Design Issues for Axially Loaded Anchors in Strengthening Applications

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ABSTRACT

Over the past few decades, due to the developments of chemical adhesives, usage of anchorages is spread out in strengthening applications. Anchorages have a vital role to ensure those applications accurate. In case of misapplications, connection between existing structural member and added one may not transfer required forces which means non-efficient retrofitting. Therefore, a number of recommendations are done regarding free-edge distance and embedment depth of axially loaded anchors embedded to both low and normal strength concrete. Furthermore, experimental results are compared with ACI-318 Appendix D recommendations.

Keywords: *chemical anchors, free-edge distance, embedment depth, tensile strength*

INTRODUCTION

Chemical adhesives are quite effective solutions for connecting structural members and transfer axial and shear forces between them [1]. Installation of adhesive anchors are done by drilling the concrete [2]. Although, appliance of chemical adhesives in reinforced concrete structures goes back to 1960s for the bonding of steel plate reinforcements [3], chemical anchors have been used widely last 2 decades due to the development of adhesive chemicals such as high-strength polyester, vynlester and epoxy [4], [5]. For the time being, many types of chemical adhesives are quite affordable via structural materials market.

Over the last two decades, behavior of cast-in-place anchors [6] and post-installed mechanical anchors [2] is investigated in detail and by the aid of these studies some limitations and procedure recommendations were proposed for cast-in-place [7] and mechanical anchors design [8]. Since early 1980s [9] studies have been held on chemical anchors. However, most of them comprise of experiments on axial performance of anchors. In these, effect of different factors on tensile strength capacity are investigated. In some of these studies, the thickness of adhesive, additional material(s) to adhesive chemical [10], embedment depth [4], bar diameter of anchor [11], [12], steel strength [13], free edge distance [14] and distance between anchors [15] are investigated. Moreover, concrete strength and aggregate variety [12], [16] and behavior of both single and group anchors are studied [2]. In addition, there are also some studies about the relation between tensile strength and loading pace rate under dynamic loads [17], [18]. Besides, there are some studies on partially bounded anchors which can be categorized in the group of chemical anchor behavior studies [6], [19]. In a very recent study, shear behavior of epoxy bonded anchors were investigated and researchers suggested capacity reduction factors for such cases [20].

According to the literature, most of the studies are done with high strength concrete and/or normal strength concrete. However, in Turkey and some other countries there are plenty of buildings having concrete strength deficiency [21]. For this reason, comprehensive researches on tensile strength capacity of anchors embedded to low strength concrete are required [22]. In addition, a comparative relation should be put forward between normal and low strength concrete. In this study authors present their experience on performance of axially loaded anchors in strengthening application design and laboratory experiments.

MATERIALS AND METHOD

Test Specimen Characteristics

To observe and compare anchorage performance in low and normal strength concrete, 5 different types of concrete blocks named as C5 (5,9 MPa), C10 (10,9 MPa), C16 (17,0 MPa), C20 (25,0 MPa) and C25 (35,6 MPa) are used. S420a steel bars having 12, 16, 20 mm diameters are embedded in the concrete blocks. For embedment depth and free-edge distance of anchors, 10, 15, 20 times the bar diameter are chosen. Specimens are named as in figure 1.

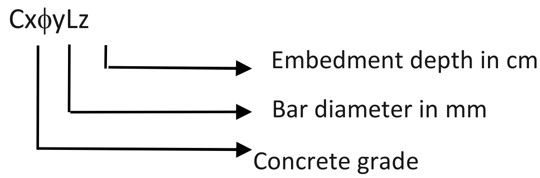


Figure 1. Labeling of specimen

Test Set-up and Loading

Anchors are applied to the tensile loading with the system shown in figure 2. A steel beam and two blocks are used to elevate load cell and pulling system in order to observe anchor behavior easily and not to prevent any occurrence of concrete cone failure.

