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Research Paper

A Study on the Evaluation of Building Reinforcement Decisions from the Perspective of Homeowners

Hakan AKBABA
Uşak University, Banaz Vocational School, Department of Construction, Uşak, Turkey
**Corresponding Author*

ABSTRACT:
Following the major earthquakes that occurred in our country in the recent past, significant regulatory changes/updates have been implemented, particularly in the areas of new building design, construction, and supervision. These changes are expected to result in newly constructed buildings being more earthquake-resistant compared to older structures. This situation raises the question of how earthquake-resistant buildings constructed before the current regulations (before 2000) are for homeowners and residents (tenants). The answer to this question can be determined after conducting a building earthquake performance analysis.

This study references the reinforcement cost and reconstruction cost as effective factors in the decision to reinforce or demolish/rebuild residential buildings that did not perform adequately after seismic performance analysis. The study evaluates the costs of reinforcement or demolition/reconstruction decisions for apartment buildings based on the number of floors, considering the applicable legislation from the perspective of floor owners. Using 3D models, the study calculates the costs of pure reinforcement, building maintenance/repair (major maintenance and repair) renewal costs, rental and relocation costs incurred during the reinforcement process, and demolition-reconstruction costs were calculated for 3-, 5-, and 7-story apartment buildings with similar characteristics, based on the 3D models created, revealing the effects of factors influencing the decision-making process.

KEYWORDS: *Residential Buildings, Earthquake, Seismic Retrofitting, Cost*

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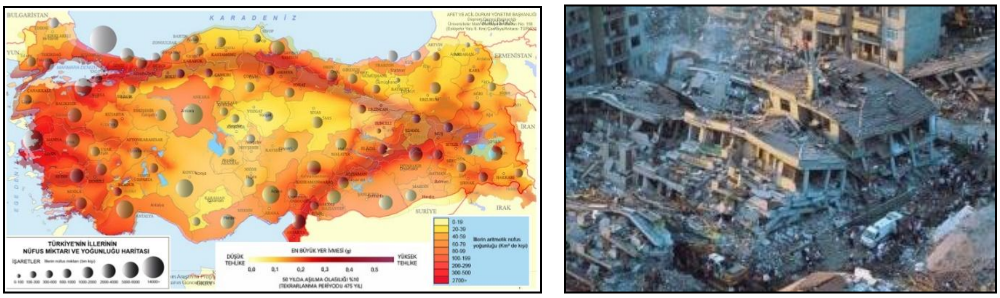
I. INTRODUCTION

Unfortunately, earthquakes cause significant loss of life and property. Besides the social and economic decline that follows devastating earthquakes, individuals also experience difficult-to-overcome psychological problems [1]. 92% of Türkiye's territory lies in earthquake zones, and its unique population density and corresponding construction activity are particularly concentrated in the most earthquake-prone zones[2,3].



(a) (b)

Figure 1. Türkiye population density map (a), Building damage after earthquake (b).

It is clearly evident from the damage and destruction resulting from natural disasters that a large portion of the existing building stock does not meet the desired standards in terms of earthquake resistance;

these buildings lack adequate electricity services, necessary inspection services, and are far more numerous than anticipated due to illegal and unlicensed constructions [4].

In our country, the regulations that establish the necessary rules and minimum conditions for the design and construction of all official and private buildings and building-type structures, or their sections, that will be rebuilt, modified, or expanded, as well as for the assessment and reinforcement of the performance of existing buildings under seismic loads, were first introduced in 1962 with the Regulation on Buildings to be Constructed in Disaster Zones (ABYYHY), 1968 (ABYYHY), 1975 (ABYYHY), 1997 (ABYYHY), 2006 Buildings to be Constructed in Earthquake Zones (DBYYHY), 2007 (DBYYHY), and finally the Turkey Building Earthquake Regulation (TBDY-2018), which came into effect in 2019. When the regulations are evaluated, it is understood that each regulation is more comprehensive than the previous one and contains significant changes in terms of structural element characteristics (cross-section, material, structural irregularity, ductility, etc.) [5, 6, 7].

The components of earthquakes can be improved by repairing existing buildings and enhancing their performance through restoration and remodeling applications, thus extending their service life. Especially robust performance depends on the material properties of the load-bearing system, and there is also the possibility of a building being demolished and rebuilt when its service life is almost exhausted.

