SECOND EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING AND SEISMOLOGY, ISTANBUL AUG. 25-29, 2014

TENSILE PERFORMANCE OF RETROFITTING ANCHORS

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ABSTRACT

Anchors are widely used for strengthening works due to easy application, especially in earthquake prone regions, in the last few decades. On the other hand, they are very critical elements transferring loads between an existing and the new structure. That is, in most of the strengthening works, concrete strength is quite low and this may result in brittle failures and the whole new system may suffer tragically. In this study, tensile performance of anchors embedded to low and normal strength concrete (5.9-35.6 MPa) are investigated. For embedment depth and free edge distance 10, 15 and 20 times anchor diameter are chosen. For the codes to be issued from now on, some recommendations are done. Regardless of concrete strength, a free-edge distance and embedment depth of at least 15 times the bar diameter is suggested, in general. However, for anchoring into different structural members, these values should be revised. In addition, since achieving such distance is very difficult in most members, a number of further recommendations are done. Besides, choosing lower anchor bar diameter is offered for better failure modes.

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

INTRODUCTION

Chemical anchorages are commonly used in strengthening applications of reinforced concrete structures, steel-concrete foundation connections and nuclear power plants constructions. They are quite effective to transfer axial and shear forces (Bouazaoui L and Li A, 2008.). Usage of chemical anchors has increased in the last 2 decades due to the development of adhesive chemicals such as high-strength polyester, vynlester and epoxy (McVay M et al., 1996), (Çolak A, 2007). As a result of investigation of cast-in-place anchors (Cook R A, 1993) and post-installed anchors (Eligehausen R, 2006) in detail, some confines and application recommendations were done for cast-in-place (ACI 318) and mechanical anchors design (ACI 355). In many studies, factors effecting tensile performance are investigated. In some of these studies, the thickness of adhesive, additional material(s) to adhesive chemical (Çolak A, 2001), embedment depth (McVay M et al., 1996), steel bar diameter (Gesoğlu M et al., 2005), (Özkul H et al. 2001), steel strength (Cook et al, 1992), free edge distance (Obata M, et al, 1998) and distance between anchors (Özturan T et al., 2004) are investigated. Moreover, concrete strength and aggregate variety (Özkul H et al., 2001), (Cook R A and Konz R C, 2001) and behavior of both single and group anchors are studied (Eligehausen R et al., 2006). Furthermore, behavior of partially bounded anchors which can be categorized in the group of chemical anchor behavior studies investigated (Cook R A, 1993), (Gürbüz T et al., 2007). On the other hand, there are capacity reduction factor suggestions for the anchor designed for shear (Çalışkan Ö et al., 2013). In a very

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recent study, a prediction model is developed, using gene expression programming, for an experimental database (Gesoğlu M et al., 2014).

According to the literature, it can be drawn that there is a lack of studies for anchorage design for strengthening projects where anchors are the key elements of them. Furthermore, they are used in low strength concrete and a concern is existing for anchoring into them (Yılmaz et al., 2013). In this study, authors give recommendations for anchor design through their experiences from experiments in laboratory and strengthening application design.

MATERIALS AND METHOD

To illustrate the concrete strength used in strengthening applications, anchors are installed into 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). S420a steel bars having 12, 16, 20 mm diameters are used. For embedment depth and free-edge distance of anchors, 10, 15, 20 times the bar diameter are chosen.

TEST SET-UP AND LOADING

Tensile loading is applied to the anchors with the system shown in figure 1. 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. Up to yield or pry-out, monotonic steady incremental axial load was applied. Then, an incremental displacement is applied till the ultimate capacity of anchorage to observe failure behavior entirely.

