ESTIMATION METHOD OF RESIDUAL CAPACITY OF MODERATELY DAMAGE BUILDINGS FOR EFFICIENT AND ECONOMICAL RETROFITTING

ETKİN VE EKONOMİK GÜÇLENDİRME UYGULAMASI İÇİN ORTA HASARLI BİNALARIN ARTIK KAPASİTELERİNİN TAHMİN METODU

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ABSTRACT

ESTIMATION METHOD OF RESIDUAL CAPACITY OF MODERATELY DAMAGE BUILDINGS FOR EFFICIENT AND ECONOMICAL RETROFITTING

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One of the biggest problems encountered after earthquakes is to determine the extent to which the buildings, which are determined as moderate damaged during the damage detection process due to the damage they have seen due to the earthquake, restrict their use in the future, and to predict whether these buildings can be retrofitted within the economic limits. In order to determine the feasibility of the retrofitting process, it is necessary to examine the level of damage experienced by the building in the earthquake, the mechanical characteristics of the load carrier system elements and the carrier system characteristics and system irregularities. During the observational damage detection process after the earthquake, it is almost impossible to determine how weak or sufficient system elements of the investigated building are. In addition, damage detection processes examine how much damage to the building under investigation in the earthquake. It is not possible to determine the extent to which the building can withstand the future earthquakes.

In this study, for the first time in the literature, a method is developed to determine whether buildings defined as moderately damaged are technically suitable for retrofitting and whether the retrofitting process is feasible for technically suitable for these buildings.

Keywords: Seismic risk estimations, moderately damaged buildings, Rapid screening score, Building Demand - Design rate, retrofitting potential

ÖZET

ETKİN VE EKONOMİK GÜÇLENDİRME UYGULAMASI İÇİN ORTA HASARLI BİNALARIN ARTIK KAPASİTELERİNİN TAHMİNİ METODU

ÖMER FARUK ÇINAR

Doktora, İnşaat Mühendisliği Bölümü

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Deprem sonrası karşılaşılan en büyük sorunlardan biri, deprem nedeniyle görmüş olduğu hasar nedeniyle hasar tespiti sürecinde orta hasarlı olduğu belirlenen binaların gelecekte kullanımlarını ne ölçüde kısıtladığının belirlenmesi ve Bu binaların ekonomik sınırlar dahilinde yenilenip güçlendirilemeyeceğini tahmin edin. Güçlendirme işleminin uygulanabilirliğini belirlemek için binanın depremde yaşadığı hasar düzeyini, yük taşıma sistemi elemanlarının mekanik özelliklerini ve taşıyıcı sistem özelliklerini ve sistem düzensizliklerini incelemek gerekir. Deprem sonrası gözlemsel hasar tespiti sürecinde incelenen binanın sistem elemanlarının ne kadar zayıf veya yeterli olduğunu tespit etmek neredeyse imkansızdır. Ayrıca hasar tespit işlemleri depremde incelenen binanın ne kadar hasar gördüğünü inceler. Binanın gelecekteki depremlere ne kadar dayanabileceğini belirlemek mümkün değildir.

Bu çalışmada, literatürde ilk kez, orta hasarlı olarak tanımlanan binaların güçlendirmeye teknik açıdan uygun olup olmadığının ve bu binalara teknik açıdan uygunsa güçlendirme işleminin uygun olup olmadığının belirlenmesine yönelik bir yöntem geliştirilmiştir.

Anahtar Kelimeler: Sismik risk tahminleri, orta hasarlı binalar, Hızlı tarama puanı, Bina Talep – Tasarım oranı tayini, Güçlendirme potansiyeli

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Ömer Faruk ÇINAR

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SYMBOLS AND ABBREVIATIONS

Symbols

σ	Standard Deviation
ε	Normalized Standard Deviation

Abbreviations

Ac	Column Cross-Sectional Area
ACC	Autoclaved Aerated Concrete
$Ainf_x$	Infill wall Cross-Sectional Area in X direction
$Ainf_y$	Infill wall Cross-Sectional Area in Y direction
ANN	Artificial Neural Network
ALR	Axial Load Ratio
Ap	Plan Area
ATC	Applied Technology Council
DDSR	Demand - Design Spectrum Ratio
DMBeam	Beam Damage Factor
DMfB	Stiffness Reduction Coefficient for Beams
DMCol	Column Damage Factor
DMfC	Stiffness Reduction Coefficient for Columns
DMfC	Stiffness Reduction Coefficient for Columns
DMInfill	Infill Wall Damage Factor
$DMSW_y$	Damage Factor Shear Wall in X Direction
$DMSW_y$	Damage Factor Shear Wall in X Direction
EAFZ	East Anatolian Fault Zone
E_c	Concrete Modulus of Elasticity
E_m	Brick Wall Modulus of Elasticity
f_{ck}	Concrete Compressive Strength

FEMA	Federal Emergency Management Agency
FFT	Fast Fourier Transform
f_m	Brick Wall Strength
FRP	Fiberglass Reinforced Plastic
f_x	Fundamental vibration period of the building in X direction
f_y	Fundamental vibration period of the building in Y direction
GABHR	Guidelines for the Assessment of Buildings under High Risk
GMM	Ground Motion Model
JBDPA	Japan Building Disaster Prevention Association
JICA	Japan International Cooperation Agency
LRFD	Load and Resistance Factor Design
ML	Machine Learning
Ml	Local Magnitude
MPa	Mega Pascal
Ms	Surface Wave Magnitude
Mw	Earthquake Moment Magnitude
NAFZ	North Anatolian Fault Zone
NoHN	Number of Hidden Neurons
NoI	Number of Inputs
NoHA	Number of Gridlines in the Horizontal Direction
NoS	Number of Storeys
NoO	Number of Outputs
NoVA	Number of Gridlines in the Vertical Direction
OhR	Overhang Ratio
OhX	Overhang in the X direction
OhY	Overhang in the Y direction

PD	Plan Depth
PGA	Peak Ground Acceleration
PW	Plan Weight
RC	Reinforced Concrete
Sa	Site Spectral Acceleration
$Sa_{[g]}$	Ground Spectral Acceleration
SH	Storey Height
SHAP	Shapley Additive Explanations
SRF	Stiffness Reduction Factor
SS	Structure Score
S_S	Soft Storey Existence
S_t	Slab Thickness
SW_x	Shearwall Cross-Sectional Area in X direction
SW_y	Shearwall Cross-Sectional Area in Y direction
Ta	Fundamental Period of Damaged Building
TEC	Turkish Earthquake Code
Tx	Fundamental Vibration Period in X Direction
Tx	Fundamental Vibration Period in Y Direction

1. INTRODUCTION

After an earthquake, one of the most significant challenges is determining whether damaged buildings can withstand future earthquakes. The first step is to assess if moderately damaged buildings can be retrofitted or if retrofitting is feasible. Investigate whether the building can be effectively retrofitted, taking into account structural elements, mechanical properties of materials and element designs in the investigation of earthquake damages. If retrofitting is technically feasible, retrofitting costs should be assessed. Following the earthquake, it is challenging to determine the structural system elements' strength and weakness of the building under investigation using observational damage assessment procedures. The post-earthquake damage assessment studies only evaluate the damage level caused by the earthquake in the building under investigation. It is not possible to determine the building's ability to withstand future earthquakes. This study presents a method for assessing the suitability of buildings for retrofitting, specifically those that have been determined to be moderately damaged in post-earthquake assessments.

1.1. Problem Definition

Moderately damaged buildings refer to structures that have experienced significant damage to their load-bearing system elements due to an earthquake, although they have not suffered severe damage overall. These buildings are evaluated in a category where the level of damage cannot be classified as low, but they have not reached a state of extensive damage where retrofitting would be considered impossible. The FEMA-306 [1] document describes moderate damage, stating that it has an intermediate impact on the structural properties of the building. The extent of restoration measures required varies depending on the type of structural components and their behavior mode. In some instances, these measures may be relatively substantial.

The use of moderately damaged buildings without reinforcement is restricted, and it is a factor that threatens the safety of life and property if these buildings are kept without retrofitting due to their existing damage. However, in this case, evaluating whether these buildings are suitable for retrofitting and/or whether the retrofitting costs correspond to the work to be done is appropriate. This study will evaluate whether it is appropriate or feasible to retrofit the buildings with a reinforced concrete carrier system, which is determined as moderately damaged, by pre-screening / filtering before proceeding to the retrofitting phase. As a result of the assessment, buildings whose retrofitting is determined to be ineffective and uneconomical shall be subject to the provisions applicable to Severe Damaged Buildings. In case retrofitting is effective and economical, the performance analysis and retrofitting project design process can be applied according to the provisions of the regulation.

1.2. Scope and Objectives

Within the scope of the dissertation, a method has been developed to determine the residual capacities of buildings by using three-stage filtering, considering the parameters of applicability and retrofitting costs of retrofitting studies in buildings determined as moderately damaged by the damage assessment studies carried out after the earthquake. Thus, it will be possible to weed out buildings that cannot be retrofitted by the filtering method or whose retrofit costs are likely to exceed the economically feasible limits. The project consist of a three-stage filtration system to investigate the suitability and sustainability of buildings with moderate damage for retrofitting.

The objective of this dissertation is to selectively identify buildings with moderate damage for potential retrofitting, considering their technical and economic feasibility. The remaining buildings will be assessed under the same criteria and regulations applied to severely damaged buildings. Consequently, the research focuses on developing a three-stage filtering methodology, with dedicated investigations conducted in this area.

The research introduces a three-stage filtration system to assess the potential retrofitting suitability of buildings that have experienced moderate damage. The stages of the filtration system are as follows:

- Stage 1: Evaluation of Building Demand and Design Capacity
- Stage 2: Rapid Screening Score Assessment
- Stage 3: Evaluation of Building Concrete Quality, Reinforcement Detailing, and Durability

In the first stage, the demand and design capacity of the building is examined and it is investigated whether it meets the required standards. To facilitate this process, the first step involves determining the ground motion spectrum at the location of the building during the earthquake event. This site spectrum is then compared with the design spectrum values specified in the regulations in force when the building under study was constructed. By comparing the actual ground motion spectrum with the building design spectrum values ($Sa_{[g]}$), it can be assessed whether the building was designed to withstand the seismic forces specified in the codes during construction. The assessment of whether a building is subjected to seismic effects exceeding the design acceleration values can be performed by comparing the ground motion spectrum obtained from the actual earthquake event with the building design spectrum values ($Sa_{[g]}$). A comparative analysis is performed to determine the result. Suppose the building under investigation experiences a spectral ground acceleration more significant than the design acceleration but remains intact after the earthquake with moderate damage. In that case, it successfully passes the first evaluation stage. Conversely, suppose the building experiences a ground acceleration lower than the prevailing spectral acceleration values during design but suffers moderate damage during the earthquake. In that case, retrofitting such a building may not be feasible or economical.

A method is proposed to calculate the response spectrum at a particular location where the building is exposed to earthquakes. This method calculates the site spectrum values at the building location using ground motion models from the ground motion records taken from the Earthquake Monitoring Station closest to the building. Using the developed site spectrum prediction model, the seismograph data recorded at the closest to the building makes it possible to predict the response spectrum at the exact location of the building.

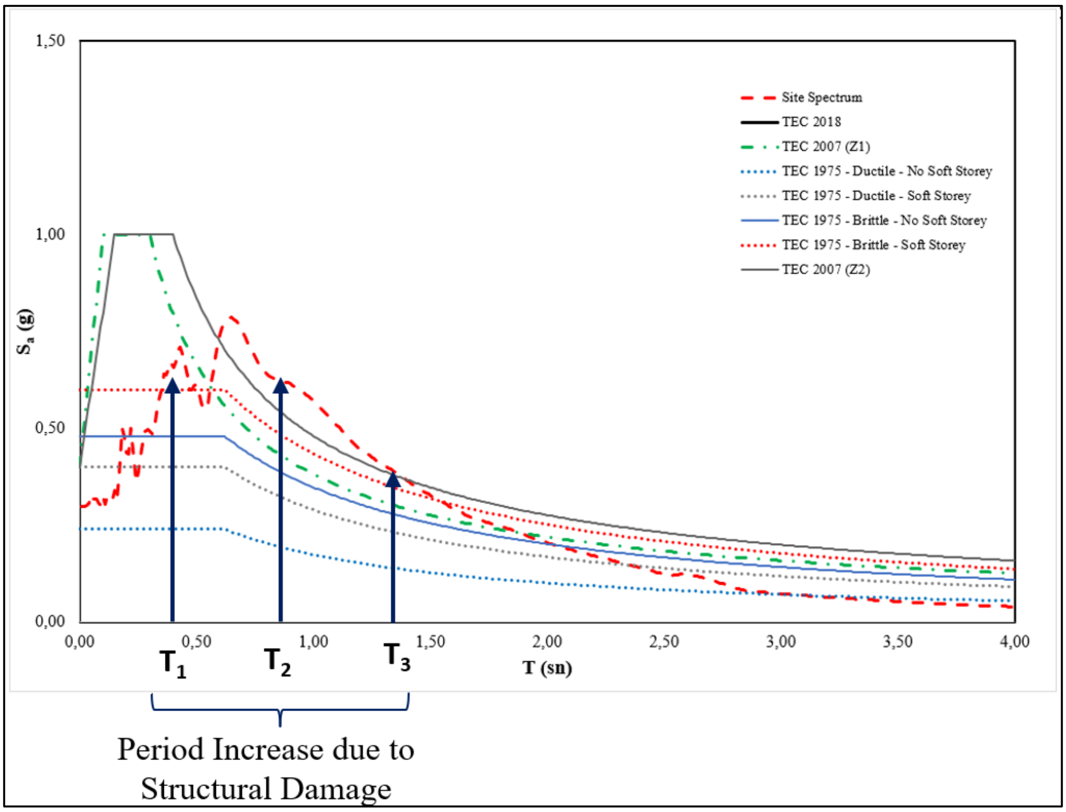


Figure 1.1 Demand design spectrum due to period variation for different earthquake codes

In order to apply the proposed method, it is essential to determine the actual period of the moderately damaged building before and after the damage. It is known that the fundamental vibration period of a building is affected by the mass of the building and the stiffness of its elements. In the case of a building moderately damaged by an earthquake, a reduction in the stiffness of the structural elements occurs. Consequently, accurately determining the period change due to element damage and the current fundamental vibration period of the damaged building is crucial for assessing its residual capacity. As part of this study, some research was conducted to determine the stiffness reduction factors associated with damage to structural system elements (such as beams, columns and shear walls) and non-structural elements (including partition walls). It also aims to determine the vibration period of the building with damaged elements by developing a machine-learning network that utilizes the physical properties of the building, structural element properties, mechanical properties of the structural system elements, and stiffness reduction factors.

The second stage involves conducting a rapid screening score assessment to evaluate the building's suitability for retrofitting further. At this stage, the building is scored according to the year of construction, ground class, and whether there is a heavy overhang - short arm or not.

Finally, the third phase thoroughly checks the building's concrete quality, structural system details and durability. For this purpose, the Building Axial Load Ratio is calculated, and the building bearing capacity is assessed using the existing concrete compressive strength value.

1.3. Literature Survey on Residual Seismic Capacity

The literature review identified the Guideline for Post-earthquake Damage Evaluation and Rehabilitation [2], initially formulated in Japan in 1991 and revised in 2001. The primary objective of this guideline is to establish quantitative criteria for assessing earthquake-induced damage to buildings. Its principal focus lies in evaluating reinforced concrete buildings with a height of fewer than 10 stories, which were designed and constructed before 1981. This guideline encompasses distinct assessments for the foundation and superstructure, outlines procedures for building retrofitting, provides visual guidance for retrofitting, and includes illustrative case studies.

In the study "Post-Earthquake Damage Evaluation of Reinforced Concrete Buildings," [3] published by Masaki Maeda and Dae Eon Kang, an assessment of a methodology designed to gauge the remaining seismic resilience of reinforced concrete structures that have suffered earthquake-induced damage. The authors employed the residual seismic capacity index, a metric defined as the proportion of the remaining seismic capacity to the pre-earthquake capacity, as outlined in the Guideline for Post-earthquake Damage Evaluation and Rehabilitation. This approach was applied to low-rise buildings that had sustained damage in recent seismic events in Japan. The study's findings indicate that the residual seismic capacity index effectively ascertains the structural safety of damaged buildings in the face of potential aftershocks.

In the study "Residual Seismic Capability Evaluation for RC Buildings Considering Reduction of Seismic Performances," [4] published by Linfei Hao et al., a method based on internal work of the structure and seismic capacity reduction factor of the members, for which numerical analysis is not needed, and the results were compared with a more accurate method based on the capacity spectrum method. It considers the damaged structural elements' reduced strength, deformation capacity and energy dissipation capacity separately.

1.4. Dissertation Outline

Buildings identified as moderately damaged by the studies carried out go through a comprehensive three-stage filtering process. This process aims to assess the adequacy of the retrofitting for these buildings, taking into account technical and economic considerations. If the evaluation indicates that retrofitting is deemed suitable for the e examined building, retrofit measures and methods will be applied accordingly. On the other hand, buildings that are determined to be unsuitable for retrofitting are categorized as severly damaged buildings and the demolition process is initiated.