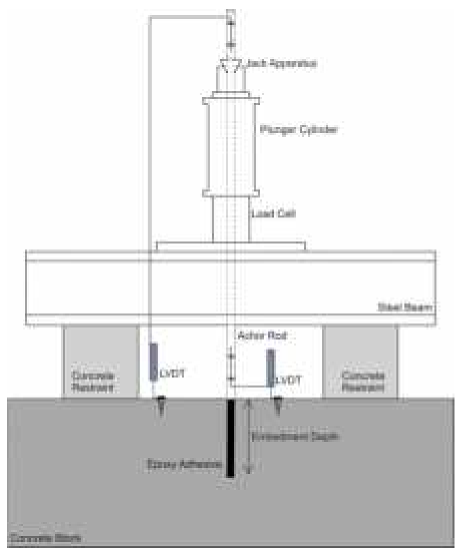
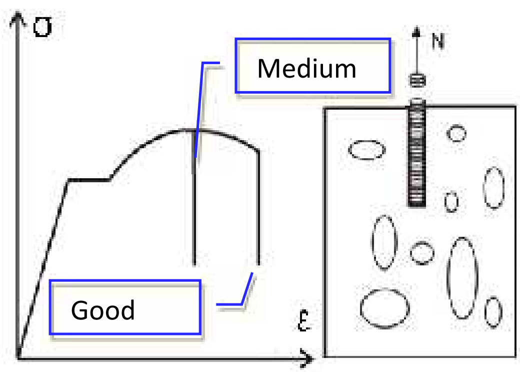


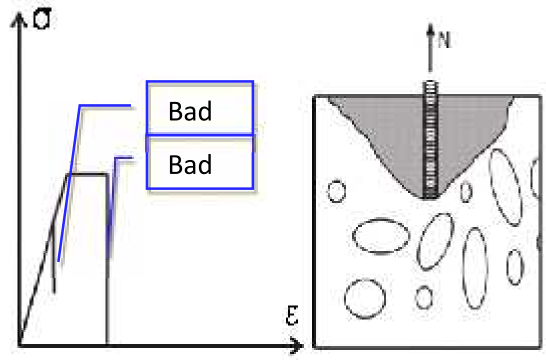
Figure 2. Test Set-up

EXPERIMENTAL BEHAVIOR OF AnchorS

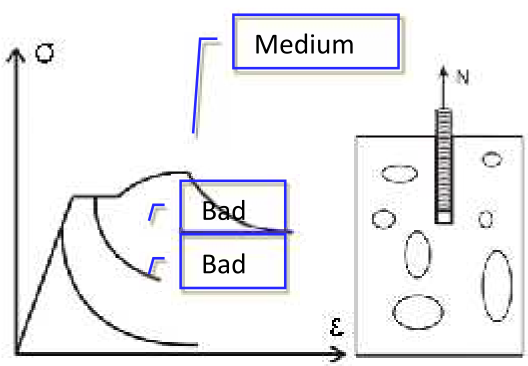
Since there are 45 groups of specimens, about 200 capacity curves are plotted by means of experiments. However for the sake of simplicity, only idealized-smoothed curve examples are given in figure 3. In addition in table 1, capacity curve, test photo and description of failure examples are given. According to the tests, an increase in bearing capacity of anchors related to the bar diameter cannot be observed as previously expected for each group of anchors. According to a great number of tests held by the authors, it is observed that the most important parameters governing the behavior of anchors are free-edge distance and embedment depths [23]. For all the concrete groups, in the cases of 15 and 20 embedment depth all the anchors satisfy at least yield strength capacity except one group. In other words, brittle failure mechanisms occurred for 10 embedment depth and free-edge distance anchors. Furthermore, it is observed that anchors having bigger diameters perform concrete failures not related to the concrete strength capacity as previously expected.