After 50-60 years of service life, many existing buildings meet the energy-related requirements of current regulations – and their robust/seismic performance – become insufficient. Approximately 35% of EU buildings are over 50 years old, almost 75% of the existing buildings under construction lack energy efficiency, and 75-80% of these will still be in use by 2050 [8, 9]. The efficiency service life value for a building is considered to be 50 years. During this period, the rapid progression of physiological processes leads to changes in the expected performance values of buildings serving the public [10].

It is generally accepted that the age of a building leads to a decrease in the wear and tear and fatigue performance of its structural elements. On the other hand, this general fatigue performance of the building may differ between the level of reflection of spatial qualities (%) and the fatigue performance level perceived by the student (%). The relationship between building age and fatigue performance (material) is shown in Figure. 2. Depending on the physically chosen load-bearing systems of the building, it lasts at least 50 years. The new building continues to be subject to aging and deterioration throughout its lifespan. Internationally, throughout the life cycle of a building, the value of the building and the demolition cost exceed the value of the land due to deterioration and aging, causing the building to become obsolete. In this case, demolition occurs as physical and aesthetic renovations cannot be carried out, and the land is valued with a new building [11, 12].

Over time, the economic and functional values of buildings may decrease due to physical and environmental effects, human-induced interventions, legal requirements, etc. Consequently, two options arise for physically deteriorated, low-performing buildings. The first option is to demolish the building. The other option is to improve its performance by strengthening the necessary load-bearing elements of the structure, i.e., strengthening. If the earthquake performance analysis of the buildings in question indicates that the building needs to be strengthened in general, system-based or element-based strengthening methods can be selected. The most frequently applied methods are adding shear wall elements to the building, bonding steel plates to the side surfaces of the load-bearing elements, jacketing, fiber-reinforced polymer wrapping, etc. The aim of strengthening is to bring the capacity of the building's load-bearing elements, especially the lateral rigidity capacity, to a sufficient level, thereby providing the performance levels stipulated in the regulations.

From the perspective of homeowners and residents (tenants), the structure used or owned meets the provisions of the legislation and regulations regarding the construction program, but the process of determining the standard performance regime is evaluated according to the latest legislation and registration rules. Following the Düzce and Gölcük earthquakes of 1999, the Buildings Regulation (DBYYHY) of 2007, which includes fracture changes, and the currently existing Turkish Building Earthquake Regulation (TBDY-2018) are used to conduct performance analysis, considering the presence or absence of structural elements. This provides a good assessment of the potential costs involved, as well as the impact on the decision to strengthen or demolish the building [5,8].

In addition to technological advancements, studies in the field of civil engineering offer a wide variety of seismic improvement techniques and intervention methods aimed at increasing earthquake safety during disruptions. Considering the volume of these structures and future demand, density concerns are a primary factor, and the costs of strengthening interventions, not only from an initial perspective but also in terms of greenhouse gas emissions over the service life, lead to increased cost savings in living expenses.

Undoubtedly, in events like earthquakes, which can be devastating and cause property damage, the most significant benefit/cost factor is the human loss and, consequently, the number of people residing in the structure [13]. The earthquakes occurring in the region and worldwide, the recurrence interval of earthquakes, temperature, and the resulting loss of life and property are all aspects that need to be considered. Testing the earthquake resistance of existing reinforced concrete structures and addressing any necessary demolition or termination is crucial.

Considering the scale of the existing building stock and the economic and social resources involved, it is not feasible to conduct this assessment all at once. A detailed examination, taking into account the large number of buildings, ensuring the visibility of public buildings, and implementing comprehensive assessments with the necessary parameters are vital for minimizing loss of life and property during an earthquake.

II. EARTQUAKE AND REINFORCEMENT

Studies show that, in addition to all these physical characteristics, the soil properties of the building and its distance from earthquake zones (fault lines) are also effective in determining the performance levels of buildings [14,15].

Building Performance Levels for Building Structural Systems Under Earthquake Effect (TBDY Section 3.4) as an evaluation criterion in the design or strengthening phase of existing buildings:

- Continuous Use (CUS) Performance Level: This performance level corresponds to a situation where no structural damage occurs in the building's load-bearing system elements, or the damage is negligible.