2. EVALUATION OF BUILDING DEMAND AND DESIGN CAPACITY

2.1. Fundamental Vibration Period of RC Buildings Estimating Studies

Within the scope of our study, the initial phase in assessing the suitability of retrofitting the partially damaged structure is to conduct a residual capacity analysis. The initial step is establishing the precise vibration period of the impaired building currently being examined to accomplish this objective. Reinforced concrete structures with moderate damage serve as the primary focus of our study. In such buildings, the stiffness of the elements declines due to damages in the structural system components and non-load-bearing partition walls, resulting in shifts in the building's fundamental vibration period [5-7]. Approximate period equations are provided in various earthquake codes to estimate the fundamental vibration period of buildings. However, several academic studies have indicated that the values obtained using these equations differ from the exact building period values [8-13]. Determining the fundamental vibration period through the Rayleigh equations or modal analysis necessitates an extensive and complicated data collection and calculation process. Determining the fundamental vibration periods of buildings in both undamaged and damaged states is crucial in evaluating the impact of seismic component damage on building performance and in making informed decisions regarding retrofitting or demolition. Modal parameters, including frequencies and mode shapes, are affected by the physical properties of the structure, such as its mass and stiffness. Hence, any alterations in the physical attributes will result in corresponding changes in the modal properties [14]. This study aims to develop a contemporary method to predict the fundamental vibration periods of reinforced concrete (RC) buildings with structural and non-structural component damage. The proposed method can be utilized in the preliminary seismic evaluation of buildings or post-earthquake residual capacity calculations. The objective is to reliably determine buildings' fundamental vibration periods in undamaged and damaged states using specific structural parameters without relying on complex numerical models.

In order to evaluate the retrofitting potential of the buildings classified as moderately damaged after the earthquake, the changes in vibration periods due to element damage were analysed. In order to determine the stiffness losses in elements such as beams, columns, shear walls, and partition walls, laboratory experiments were conducted and "Stiffness

Reduction Factors" were established. Subsequently, the structural parameters that potentially affect the vibration period values were determined by reviewing the existing literature. Three-dimensional building models were then created by varying these identified parameters, and the vibration periods of these models were computed using specialized software.

2.1.1. Determination of Stiffness Reduction Factors

One of the objectives of this study is to determine the impact of damaged structural or non-structural components on the building period during seismic events. To assess the effect of damaged structural components on the building period, it is necessary to determine the extent of stiffness reduction in these members based on the severity of the damage. Stiffness reduction coefficients (SRFs) have been determined for beams, columns, shear walls, and partition walls, considering different levels of damage ranging from slight to severe. In the determination of these coefficients, information from laboratory experiments conducted by the authors and previous studies has been utilized. The laboratory experiments involved analyzing the load-displacement curves of tested specimens and comparing them with the observed damage. By examining the change in secant slope at specific displacement values, a correlation between damage and stiffness reduction is established. The secant slopes obtained for a particular damage state are then scaled relative to the slope values for the undamaged state, serving as a reference case. Through this process, the SRFs are ultimately derived. This procedure is repeated for various types of elements, including beams, columns, shear walls (with different section geometries), and partition walls (with different material properties), as discussed in subsequent sections.

2.1.1.1 Determination of Stiffness Reduction Factors for Beams

The changes in beam stiffness resulting from damage were obtained from the force-displacement curves obtained in bending tests conducted by Akduman et al [15]. In their experimental study, the authors provided load-displacement curves and recorded the observed damage states. Utilizing this data, the stiffness reduction ratios for each damage state were determined by comparing it to the stiffness of undamaged beams. This approach allows for a more accurate representation of stiffness reduction due to damage in beams with identified damage states. To achieve this, stiffness reduction factors were determined for four different damage states: undamaged, slight damage, moderate damage, and severe damage. The correlation between the observed element damage and the displacement at the midpoint of the beam element was established (Table 2.1). The slopes of the secant stiffness corresponding to the different damage states detected during the tests were considered as representative of the elastic behavior, yield point, significant cracking, and ultimate capacity, respectively (Figure 2.1.b).

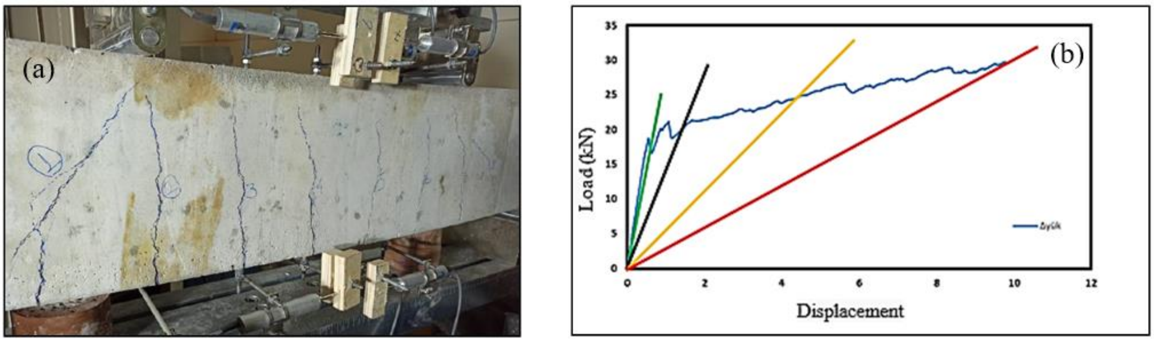


Figure 2.1. (a) Damaged beam specimen and (b) typical load - vertical midpoint displacement graph

The average stiffness ratios obtained from the secant stiffness values reported by Akduman et al. [15] are determined as 0.45, 0.20, and 0.10 for slightly damaged, moderately damaged, and severely damaged states, respectively. These values represent the Stiffness Reduction Factors (SRFs) that should be applied to beams in order to account for the corresponding damage states.

Table 2.1. Stiffness Reduction Factors for Beam Members

Beam Damage Status	Stiffness Ratio
No Damage	1.00
Minimum	0.45
Significant	0.20
Heavy	0.10

2.1.1.2. Determination of Stiffness Reduction Factors for Columns

In the context of this study, a series of experiments were conducted on column specimens, encompassing three distinct axial load ratios: no axial load, 10% axial load ratio, and 20% axial load ratio. Concurrently, cyclic lateral displacements were applied at the upper end of the column specimens (Figure 2.2). Throughout these experiments, secant stiffness values were determined for predefined states, namely: the moment of initial crack formation, the yielding state, the point of cover spalling, and the point of core concrete crushing or reinforcement buckling. Prior to the occurrence of the first hairline crack, it was assumed that the specimen remained undamaged. The yielding of reinforcement or the development of significant cracks represented a state of minor damage. The point at which the cover concrete experienced crushing indicated a moderate damage state, whereas the occurrence of column reinforcement buckling or core concrete crushing was considered indicative of severe damage. The average stiffness ratios, derived from the secant stiffnesses of the examined column tests, are summarized in Table 2.2.

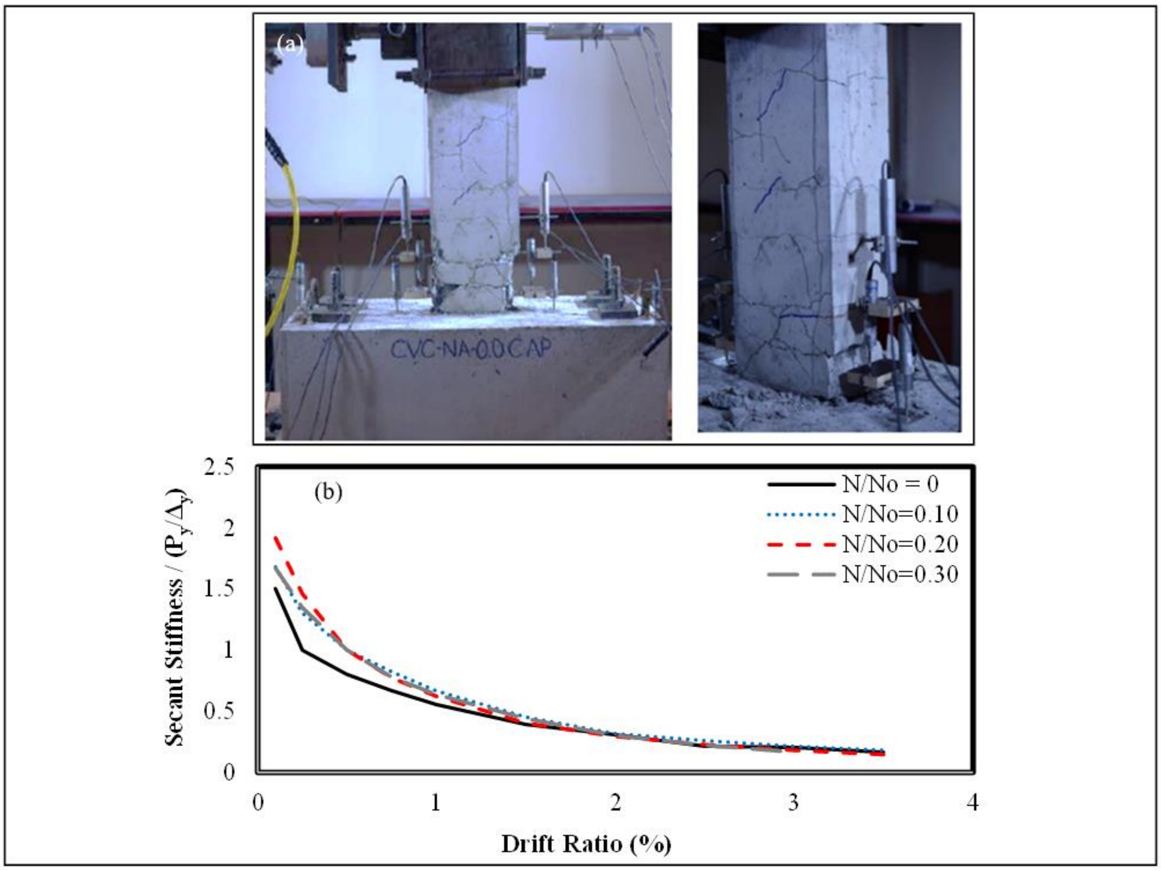


Figure 2.2. Photos from column tests and (b) Curves for secant stiffness reduction

Table 2.2. Stiffness Reduction Factors for Column Members

Column Damage Status	Stiffness Ratio
No Damage	1.00
Minimum	0.60
Significant	0.25
Heavy	0.10

2.1.1.3. Determination of Stiffness Reduction Factors for Shearwalls

The stiffness reduction factors for shearwall members were determined by utilizing shearwall experiments presented in Aldemir and Binici et al. [16, 17]. This particular study examined shearwall specimens with rectangular, T-shaped, and U-shaped sections, where load-displacement curves and changes in damage states were observed. The experiments enabled the monitoring of stiffness reduction as damage levels increased across various specimens. Consequently, the stiffness ratios, represented as reduction coefficients, for three distinct damage states of shearwall specimens are presented in Table 2.3.

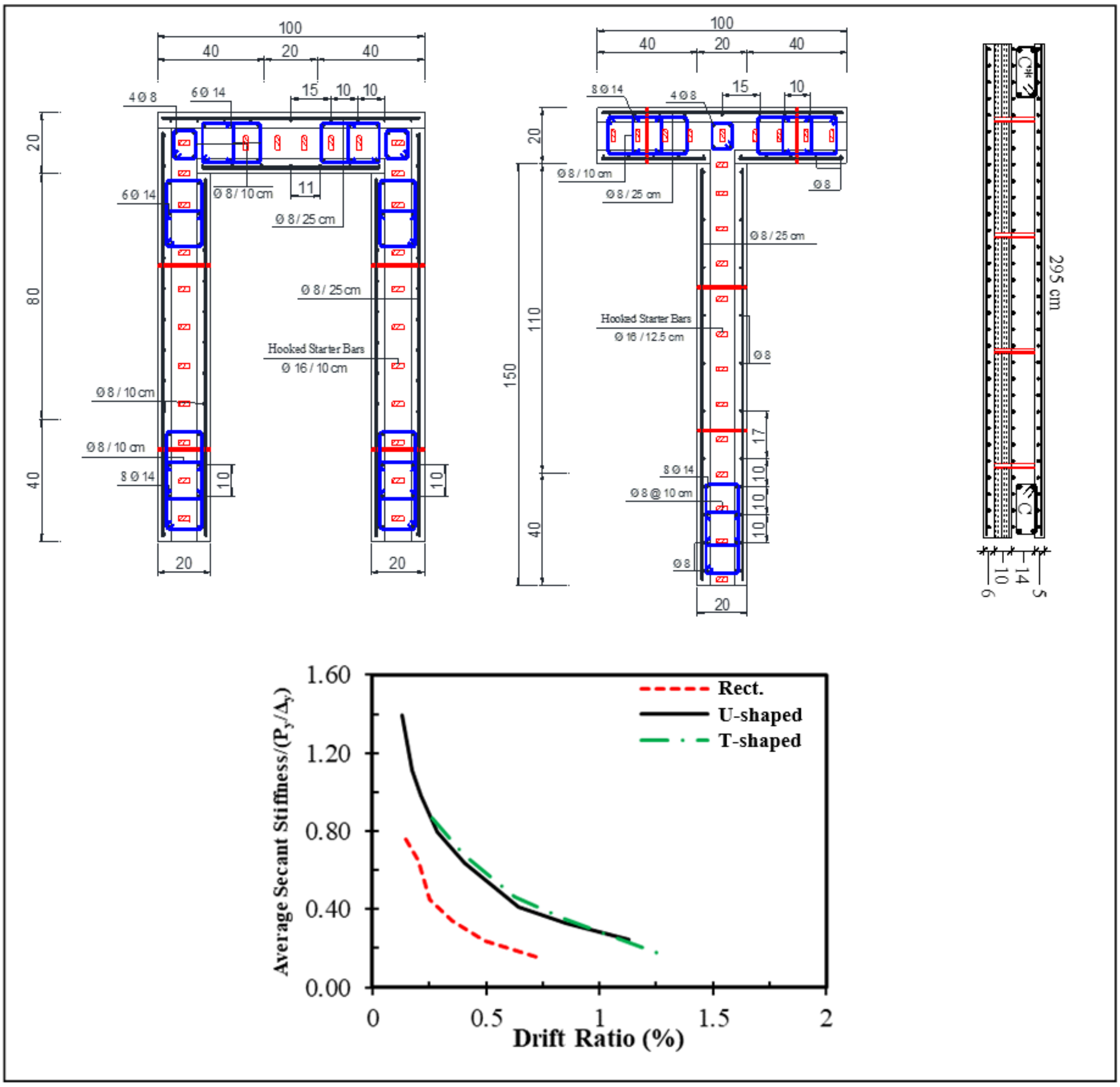


Figure 2.3. Sectional properties of the tested shearwall specimens with (a) U-shaped section, (b) T-shaped section, (c) rectangular section; (d) average secant stiffness vs. drift ratio graphs for the specimens

Figure 2.4. Photos from the experimental setup of the shear wall specimens in Aldemir et al.

Table 2.3. Stiffness Reduction Factors of Shearwall Members

Shearwall Damage Status	Stiffness Ratio
No Damage	1.00
Minimum	0.40
Significant	0.20
Heavy	0.10

2.1.1.4. Determination of Stiffness Reduction Factors for Non-structural Walls (Partition Walls)

Demirel et al. [18] conducted a study to investigate the impact of accumulated damage on the stiffness of infill walls made from different materials. The research involved experimental testing to examine the in-plane behavior of walls constructed with various materials. The in-plane stiffness values for the wall specimens, which incorporated infill wall materials such as hollow brick without plaster, hollow brick with plaster, and autoclaved aerated concrete (ACC), were determined based on the drift ratio within a reinforced concrete frame system (Figure 2.5.a). The plotted curves in Figure 2.4.b indicate that the reduction in secant stiffness, with respect to the drift ratio, demonstrates similarity across different types of infill materials. As a result, a single stiffness reduction factor can be applied to all available infill wall materials used in current construction practices. The stiffness reduction factors for non-structural partitional walls are provided in Table 2.4.

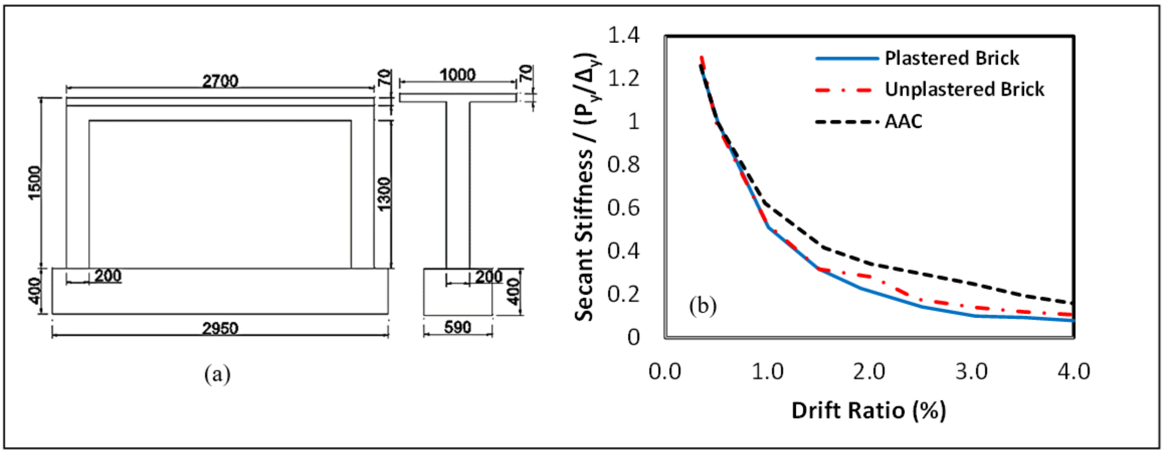


Figure 2.5. (a) Experimental setup of the infill walls and (b) Secant Stiffness vs. Drift Ratio plots

Table 2.4. Damage Stiffness Ratios for Non-structural (Partition) Walls

Partition Walls Damage Status	Stiffness Ratio
No Damage	1.00
Minimum	0.40
Significant	0.20
Heavy	0.10

2.1.2. Determination of the Effective Parameters in the Vibration Period

In order to accurately estimate the fundamental periods of existing buildings in their undamaged states, it is crucial to consider specific structural parameters, such as the number of stories, floor height, plan dimensions, and more. For this study, a comprehensive range for each selected structural parameter is determined based on existing literature [5-7, 19-21] to represent construction practices rationally. These parameters are presented in Table 2.5. Stiffness reduction factors are used in the stiffness matrices to determine the periods of damaged buildings, considering that damage leads to a reduction in the stiffness of structural and non-structural elements. Period values are calculated for both principal directions in all the developed building models, and the fundamental mode direction is determined by considering modal mass contributions. The primary objective is to achieve accurate period estimations for buildings using the structural parameters listed in Table 2.5., ensuring that the estimated period values closely align with the calculated values obtained from eigenvalue analysis of numerical models.