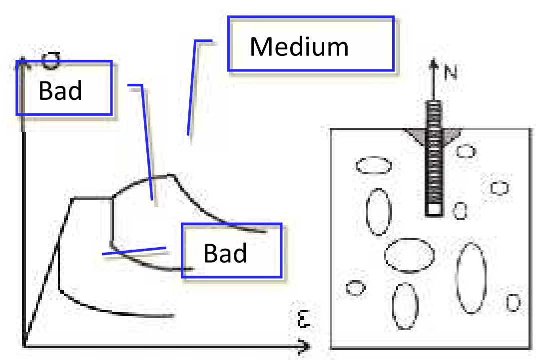
Capacity curve of anchorage in the case of bar failure (ductile failure)



Capacity curve of anchorage in the case of concrete cone (brittle failure)



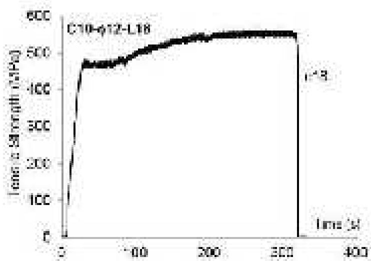
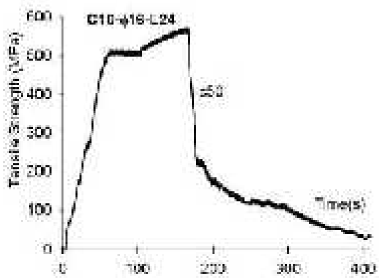
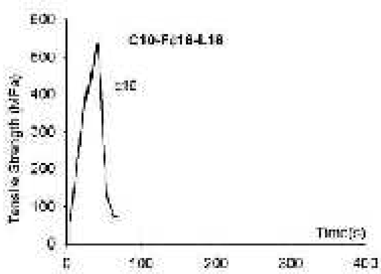
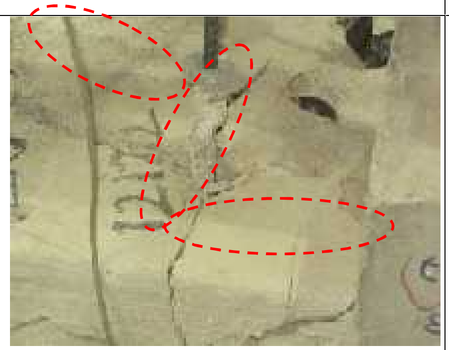
Capacity curve of anchorage in the case of pry-out (brittle failure)



Capacity curve of anchorage in the case of pry-out&concrete-cone combination (brittle failure)

Figure 3. Stress-strain curves related to failure modes

Table 1. Failure Modes

Behavior	Capacity curve	End photo of test	Description of damage
Good			Anchor bar failure (ductile failure)
Medium			Concrete cone (brittle failure)
Bad			Cracking of concrete (brittle failure)

COMPARISON OF RESULTS WITH ACI318

Tensile strength values of all the tested anchors are compared with the nominal and reduced (design) strength values according to ACI 318 Appendix D (2005) in Figure 4.

It is observed that especially for anchors with an embedment depth of 10 , ACI 318 specifications yield quite conservative results. Moreover, ACI318's approach for shallow anchors are more conservative than for deep ones. This such result keeps designers away from brittle failure modes. In addition, it is seen that formulations are more suitable for C16 and above group anchors than C5 and C10. If reduced tensile strengths are taken into account it conservatism will increase.