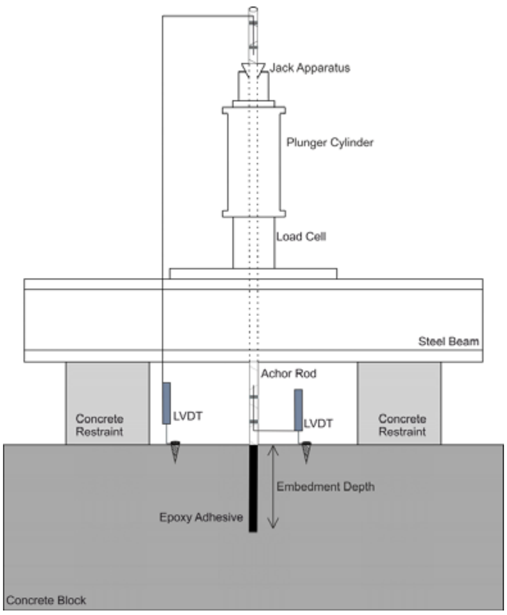

Figure 1. Test Set-up

ANALYSIS OF TEST RESULTS

According to 45 different groups of specimens in 5 different type of concrete blocks, changes in anchor strength related to free edge distance (c/ϕ) and embedment depth (l_e/ϕ) for 12, 16 and 20 mm steel bars are given in Figure 2 and 3. Yield and ultimate tensile strengths of steel bars are shown as horizontal lines in the graphs. For C5-12 mm anchors, especially for c/ϕ=10, there is an obvious performance problem meaning that the failure mechanism is brittle for those. Interestingly, the same situation in C16 for 12 mm anchor diameter is existing. It is due to the pry-out capacity problem of those anchors. Besides, for C10, a considerably better behavior is seen where for the two of five anchors with the same diameter and same free-edge distance, 10ϕ, failed below the line of yield strength. Here, it can be also said that the anchors in C5 and C10 blocks with c/ϕ=15 and above, show ductile failure behavior. On the contrary, for 12 mm anchor diameter in C16 blocks, this performance cannot utterly meet for c/ϕ=15 and more. Although the obtained capacities for that group of anchors are more than 400 MPa the failure is brittle which is undesirable. As for 16 mm anchors, c/ϕ=10 and le/ϕ=10 ones show brittle failure modes such as pry-out, concrete cone or combined. For the anchors having 20 mm diameter with c/ϕ=10 and le/ϕ=10 embedded into C5 and C10 it can be seen that they cannot meet the performance level of steel yield strength. However, the same group of anchors having more than c/ϕ=10 and le/ϕ=10 show ductile failure modes mostly.

It can be said that for all diameter anchors embedded into C16 having 10ϕ embedment depth and free edge distance, the performance level is under the yield strength of steel bar. Similarly, for those having 12 mm diameter and 15ϕ embedment depth and 15ϕ free edge distance anchors performed a brittle failure mechanism.