Table 2.5. Numerical representations of structural parameters that are employed for period estimation.

Parameters	**Range (min – max)**
Number of stories	1-20
Height of ground floor (m)	2.80-3.40
Height of other floors (m)	2.80-3.10
Concrete compressive strength (f_{ck} -MPa) (Between 1 - 9 floors)	5-25
Concrete compressive strength (f_{ck} -MPa) (10 and up)	10-30
Non-structural wall strength (f_{ck} -MPa)	0.50-10
Short side dimensions of the shearwall (m)	0.25-0.45
Long side dimensions of the column (m)	0.40-0.80
Short side length of the column (m)	0.20-0.50
Beam width (m)	0.15-0.35
Beam height (m)	0.40-0.80
Overhang ratio	0-0.10
Floor plan, short edge dimensions (m)- (X direction)	6-25
Floor plan, long edge dimensions (m)- (Y direction)	8-30
Slab thickness (m)	0.08-0.20
Number of shearwall at X direction	0-10
Number of shearwall at Y direction	0-10
Number of axes at X direction	3-10
Number of axes at Y direction	3-10
Partition wall thickness (m)	0.20-0.40
Stiffness reduction coefficients for columns	0.05-1.00
Stiffness reduction coefficients for Beams	0.05-1.00
Stiffness reduction coefficients for shearwalls at X direction	0.05-1.00
Stiffness reduction coefficients for shearwalls at Y direction	0.05-1.00
Stiffness reduction coefficients for non-structural walls	0.05-1.00

As indicated in the table above, the determined parameters include the Number of Floors, First Floor Height (m), Heights of Other Floors (m), Concrete Compressive Strength (fck -MPa) (for Floors 1-9), Concrete Compressive Strength (fck -MPa), Partition Wall Compressive Strength (fck -MPa), Short Side of Shear Wall (m), Long Side of Column (m), Short Side of Column (m), Beam Width (m), Beam Height (m), Heavy Projection Ratio, Plan Short Side Length (X Direction) (m), Plan Long Side Length (X Direction) (m), Slab Thickness (m), Number of Shear Walls in X Direction, Number of Shear Walls in Y Direction, Number of Gridlines in X Direction (Gridlines x), Number of Gridlines in Y Direction (Gridlines y), Partition Wall Thickness (m). Additionally, it considered the information that damage in the elements leads to a decrease in stiffness, it is appropriate to use Stiffness Reduction Factors in the stiffness matrices of the developed models to determine the periods of damaged buildings. Stiffness reduction varies between a minimum value of 0.05 (severely damaged or collapsed state) and a maximum value of 1 (undamaged state). Period values were obtained for both directions in all models, and the dominant mode direction is determined by considering mass contributions. The aim is to estimate the periods of buildings using the estimation parameters and obtain period values that align with the theoretically determined values through calculations.

2.1.2.1 Studies on the Estimation of the fundamental Vibration Period of Buildings

Three-dimensional models were generated using the SAP2000 [22] software, widely used in Civil Engineering, based on the determined parameters. The complete three-dimensional geometry of the buildings models was designed. During the construction of the models, two different structural systems were considered: reinforced concrete frame systems and reinforced concrete frame systems with shearwalls. Partition walls, shear walls, and slabs were modeled using shell elements, while columns and beams were represented by frame elements (Figure 2.6). The generated models included varying numbers of stories ranging from 1 to 21, concrete compressive strengths ranging from 5 to 40 MPa, floor heights ranging from 2.8 m to 3.6 m, and slab thicknesses ranging from 0.08 m to 0.22 m. The models consisted of both shear wall and frame structural elements, with varying numbers of gridlines in the X and Y directions ranging from 3 to 11. Period values were obtained for all models' X and Y directions, and the dominant mode direction was determined by considering mass contributions. A total of 16,000 numerical analyses were performed using the generated models. Out of these analyses, 10,100 were used to train the statistical models, while the remaining 5,900 models were utilized for testing the developed numerical models.

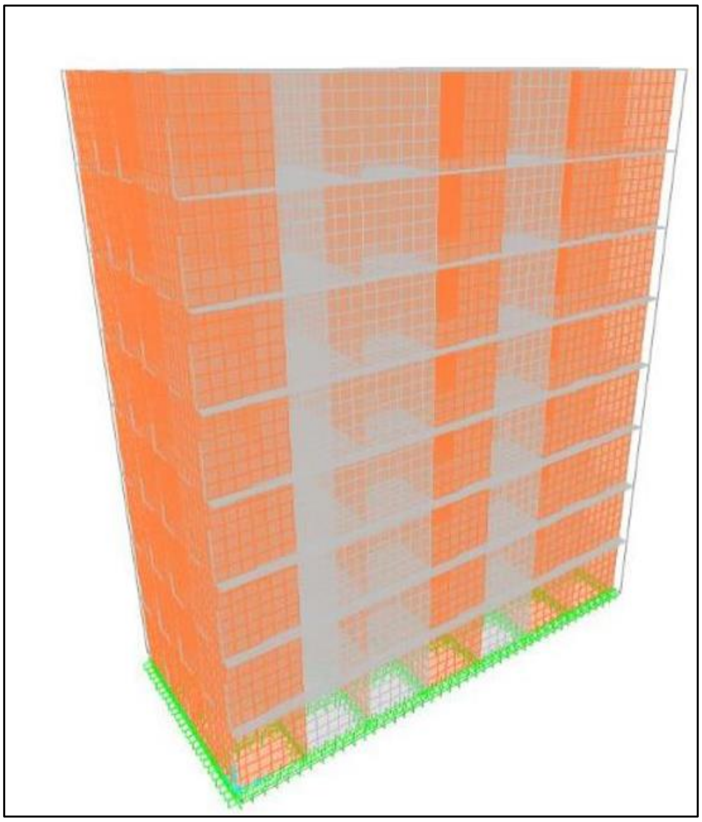


Figure 2.6. 3D sample building modelled with SAP2000

2.1.2.2. Nonlinear Regression Analysis

Nonlinear regression analysis was conducted in this study to develop a regression model that can accurately predict the relationship between the variables. Unlike linear regression, which assumes a linear relationship between the independent and dependent variables, nonlinear regression allows for more complex and flexible relationships to be modeled.

In the context of this study, the nonlinear regression analysis aimed to establish a mathematical equation that can predict the period of reinforced concrete buildings, taking into account various input parameters and considering the effects of damage. The regression model is developed based on the collected data and the relationships observed between the variables. The process of nonlinear regression analysis involved several steps. First, an appropriate mathematical model is selected based on the characteristics of the data and the research objectives. Then, the model parameters were estimated using statistical techniques such as the least squares method or maximum likelihood estimation. The goodness of fit of the regression model is assessed using various statistical measures, such as the coefficient of determination (R-squared), adjusted R-squared, and standard error of the estimate. It is important to note that the accuracy and reliability of the regression model depend on the quality and representativeness of the data used for model development. Due to the large number of input parameters in this study, principal component analysis (PCA) [23] performed to determine the extent to which the parameters could be classified based on their effects on period values.

Principal component analysis is a widely used subspace projection method in pattern recognition studies [24]. It investigates how all variables can form independent vectors in the selected n-dimensional space. In other words, it examines which "n" variables can have independent effects to a certain extent. If the eigenvalue obtained from this analysis is more significant than a certain threshold, it is considered that the corresponding eigenvector contributes significantly to the output. Through the conducted principal component analysis, it was determined that the prediction parameters have a significant contribution to obtaining the theoretical period values. These parameters were considered in the equation of the prediction model as follows: Number of stories (NoS), Concrete compressive strength (fck), Concrete elastic modulus (Ec), Brick wall strength (fm), Brick wall elastic modulus (Em), Storey height (SH), Plan width (PW), Plan depth (PH), Slab thickness (St), Number of gridlines in the X direction (NoHA), Number of gridlines in the Y direction (NoVA), Overhang ratio (OhR), Overhang in the X direction (OHX), Overhang in the Y direction (OHY), Soft storey condition (SS), Ratio of column area to floor area (AcAp), Shear wall-to-floor area ratio in the X direction (SWx/Ap), Shear wall-to-floor area ratio in the Y direction (SWy/Ap), Brick wall-to-floor area ratio in the X direction (Ainfx/Ap), and Brick wall-to-floor area ratio in the Y direction (Ainfy/Ap).

Additionally, in order to reflect the influence of damaged structural elements on the period, stiffness reduction parameters were introduced for columns (DMfC), beams (DMfB), shear walls in the X direction (DMSWx), shear walls in the Y direction (DMSWy), and brick walls (DMinf). The determination of coefficients related to the usage of different stiffness reduction factors for different levels of damage in different types of structural elements is explained in the section "Determination of Stiffness Reduction Factors". The eigenvalue variation graph in Figure 2.7 was obtained to determine the period value by considering all variables using the training database. Furthermore, the determination coefficients corresponding to each component are summarized in Table 2.6.

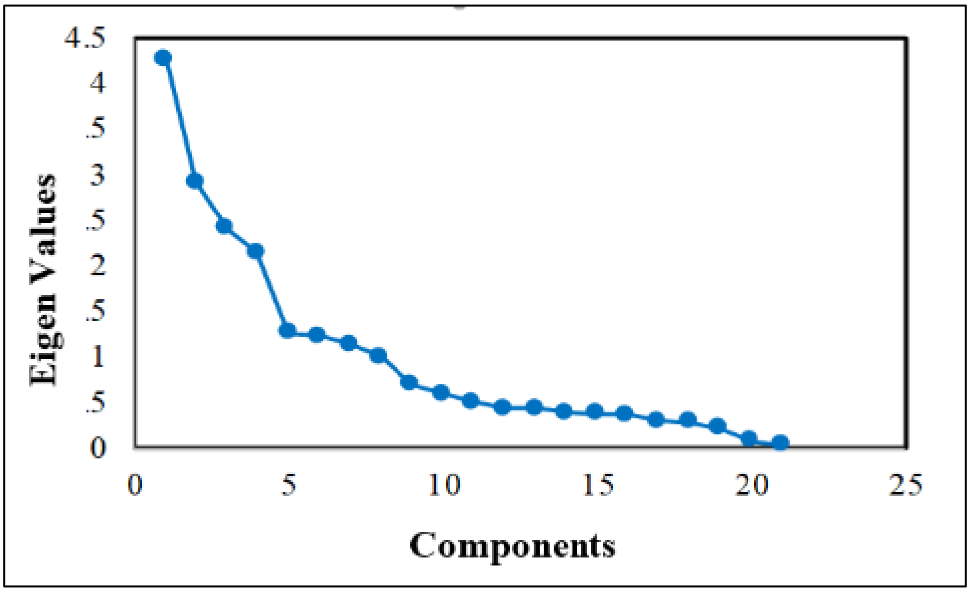


Figure 2.7. Eigen value variation graph for Nonlinear Regression Analysis

Table 2.6. Numerical Representations of Prediction Parameters

	Components						
Parameters	1	2	3	4	5	6	7
Number of Stories (NoS)	0.035	0.122	0.650	0.117	0.051	0.396	0.023
Concrete Compressive Strength (fck)	0.032	0.164	0.681	0.120	0.122	0.399	0.011
Brick Wall Strength (fm)	0.044	0.178	0.663	0.105	0.096	0.363	0.004
Storey Height (H)	0.068	-0.033	0.088	-0.014	-0.208	-0.065	0.916
Plan Width (PW)	-0.008	0.455	-0.213	0.476	0.623	-0.108	0.130
Plan Heigh (PW)	0.012	0.562	-0.182	0.359	-0.601	0.171	-0.100
Slab Thickness (ts)	0.007	0.037	0.011	-0.015	0.039	0.069	-0.039
Plan Area (Ap)	0.005	0.702	-0.276	0.575	0.051	0.029	0.022
Overhange Ratio(OH)	0.007	0.101	0.569	0.229	-0.144	-0.679	-0.086
Overhange Direction (OH_Dir)	0.016	0.123	0.716	0.251	-0.079	-0.490	-0.095
Column Damage (DMCol)	0.812	-0.109	-0.033	0.121	0.013	0.013	-0.082
Beam Damage (DMBeam)	0.809	-0.111	-0.063	0.118	0.012	-0.004	-0.073
Shearwall$_x$ Damage (DMSWx)	0.929	-0.012	-0.014	-0.024	0.032	0.002	-0.090
Shearwall$_y$ Damage (DMSWy)	0.927	-0.016	-0.016	-0.037	0.031	0.007	-0.093
Infill Wall Damage (DMInfill)	0.811	-0.107	-0.060	0.124	0.000	-0.001	-0.088
Soft Storey (SS)	0.682	-0.099	0.044	0.094	-0.112	-0.012	0.445
Column Area / Plan Area (AcAp)	-0.137	-0.857	0.094	0.252	-0.005	0.054	-0.025
Shearwall$_x$ Area/ Plan Area (SWxAp)	0.167	0.275	0.166	-0.757	0.208	-0.081	0.022
Shearwall$_y$ Area/ Plan Area (SWxAp)	0.168	0.247	0.164	-0.722	-0.097	-0.042	-0.038
Infill Wall$_x$ Area/ Plan Area (InfillxAp)	-0.099	-0.710	0.059	0.213	0.429	-0.054	0.067
Infill Wall$_y$ Area/ Plan Area (InfillxAp)	-0.096	-0.616	0.056	0.205	-0.406	0.131	-0.118

A Fundamental Period prediction equation for period estimation was constructed using three separate regression models by incorporating prime components into Nonlinear Regression Equations. These equations were utilized in the SPSS [25] program for nonlinear regression analysis, and the determination coefficient (coefficient of determination) for the predicted periods and the period values obtained from the numerical model were provided. The determined period prediction equations are presented in Table 2.7. Furthermore, the Nonlinear Regression Coefficients associated with the obtained equations are summarized in Table 2.8.

Table 2.7. Fundamental Period Prediction Equations

Regression Models	Equations	R^2
1	$C_1 e^{C_2 DMCol + C_3} e^{C_4 DMBeam + C_5} e^{C_6 DMSW_x + C_7} e^{C_8 DMInfill + C_9} e^{C_{10} SS + C_{11}}$	0,467
2	$C_1 e^{C_2 DMCol + C_3} e^{C_4 DMBeam + C_5} e^{C_6 DMSW_x + C_7} e^{C_8 DMInfill + C_9} e^{C_{10} SS + C_{11}} + C_{12}(N * Oh * f_{ck} * f_m)^{C_{13}}$	0,673
3	$C_1 e^{C_2 DMCol + C_3} e^{C_4 DMBeam + C_5} e^{C_6 DMSW_x + C_7} e^{C_8 DMInfill + C_9} e^{C_{10} SS + C_{11}} \left(\ln\left(C_{12} A_c A_p C_{13} SW_x A_p + C_{14} Infill_x A_p + C_{15}\right)\right) + A_p C_{16}(N * Oh * f_{ck} * f_m)^{C_{17}}$	0,652

Table 2.8. Nonlinear Regression Coefficients

	1	2	3
C1	0.492	0.159	0.834
C2	-0.106	-0.107	-0.135
C3	0.084	0.292	-0.005
C4	-0.084	-0.109	-0.092
C5	0.209	0.292	-0.005
C6	-0.654	-0.576	-0.550
C7	-0.402	0.292	-0.005
C8	-0.078	-0.096	-0.097
C9	0.086	0.292	-0.005
C10	-0.008	-0.301	-0.025
C11	0.611	0.292	-0.005
C12		0.155	1.294
C13		-8.500E-09	-0.316
C14			0.474
C15			2.304
C16			0.025
C17			-8.051E-08

It has been observed that the obtained determination coefficients are quite low, and the predicted periods by the regression equations can deviate significantly from the theoretical periods. Therefore, it is concluded that it is not possible to create the period prediction equation with the desired accuracy through nonlinear regression analysis. The performance of the Nonlinear Regression Equation for Regression Model 2 is shown in Figure 2.8.

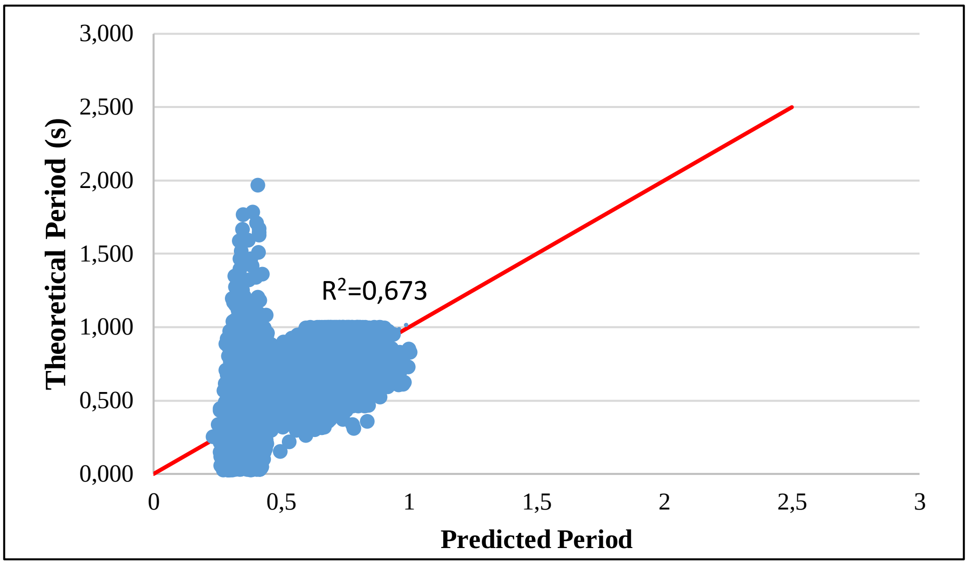


Figure 2.8. Performance of Nonlineer Regression Equations (Regression Model 2)

The purpose of conducting nonlinear regression analyses within the scope of this study was primarily to aim for period prediction using equations, a more common method in the engineering community. Nonlinear regression equations were determined for three separate regression models, and the regression coefficients for these equations were determined using the SPSS software. However, the highest value of the calculated regression coefficients was reached in Regression Model 2, which was determined as R^2-Model 2= 0,673. It is known that the regression coefficient can measure the performance of the established regression model, and the closer the R^2 value is to 1, the more significant and determinative the regression is considered. Since the highest regression coefficient obtained is significantly far from the value of 1, it is understood that the periods of the examined buildings cannot be predicted with sufficient accuracy using the determined three regression models. It was therefore determined that there was a more complex relationship between the initially determined period estimation parameters and the period, and that the Regression Analysis method was not suitable for the building fundamental vibration period.