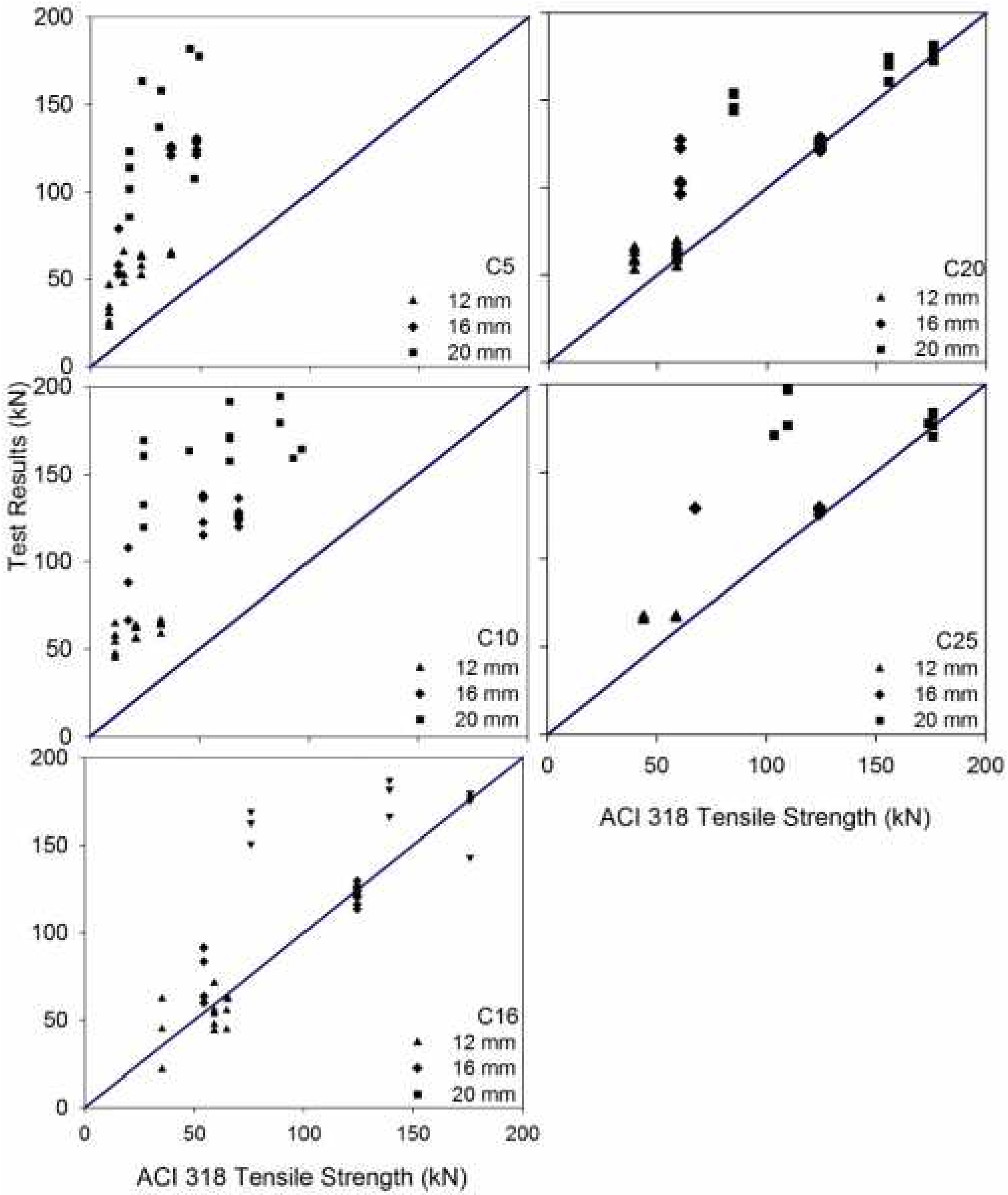


Figure 4. Comparison of test results with ACI 318

CASE STUDIES AND RECOMMENDATIONS FOR DESIGN

Designer of a strengthening project should detect the existing structural system in detail and while creating the project all the deficiencies must be taken into account. Some examples of unprofessionally installed anchors are shown in figure 5. In figure 5-a, there is a horizontal crack along the concrete cover of column. However, in the designer's project anchorage installation is given into the middle surface of column. As for figure 5-b, there is a concretewise member which may have a normal compressive strength. However, compressive strength does not mean to a good performance for anchorage behavior. Also gradation of that must be observed with a heuristic approach. In that photo, low free-edge distance is again another issue had to be solved. In figure 5-c, it is not possible to end up with a ductile behavior due to low concrete strength and/or the cracks on the structural member and/or may be low speed rate of heavy duty driller. In case of such hazardous conditions, for example in columns, addition to installing anchors these members should be jacketed. Thus, the goal of strengthening can be achieved securely. Otherwise, detrimental damages on strengthened buildings may occur. According to test results it can be easily said, these anchors perform nearly half of the yield strength of bars with a brittle failure. Therefore, the seismic loads cannot be transferred to infill shear wall in case of an earthquake and this will cause a dramatic change in the behavior of structural system.

