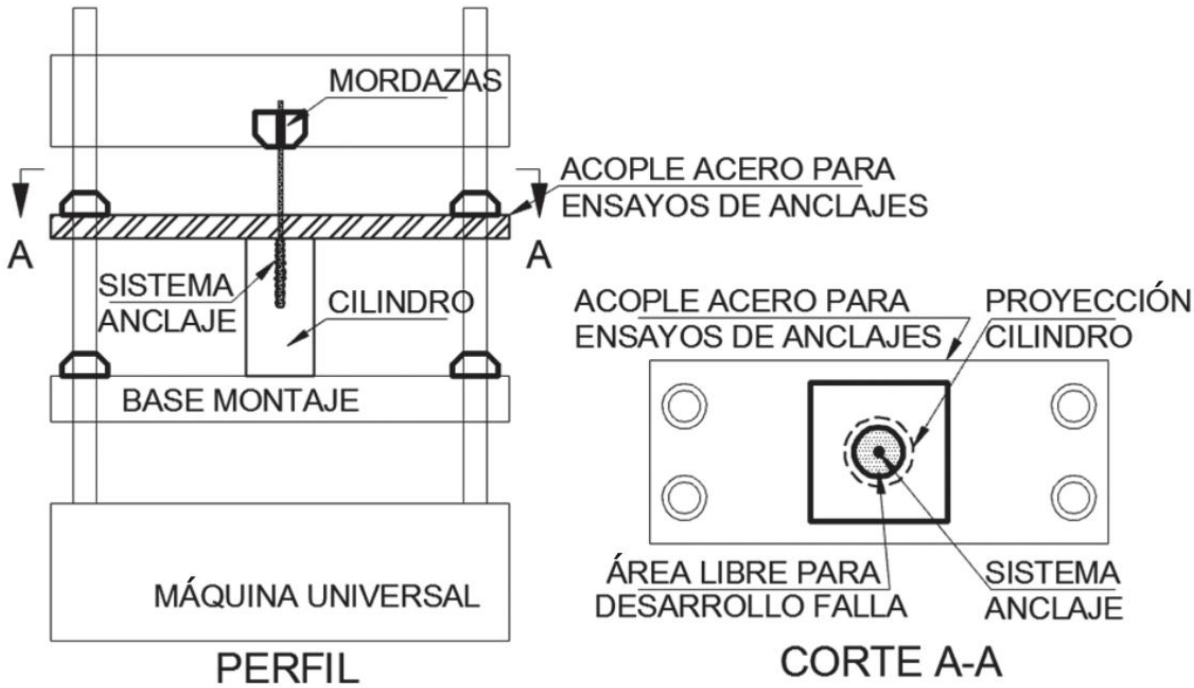


Figure 2. Assembly diagram of tensile test of post-installed anchor system. Source: own elaboration.

4. Evaluation of Effective Length

For the two concrete strengths, specimens with the three depths were failed to evaluate the effective anchorage length with 3/8" (9.5 mm) and 5/8" (15.9 mm) reinforcing bars. As a basis for correlating the results of the post-installed anchorage systems, tensile tests of the reinforcing steel used were performed [25]. Fig. 3 shows the results of the tensile strength curve of the 3/8" (9.5 mm) reinforcement on the left and the 5/8" (15.9 mm) tensile strength curve on the right.

