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Application Problems of Anchor Dowels in Reinforced Concrete Shear Wall and Frame Connections

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Abstract**—**Strengthening of the existing seismically deficient reinforced concrete (RC) buildings is an important issue in earthquake prone regions. Addition of RC shear wall as infill or external walls into the structural system has been a commonly preferred strengthening technique since the Big Erzincan Earthquake occurred in Turkey, 1992. The newly added rigid infill walls act primarily as shear walls and relieve the non-ductile existing frames from being subjected to large shear demands providing that new RC inner or external walls are adequately anchored to the existing weak RC frame. The performance of the RC shear walls-RC weak frame connections by steel anchor dowels depends on some parameters such as compressive strength of the existing RC frame concrete, diameter and embedment length of anchored rebar, type of rebar, yielding stress of bar, properties of used chemicals, position of the anchor bars in RC. In this study, application problems of the steel anchor dowels have been checked with some field studies such as tensile test. Two different RC buildings which will be strengthened were selected, and before strengthening, some tests have been performed in the existing RC buildings. According to the field observation and experimental studies, if the concrete compressive strength is lower than 10 MPa, the performance of the anchors is reduced by 70%.

Keywords**—**Anchor dowel, concrete, damage, reinforced concrete, shear wall, frame.

I. Introduction

THERE are significant defects in RC structures built until 2000 in Turkey, in terms of seismic performance. Especially, in the 1999 Marmara Earthquake, a great number of casualties and economic loss occurred, associated with the critical damages in RC structures and total collapse failures [1]-[3]. Public buildings constitute the majority of the damaged structures. Because of this issue, the significant portion of the public buildings such as schools, hospitals, etc. is subjected to the seismic performance analysis.

The seismic performance analysis of the buildings, which was lastly renovated in 2007, is conducted in accordance with the Turkish Earthquake Code (TEC – 2007, hereafter) [4] regulations. Structural performance outputs of the buildings are obtained immediately with this analysis. If the performance of the structure is not sufficient for the related seismic effects, strengthening or demolition orders are given by the engineers. In Figs. 1 and 2, a seriously damaged RC building in Marmara Region of Turkey and the effect of strengthening are given, respectively.

When strengthening RC structures, the following methods are used: especially the strengthening the foundation system, RC jacketing of the columns, the wrapping of beams and columns with carbon-fiber-reinforced polymer (CFRP), and adding additional RC infill shear wall. The method to be used varies according to the structural performance, damage distribution, and damage type. The most preferred methods are adding additional RC shear wall, jacketing of the columns as RC, strengthening the base system, in particular. The biggest disadvantages of these methods are the architectural concerns, the changing function of the structure, and the unavailability of the structure for a long period of the time. Also, the cost of reinforcement to the cost of reconstruction of RC structure must be calculated proportionally.

Fig. 1 A seriously damaged RC building in Marmara region

During the strengthening process, the new RC elements must be attached to the existing building accordingly, and they should be ensured to work together. For this reason, the mechanical anchorages applied to the existing structure are often preferred in practice. Mechanical anchorages are attached to the existing building with the chemical adhesives, and later, the reinforcing elements are combined with these anchorages and cast. Therefore, the performance of the mechanical anchorages also indicates whether the strengthening works effectively or not.

In this study, especially the following issues are discussed: the matters to be considered during the application of mechanical anchorages on the combination of RC shear wall - current weak frame, the problems that occur in the applications, and the factors that affect the anchorage strength. In the present study, examples are given from a sample

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strengthening project [5]. The epoxy quality and concrete quality elements which are affecting especially the anchorage performance are discussed over the example project.

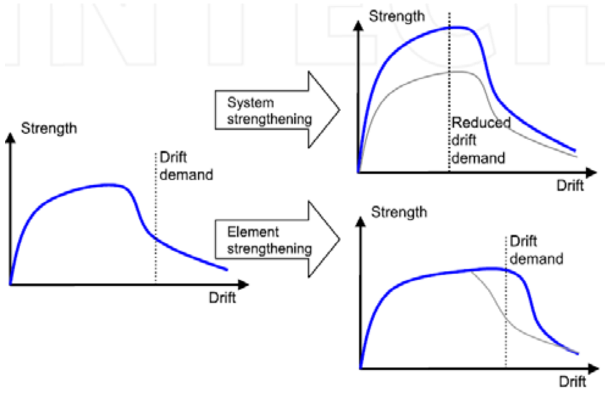

Fig. 2 Effect of strengthening [6]