Figure 5 a-b-c. Misapplications of Anchors (photo a-b-c: Ahmet Sarışın)

Some other examples of incorrect anchor installations are shown in figure 6. Other than design, workmanship in these applications are quite important that should be ensured by the area engineer. In figure 6-a, installation angles between both horizontal and vertical directions are quite important to achieve an effective strengthening application. In figure 6-b, in order to transfer enormous forces to additional shear forces, a great number of anchors had been designed. However, this may result capacity problems thus alternative solutions must be put.

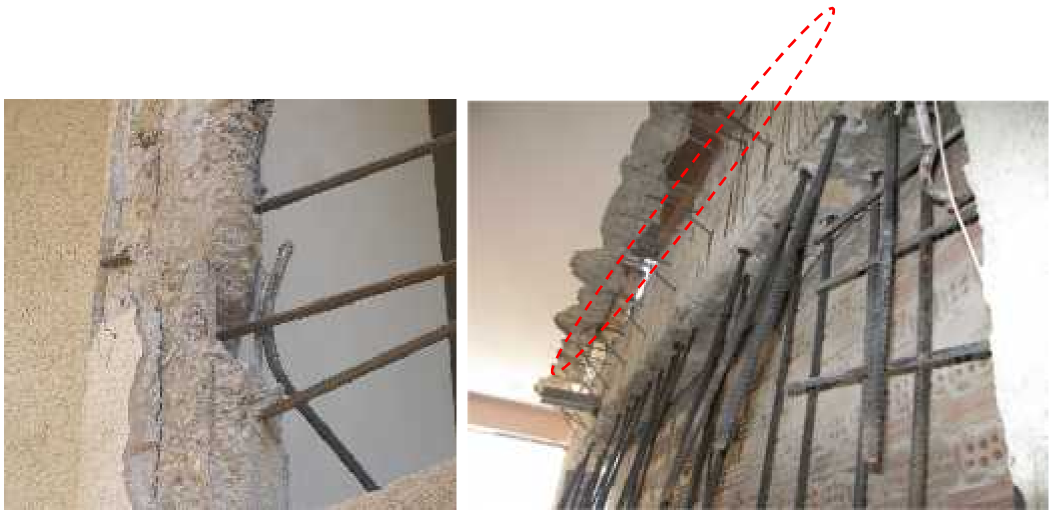


Figure 6 a-b. Misapplications of Anchors (photo a: A. Sarışın, photo b: M.A. Özen)

CONCLUSIONS

1. Anchors having 10 times bar diameter free edge distance and embedment depth show brittle failure.
2. For 10 MPa and more compressive strength concrete, having 15 times the bar diameter free edge distance and embedment depth anchors exhibit a considerably good performance. Therefore, choosing that much of embedment and free edge distance is recommended at least.
3. In the case of embedment depth of 10 times the anchor diameter, ensuring a sufficient free edge distance strongly recommended. It is recommended to form this edge distance at least 20 times the anchor bar diameter, especially for the anchor bar diameters larger than 16 mm. If it is not possible to provide such a free distance just like the most cases in column anchors, it will be suitable to increase the embedment depth. In addition some other strengthening solutions should be taken into account in order to reduce the risk in critical structural member additions.
4. Especially for the anchors installed for lap splicing the steel bars in bending structure members with the same diameter, it will be quite efficient to choose the embedment depth at least 20 times the bar diameter. But it must be kept in mind that larger bar sizes

create greater moments and forces; therefore, providing a sufficient free edge distance should be accomplished.

5. It can be inferred that ACI recommendation can be used also for low strength concrete grades.
6. It is recommended that choosing lower anchor bar diameters can contribute to obtain ductile behavior for seismic strengthening projects.

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