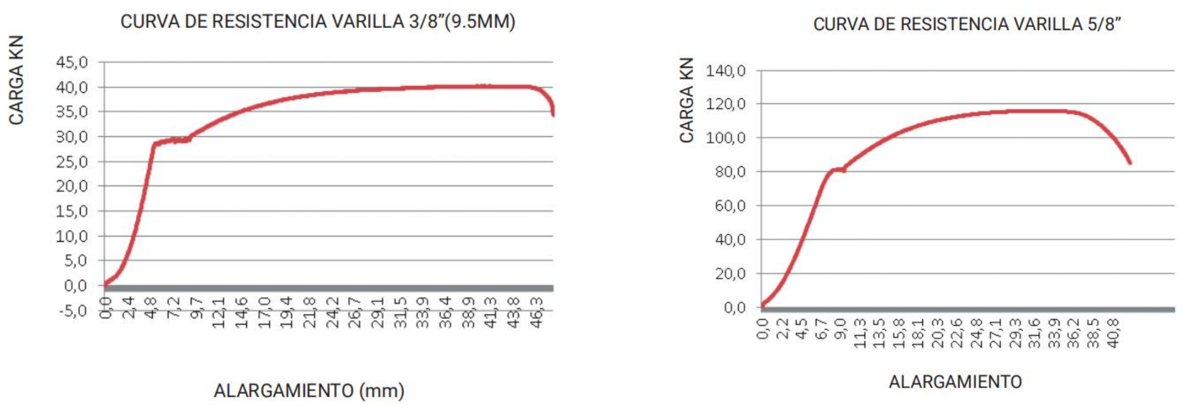


Figure 3. Tensile strength curves 3/8" (9.5 mm) and 5/8" (15.9 mm). Source: own elaboration.

From the strength curves of the steel bars, the "basis" parameter of the effective anchorage length was identified. From the control samples shown in Fig. 3, the maximum yield load of the steel was defined as the main parameter. Based on the aforementioned value, it was sought that the post-installed anchorage system should guarantee the condition under which the reinforcing bar of the anchorage system is able to develop the maximum influence load of the reinforcement corresponding to the assembled specimen. The "maximum yield load" strength values corresponding to each rod were 3/8" (9.5 mm) = 29.43 kN and 5/8" (15.9 mm) = 81.73 kN. The anchorage (drilling) length was analyzed as a function of the percentage of strength achieved for each concrete strength, with each reinforcing rod according to the depth of drilling (times the diameter of the rod), as shown in Fig. 4, 5 and 6. The developed percentage of the anchorage system with respect to the yield load of the steel is calculated with the arithmetic average of the specimens according to their diameter and anchorage depth.

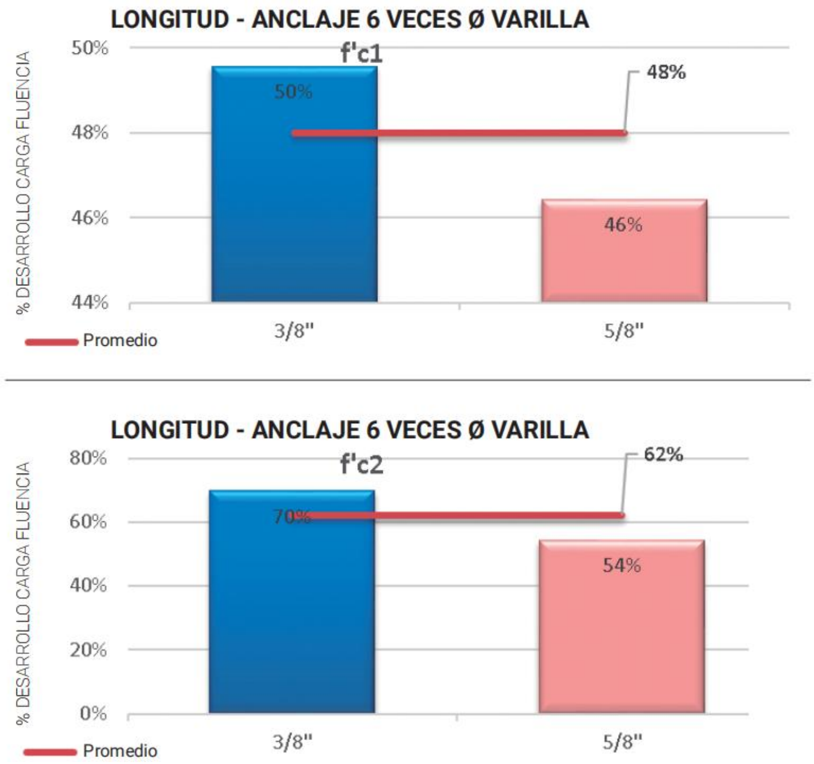


Figure 4. Anchor length six times the diameter, average strength. Source: own elaboration.