- Limited Damage (MD) Performance Level: This performance level corresponds to a damage level where limited damage occurs in the building's load-bearing system elements, in other words, where nonlinear behavior is limited.

- Controlled Damage (CD) Performance Level: This performance level corresponds to a controlled damage level in the building's load-bearing system elements that is not very severe and is mostly repairable, in order to ensure life safety.

- Prevention of Collapse (PC) Performance Level: This performance level corresponds to a pre-collapse situation where severe damage occurs in the building's load-bearing system elements. Partial or complete collapse of the building has been prevented.

For existing buildings, performance targets and performance evaluation/design strategies according to seismic design classes are determined separately according to the building's purpose/type of use; Buildings Requiring Post-Earthquake Use (hospitals, schools, manufacturing and marketing services, etc.), Buildings Where People Are Present for Short Periods and in High Concentrations (shopping malls, cinemas, theaters, concert halls, places of worship, etc.), and Other Buildings (residences, workplaces, etc.).

To determine the seismic performance of a building, specific information about its current condition is required. The scope of information to be collected from existing buildings regarding structural system characteristics, dimensions, materials, and details is detailed in the regulations. Using this information, a structural model of the building is created, and the internal forces and deformations that will occur in the elements under seismic effects are calculated. If the building and its load-bearing elements have a sufficient performance level for the seismic levels specified in the regulations, strengthening the building is not necessary. There is no problem with using it in its current state. However, based on the determination of the building's seismic performance levels, interventions aimed at increasing the capacity of the necessary structural elements by using various strengthening methods to bring the structure to the predicted safety/performance level are defined as structural strengthening.

In the literature, processes applied to undamaged structures or structural elements are generally categorized as "strengthening," while those applied to damaged structures or structural elements are defined and classified as "repair" [16, 17]. Reinforcement methods are generally examined under two categories. When the structural performance expected from the building cannot be met with the existing condition, one of the strategies of "element-based strengthening" or "system-based improvement" is applied. Methods can be applied together to elements with certain parameters and to certain systems within the system.

Figure 2. Images for the reinforcement application [18].

For an existing structure, an initial preference might seem easy, assuming sufficient structural safety and the absence of any repairs or improvements, etc. However, it must be accessible only after all doubts are dispelled and it is deemed completely reliable. The results are obtained after a performance analysis of the building's current condition, followed by an evaluation by a team of experts. If strengthening the building is deemed necessary, a strengthening project is prepared, and the final decision is usually based on an economic assessment. If the building is privately owned, the final decision rests with the property owners. In cases of disagreement among the co-owners, the competent court may make a decision based on the provisions of the Civil Code, the Condominium Law, and Law No. 6306 on the Transformation of Areas Under Disaster Risk [19, 20].

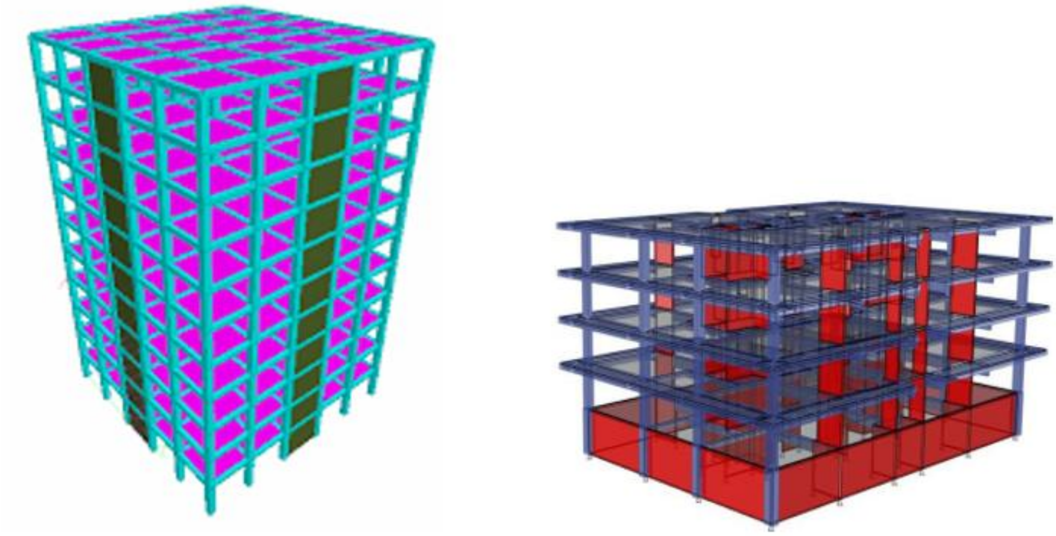


Figure 3. 3D modeled building visuals related to reinforcement projects [21].