II. Factors Affecting the Anchorage Strength

The connection of the structural components with RC elements existing in the structure, is provided with the anchorages. Most commonly used anchorage types are chemical anchorages, for the reason of the application convenience and low costs. To ensure that the concrete and the fittings work together in RC structures, the adherence between the concrete and the fittings should be fully provided. To preventing the anchor from stripping out from the concrete, it should be extended as long as the embedment length in the concrete. It is not practically possible to place the fitting dowels inside the existing concrete for the purpose of repairing and reinforcing, with the lb embedment length given in the Turkish Building Code-2000 (TBC-500-2000, hereafter) [7].

According to the codes, anchorage can be achieved by extending the reinforcing bars a distance of lb beyond the point where the stress in the bar is maximum. This length is defined as the development length and it can be calculated as:

$$l_b=0.12\ (f_{ctd}/f_{yd})\ \phi \geq 20\ \phi \quad (1)$$

f_{yd} is the design yield strength of bars, f_{ctd} is the concrete design tensile strength, and ϕ is the diameter of the bars. Thus, providing the necessary embedment length in an applicable short distance is only possible with the subsequent application of anchorages. Anchorages transfer the tensile loads to the attached concrete with the help of adherence stresses which occur through the attachment depth of the anchorage.

The adherence in chemical anchorages is basically subject to the a) to friction between the concrete and the epoxy, b) to friction between the steel and the epoxy, c) to the chemical bond between the concrete and the epoxy, d) to the chemical bond between the steel and the epoxy, and e) to mechanical gear force over the steel. The factors affecting the anchorage strength are highly variable as;

1. The main factor is the type of the binder. In the studies, it is shown that, the chemicals used in the anchorage placing, may increase the anchorage performance two or three times [8], [9].
2. Instead of the compressor used for cleaning the anchorage hole, wet cleaning method is sometimes preferred. In this case, the inside of the hole must be completely dry during the application of anchorage. It has been observed that the bond strength formed during the anchorage applied on wet (humid) surfaces is an average of 77% of the reference bond strength found on dry and clean surfaces, and the bond strength formed during the anchorage applied on wet surfaces is an average of 43% of the reference bond strength [10].
3. The cleaning of the anchorage hole is extremely important for the behavior of the chemical, which will bind the anchorage [10]. The inadequate cleaning of the hole leads to the decrease of the anchorage strength, down to 30% in many products.
4. The location of the anchorage is especially effective in the collapse mode of the anchorage. If the anchorage is close to the free edge, a collapse failure may occur by the crack of the concrete base. If the anchorage reaches to its capacity due to the collapse occurred on the concrete under the axial tension, the cracks formed in the concrete will affect the capacity of the adjacent anchorages [11], [12]. The cracks, which were formed when insufficient distance is left between the anchorages, may reduce the capacity of neighboring anchorages. The splitting of concrete occurs when the size of concrete is small, the anchor is installed close to an edge, or a line of anchors is installed in close proximity to each other [13].
5. The ultimate capacity of the chemical anchorages increases as the compression strength of concrete increases. Therefore, the compression strength of the concrete where the anchorage is placed is one of the important factors that affect the anchorage collapse failure load.
6. The collapse load increases as the anchorage embedment length increases. After a certain anchorage depth, the impact of the depth increase to the anchorage capacity begins to decrease. The non-linearity of the relationship between the anchorage depth and the anchorage capacity is the indication that shearing stress that occurs through the anchorage depth is not uniformly distributed. It has been observed that, while the load carrying capacity of anchorages increases with the placement size, this increase is not always linear.
7. Increasing the curing period significantly increases the bond strength of the anchorages [10].
8. Since the increase of the anchorage diameter causes the increase of the surface area where the adherence stress occurs, it affects the anchorage capacity [8]. In the studies carried out, it has been found that the fittings with larger diameters can carry greater load.