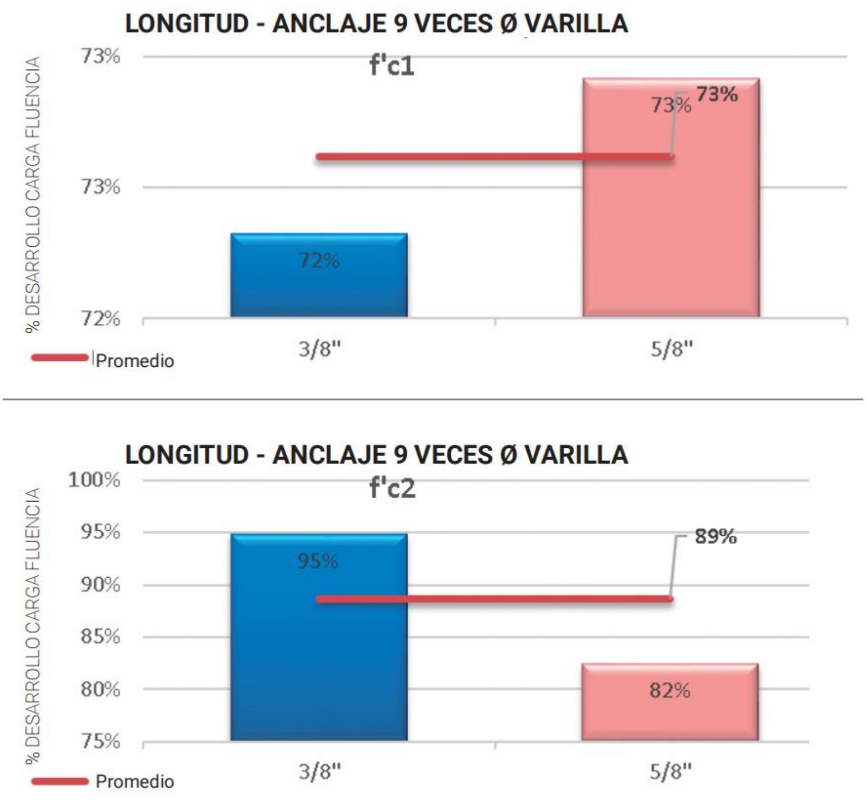
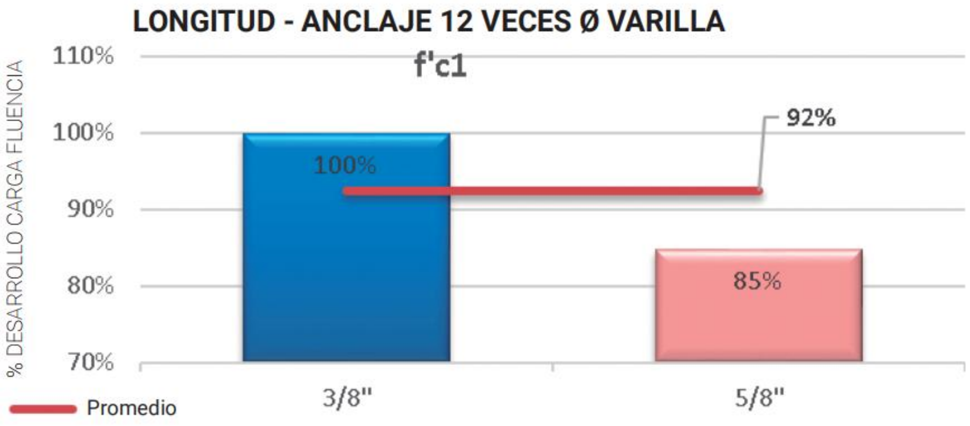


Figure 5. Anchorage length nine times the diameter, average strength. Source: own elaboration.