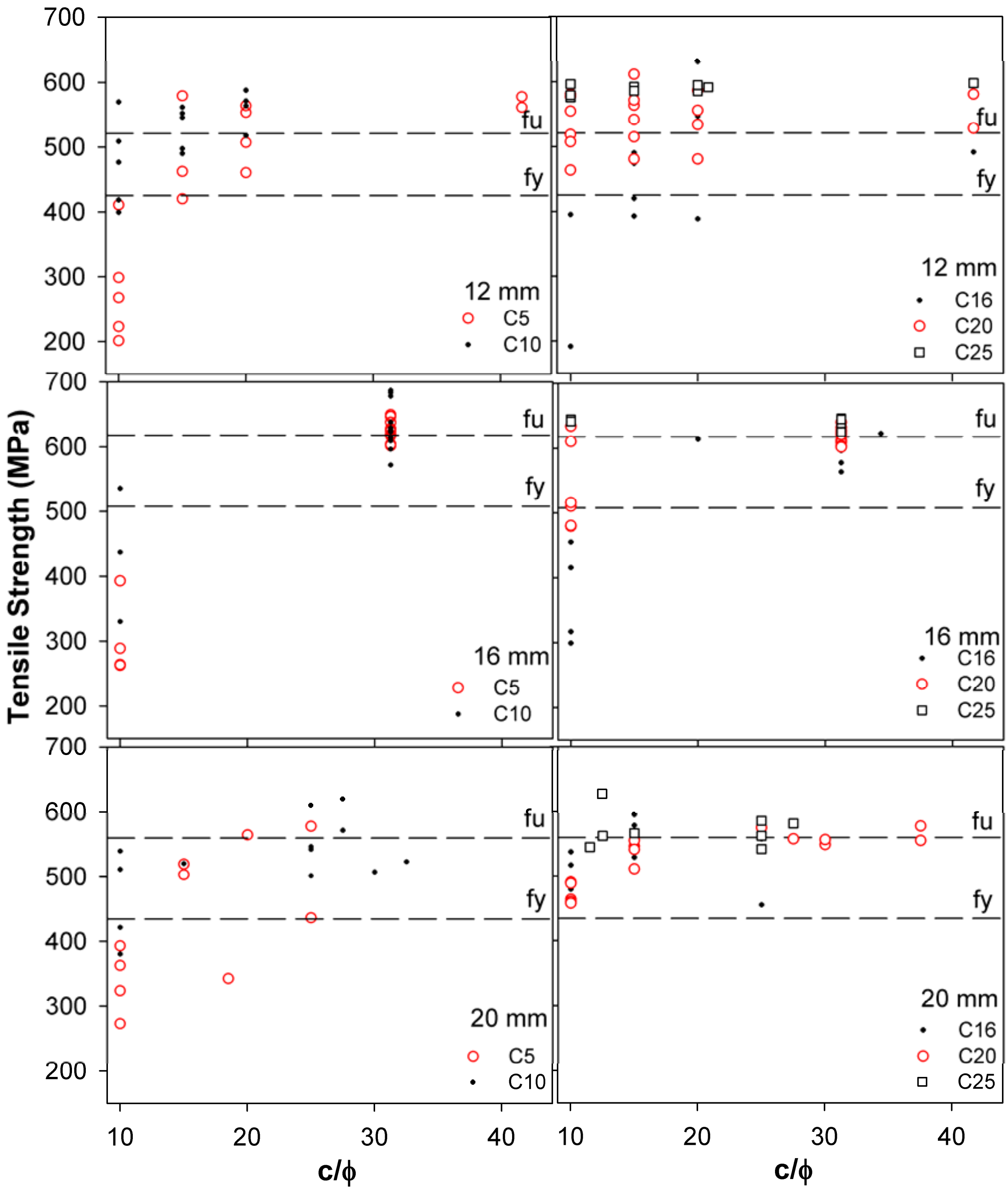

Figure 2. Tensile strength-free edge distance (c/ϕ) relations

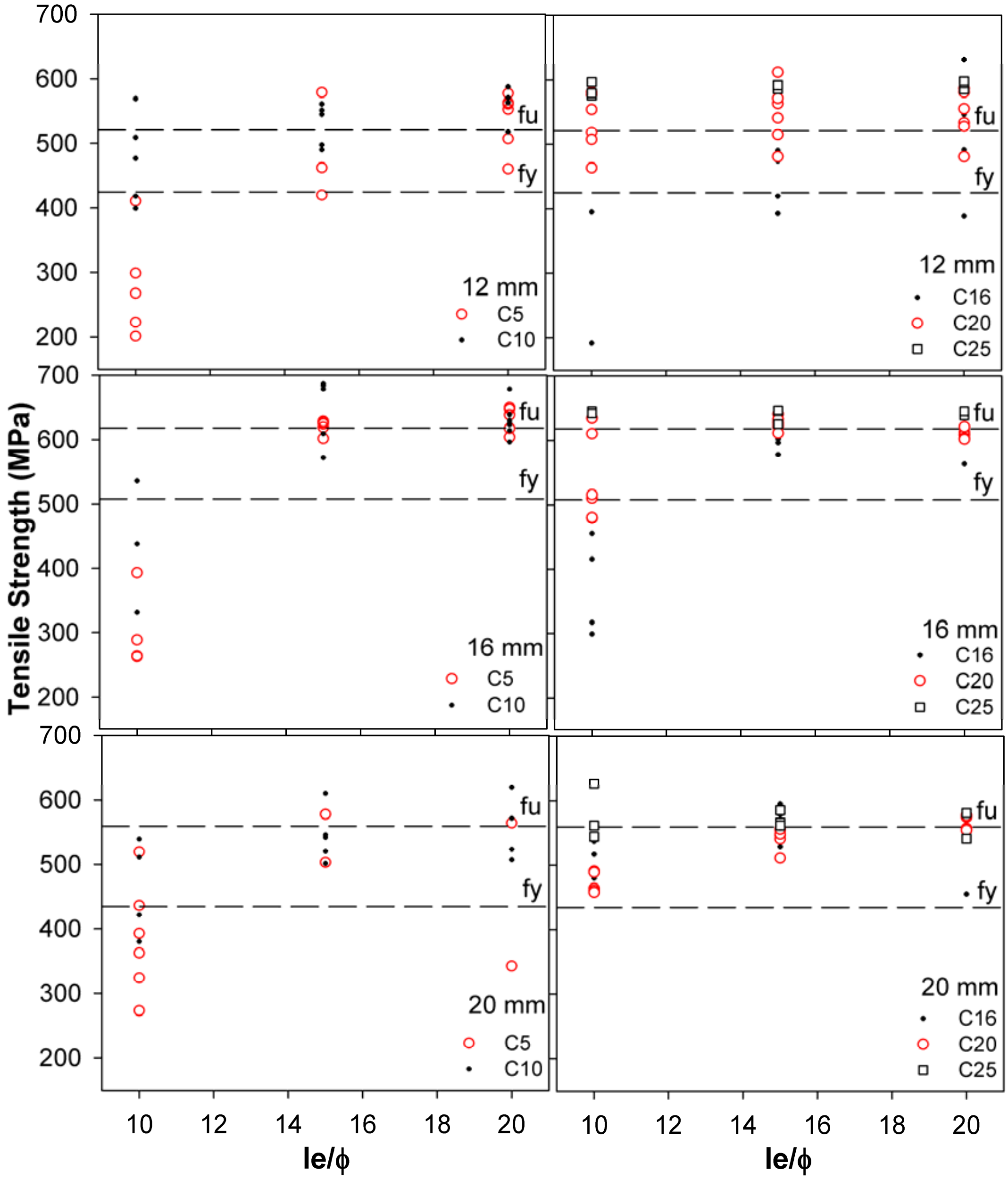

Figure 3. Tensile strength-embedment depth (le/ϕ) relations

ANCHOR DESIGN RECOMMENDATIONS

Added shear walls are commonly used in strengthening applications. Although, there are many different types, infill and external shear walls are mostly used (Figure 4-5). Anchors are vital components of shear wall strengthening. They provide a load transfer mechanism between old frame and new shear wall. As a modern seismic design philosophy, capacity design concept must be issued for anchor design.

Number of added shear walls is mostly limited and therefore a huge amount of moment are carried by these members since the needed capacity cannot be distributed to many of them in the plan. As a consequence of that, a really enormous amount of moments have to be bore by the foundation under these members. Therefore, the most important anchors are the ones embedded into existing foundation to transfer shear walls' huge moments. Here, especially the corner anchors transfer really extreme tension forces to the foundation and the design is done for yield strength (f_y=420 MPa) of steel bars used. However, according to the experiments done by the authors, embedded into 5,9 MPa, 10,9 MPa and 17,0 MPa concrete having 10ϕ embedment depth and free edge distance cannot absolutely meet that much of strength. In addition, in these applications, some foundations may have humidity problem and the geometry of the beams or dimensions are not adequate to embed anchors deeply and distant from free edge. Furthermore, while the design is being done, the amount of anchors exceeds the possible installation amount and adequate distances between each other. Then, the designer increase the diameter of them since there is no upper limit for diameter in Turkish Earthquake Code, 2007. As a result of that, a stress concentration occurs on the existing low strength concrete which yields brittle types of failure modes. Accordingly, moment transferred to the foundation becomes quite less than the capacity of shear wall.