III. Anchorage Problems in Practice: Case Studies

Structural defects in the existing RC structures built in Turkey, especially before the year of 2000, are seen quite often. It can be said that the main reason for this is, the control mechanisms are not provided as much as the required levels. The Earthquake Regulations of Turkey (TEC-1975) [14] which came into force in 1975, the revised Earthquake Regulations (TEC - 1998) [15], contain extensive and detailed information compared to the international regulations of the same period. Despite this fact, the main problem is the construction deficiencies (mis-construction of the structures), while their projects were appropriate with the regulations. The most important indicator of the lack of inspections is the very low concrete compression strength of RC structures, especially the ones built before 2000. There are many publications proving that the existing average concrete compression strength in the public buildings is 7 MPa or lower.

The building data given in Fig. 3 below are from a school building in Turkey, which is planned to be reinforced. The structure consists of two blocks. Block A is composed of Ground Floor + 2 Normal Floors, and Block B is composed of Basement + Ground Floor + 2 Normal Floors. The structure was completed in 1978. The structure is in first seismic zone according to the zoning map of Turkey. The load carrier system is a RC frame system. According to the concrete core samples taken from the load carrier system of the structure, the average concrete compression strength has proven to be 5.2 MPa (52 kg/cm^2). Based the analysis carried out in accordance with the TEC-2007 [4] principles, a strengthening project was prepared since the current situation remains inadequate for the seismic performance.

Fig. 3 Weak framed typical school building in Turkey

The strengthening is constituted of two parts, namely superstructure and infrastructure. Since the single foundation forming the infrastructure was insufficient, the foundation system is completely strengthened. As for the superstructure, due to the lack of stiffness, RC shear wall added in both two directions on the carrier system and the columns in the related were jacketed with RC. According to the analysis carried out after the strengthening, the structures have reached to the desired theoretical performance level analytically. In Fig. 4, the first story plan of the building is given. In the plan, red and blue labels show the added strengthening member such as shear walls and column jacketing to the weak RC frame. The foundation system is proposed to be completely strengthened in the project.

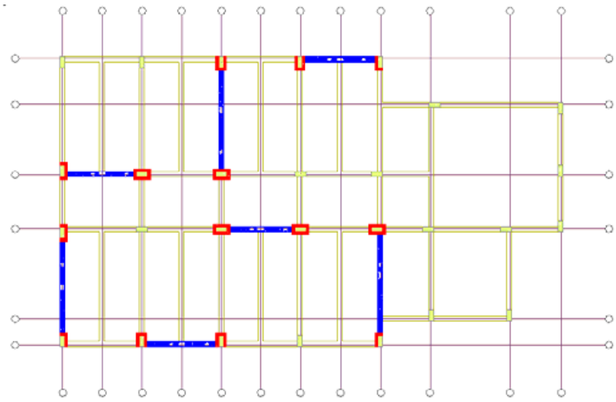

Fig. 4 The first story plan of the strengthening building

It is expected that, since the concrete strength of the structure is too low, some problems will occur related to the application of the anchorages and the anchorage performance mentioned in the project. The proposed anchorage details of shear wall-frame connection are given in Figs. 5 and 6. Also a typical anchorage application of a foundation is also given in Fig. 7.

The greatest expected risk is the anchorages stripping out from the concrete before reaching shear and bending the capacity of a new added member. For this reason, pull-out tests were carried out on the anchorages. In this experiment, 12 ϕ20 anchorages were tested. Firstly, holes with 24 mm diameter were drilled, they were cleaned with compressed air and later a brand "A" epoxy filled the hole by squeezing the anchorage bars.

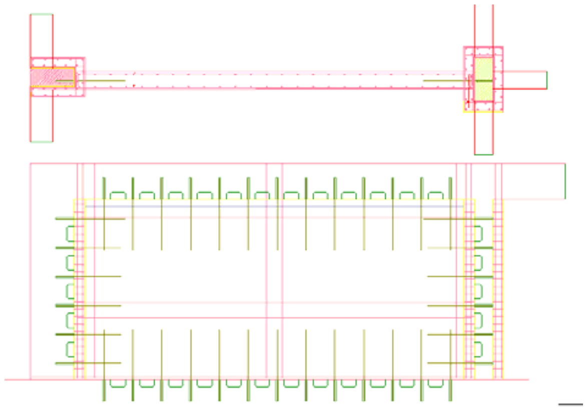

Fig. 5 Typical shear wall-frame connection anchorage details and section in project

The sample anchorage bars are inserted by rotating, to the hole filled with the brand "A" epoxy. After the placing, one day later, the pull-out test was conducted. Some steps of the operation are given in Fig. 8. The test results showed that all fittings were stripping out before reaching to the required strength. According to the tests carried out, since the concrete strength is considerably low in this building, the operating of the steel anchorages placed on both foundation and beams-columns at the desired capacity will be prevented. Anchorages will be stripped out before reaching the capacity.