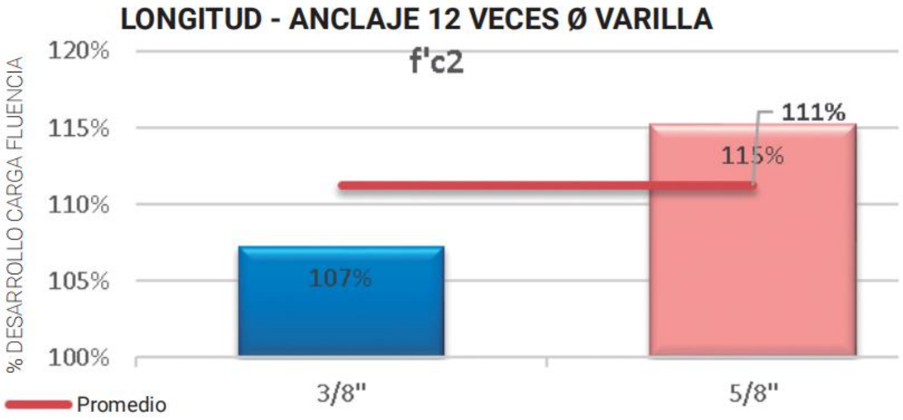


Figure 6. Anchor length 12 times the diameter, average strength. Source: own elaboration.

Research has shown that for concrete strength f'c1, the anchorage length is 6 times the rod diameter, and the maximum yield load of the steel bar is on average 48%. For an anchorage length of 9 times the rebar diameter, the average diameter of the rod is 73%. Finally, for an anchorage length of 12 times the rebar diameter, 92% is developed on average.

Therefore, it is determined that with an anchorage length of 12 times the rebar diameter, the maximum yield strength of the reinforcing steel is "acceptably" met. For the concrete strength f'c2, taking an anchorage length of 6 times the rebar diameter, 62% of the maximum yield load of the reinforcing steel is developed on average. For an anchorage length of 9 times the rod diameter, an average of 89% of the maximum yield load of the reinforcing steel is developed. Finally, for an anchorage length of 12 times the rod diameter, an average of 111% of the maximum yield load of the reinforcing steel is developed. In view of the above, it is verified that with an anchorage length of 12 times the rod diameter, the maximum yield strength of the reinforcing steel is amply met.

The percentage of the maximum load of the anchorage system depends on the diameter of the rod; that is, the smaller the diameter, the greater the resistance of the anchorage system will develop. Therefore, once the reinforcement area is defined, it will be more convenient to use a large quantity of steel with a smaller diameter, as mentioned in the article "Behavior of post-installed large-diameter anchors in concrete foundations" [11], where it was indicated that increasing the reinforcement diameter marginally increased the resistance of the anchorage system. Another correlation that was analyzed was the anchorage length as a function of concrete strength, which is shown in Fig. 7. The above process was also performed for the anchorage results for specimens with 9 and 12 times the rod diameter. This indicator was calculated for each of the strengths, so that the results could be comparable. The results shown in Figure 7 were obtained.