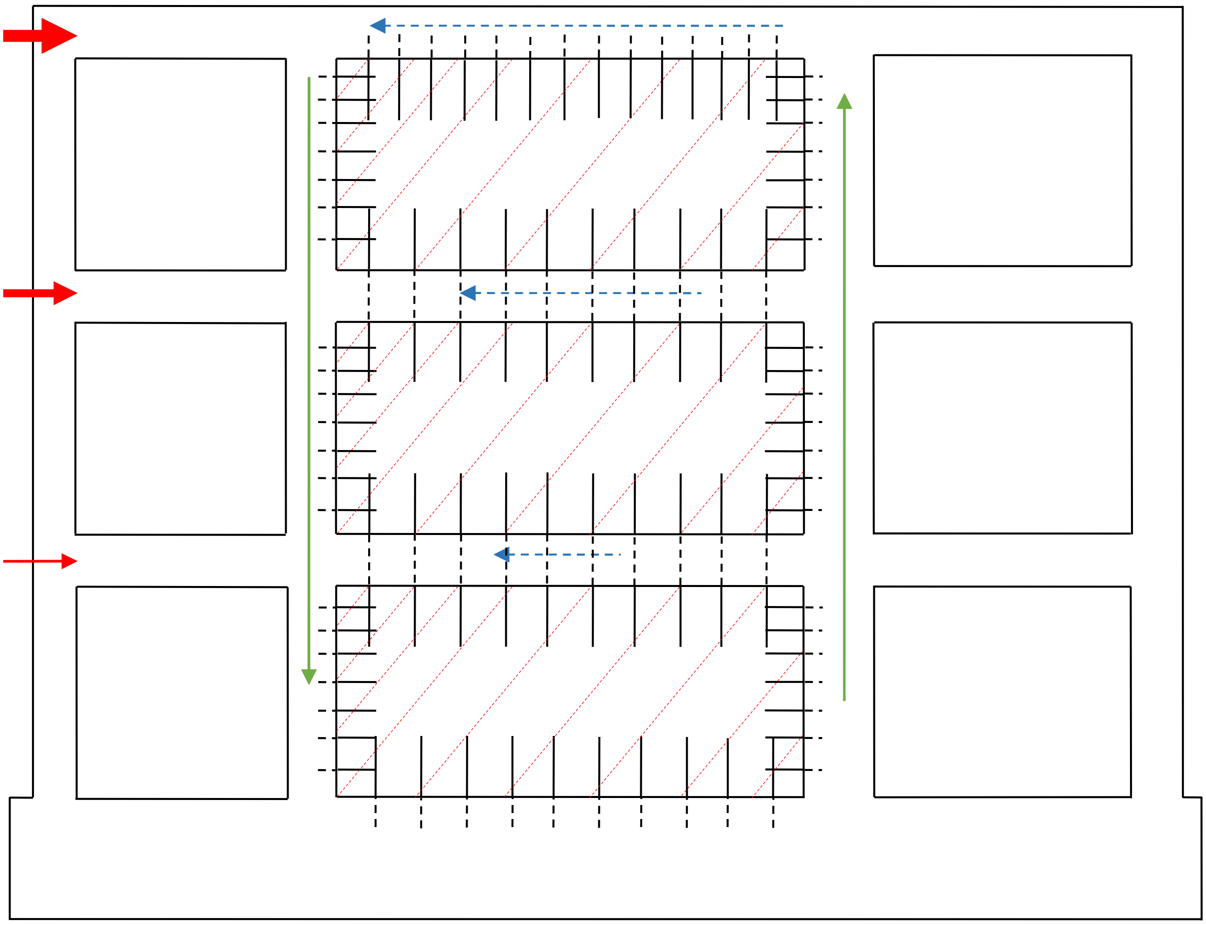

Figure 4. Infill shear wall addition to RC frame

CONCLUSIONS

The following conclusions can be drawn in the light of experimental study;

1. In order to accomplish transfer loads fully between existing and new structural members, the designer must avoid brittle failure modes; therefore, free edge distance and embedment depth should be at least 15 times bar diameter.
2. For the anchors, installed for lap splicing embedded into foundation and transferring huge amount of moments, ductile failure modes must be ensured concerning the embedment depth. For embedment depth, it is recommended to meet at least 20 times the bar diameter.
3. If an embedment depth of more than 10 times the anchor diameter cannot be achieved, ensuring a sufficient free edge distance is strongly recommended. If it is possible, this edge

distance must be 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 some other strengthening techniques should be taken into account.