An Artificial Neural Network (ANN) - a machine learning approach, was developed to obtain the fundamental vibration period values using the selected input parameters. The ANN architecture aimed to determine the effect of the initially determined structural parameters as well as the stiffness reduction coefficients that account for element damage on the vibration period of buildings. The developed ANN architecture was evaluated based on period values obtained from experimental studies on undamaged buildings and vibration period values obtained from acceleration measurements on moderately damaged buildings. Using ANN architecture and incorporating Stiffness Reduction Coefficients, it is aimed to predict the periods of both undamaged buildings and buildings with element damage. This comprehensive approach aimed to consider the effects of element damage on the vibration period.

2.1.3. Machine Learning Network

2.1.3.1. Literature Survey on Vibration Period Estimation of Buildings by using Machine Learning Techniqs

Adeli and Yeh [26] conducted a prominent study that applied artificial neural networks (ANNs) to civil engineering problems. They developed a single-layer perceptron ANN model to predict steel design outputs based on the Load and Resistance Factor Design (LRFD) regulation. Following this pioneering work, ANNs have been widely utilized in various civil engineering research areas, such as design optimization, stress level prediction, and vibration period estimation. Several publications in the literature have focused on investigating changes in building period or frequency resulting from damage to structural elements, often measured through building accelerations during vibrations.

Habtour et al [27] determined that damage-induced frequency changes decrease the resonance frequency of a system during strong ground motion. Kudva et al [28] developed a backpropagation neural network model to identify damage locations on rigid plates, which helped in determining the appropriate hole diameters to be drilled at various points. However, they achieved only a 50% success rate in determining the hole diameters accurately. Elkordy et al. [29] trained an Artificial Neural Networks with analytically generated sample building models. The numerical models are then subjected to a series of shake table tests and the diagnostic capability of the network is verified using the damage state of the building models.

Sohn et al. [30] performed time-dependent acceleration measurements in both undamaged and damaged states of buildings to investigate the effects of structural member damage on fundamental vibration accelerations. They developed an autoregressive model using the collected data. Similarly, another autoregressive model was created to separate the components with damage-related noise in acceleration record measurements, with the aid of ANNs [31].

Caglar et al. [32] developed an ANN model to assess the collapse risk of existing buildings during seismic events. The input parameters for this model were determined based on the P25 Rapid Evaluation Method [33]. The proposed model's performance was evaluated using data from buildings damaged in the 2003 Bingol earthquake in Turkey. The results indicated that the developed model achieved an accurate risk assessment rate of 89% [32].

2.1.3.2. Employment of Mechine Learning Network

Machine learning (ML) is a subset of artificial intelligence that allows computers to improve their performance on given tasks by leveraging previous experience. ML focuses on data-driven models that can learn about a system directly from observed data without relying on predetermined mechanical relationships governing the system [34]. ML algorithms can adaptively enhance their performance with each new data sample, update weights based on new data, and discover relationships within complex and high-dimensional data [35]. In this study, the artificial neural network (ANN) approach, one of the ML algorithms, is utilized.

The ANN approach is based on an algorithm that mimics the human brain's learning process and has been widely applied in engineering applications for a considerable time [36]. Previous studies have employed ANN in classification studies [37, 38], optimization studies [39, 40], and in investigating the relationship between structural parameters and fundamental vibration frequencies [41, 42] within the field of civil engineering.

By utilizing a database, ANN algorithms can establish the correlation between different input and output parameters. Neural networks are composed of neurons, which are arranged hierarchically to create input layers, output layers, and hidden layers. Neurons in neural networks are interconnected through weighted connections, where the output values from neighboring neurons are multiplied by these connection weights and passed to the relevant neuron. The neuron then produces an output by subjecting the received values to a mathematical function known as the activation function. Based on the direction of data flow among neurons and the choice of activation functions, neural networks can be categorized into various sub-branches [43, 44].

The methodology employed in this study involves nonlinear regression analysis, utilizing a neural network with a feedforward network and backpropagation algorithm. In this type of neural network, information flows from the input to the output layer, with no connections between neurons within the same layer. The sigmoid function, represented by Eq. (1), is chosen as the activation function.

$$F(x) = \frac{1}{1 + e^{-x}} \tag{1}$$

The artificial neural network employs an iterative process to establish the relationship between input and output parameters using the values in the database. This process shares similarities with nonlinear regression analysis. The iteration algorithm aims to minimize the discrepancy between the output values calculated by the artificial neural network and the corresponding values in the database. There are various algorithms available to minimize errors, categorized as first-order (such as Delta-bar-delta and Quickprop) [45, 46], or second-order (such as Levenberg-Marquardt) [47, 48]. In this study, the Levenberg - Marquardt algorithm is selected as it offers superior performance compared to the other algorithms [48-50]

In order to determine the significant structural parameters that contribute to the calculated period values from the numerical model, principal component analysis is conducted using three-dimensional building models generated by the SAP2000 [22] program. The structural parameters listed in Table 2.5. are considered in this analysis. The relationship between these structural parameters and the calculated fundamental vibration periods in the building models' X and Y directions is examined.

For the artificial neural network (ANN), the following input parameters are selected: number of storeys (NoS), characteristic concrete compressive strength (fck), concrete elasticity modulus (Ec), partition wall strength (fm), non-structural wall elasticity modulus (Em), storey height (SH), plan width (PW), plan depth (PH), slab thickness (St), number of axes in X direction (NoHA), number of axes in Y direction (NoVA), overhang area to ground floor area ratio (OhR), presence of overhang in X direction (OHX), presence of overhang in Y direction (OHY), stiffness reduction coefficient for columns (DMfC), stiffness reduction coefficient for beams (DMfB), stiffness reduction coefficient for X-direction shear walls

(DMSWx), stiffness reduction coefficient for Y-direction shear walls (DMSWy), non-structural wall stiffness reduction coefficient (DMinf), soft storey condition (SS), column area-to-floor area ratio (AcAp), shear wall-to-floor area ratio in the X direction (SWx/Ap), shear wall-to-floor area ratio in the Y direction (SWy/Ap), non-structural wall-to-floor area ratio in the X direction (Ainfx/Ap), non-structural wall-to-floor area ratio in Y direction (Ainfy/Ap). The output parameters are the fundamental fundamental vibration period (Tx and Ty) in the X and Y directions of the building models.

The study utilizes input parameters from 16.000 building models and the corresponding numerical analysis results. The period values of the numerical models serve as the output values, creating a database with input-output data. The database consists of 8.585 samples for training, 1.515 samples for cross-validation, and 5.900 samples for testing.

The architecture of the ANN in this study, including the number of hidden layers and the number of neurons in each layer, is determined based on relevant previous research. Studies by Rafiq et al. [44] and Hadi [51] have shown that a single hidden layer is sufficient when an adequate number of neurons are employed. The appropriate number of hidden neurons can be calculated using either Equation (2), proposed by Papadrakakis et al [52], or Equation (3), suggested by Halim [53].

$$NoHN = \frac{NoI + NoO}{2} + NoO \tag{2}$$

$$NoHN = \frac{NoI + NoO}{2} + 1 \tag{3}$$

The equation mentioned in Eq. (2) provides a equation for determining the number of hidden neurons in an artificial neural network. NoHN represents the number of hidden neurons, NoI corresponds to the number of inputs, and NoO corresponds to the number of outputs. According to Rafiq et al. [44], the optimal number of neurons should be determined through trial and error. Based on this information, using equation. (3) with 25 input variables and 2 output variables, it was calculated that 39 neurons should be used.

However, considering that the optimal number of neurons should be determined through trial and error, single-layer neural networks with 15, 20, 25, 30, 35, and 40 hidden neurons were trained and tested, and their performances were compared based on the correlation coefficient values. In the studies, the neural network with 40 hidden neurons achieved the minimum training error. On the other hand, the network with 35 hidden neurons obtained the most minor cross-validation error. It is important to note that as the number of hidden neurons in the ANN increases, it may overly fit the training data and lose its ability to generalize (overfitting). Hence, the decision was made to prioritize the cross-validation performance as the main criterion when selecting the most suitable neural network architecture. Consequently, the network model with 35 hidden neurons was chosen for the ANN architecture (Figure 2.9).

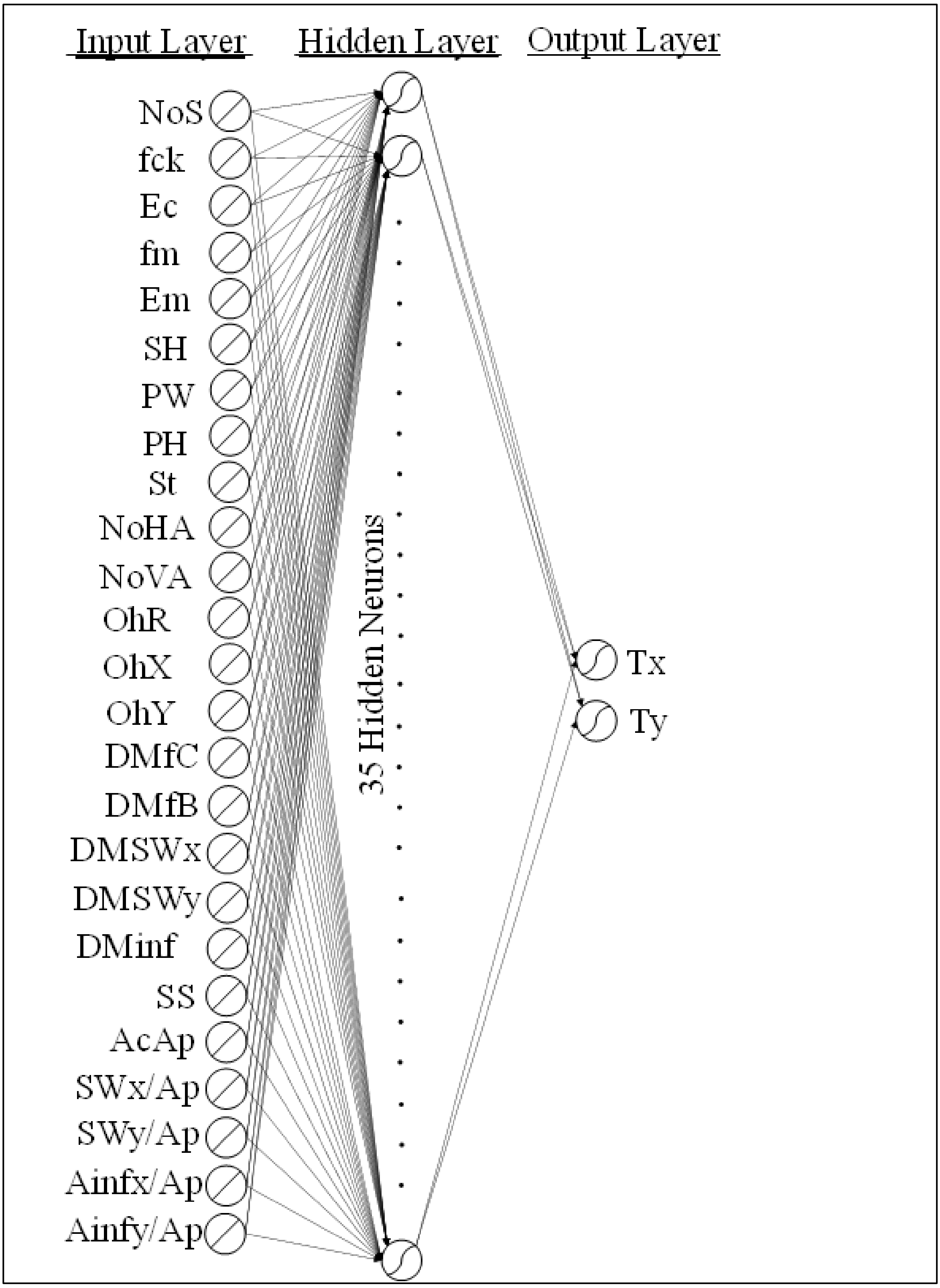


Figure 2.9. Schematic representation of the building period estimation process by using the Artificial Neural Network

The performance of the developed artificial neural network (ANN) was found to be highly successful in the testing phase. The correlation coefficients between the predicted fundamental vibration periods in the X and Y directions and the corresponding theoretical expected values were calculated as 0.95 and 0.94, respectively. Figures 2.10.a and 2.10.b demonstrate a strong positive linear relationship between the estimated and expected period values. The predicted period values align closely along the diagonal line, indicating a high level of agreement between the predicted and expected values. This clustering around the diagonal line supports the accuracy and reliability of the ANN predictions.

The test results confirm that the developed ANN model effectively captures the relationship between the input parameters and the fundamental vibration periods, yielding accurate and closely aligned predictions.

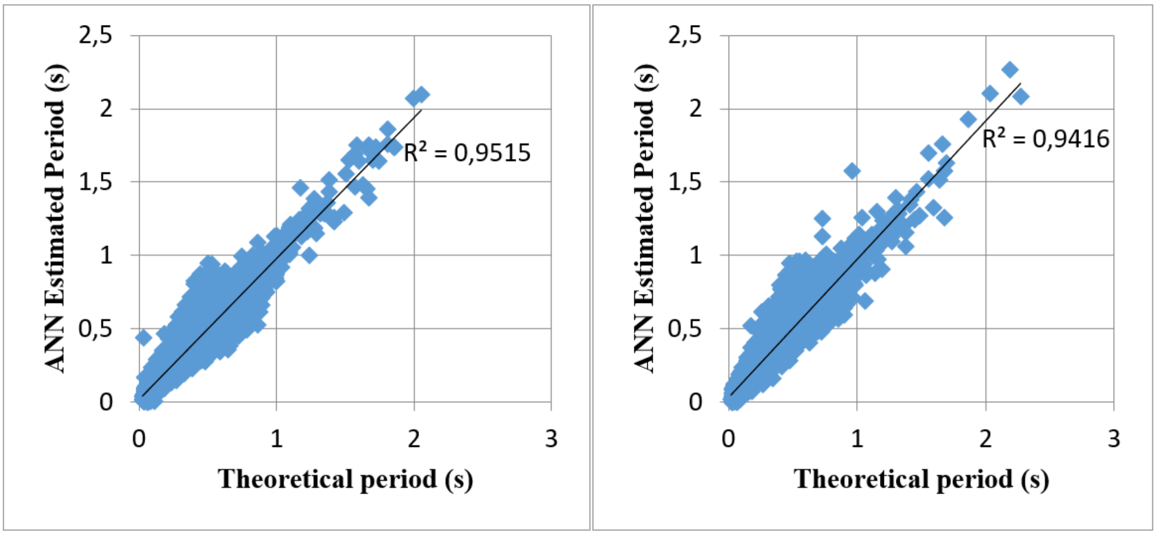


Figure 2.10. Estimated and theoretical period comparison for (a) X direction and (b) Y direction

After confirming the artificial neural network (ANN) model's high-precision prediction capacity, we examined the primary determinants for forecasting fundamental vibration period values from input parameters. We analyzed the importance of the features using the SHapley Additive exPlanations (SHAP) library [54]. The study attempted to determine the effectiveness of the input parameters in estimating building period values. This analysis provides engineers and researchers with insight into the key variables that have the most significant influence on the fundamental vibration periods exhibited by structures.

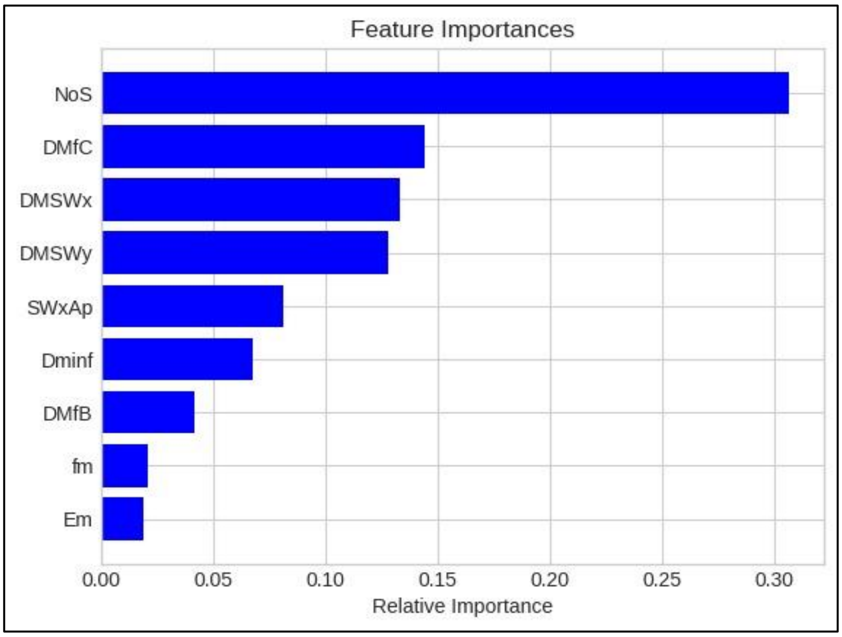


Figure 2.11. Relative Importance of Parameters for Predicting Building Periods from Feature Importance Analysis

The feature importance analysis suggests that the Number of Storeys (NoS), Stiffness Reduction Coefficient for Columns (DMfC), Shear Walls Stiffness Reduction Coefficients (DMSWx and DMSWy), and Shear Wall-To-Floor Area Ratios (SWxAp) parameters are the most effective when estimating the fundamental vibration period of a building (Figure 2.12). This observation is supported by the fundamental period equation: $2\pi\sqrt{\frac{m}{k}}$. The number of floors in the equation determines the building mass, while other parameters such as DMfC, DMSWx, DMSWy, and SWxAp affect the stiffness.