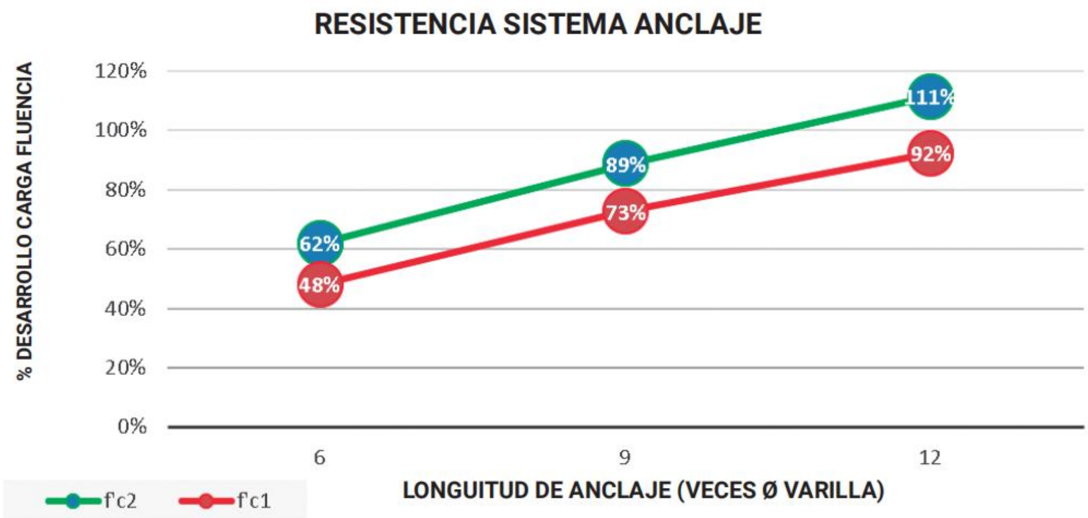


Figure 7. Resistance according to anchorage length for each f'c. Source: own elaboration.

The anchorage length performs better depending on the concrete strength. As shown in Fig. 7, the anchorage system with 6, 9 and 12 times the anchorage length of the rod for f'c2 strength is higher in all cases than the strengths developed for f'c1. From the above, it could be preliminarily indicated that for every 1000 Psi of strength in high strength concretes, the load resistance development could be improved by 15%. This is consistent with studies showing that the resistance of the anchorage system changes with the quality of the material [1]. On the other hand, the trend of the anchorage length as a function of n (times the rod diameter) is linear, so that through tests such as those proposed in the present experimental study and by performing the proposed analysis methodology, the effective length for any post-installed anchorage system with a defined concrete strength f'c could be determined.

By correlating the behavior obtained in the test with similar studies developed, it was possible to validate that the design of individual adhesive anchors in uncracked concrete applies to high-strength concrete [26].

5. Evaluation of Effective Resistance

The resistance curves of the results obtained in the tests for 12 times the diameter of the rebar with 3/8" (9.5 mm) (Fig. 8) and 5/8" (15.9 mm) reinforcing steel (Fig. 9) were plotted to observe the behavior during the tensile test of the anchor systems [27]. For each group of concrete resistance f'c1 and f'c2, each of the specimens is identified to correlate them with each other.

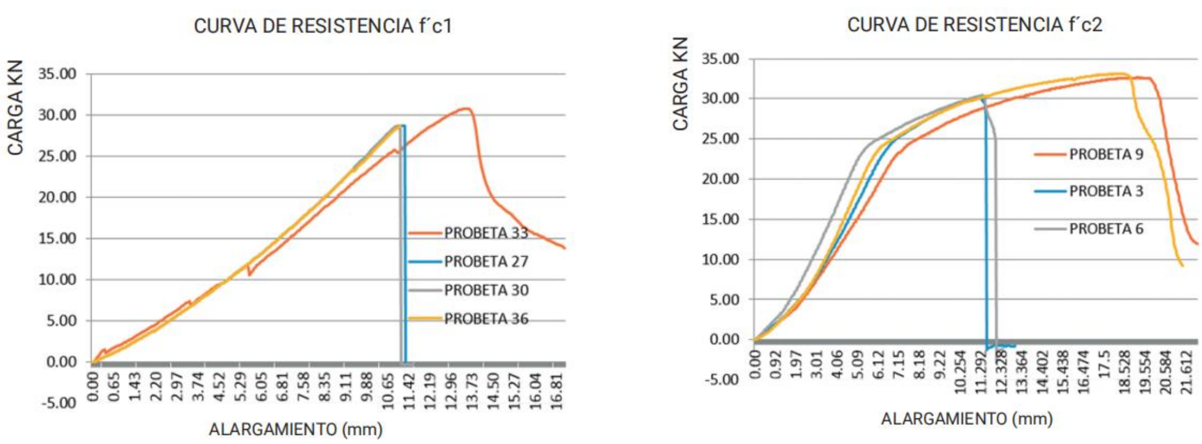


Figure 8. Strength curves of f'c1 (3/8", 9.5 mm) and f'c2 (3/8", 9.5 mm). Source: own elaboration.