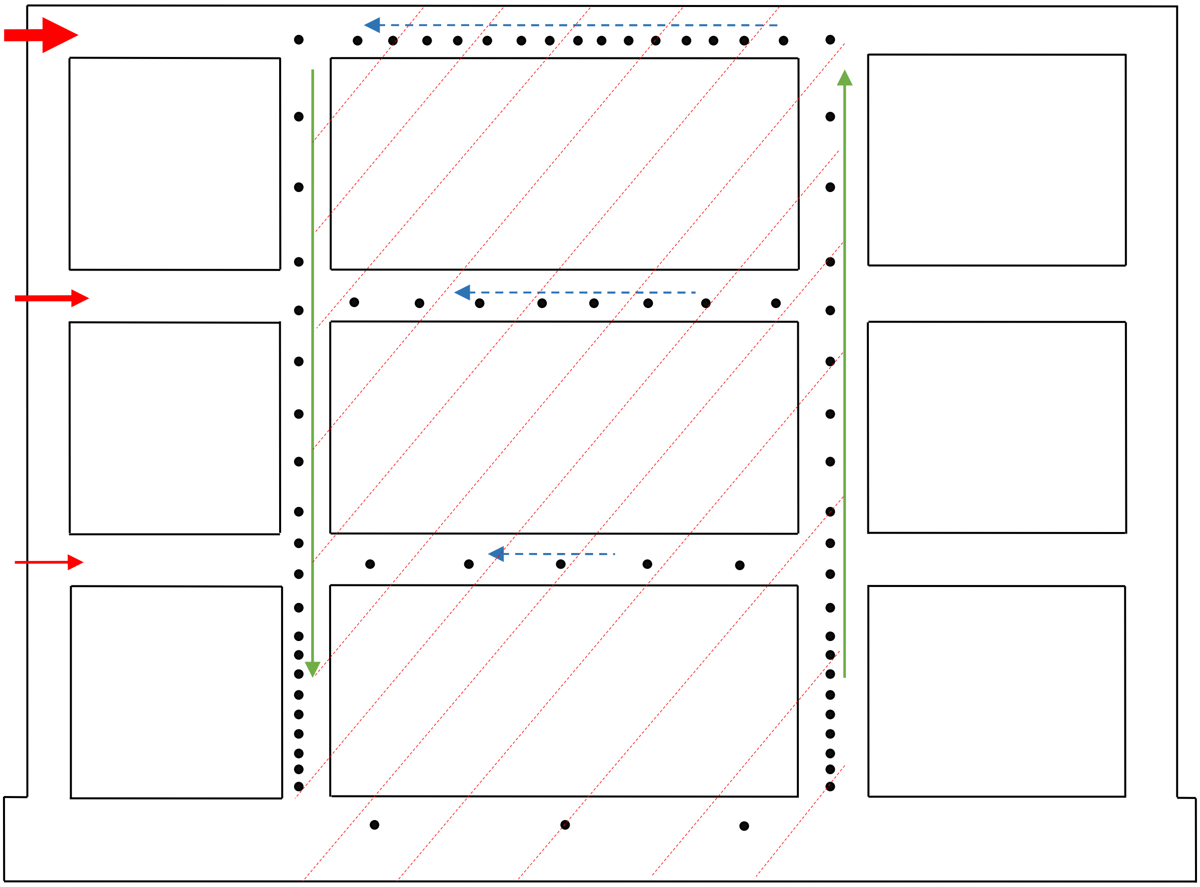

Figure 5. External shear wall addition to RC frame

4. It is recommended that choosing lower anchor bar diameters, to circumvent stress concentration problem in the concrete, can contribute to obtain ductile behavior for seismic strengthening projects.
5. The maximum distance between anchors is specified in Turkish Earthquake Code, 2007 as 40 cm; however, there is no limit for a minimum value of it. Therefore, a lower boundary must be defined and this should be restricted for each structural members discretely due to different behaviors and geometric difficulties.

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