III. MATERIALS AND METHODS

The Turkish Republic Ministry of Urbanization, in its assessment and based on literature studies, states that it is economically feasible to terminate a project if the Building Reinforcement Cost/Demolition + Reconstruction Cost exceeds 40%, and this ratio is understood in terms of importance, completion status, and historical and identity-carrying properties [22]. Therefore, considering the age of the building, the zoning status of the land, the general condition of the building, etc., the reconstruction cost for building renovations should be

10%, 20%, 30%, 40% (reference values), 50%, and the components of the property owners should be separated from other components throughout the working period.

In this study, residential buildings were modeled in 3D as 3-story, 5-story, and 8-story apartment buildings. The 3-story building was modeled with a base area of 200 m^2 (2 columns per floor, 100 m^2 gross per apartment), while the 5 and 8-story buildings were modeled with a base area of 400 m^2 (4 columns per floor, 100 m^2 gross per apartment) Figure 4.

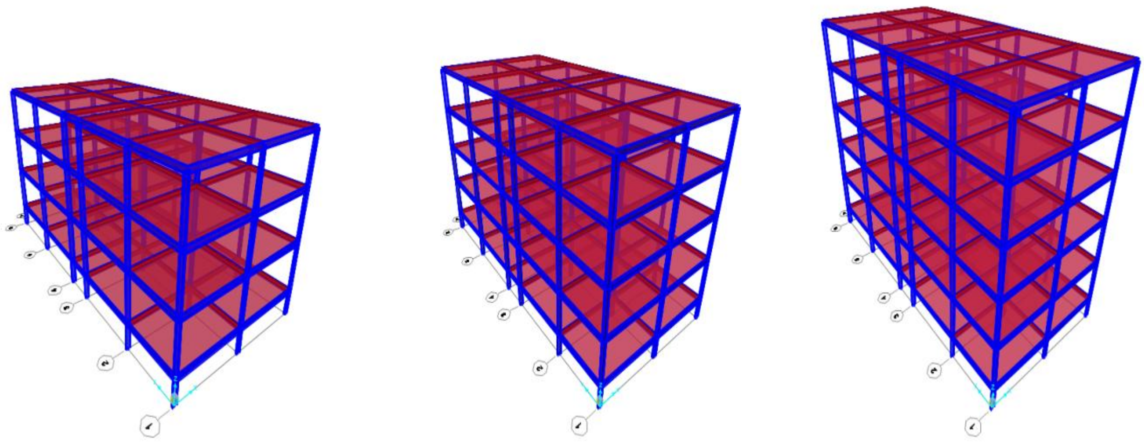


Figure 4. Models of 3-story, 5-story, and 8-story apartment buildings.

The cost of reinforcement or demolition-reconstruction, including the cost of moving belongings and rent for apartment owners, is distributed based on the region, city, district, and neighborhood/district of residence. To minimize this variation, the approximate construction cost values used as a reference for apartment buildings in Uşak, Turkey, are determined by the unit area cost (BM) TL/m^2 table of architectural services, as defined in the "Circular on Approximate Unit Costs of Buildings for 2025 to be Used in the Calculation of Architectural and Engineering Service Fees" published annually by the Ministry of Environment and Urbanization. This table is used for apartment buildings (buildings above 21.50 m - three floors and above, including 21.50 m) [22].