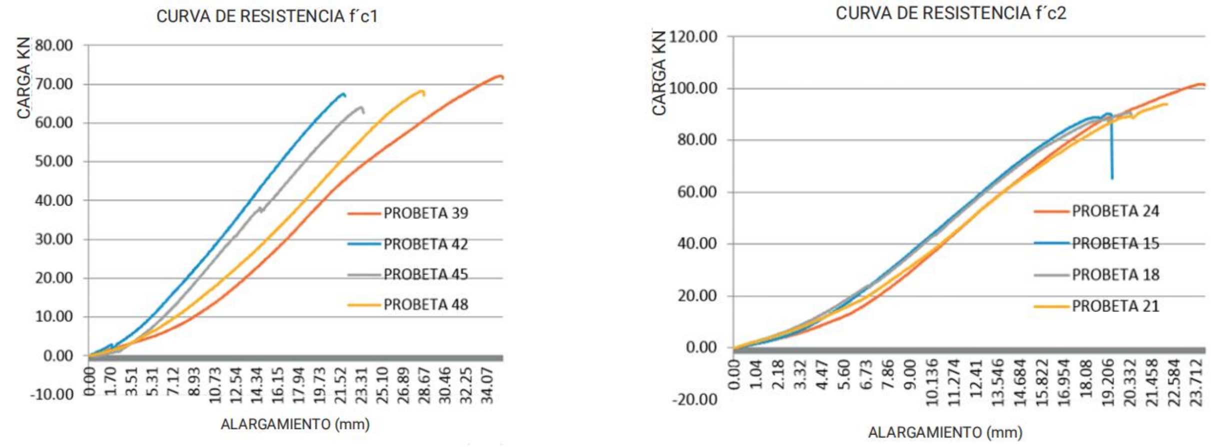


Figure 9. Resistance curves of f'c1 (5/8", 15.9 mm) and f'c2 (5/8", 15.9 mm). Source: own elaboration.

The behaviour for the 3/8" (9.5 mm) diameter bars (Fig. 8) was found to be similar to that of the steel resistance curve [28], while for the 5/8" (15.9 mm) diameter bars (Fig. 9) the curves developed in the elastic zone up to failure of the concrete in the anchorage system. In general, based on the curves shown, the elastic zone, the maximum yield load, the plastic zone and the ultimate load of the reinforcing steel can be identified. The point where the graph decreases indicates the instant of the specimen failure or the breaking point of the reinforcing bar. Correlating the above with research carried out on low strength concrete, the use of smaller diameters of reinforcement can provide a safer design, as smaller diameters of reinforcement are more likely to fully develop the strength curve to ultimate loads [7].

When comparing the group of tensile load results of concrete strength f'c1 and f'c2, it is observed that the curves of the higher strength concrete develop higher maximum loads of the anchorage system. Even if the failure is by the concrete or by the steel in the anchorage system, in both cases the reinforcing steel had already reached the maximum yield strength fy = 4200 k/cm^2. It can also be stated that in either case the anchorage system would always be guaranteed to meet the strength requirements.

In Figures 8 and 9, it was found that for the post-installed anchorage systems, most of the specimens failed due to concrete, while in the strength curve, it was determined as a steep slope change (descent), or it can also be identified at the end of the strength curve without showing the development of the complete strength curve of the reinforcement, as shown in Figure 3 (control specimens).

In this research project, 12 times the diameter was pre-determined to determine the effective strength of the anchoring system (which generates 100% of the maximum yield load), and tensile test results were observed for the vast majority of concrete failures (although ensuring the functioning of the anchoring system), but the failure may not be ductile. The above mentioned scenario takes into account the experimental method proposed in the project, which involves using a simple concrete specimen with an anchoring system. In addition, it is important to consider that the manufacturing of the specimens did not consider variables, such as the experimental comparison of the strength of epoxy resin anchors [29], which studied the constraints of reinforced concrete, taking into account specimens with constrained steel bars, such as components of reinforced concrete systems.

On the other hand, through direct tensile tests, the effective tensile strength in post-installed anchors, gave as a result that it depends directly on the anchorage length. Finally, the effective tensile strength is calculated as a function of the anchorage depth for each reinforcing bar. The calculation is made with the arithmetic average of the results of the maximum loads recorded in the tests in the two concrete qualities f'c1 and f'c2 and are shown in Figs. 10, 11 and 12.