The SHAP library was used to identify the most effective parameters for estimating the fundamental vibration period. The presented bar graph shows the mean SHAP values for each individual feature across all observations. It aggregates values that have both positive and negative impacts on the period value. The overhang parameter demonstrates the most substantial average SHAP values in this context (see Figure 9). Furthermore, the Bee-Swarm graph generated by the SHAP library indicates that the presence of overhang significantly affects the predicted vibration period values (see Figure 10).

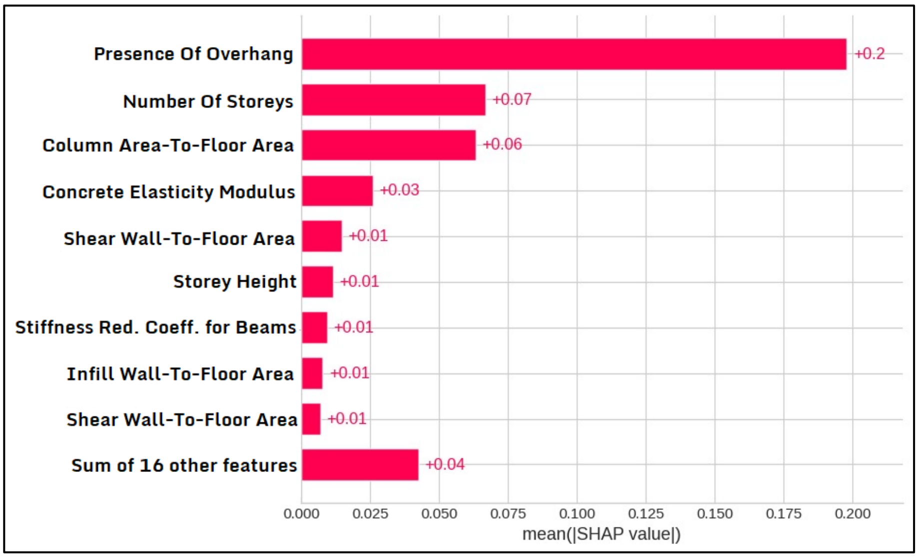


Figure 2.12. Mean SHAP values that has effect on predicted period values

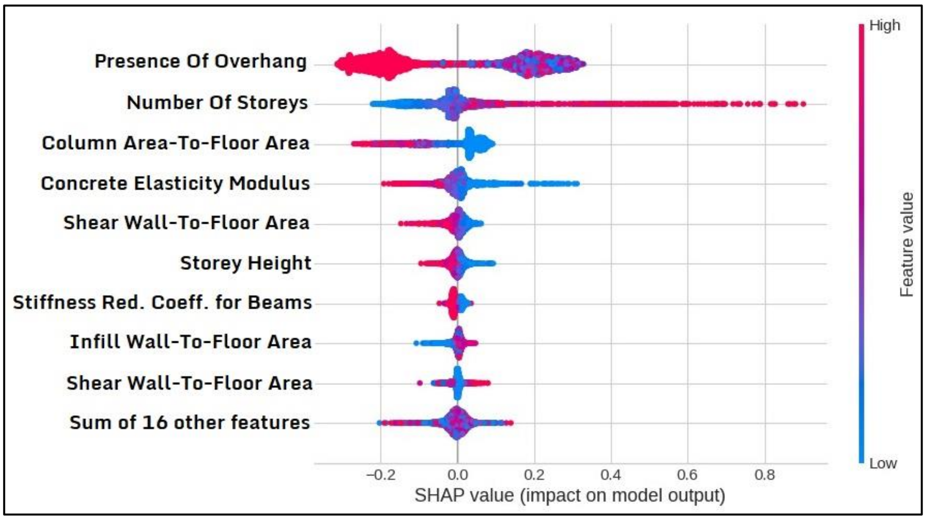


Figure 2.13. Bee-Swarn plot for mean SHAP values period predicted parametres

2.1.4. Determining "Building Period Estimation Artificial Neural Network" Performance

2.1.4.1. Validation of the proposed ANN approach for period estimation with Experimental Data from the Literature

In order to further validate the performance of the machine learning network in estimating building periods, the results are compared with experimental data obtained from previous studies in the literature. These studies provide information on the mechanical and physical properties of the buildings, as well as the necessary parameters for inputting into the artificial neural network (ANN). The fundamental period values of the buildings in these studies were either determined through ambient vibrations or vibrations caused by external disturbances.

The output values of the ANN are compared with these experimental values, and the results are presented in Table 2.9. This table includes building data from three studies: the first 23 lines are from the study conducted by Yigit et al. [55] while the remaining lines are from the studies by Celik [56] and Celik et al. [57].

Various parameters are collected for each building, including the number of stories, concrete compressive strength, storey height, plan dimensions, slab thickness, number of axes in X and Y directions, presence of overhang, presence of soft storey, the ratio of the total cross-sectional area of critical storey columns to storey area, and the ratio of total shear wall cross-sectional area in both X and Y directions to storey plan area. The modulus of elasticity of concrete is determined using the equation provided in TEC 2018 given as $500\sqrt{f_{ck}}$. Similarly, the elasticity modulus of the masonry infill wall material is calculated using the formulation in TEC 2018, i.e., 750 × fm. The stiffness reduction factors for beams, columns, shear walls, and infill walls are assumed to be unity for determining period values in undamaged cases.

This comparison with experimental data allows for an evaluation of the accuracy and reliability of the machine-learning network in estimating building periods, providing further evidence of its effectiveness.

Table 2.9. Comparison of Estimated Period Values by the Machine Learning Network to the Measured Period Values from Past Studies in the Literature

No	Strc. System	Nof Str	f_{ck} (MPa)	Ec (MPa)	f_m (MPa)	SH (m)	PlW (m)	PlH (m)	SS	Ac/ Ap	SWx/ Ap	SWy/ Ap	$Ainfill_x$ /Ap	$Ainfill_y$ /Ap	T_{test} (s)	$T_{Neural Network}$ (s)	Error (%)
1	RC SW	4	12	17321	4.13	3.70	24.9	14	0	0.022	0.016	0.022	0.021	0.018	0.144	0.144	0.382
2	RC SW	4	11	16583	4.13	3.90	43.2	32	0	0.014	0.011	0.014	0.006	0.004	0.212	0.217	-2.375
3	RC SW	4	13	18028	4.13	3.38	17.5	17	0	0.011	0.016	0.015	0.008	0.017	0.144	0.148	-3.169
4	RC SW	4	18	21213	4.13	3.38	14.3	16.2	0	0.017	0.009	0.011	0.004	0.037	0.172	0.172	-0.311
5	RC SW	4	15	19365	4.13	3.38	34.3	17	0	0.010	0.017	0.015	0.006	0.007	0.163	0.154	5.530
6	RC SW	4	19	21794	4.13	3.38	17.5	17	0	0.011	0.016	0.015	0.008	0.017	0.137	0.146	-6.423
7	RC SW	4	13	18028	4.13	3.38	14.3	16.2	0	0.017	0.009	0.011	0.004	0.037	0.178	0.176	1.108
8	RC SW	4	15	19365	4.13	3.38	34.8	17.3	0	0.009	0.016	0.015	0.006	0.007	0.164	0.158	3.500
9	RC SW	3	11	16583	4.13	3.87	33.9	23.4	0	0.013	0.018	0.016	0.003	0.003	0.150	0.148	1.725
10	RC SW	3	10	15811	4.13	3.87	39.9	23.4	0	0.011	0.015	0.013	0.001	0.004	0.165	0.167	-1.070
11	RC SW	3	11	16583	4.13	4.37	33.9	23.4	0	0.013	0.018	0.016	0.003	0.003	0.172	0.162	5.705
12	RC SW	3	13	18028	4.13	4.37	39.9	23.4	0	0.011	0.015	0.013	0.001	0.004	0.180	0.193	-7.172
13	RC SW	3	25	25000	4.13	3.87	48.3	16.5	0	0.015	0.009	0.013	0.016	0.012	0.244	0.263	-7.517
14	RC SW	3	10	15811	4.13	4.00	36.4	22.4	0	0.009	0.019	0.019	0.012	0.005	0.172	0.156	9.509
15	RC SW	4	14	18708	4.13	3.00	52.5	22.4	0	0.011	0.016	0.016	0.006	0.005	0.176	0.180	-1.818
16	RC SW	5	11	16583	4.13	3.04	52.5	22.4	0	0.011	0.016	0.016	0.008	0.006	0.201	0.193	4.240

17	RC SW	2	14	18708	4.13	3.75	28	24	0	0.008	0.007	0.012	0.013	0.015	0.205	0.191	6.596
18	RC SW	4	9	15000	4.13	3.40	28.2	13.7	0	0.019	0.013	0.018	0.005	0.028	0.142	0.154	-8.458
19	RC SW	4	10	15811	4.13	3.40	28.2	13.7	0	0.019	0.013	0.018	0.028	0.005	0.138	0.149	-8.000
20	RC SW	5	11	16583	4.13	3.20	13.5	20.4	0	0.020	0.017	0.010	0.005	0.016	0.190	0.205	-7.768
21	RC SW	2	9	15000	4.13	3.40	36	36	0	0.013	0.005	0.006	0.010	0.009	0.211	0.202	4.277
22	RC SW	3	11	16583	4.13	4.37	33	16.7	0	0.019	0.014	0.016	0.008	0.010	0.159	0.159	-0.143
23	RC SW	3	9	15000	4.13	4.37	33	16.7	0	0.019	0.014	0.016	0.008	0.006	0.142	0.146	-2.936
24	RC Fr.	6	35	29580	1	4.65	15.8	53.2	1	0.015	0.000	0.000	0.000	0.000	0.496	0.576	*-16.08*
25	RC Fr.	2	25	25000	8	4.00	6.3	30	1	0.008	0.000	0.000	0.079	0.020	0.164	0.174	-5.995

2.1.4.2. Validation of the ANN-Based Period Estimation Procedure by Using Acceleration Data Monitored in Damaged Buildings

As part of the validation process to assess the performance of the proposed machine learning network in predicting the foundation vibration period of damaged buildings, this chapter includes the analysis of the floor accelerations obtained from the final test ambient vibrations. Digital accelerometers were used to record these ambient vibrations and were installed in the reinforced concrete slabs of the selected damaged buildings. The buildings selected for this test are located in Izmir and were moderately damaged in the 2020 Samos earthquake (Mw=7.0).

Signal processing techniques were used to determine the fundamental vibration period of the buildings from the recorded acceleration data. A total of 10 buildings were analyzed, all of which did not undergo retrofitting or demolition. Extensive structural information was collected to facilitate detailed analysis. The TDG-EQUAKE-MONITOR accelerometer (Figure 2.11) recorded triaxial accelerations, including horizontal and vertical components, for at least 10 minutes.

Signal processing techniques were applied to the recorded acceleration data to determine the fundamental vibration period of the buildings. A total of 10 buildings were selected for this analysis, which has yet to undergo retrofitting or demolition. Comprehensive structural information was collected for these buildings to facilitate detailed analysis. Three-axis accelerations, horizontal and vertical components, were recorded using the TDG - EQUAKE-MONITOR accelerometer device (Figure 2.11). The acceleration records were captured for a minimum duration of 10 minutes.

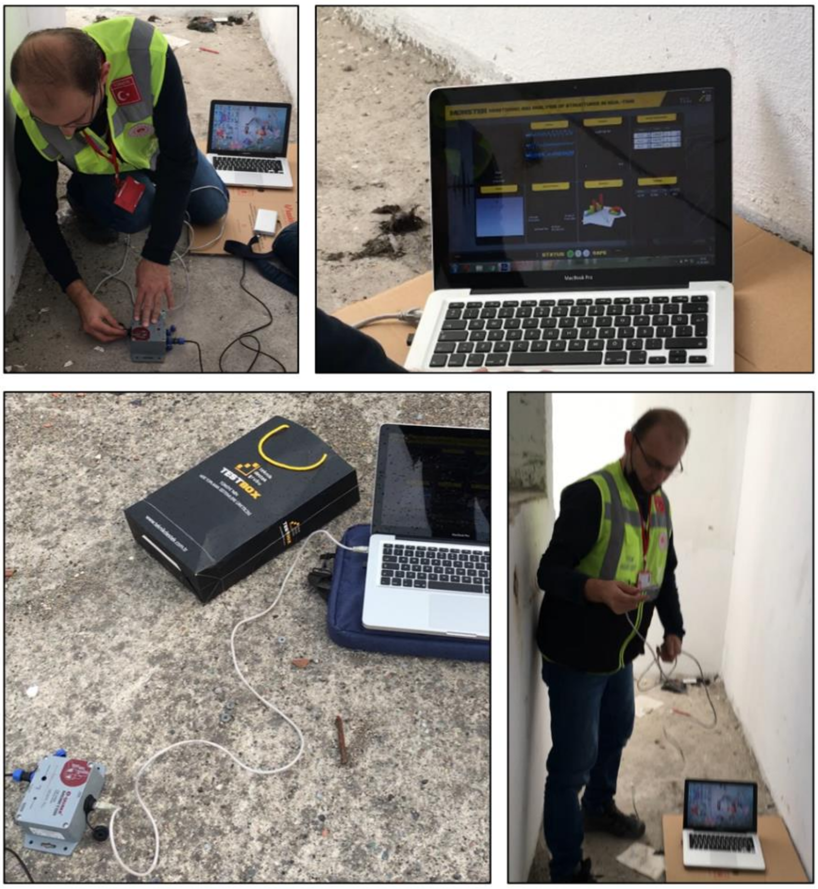
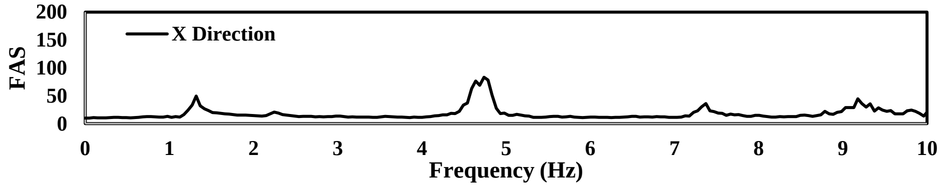


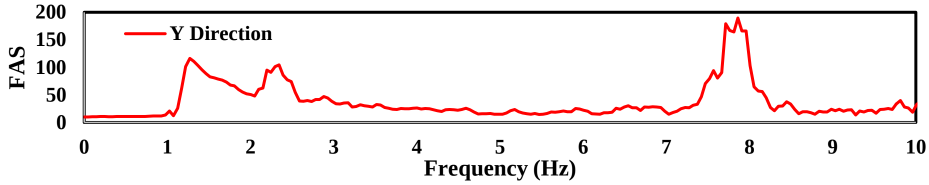
Figure 2.14. Recording the acceleration data in the damaged buildings

The fundamental vibration frequencies in both horizontal directions were monitored using the acceleration records obtained during the field studies. The data was sampled at a frequency of 200 Hz. In order to accurately determine the building's vibration frequencies, signal processing techniques were employed to eliminate noise and correct deviations from the horizontal baseline. Firstly, a baseline correction was applied to the acceleration data to account for any linear baseline shift during the data collection. Next, low-frequency noise, which corresponds to signals with frequencies below 0.1 Hz, was filtered out. These noisy data can dominate the Fast Fourier Transform (FFT) [58] response and affect the accuracy of the results. Subsequently, the FFT operation was performed on the filtered data using a window width of 1000 data points, with a 30% overlap between successive windows. This operation generated a Fourier Amplitude versus Frequency graph. The frequency at which the Fourier amplitude value first peaked in this graph was identified as the first fundamental vibration frequency of the investigated building. The obtained fundamental vibration frequencies are presented in Table 2.10.