As for the tests carried out in another building given in Fig. 9, in Turkey with the same compression strength (average value of the compressive strength of concrete is 5.5 MPa), a brand "B" epoxy was used instead of the brand "A" one. The anchorage placement procedure is the same as the first example. As a result of the anchorage placing operation, it has found that the anchorages were able to hold the load to the desired capacity.

Fig. 6 A typical anchorage details in RC shear wall and frame connection

Fig. 7 A typical anchorage details in RC foundation connection

Fig. 8 Anchorage pull out test

Fig. 9 Weak framed typical official building in Turkey

IV. Results and Findings

In Turkey, chemical anchorages are often used in the repairing and strengthening of the existing RC structures, because of their quick and easy-to-apply attributes. It can be seen that the repairing and strengthening applications began to be implemented seriously and in more detailed manner, after the recent earthquakes. New chapters were created for this issue in TEC - 2007.

Many buildings which have the equal values of the sample building's concrete compression strength discussed in this study, are waiting to be strengthened. During the strengthening of the buildings, the low concrete compression strength of the existing building on which the new RC elements will be applied, will directly affect the performance of the anchorage to be placed. Moreover, the anchorage performance is a factor on the reinforced building's general performance.

The anchorage strength may vary depending on several factors. It is believed that the most important of these parameters is the quality of the epoxy material used. In this study, the pull-out tests of the anchorages which are placed on the concretes of the buildings, with the similar strength of the selected sample building's (approximately 5-5.5MPa), were carried out. According to the tests, it has been observed that in the anchorage application where the first type of (A) epoxy was used, the anchorages were stripped out of the concrete. As for the pull-out experiment where the second type of (B) epoxy was used, it has been observed that the anchorages were operating with 90% capacity (Figs. 10 and 11). In the light of these results, it is seen that the epoxy choice for the strengthened projects, which initially affects the anchorage capacity, is of critical importance. The quality, composition, and the type of the epoxy to be used on the anchorage placing, must be submitted like details of an in the strengthening projects.

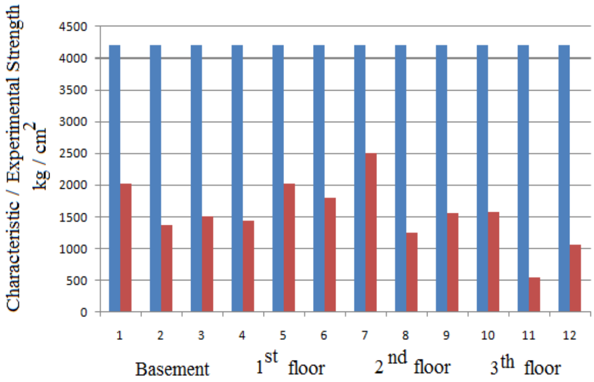

Fig. 10 Pull-out test results for brand "A" epoxy (The average concrete compressive strength is 5.2 MPa)

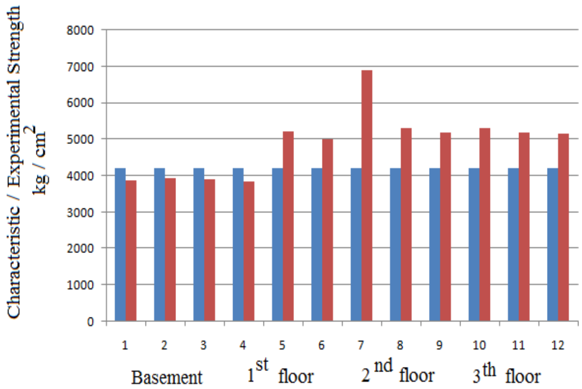

Fig. 11 Pull-out test results for brand "B" epoxy (The average concrete compressive strength is 5.5 MPa)

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