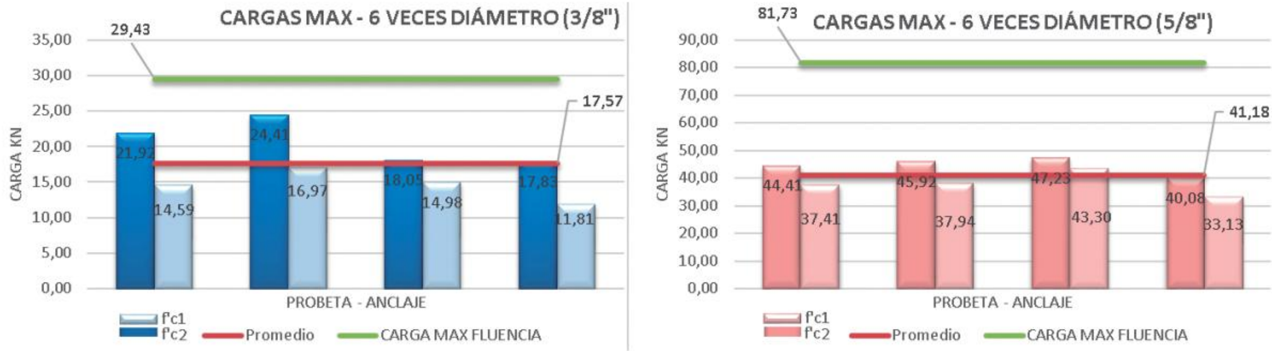


Figure 10. Effective strength (anchorage depth: 6 times the rod diameter). Source: own elaboration.

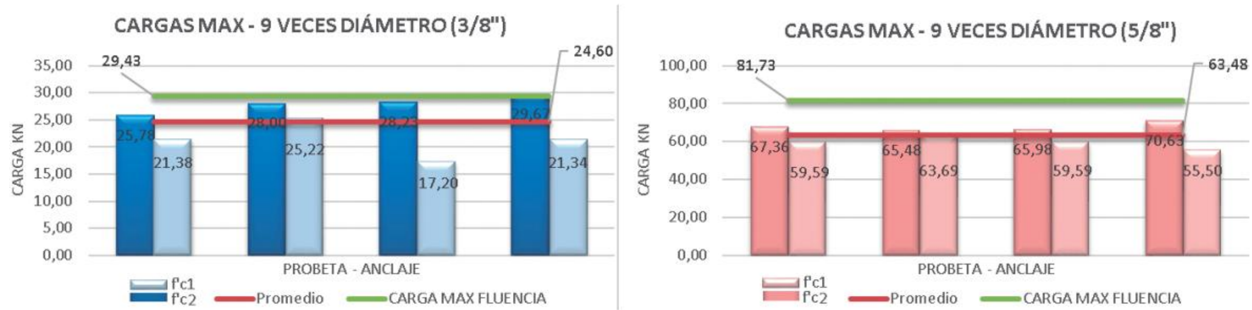


Figure 11. Effective strength (anchorage depth: 9 times the rod diameter). Source: own elaboration.

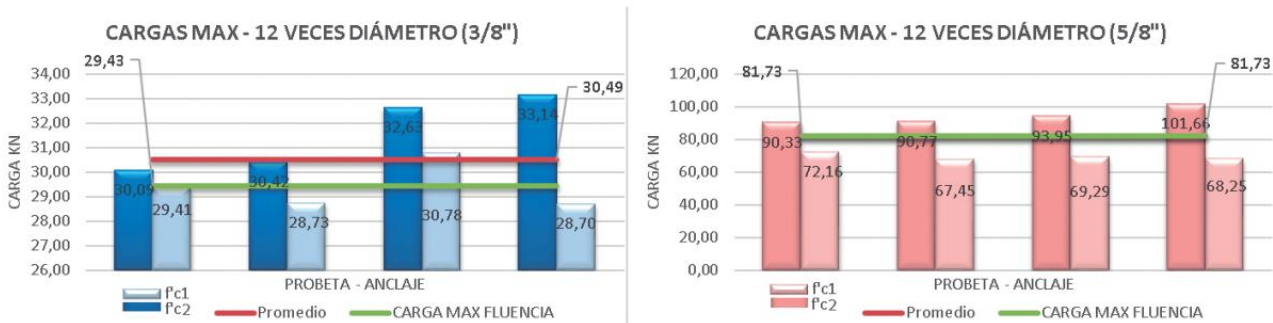


Figure 12. Effective strength (anchorage depth: 12 times the rod diameter). Source: own elaboration.