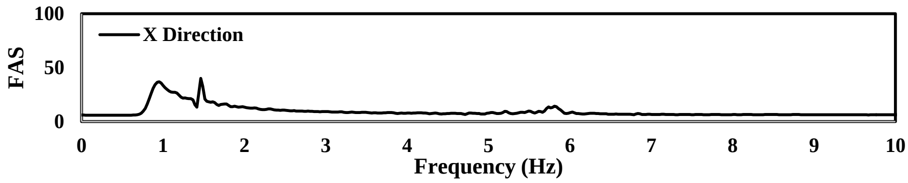
Table 2.10. Determination of fundamental vibration period from acceleration record performed in RC buildings damaged during the 2020 Aegean Sea Earthquake

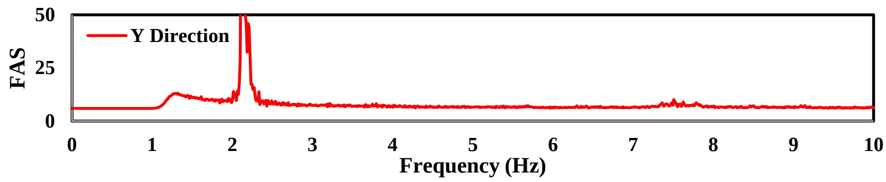
Test Building 1 | **f_x = 1.318 Hz T_x = 0.759 sec** | **f_y = 1.271 Hz T_y = 0.787 sec**



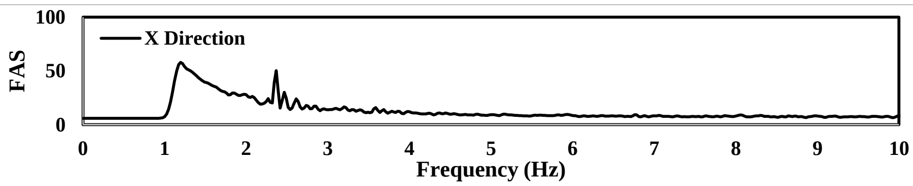


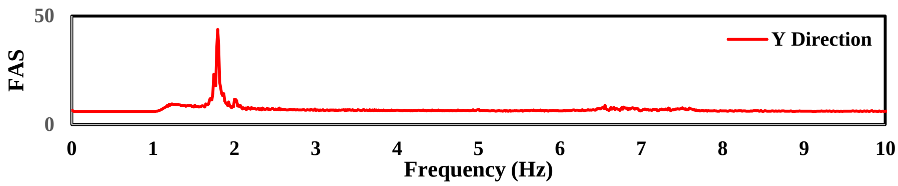
Test Building 2 | f_x = 0.952 Hz T_x = 1.050 sec | f_y = 1.318 Hz T_y = 0.759 sec



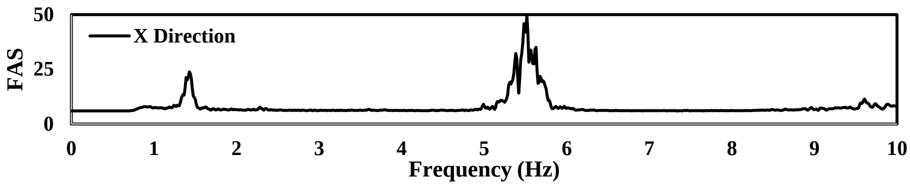


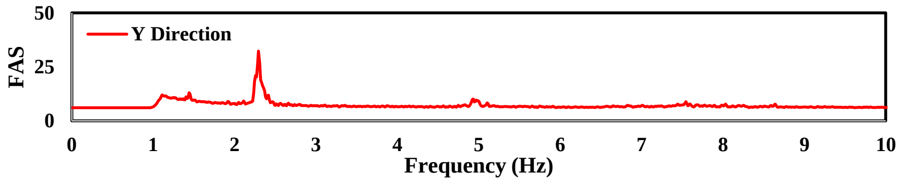
Test Building 3 | f_x = 1.196 Hz T_x = 0.836 sec | f_y = 1.233 Hz T_y = 0.811 sec



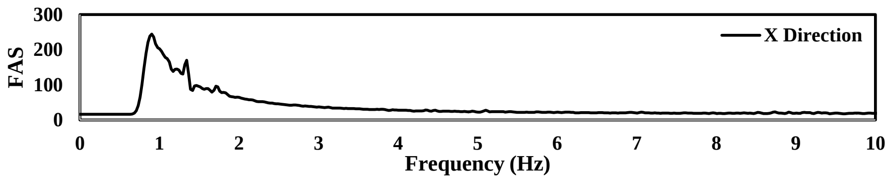


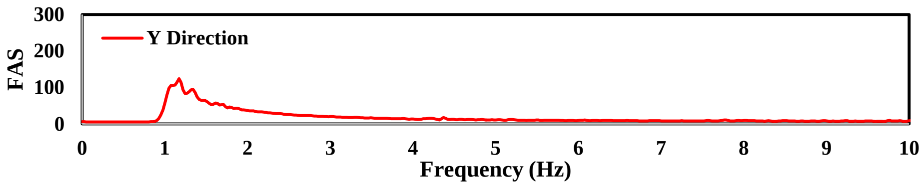
Test Building 4	$f_x = 0.891$ Hz $T_x = 1.122$ sec	$f_y = 1.147$ Hz $T_y = 0.872$ sec



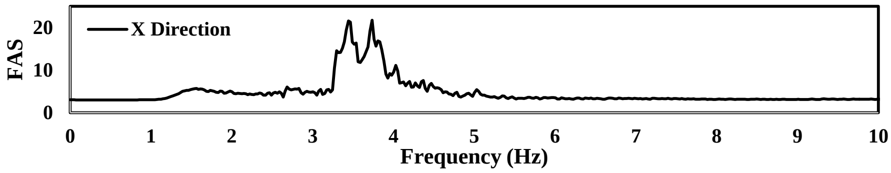


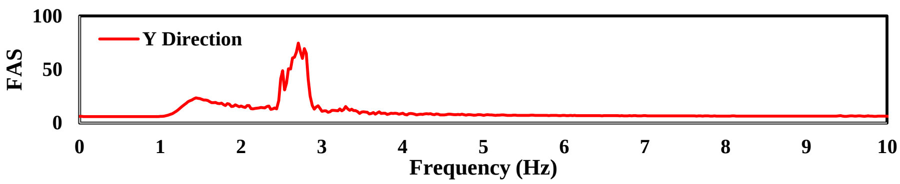
est Building 5	$f_x = 0.903$ Hz $T_x = 1.107$ sec	$f_y = 1.172$ Hz $T_y = 0.853$ sec



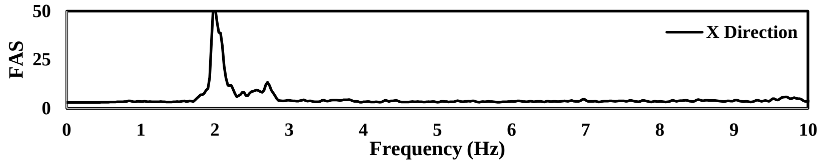


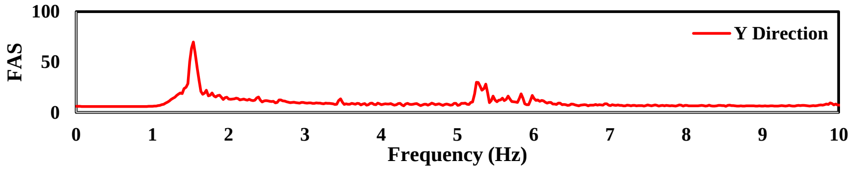
Test Building 6	$f_x = 1.563$ Hz $T_x = 0.640$ sec	$f_y = 1.440$ Hz $T_y = 0.694$ sec



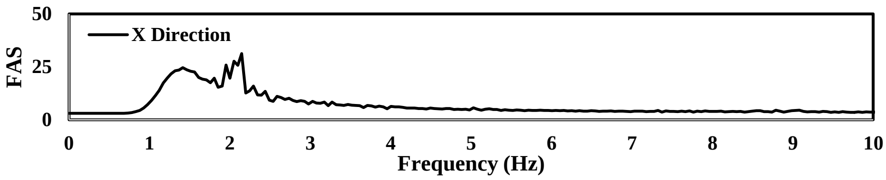


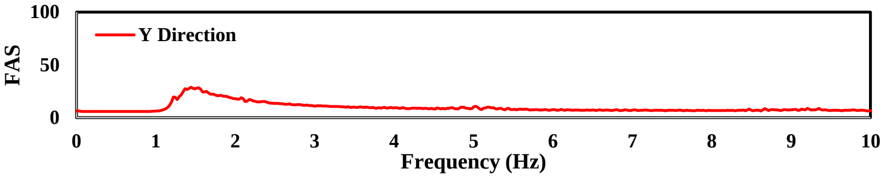
Test Building 7 $f_x = 2.020$ Hz $T_x = 0.495$ sec $f_y = 1.538$ Hz $T_y = 0.650$ sec



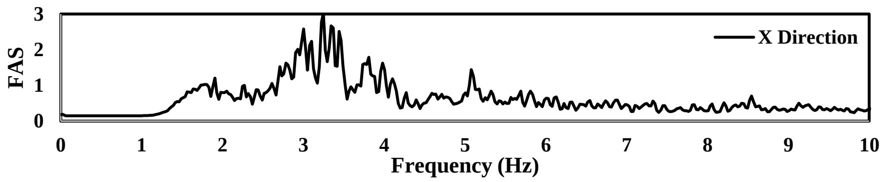


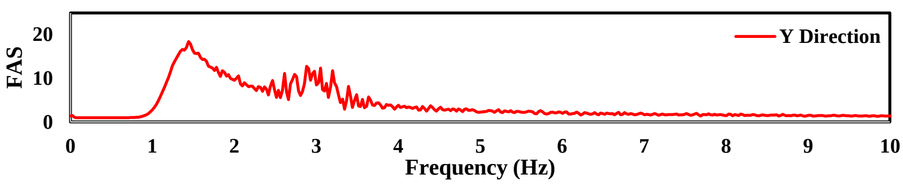
Test Building 8 $f_x = 1.416$ Hz $T_x = 0.706$ sec $f_y = 1.440$ Hz $T_y = 0.694$ sec



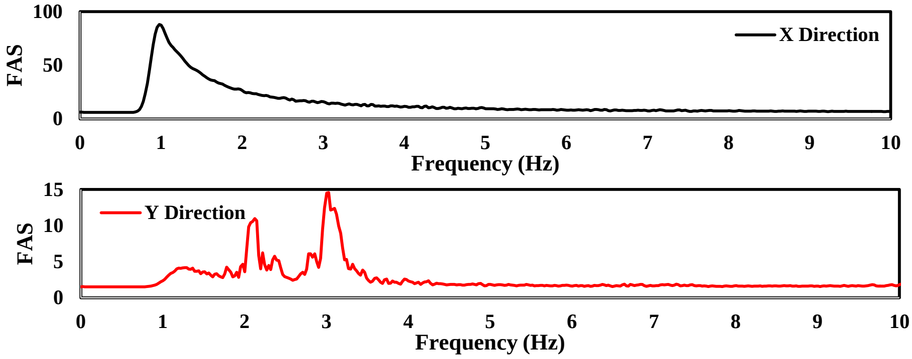


Test Building 9 $f_x = 1.904$ Hz $T_x = 0.525$ sec $f_y = 1.440$ Hz $T_y = 0.694$ sec





Test Building 10	f_x = 0.977 Hz T_x = 1.024 sec	f_y = 1.294 Hz T_y = 0.773 sec



During the data entry process, the stiffness reduction factors of the elements were determined based on the damage photographs obtained from the visited buildings, which provided visual evidence of their damage status. These stiffness reduction factors, namely DMfC (stiffness reduction coefficient for columns), DMfB (stiffness reduction coefficient for beams), DMSWx (stiffness reduction coefficient for X-direction shear walls), DMSWy (stiffness reduction coefficient for Y-direction shear walls), and DMinf (non-structural wall stiffness reduction coefficient) were utilized in the calculations of the artificial neural network (ANN). The input data for the ANN calculations and the recorded and estimated vibration periods for each direction are presented in Table 2.10. The stiffness reduction factors were assigned values according to the information provided in Tables 2.1, 2.2, 2.3, and 2.4, which define the relationship between the damage level and the corresponding reduction in element stiffness.

In Table 2.11, the fundamental vibration frequencies obtained from the field measurements in the buildings are converted to fundamental vibration period values and presented. When comparing the period values estimated by the ANN (Test) with the ones obtained during the field measurements (Trec), it is evident that the proposed network can estimate the fundamental vibration period values with an average absolute error of 7.73%. The standard deviation is calculated to be 5.46%. The maximum absolute percentage error is 15.46%, while the minimum absolute percentage error is 0.14%. These findings, based on 20 test data conducted on actual damaged structures, demonstrate the effectiveness of the proposed ANN model in estimating the fundamental vibration values of damaged RC buildings. Such estimations can be valuable in modifying expected demands during aftershocks or future strong ground motion events.

Table 2.11. Determining the performance of Developed Period Prediction Machine Learning Network with site study

No	Structural System	N	fck (MPa)	Ec (MPa)	SH (m)	Pl W (m)	Pl H (m)	No HA	No VA	SS	OhR	OhX	OhY	Ac /Ap	SWx /Ap	SWy /Ap	Ainfill,x /Ap	Ainfill,y /Ap	DMfC DMfB DMSWx DMSWy DMinf	T_{rec} (s)	T_{est} (s)	Error (%)
1	RC SW	9	10.65	16317	2.68	13.10	19.50	8	6	0	0.00	0	0	0.013	0.0031	0.0027	0.045	0.067	**1 0.45 1 1 0.30**	X: 0.759 Y: 0.787	X: 0.834 Y: 0.689	-9.88 12.45
2	RC Fr	8	5.87	12114	2.84	15.80	21.90	7	5	1	0.11	1	1	0.028	0.0000	0.0000	0.045	0.049	**1 0.45 1 1 0.15**	X: 1.050 Y: 0.759	X: 1.037 Y: 0.778	1.25 -2.51
3	RC Fr	8	6.30	12550	2.84	15.80	21.90	7	5	1	0.11	1	1	0.028	0.0000	0.0000	0.028	0.046	**1 0.45 1 1 0.30**	X: 0.836 Y: 0.811	X: 0.899 Y: 0.686	-7.54 15.42
4	RC Fr	8	8.58	14646	2.80	10.30	27.70	4	9	1	0.13	1	1	0.028	0.0000	0.0000	0.028	0.046	**1 0.45 1 1 0.15**	X: 1.122 Y: 0.872	X: 1.106 Y: 0.765	1.50 12.22
5	RC Fr	8	8.58	14646	2.80	10.30	27.70	4	9	1	0.13	1	1	0.028	0.0000	0.0000	0.028	0.046	**1 0.45 1 1 0.15**	X: 1.107 Y: 0.853	X: 1.106 Y: 0.765	0.14 10.30
6	RC Fr	4	3.78	9721	2.78	10.80	15.80	5	8	1	0.14	1	1	0.023	0.0000	0.0000	0.044	0.046	**1 1 1 1 0.30**	X: 0.64 Y: 0.694	X: 0.541 Y: 0.649	15.40 6.52
7	RC Fr	8	5.61	11843	2.78	14.90	18.10	6	10	0	0.00	0	0	0.021	0.0000	0.0000	0.045	0.044	**1 1 1 1 0.30**	X: 0.495 Y: 0.65	X: 0.572 Y: 0.699	-15.51 -7.45
8	RC SW	8	5.14	11336	2.78	14.90	18.10	6	10	0	0.00	0	0	0.022	0.0023	0.0035	0.045	0.044	**1 1 1 1 0.30**	X: 0.706 Y: 0.694	X: 0.597 Y: 0.751	15.46 -8.21
9	RC Fr	5	6.73	12971	2.85	14.50	17.63	5	7	1	0.13	1	0	0.017	0.0000	0.0000	0.079	0.068	**1 1 1 1 0.30**	X: 0.525 Y: 0.694	X: 0.524 Y: 0.644	0.21 7.33
10	RC Fr	4	10.26	16016	3.80	16.00	29.00	4	8	1	0.09	1	0	0.019	0.0000	0.0000	0.151	0.454	**1 0.45 1 1 0.30**	X: 1.024 Y: 0.773	X: 0.991 Y: 0.756	3.17 2.18

2.1.5. Achived Results on Determining Rapid Building Fundamental Period

In this part of the study, machine learning algorithms are developed to estimate the fundamental vibration period values of damaged RC buildings. Based on experimental data, the method relies on determining stiffness reduction factors for different structural and non-structural elements. A database of 16,000 numerical building models was created, considering various combinations of input parameters and reflecting different levels of damage. The proposed method aims to provide a reliable estimation of undamaged and damaged fundamental vibration periods using the buildings' key geometric and mechanical properties without the need for extensive numerical models.

The validity of the method was tested in three stages. The first stage involved using numerical data from the generated building database, demonstrating successful performance with high correlation coefficients. The second stage involved comparing the estimated period values with experimental results from undamaged buildings, showing an average absolute error of 4.87%. Finally, the method was tested using ambient vibration data from damaged buildings, resulting in an average absolute error of 7.73%.

Overall, the proposed method offers a contemporary approach for predicting the fundamental vibration periods of damaged RC buildings, allowing for preliminary seismic evaluation or post-earthquake condition assessment calculations. It provides a practical and reliable means of estimating period values without relying on complex numerical models, facilitating more accurate demand estimations during aftershocks or potential future strong ground motions.

This method determines the fundamental vibration period of the investigated moderately damaged buildings to be used in determining the Demand and Design Capacity of the investigated building. Subsequently, in the next section, the Site Spectrum at the location of the building is evaluated according to the earthquake that caused moderate damage to the structure. By substituting the period value of the damaged building in the Site Spectrum table in the next section, the acceleration value (Sa) to which the building was exposed during the earthquake is determined.

2.2. Estimating the Site Spectrum at the Building Location by Using Ground Motion Models After Earthquake

Ground Motion Models (GMMs) aim to determine the effect of earthquake motion at a specific location. This is dependent on the earthquake's magnitude, the distance between the epicenter and the spesific location, and the geological and mechanical properties of the soil along that distance between epicenter and investigated site [59]. The aim of this thesis is to determine the effect of earthquake on the investigated building. For this, it is aimed to conduit the earthquake accelerations recorded at the Accelerometer stations to the location of the investigated moderately damaged building.

2.2.1. Literature Survey on Estimating the Site Spectrum of the Building

Since 1964, various empirical equations and methods have been developed for the estimation of Peak Ground Acceleration. The first of these in the literature was Esteva & Rosenblueth [60]. Douglas [61] compiled Ground Motion Models (formerly known as Ground Motion Prediction Equation) published between 1964 and 2021. In his report, the properties of a total of 289 empirical GMMs for the prediction of peak ground acceleration (PGA) and 188 models for the prediction of elastic response are compiled. The study by Boore et al. that we use in this thesis is based on the BSSA13 and BSSA14 methods published in 2008 [62] and updated in 2014 [59]. These methods will be applied in tectonically active crustal regions using earthquake records selected from the NGA-West2 database. The study determined estimation equations.