When the demolition cost of the modeled buildings increased, the unit prices of the Ministry of Environment and Urbanization and the State Hydraulic Works (DSI) for 2025 were used as the item cost of "Demolition of reinforced concrete or unreinforced concrete structures using explosives/m^3 (52.165.1005)". However, this value can be significantly adjusted by factors such as the amount of rubble (iron and scrap material) obtained from the demolition work and the distance to the rubble/excavation site. In this way, a performance reference was taken with a price level that could have a 56% change in rubble cost/demolition cost recorded in demolition tenders conducted by the Public Procurement Authority (KİK). In addition, the housing (rent) costs required for resettlement and reconstruction for the demolition or reconstruction of the residential buildings in question were given as a current approximate cost reference (Table 1).

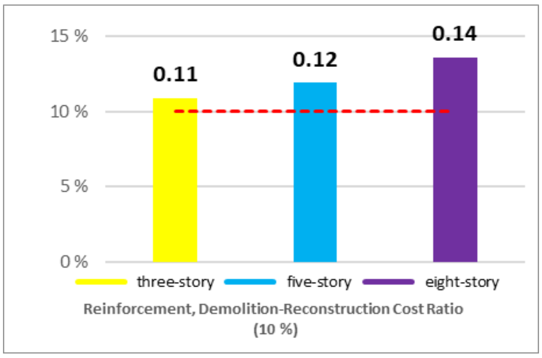
Table 1. Reference values used in the approximate cost calculation.

Reference Values for Modeled Apartment Buildings	
Building Type	Apartment / Residential
Number of Floors	3, 5 ,8
Floor Height	2.7 m
Building Footprint	200 m^2, 400 m^2, 400 m^2
Apartment Area (gross)	100 m^2
Reinforcement / (Demolition + Reconstruction) Ratio	10 %, 20 %,30 %,40 %,50 %
Relocation Cost / (Apartment x 2)	24.000 TL
Housing Cost / Apartment	15.000 TL
Reinforcement Work Duration	3~8 month
Demolition + Reconstruction Work Duration	12~24 month

The study models a total of 15 buildings: five for the "Reinforcement/(Demolition + Reconstruction) Ratio" variable and three for the number of floors variable, all apartment buildings. For each building, the approximate cost per apartment value required if the " Reinforcement" option is chosen and the approximate cost per apartment value required if the "Demolition + Reconstruction" option is chosen were determined. The variation in the approximate cost depending on the number of floors was shown for Reinforcement/(Demolition + Reconstruction) Ratios of 10%, 20%, 30%, 40% (reference value), and 50%, respectively.

IV. FINDINGS AND DISCUSSION

This study focuses on cost-related factors influencing the decision to reinforce or demolish and rebuild residential buildings requiring seismic strengthening. For apartment buildings, the study examines the cost of reinforcement or demolition/reconstruction based on the number of floors, considering current legislation from the perspective of apartment owners. The obtained values are presented practically below. Simulated residential buildings are designed with two apartments per floor and a building footprint of 200 m². Using 3D models, the pure reinforcement costs, renovation costs arising from building maintenance/repair (major maintenance and repair), rental and relocation costs incurred during the reinforcement process, and demolition/reconstruction costs are calculated for similar 3, 5, and 7-story apartment buildings, revealing the impact of factors affecting the decision-making process. Changes in building footprint and number of floors, which are fixed and variable values as mentioned above, and the reinforcement cost are shown for 10%, 20%, 30%, 40% (reference value), and 50% reinforcement/(demolition + reconstruction) ratios, respectively, in the following cases.



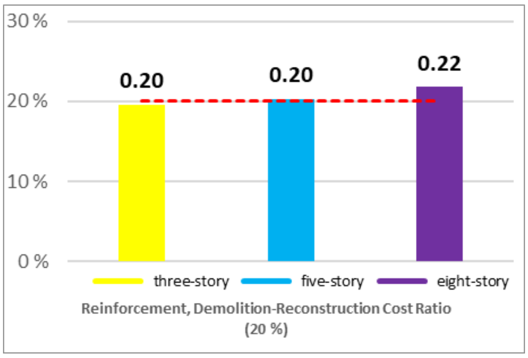
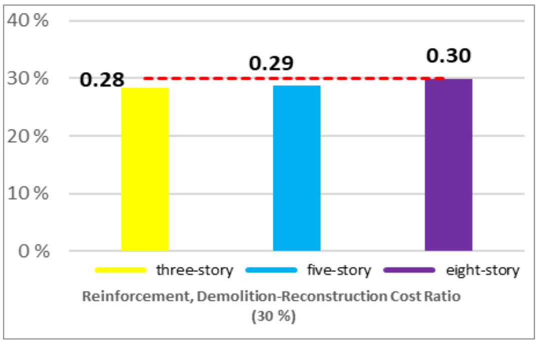