As a result of the analysis, it was determined that with an anchorage length of 6 times the rod diameter, the effective tensile strength develops between 50% and 60% of the maximum yield load of the reinforcing steel (see Fig. 10). With an anchorage length of 9 times the rod diameter, the effective tensile strength develops about 80% of the maximum yield load of the reinforcing steel (see Fig. 11). Finally, with an anchorage length of 12 times the rod diameter, the effective tensile strength guarantees 100% of the maximum yield load of the reinforcing steel (see Fig. 12). For the case under study, the maximum load of the reinforcing steel being between 30 % and 40 % higher than the maximum yield load, the anchorage system would be conditional on not exceeding these values.

6. Conclusions

In previous research, it was observed that the studies of post-installed anchors have grown, depending on their use in construction works, and the anchor length is the most analyzed variable [1], and, as proved in the present research, it turns out to be the most sensitive in the results analysis.

Taking into account that nowadays the production of high-strength concretes is being directed to road infrastructure projects and also that the use of post-installed anchors is more frequent during the construction process, the evaluation of post-installed anchors in high-strength concretes was justified in this research.

In high strength concrete, systems with an anchorage length of 9 times the rebar diameter, with reinforcement of diameter equal to or less than 3/8" could satisfy the design requirements, as it was found that with this depth a minimum of 85% of the strength of the reinforcing steel can be developed. The above is mentioned in case the condition stated in NSR10 - Paragraph C5.6.5.4, where a specimen with 85% of the (concrete) strength is approved and similarly applied [30].

From the results of the maximum loads of the anchorage systems, it was observed that anchorage systems with 12 times the rod diameter are guaranteed to develop the maximum yield load of the reinforcing steel.

By analyzing the anchorage length with the diameter of the rebar, it could be seen that the smaller the diameter of the rebar, the higher the tensile strength of the post-installed anchorage system. This confirms that after defining a reinforcement area, it will be more convenient to use a larger amount of steel of smaller diameter [7].

The effective anchorage length for two diameters of rebar in two high strength concretes was identified by direct tensile testing to be 11 times the rebar diameter. The supplier's recommendations [23], by defining the anchorage length as 12 times the rebar diameter, would ensure that the reinforcing steel would satisfy the strength demands. For the case study, as the quality of concrete increases, the tensile strength of the post-installed anchorage systems increases. It was observed that for every 1000 Psi of strength in high strength concrete, the load bearing capacity of the post-installed anchors could be improved by 15%.

Even if the failure in the anchorage system specimens is due to the concrete or the steel, with an anchorage depth of 11 times the diameter of the reinforcing steel, it will reach the maximum yield strength fy = 4200 k/cm^2. This is why it can be defined that in either of the two cases it would be guaranteed that the anchorage system always complies with the strength requirements (solicitations). It has been clarified that the experiment was conducted using simple concrete specimens rather than constrained concrete, as considered in some studies where this variable is implicitly integrated [29].

Additionally, it was identified that with an anchorage length of 6 times the rod diameter, the effective tensile strength develops between 50% and 60% of the maximum yield load of the reinforcing steel. With an anchorage length of 9 times the rod diameter, the effective tensile strength develops about 80%. Finally, it was determined that with an anchorage length of 12 times the rod diameter, the effective tensile strength guarantees 100% of the maximum yield load of the reinforcing steel.

With higher concrete quality, the strength of the post-installed anchorage system increases, as shown in the study when comparing the anchorage systems in high strength concretes used in the case study. The above is mentioned when correlating the results of anchorage straction in different qualities of materials, in the studies carried out in low strength concrete, standard concrete, stone [4] and masonry [5].

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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