The first study on GM Models for Turkey was published by Aydan in 1997 [63]. In 2004, Kalkan and Gülkan proposed ground motion models in 2002 [64], 2004 [65] and 2005 [66] by utilizing 1999 Kocaeli, Duzce, and other earthquakes in Turkey. Also Özbey et al. [67] proposed an empirical method for Ground Motion prediction in 2004. Akkar and Bommer, in their studies in 2007 [68, 69] and 2010 [70], they worked on empirical equations for GMM utilizing earthquakes in Turkey. In their study published in 2009, Akyol and Karagöz [71] applied regression analysis to the earthquake records obtained for Western Anatolia and attempted to determine empirical attenuation relationships. In their paper published in 2009 [72], Ulutas and Ozer proposed a regression equation to determine the relationship between moment magnitudes and PGA attenuation by utilizing the Kocaeli and Duzce earthquakes and their aftershock records. In 2010, Akkar and Çağnan proposed a Ground Motion Model that provides ground motion amplitudes for reverse, normal, and strike-slip faulting types, taking into account nonlinear ground behavior [73]. Askan et al. (2015) [74] conducted seismic hazard analyses for Erzincan province using locally derived site-ground parameters. They also created local seismic velocity models and performed probabilistic and deterministic seismic hazard analyses, estimating the corresponding strong ground motions. Kale et al. [75] developed a Horizontal Ground Motion Model (GMM) for Iran and Turkey in 2015 to obtain the PGA and PGV values. In this thesis, GMMs developed by Kale et al. and Boore et al [59] are used to determine the PGA value of the earthquake at the location of the moderately damaged building. Sandıkkaya et al. (2023) [76] proposed a simulation-based GMM (one of the most recent studies for Turkiye) and hazard analysis method for the Marmara and Aegean regions in Turkey.

2.2.2. Selecting Suitable Ground Motion Models and Earthquake Data Comparison

Turkey is located in the Alpine-Himalayan tectonic belt. The three main structures that shape the neotectonics of the country are the North Anatolian Fault Zone (NAFZ) (right-lateral strike-slip), the East Anatolian Fault Zone (EAFZ) (left lateral strike-slip), and the Aegean-Cyprus Arc. The Dead Sea Fault Zone also plays an important role in the earthquakes that occur in the country. The characteristics of these four different tectonic regimes were taken into account in determining the tectonic zone.

In Turkey, earthquake data has been recorded since 1903 when dedicated stations were established. It is important to continue monitoring seismic activity in the region for the safety of the population. Between 1903 and 2023, roughly 120 earthquakes with magnitudes greater than 6 and resulting damage have occurred. Some of these earthquakes that can be considered important in the last 30 years: 2023 Kahraman Maraş Pazarcık - Elbistan Earthquakes (Mw=7.7 and 7.6), 2020 İzmir-Samos Earthquake (Mw=6.6), 2020 Elazig-Sivrice Earthquake (Mw=6.8), 2017 Gokova Bay Earthquake (Mw=6. 6), 2017 Aegean Sea Earthquake (Mw=6.1), 2012 Mugla Earthquake (Mw=6.0), 2011 Tabanli-Van Earthquake (Mw=7.2), 2011 Kutahya-Simav Earthquake (Ml=5.9), 2010 Elazıg-Karakocan Earthquake (Ml=6.0), 2007 Bala Earthquake (Ml=5. 7), 2007 Elazıg-Sivrice Earthquake (Ml=5.9), 2003 Izmir-Urla Earthquake (Ml=5.6), 2003 Bingol Earthquake (Ms=6.4), 2003 Tunceli-Pulumur Earthquake (Ms=6.2), 2002 Afyon-Sultandagi Earthquake (Ms=6. 4), 2000 Cankırı - Orta Earthquake (Ms=6.1), 1999 Duzce Earthquake (Mw=7.2), 1999 Golcuk (Kocaeli) Earthquake (Mw=7.4), 1998 Adana-Ceyhan Earthquake (Ms=6.2), 1995 Afyon - Dinar Earthquake (Ms=6.1) and 1992 Erzincan Earthquake (Ms=6.8). The appropriate ground motion records selected from these earthquakes were used to determine the ground motion model of our study.

This thesis utilised Ground Motion models from the literature. As described in the Literature Survey section, Boore et al. (2014) (BSSA14) [59] and Kale et al. (2015) (KAAH15) [75] models are used to conduit PGA recorded values from accelerogram stations to building locations, Two GMMs were calibrated using the methods outlined in Askan et al. (2019) [77] and Altındal et al (2023) [78]. Table 2.13 displays the selected model and weight for different fault zones.

The general functional equation for ground motion models is shown below. In this equation, lnY is the fundamental logarithm of the ground motion intensity parameter to be estimated (spectral acceleration, peak ground acceleration, etc.), F_E is the source function, F_P is the propagation path function, F_S is the site effect function, σ is the total standard deviation of the model. Finally, ϵ is a parameter that indicates how many standard deviations the predicted value differs from the fundamental logarithm of the measured ground motion. A positive value of this parameter means that the measured ground motion parameter is larger than the predicted median value. Ground motion models are usually assumed to follow a standard normal distribution.

$$lnY = F_E + F_P + F_S + \epsilon\sigma \quad (4)$$

The equation uses inputs such as earthquake magnitude and fault mechanism to estimate the shaking caused by earthquake source effects (F_E). The propagation path function (F_P) is calculated with parameters such as earthquake magnitude, site-source distance, and earthquake zone. The site effect function (F_S) is calculated with parameters Vs_{30} (average shearwave velocity at a depth of 30 meters) and z1 (depth required to reach a shearwave velocity of 1000 m/s). The sum of these three functions provides an estimate of the mean ground motion intensity. This value represents the model error (εσ) between the predicted average value and the actual recorded intensity value. Using this data, the ground motion intensity parameter is evaluated.

General representation of the Boore et al. (2014) BSSA14 equation:

$$\mathrm{lnY} = \mathrm{Fe}(\mathrm{M}, \mathrm{mech}) + \mathrm{Fp}\ (Rjb, M, reg) + \mathrm{Fs}(Vs30, Rjb, M, reg + \varepsilon\mathrm{n}\sigma(M, Rjb, Vs30) \quad (5)$$

General representation of the Kale et al. (2015) KAAH15 equation:

$$lnY = fmag\ +\ fdis\ +\ fsof\ +\ faat\ +\ fsite \quad (6)$$

Turkey is divided into four main neotectonic regions: Eastern Anatolia, Northern Anatolia, Western Anatolia, and Central Anatolia. The ground motion models were tested using reliable instrumental earthquake records from each region. Table 2.12 displays the earthquakes considered, and Figure 2.12 shows their response spectra. The BSSA14 and KAAH15 ground motion models were used to estimate ground motion magnitudes.

Table 2.12. Earthquake records used for testing ground motion models

Location	**Date**	**Lat.**	**Lon.**	**Depth (km)**	**Mw**	**Region**	**Number of Rec.**
İzmir-Samos	10/30/2020	37.8881	26.777	16.54	6.6	Western Anatolia	17
Elazıg-Sivrice	1/24/2020	38.3593	39.063	8.06	6.8	Eastern Anatolia	6
Duzce	11/12/1999	40.806	31.226	11.00	7.1	Northern Anatolia	3
Golcuk-Kocaeli	8/17/1999	40.77	30.004	15.00	7.6	Northern Anatolia	8
Yuregir-Adana	6/27/1998	36.9358	35.3664	10.00	6.2	Eastern Anatolia	2
Dinar-Afyon	10/1/1995	38.075	30.142	30.90	6.4	Western Anatolia	2
Erzincan	3/13/1992	39.72	39.632	22.20	6.6	Northern Anatolia	2

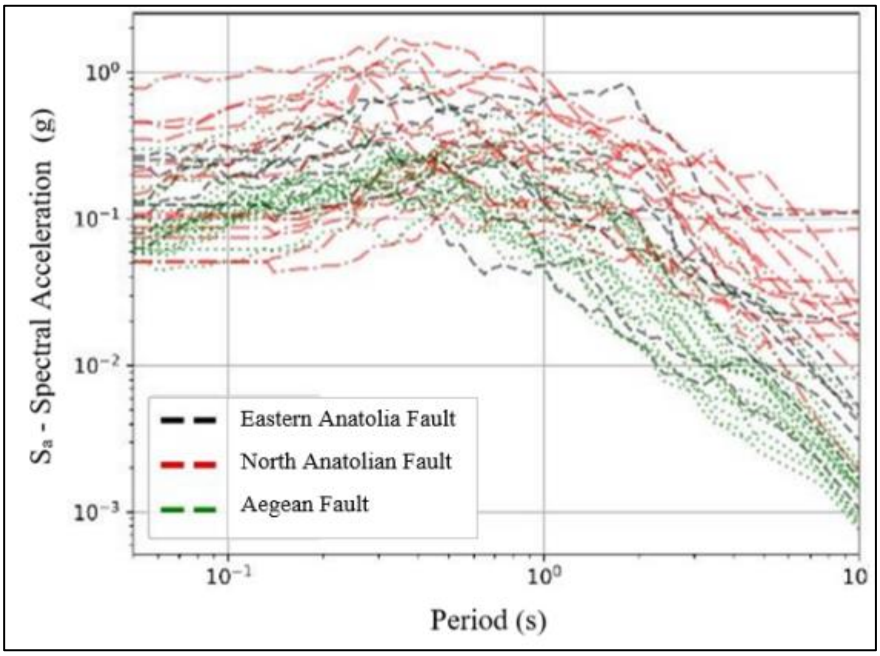


Figure 2.15. Utilized response spectra of the ground motion records.

Our study compared ground motion records from four distinct tectonic regions with ground motion magnitudes calculated by ground motion models based on earthquake magnitude, location, and ground conditions. The resulting analysis calculated the prediction error for each period in the response spectra. The weight values with a sum of 1.0 were calculated inversely proportional to the average prediction error for both models (BSSA14 and KAAH15), and this value was used in the weighted average calculation. However, since no earthquake records suitable for our study exist in the Central Anatolian Plain Region, we distributed the weights of both prediction models equally at 50% - 50%. The weight value coefficient for this area was set as 0.5 for both models. The determined weight coefficients are shown in Table 2.13.

Table 2.13. Ground motion models, weighted coefficient

Region	BSSA14	KAAH15
Eastern Anatolia Fault	0.63	0.37
North Anatolia Fault	0.59	0.41
Westwern Anatolia Fault	0.59	0.41
Central Anatolia Fault	0.50	0.50

2.2.3. Algorithm Steps of the Proposed Method Field Response Spectrum Estimation

Selected ground motion records in four different tectonic regions were compared with ground motion magnitudes calculated by ground motion models using earthquake magnitude, location and ground conditions. The proposed method consists of 6 steps.

- Step 1

In the first step of the proposed method, we obtain the response spectra of the two horizontal ground motion components recorded at the measurement station nearest to the investigation site. Then, we calculate the geometric mean of the spectrum values obtained for the X and Y directions.

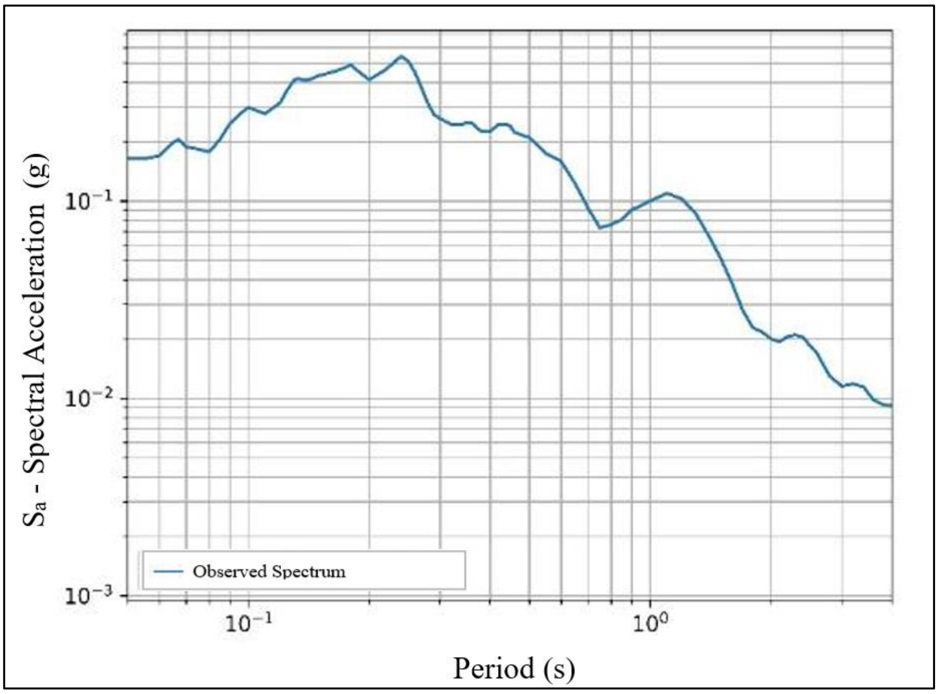


Figure 2.16. Calculation of the response spectrum at the closest station to the site

Step 2

In the second step, the median spectrum is estimated through the selected ground motion prediction method, using the source information of the earthquake and ground conditions at the station.

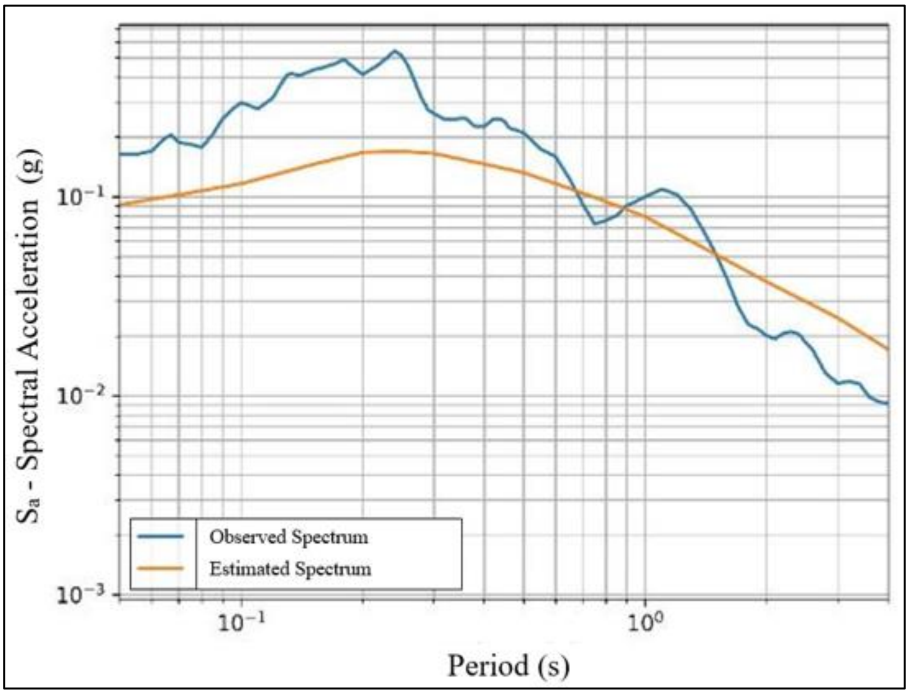


Figure 2.17. Determination of the median response spectrum at the accelerometer station using GMMs

Step 3

In the third step, the difference between the fundamental logarithm of the spectral acceleration value observed for each period and the median value calculated with the ground motion estimation method is calculated. This difference value obtained is determined by the standard deviation (σ) value. The value (ε) is calculated by the normalization of the standard deviation values.

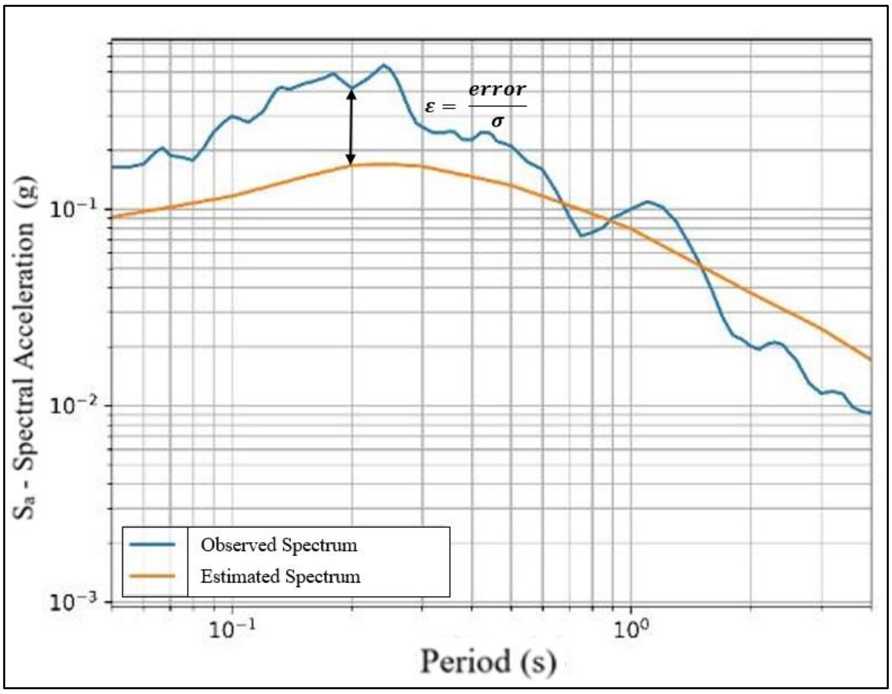


Figure 2.18. Calculating the error of the GMM and determining the standard ε (Normalization by using standard deviation: σ)

- Step 4

In the fourth step, the median spectrum at the site is calculated through the ground motion model. The first four steps should be applied separately with the BSSA14 and KAAH15 methods to obtain separate median spectra for the two separate models.