Figure 5. Reinforcement, Demolition-Reconstruction Cost Ratio (10% and 20%)



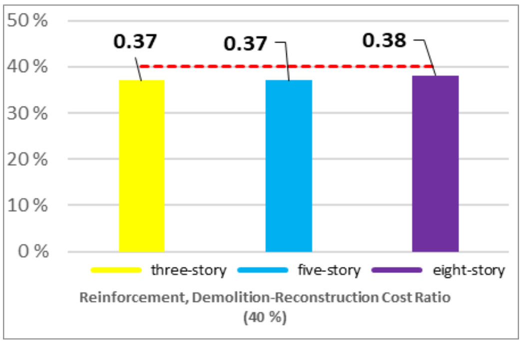


Figure 6. Reinforcement, Demolition-Reconstruction Cost Ratio (30% and 40%)

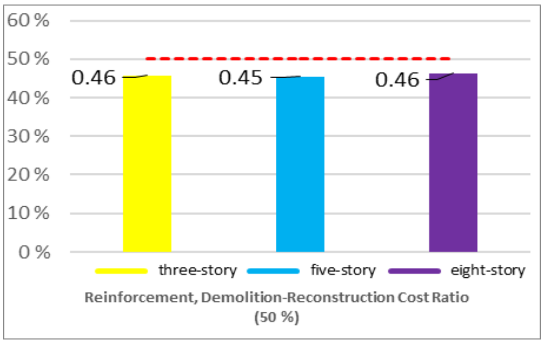


Figure 7. Reinforcement, Demolition-Reconstruction Cost Ratio (50%)

For buildings where the ratio of reinforcement cost to reconstruction cost is 10%, taking floor height as a reference and factoring in the accommodation and transportation costs that must be borne during the reinforcement period, the ratio of reinforcement cost to demolition and reconstruction cost is determined to be 0.11 for three-story buildings, 0.12 for five-story buildings, and 0.14 for seven-story buildings. A similar increase was observed in the cost analysis conducted for buildings where the ratio of reinforcement cost to reconstruction cost is 20%.

In buildings where the increase in the ratio of reinforcement cost to reconstruction cost is 40% or 50%, it has been determined that the total cost ratio to be borne during the reinforcement period decreases depending on the floor height. For 3-story, 5-story, and 7-story residential buildings, the ratio of reinforcement/demolition - reconstruction cost ratio for 3-story, 5-story, and 7-story residential buildings was determined to be an average of 12% for a 10% value, an average of 29% for a 30% value, and an average of 46% for a 50% value, compared to the ratio calculated for the total cost values that must be borne during the seismic reinforcement period required for the building. For normal-story residential buildings, it is observed that the cost value to be incurred during the reinforcement period decreases as the number of stories increases.

V. CONCLUSION

In building reinforcement applications, the general aim is to improve the load-bearing capacity (load-carrying strength), rigidity, ductility, and stability of the building's structural elements, or several of these properties, beyond their current state, thereby bringing them up to the level required by the relevant regulations. This situation generally results in high costs, which are undesirable for building owners.

The study created a data set that includes demolition, accommodation, and transportation costs as effective factors in the decision-making process for seismic reinforcement of residential buildings or in the decision to demolish/rebuild. From the perspective of building owners, the change in the cost factor, which is the most important parameter for the reinforcement decision, depending on the number of floors of the building has been revealed.

In residential buildings, it is considered that, in addition to the reinforcement cost, the most direct costs such as relocation, accommodation, major/minor maintenance and repair, demolition, etc., should also be taken into account. For 3-story, 5-story, and 7-story residential buildings, the total costs that must be borne during the seismic reinforcement period were calculated for the Reinforcement/ (Demolition + Reconstruction) Ratio for the 10% value shows an average increase of 20%, the 30% value shows a decrease of 3%, and the 50% value shows an average decrease of 8%. For normal-story residential buildings, it is observed that the total cost value that must be borne during the reinforcement period decreases as the number of floors increases.

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