Step 5

In the fifth step, the ε value calculated at the station closest to the site for each period is multiplied by the σ value. In this way, the median spectrum of the ground motion model is obtained. This should be applied for both the BSSA14 [59] method and the KAAH15 [75] method. In the process of obtaining the median spectrum, if the calculated ε value is less than -0.5, the ε value should be considered equal to -0.5 in order to avoid underestimation of ground motion. Similarly, very high spectral acceleration values may appear in the field measurement values due to outlier values measured at the station. In order to avoid unusually high values, if the calculated ε value is higher than 1.5, the ε value should be considered equal to 1.5.

- Step 6

After determining the response spectra for each ground motion prediction model (BSSA14 and KAAH15) with the proposed method, the final response spectrum for the site is calculated by taking the weighted average of the two spectra. In this weighted average calculation, the weighting coefficients in Table 2.13 are used depending on the location of the site.

2.2.4. Validation of the Proposed Algorithm

To validate the proposed method, we utilized spectral acceleration records from three earthquakes: the 2020 Samos earthquake (Mw = 6.6), the 2020 Sivrice earthquake (Mw = 6.8), and the 1999 Kocaeli earthquake (Mw = 7.6). For the Samos earthquake, we used data recorded at stations 0905 and 0911 in the national strong ground motion observation network. For the Sivrice earthquake, we used data recorded at stations 2301 and 2308. For the Kocaeli earthquake, we used data recorded at stations 1404 and 1406.

To implement the method, select one of the two stations as the “field” and adapt the measured values at the other station to the field values using ground motion models and the algorithm steps mentioned above. This will provide the site spectrum using the proposed GMM method. Compare the obtained prediction spectrum with the actual spectrum obtained at the measurement station named “site”. The verification process was repeated using the 'field' as the other station.

In our study, we applied the above-mentioned process to three different earthquakes and compared the prediction spectra generated by the ground motion model with the actual recorded spectra. We observed that for the 2020 Samos and 2020 Sivrice earthquakes, the response spectra calculated with the proposed method closely matched the actual recorded values. In the 1999 Kocaeli earthquake, the response spectrum calculated by the proposed method had a higher error compared to the other two earthquakes. This could be due to the high absolute (ϵ) values or the large distance (37 km) between the two stations used in the validation. Figure 2.20, 2.21, and 2.22 show a comparison between the response spectra estimated by the proposed method for the three earthquake scenarios and the spectra actually recorded at the station.

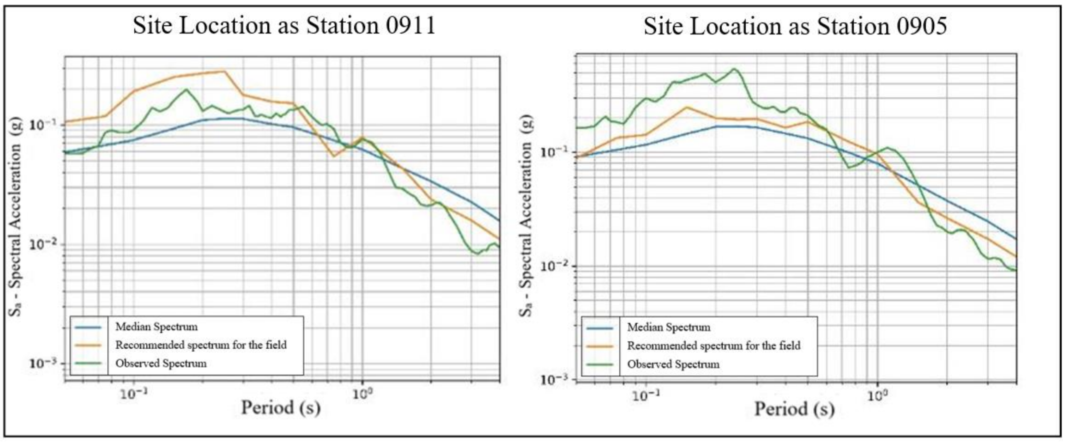


Figure 2.19. Validation of the proposed method with Samos 2020 earthquake records.

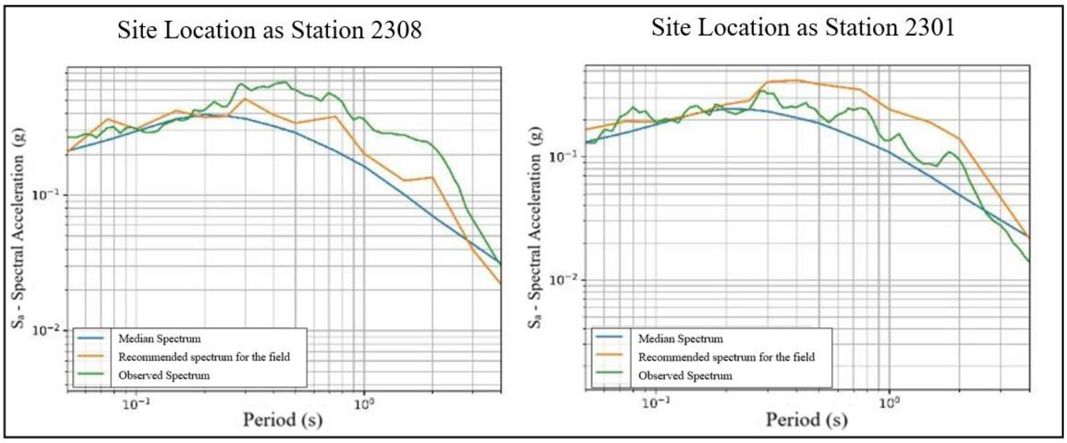


Figure 2.20. Validation of the proposed method with Sivrice 2020 earthquake records.

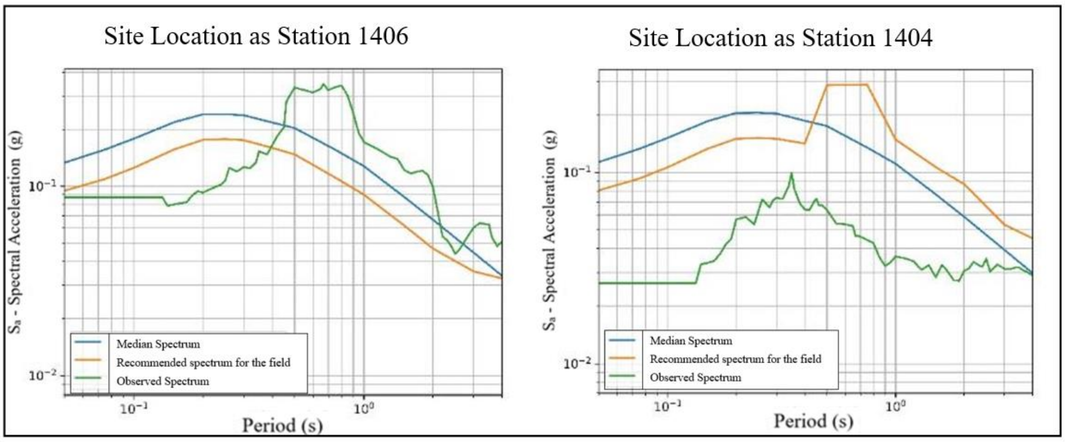


Figure 2.21. Validation of the proposed method with Kocaeli 1999 earthquake records

2.2.4. Obtained Results on Estimating the Site Spectrum

As a result, it is attempted to determine the response spectrum of the earthquake at any building location after an earthquake occurs in an approximate but realistic manner. Within the scope of the study, 6-step algorithm is proposed by utilizing BSSA14 and KAAH15 ground motion models. The proposed algorithm was validated using acceleration records of past earthquakes and it was found that the response spectra at the relevant sites were accurately predicted by the proposed method to stay on the safe side.

The forecasting spectrum of the site obtained after these studies will be used in the Evaluation of Building Demand and Design Capacity process. The predicted site spectrum and the design spectrum specified in the regulations valid at the time the investigated buildings' construction date are plotted together. Using the period estimation method in section 2.1, the Spectral Acceleration value is obtained by using the period (Ta) of the damaged building. If the determined S_a value takes a value greater than the design acceleration, it is concluded that the building survived the earthquake with moderate damage despite being exposed to an earthquake force greater than the design values. On the contrary, if the building survived the earthquake with moderate damage even though it was subjected to an earthquake force less than the design acceleration, this situation is considered as a negative for the building.

2.3. Achived Results on Evaluation of Building Demand and Design Capacity

In order to determine the Deman - Design capacity of the investigated building, a machine learning network was first developed to determine the actual fundamental vibration period of the moderately damaged building in the undamaged and damaged condition. This method was validated by comparing the measurements obtained from both damaged and undamaged buildings. In this way, two different period values of the investigated building (undamaged and element damaged) can be used in the developed method.

Then, in order to determine the effect of the earthquake that caused damage to the building on the building location, GMMs that adapt the earthquake records to the building location were utilised. In this context, the adaptations obtained from BSSA14 and KAAH15 models were used with suitable weigh-coefficients for different regions of Turkey and final PGA values were obtained. The implementation of these parameters in the developed method will be explained in the section "Application of the Three Stage Filtering Method".

3. RAPID SCREENING METHOD FOR REINFORCED CONCRETE BUILDINGS

Anatolia is located in a region known for frequent and intense seismic activity, which often leads to substantial and devastating earthquakes. Unfortunately, a significant portion of the country's buildings were constructed without proper engineering oversight, leaving them highly vulnerable to potential seismic events. Previous seismic events have resulted in significant human and property losses, emphasizing the urgency and importance of urban renewal initiatives aimed at renovating and retrofitting structurally vulnerable buildings. Recently, Kahramanmaraş, Hatay, Adıyaman, Malatya, İzmir, and Elazığ have experienced significant structural deterioration and tragic loss of human life due to seismic activities. Moreover, there have been alarming instances of sudden building collapses in Istanbul, which emphasize the widespread susceptibility of the country's building stock, even in the absence of seismic activity. Therefore, this underscores the urgent necessity to promptly initiate urban renewal projects for these vulnerable structures.

The Law on the Transformation of Areas under Disaster Risk No. 6306 [79] and its corresponding Implementing Regulation, established in 2013 [80], provide a legal foundation for urban transformation efforts aimed at mitigating earthquake risk. These regulations require that urban transformation projects adhere to specific guidelines. The guidelines for identifying risky structures are outlined in the “Guidelines for the Assessment of Buildings under High Risk” (GABHR) [81], which are included as an annex to Law No. 6306. This regulation declares the simplified methods that can be used to determine the regional earthquake risk distribution of buildings, as well as the observational risk assessment method, which has been officially registered.

The “Guidelines for the Assessment of Buildings under High Risk” (GABHR) [81] annexed to Law 6306 provide technical criteria for identifying hazardous buildings. The regulation outlines the “Simplified Methods” for determining the Regional Earthquake Risk Distribution of Buildings and details the official registration process for the observational risk assessment method. In this study, we examined and validated the appropriateness of the “Sructure Score” method, which was developed by adding data to the rapid screening form and updating the scoring system.

3.1. Literature Survey on Rapid Screening Method

The regulation known as the "Standard for Seismic Safety Evaluation and Guideline for Retrofitting of Existing R/C Buildings" [82] issued by the Japan Building Disaster Prevention Association (JBDPA) in 1977, came to light following the initial application of quick screening methods. In 1988, documents titled FEMA 154 [83]- ATC-21 [84] and ATC-21-1 FEMA 155 [85], prepared by ATC (Applied Technology Council) and endorsed by FEMA (Federal Emergency Management Agency), introduced rapid screening methodologies significantly into the literature. These regulations were subsequently updated in 2002 and 2015, accompanied by the publication of *"Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook"*. In 1993, the National Research Council of Canada introduced the Manual for Seismic Screening of Buildings for Seismic Investigation [86] as another preliminary building evaluation approach.

When rapid screening studies investigated in Turkey, it is recognised that the evaluation of rapid screening studies commenced after the 1992 Erzincan earthquake. Nonetheless, the first comprehensive endeavor was the *"Study on a Disaster Prevention/Mitigation Basic Plan in Istanbul Including Microzonation in the Republic of Turkey"* [87] commonly referred to as the JICA report. This study, commissioned by the Government of the Republic of Turkey, was carried out to prepare Istanbul for a possible earthquake after the earthquakes of August 17 and November 12, 1999. It was carried out and compiled by the Japan International Cooperation Agency (JICA) in response to the Turkish government's request. Within the scope of this study, damage estimation studies were carried out with district and neighborhood-based microzonation. The physical attributes considered for building screening from the street were used as the foundation and initial point for the *"Simplified Methods that can be used to determine the Regional Earthquake Risk Distribution of Buildings"* evaluation methods, as outlined in Annex 2*: "Guidelines for the Assessment of Buildings Under High Risk"* [81]. Another critical study is the "*Earthquake Risk Analysis of Istanbul Metropolitan Area"* [88] conducted by the Kandilli Observatory, Earthquake Research Institute, Department of Earthquake Engineering. This study aims to develop a risk model for Istanbul, assess the hazards of projected seismic scenarios, estimate building damages, losses, infrastructure damages, and lifeline interruptions objectively. In this study, a damage estimation methodology was developed based on the "Displacement Coefficient Method" from FEMA-356 (2000) [89], also known as the KOERILoss Method in the literature.

Furthermore, a rapid screening method, referred to as the P25 method, was introduced. In this method, a total of seven collapse scores, accounting for different building collapse modes, were computed alongside the fundamental structural score, P1. P1 was calculated based on parameters such as column dimensions, shear wall characteristics, infill wall dimensions, stiffness, structural system layout, building height, structural irregularities defined in regulations, material properties, and soil properties [90]. In a study published in 2019, the PERA Method 2014 (Performance-Based Rapid Seismic Assessment) [91] was introduced. This method established an evaluation approach for determining the ratio of the base shear force resulting from ground acceleration acting on the investigated building to the base shear force, it should adhere to in accordance with the Turkish Building Earthquake Code [92]. This value was then assigned to the structure as part of a scale consisting of over 100 base scores. Additional rapid screening methods were proposed for reinforced concrete and masonry buildings through master's theses, titled “Development of an Alternative Rapid Screening Method to Determine the Risk Level of Reinforced Concrete Buildings” [93] and “Development of an Alternative Rapid Screening Method to Determine Regional Risk Distribution of Masonry Buildings” [19]. The rapid screening method developed in the “Development of an Alternative Rapid Screening Method to Determine the Risk Level of Reinforced Concrete Buildings” study was used by the Ministry of Environment, Urbanization and Climate Change to determine the seismic performance of public buildings all over the country called as "Public Buildings Inventory System". In this thesis study, the rapid assessment method developed in the *"Development of an Alternative Rapid Screening Method to Determine the Risk Level of Reinforced Concrete Buildings"* method was applied in the rapid screening process in Stage 2: Rapid Screening Score Assessment.

3.2. Implementation of Rapid Screening Method

In this part of the thesis, the risk status of the buildings is evaluated by using the "Simplified Methods for Determining the Regional Earthquake Risk Distribution of Buildings" in the Regulation on the Principles Regarding the Determination of Risky Buildings. 3.2.1. Simplified Methods that can be used to determine the Regional Earthquake Risk Distribution of Buildings. The parameters and their explanations in the "Simplified Methods that can be used to determine the Regional Earthquake Risk Distribution of Buildings" method are shown below.

- **Load-bearing system type:** The building's structural system is determined based on its vertical load-bearing members, whether they are columns or shear walls with - without columns.
- **Number of storeys:** It is determined by counting the number of slabs above ground, including basements and lofts.
- **Current situation and appearance:** This parameter evaluates the quality of materials, workmanship, and maintenance of the building. It is assessed as good, average, or bad in three different scenarios.
- **Soft / Weak storey:** Brick core walls are not typically constructed on the ground floors of commercial buildings, resulting in weaker lateral storey deflections on these floors compared to upper floors. This parameter can be determined through observation of the difference in storey heights or by considering the distinct stiffness difference between floors.
- **Vertical irregularity:** Columns and/or shear walls that do not continue through all floors are considered as vertical irregularities.
- **Overhang:** The distinction between the floor plan area at ground level and that on upper floors is referred to as Overhang.
- **Plan irregularities:** The building design may be either geometrically symmetrical or have irregularly arranged vertical structural elements. Any plan irregularities that could cause torsion during an earthquake are carefully considered in the design process.
- **Short column effect:** Due to the architectural and aesthetic considerations of the columns or the improper arrangement of the structural system, a certain section of the column is left unbraced, and the remaining part is stiffened in a manner that prevents lateral deflection. As a result, the unbraced section of this column experiences significantly higher shear force than intended, which is commonly referred to as the "short column effect". In order to facilitate lighting, ventilation, and air conditioning on the outer walls of the basement or ground floors, infill walls are constructed at varying heights with band (strip) windows created.
- **Position of neighbouring slabs (Hammering effect):** Adjacent buildings can damage each other during earthquakes due to collisions. This risk is heightened when the height levels of the floors between buildings are different, as the slab element may break the vertical bearing elements (especially columns) of the neighboring

building. Additionally, the location of the adjacent buildings, either at the edge or in the middle, is an important factor for assessing the potential damage during an earthquake.

- **Slope of the Soil:** This parameter will be determined based on whether the evaluated buildings are constructed on slopes exceeding a specific incline.
- **Seismic zone:** This parameter is determined by utilizing the Ss coefficient, obtained from the Turkiye Earthquake Hazard Map based on the building coordinates, and the Sds coefficients obtained from the soil class data, as presented in Table 1 below.

DATA COLLECTION FORM FOR REINFORCED CONCRETE BUILDINGS					
BUILDING IDENTITY INFORMATION				DATE:	
				SEQUENCE NO:	
BUILDING IDENTIFICATION NUMBER:				BUILDING PHOTOGRAPHY (THERE MUST BE A CLEAR PHOTO FROM THE FRONT FACADE OF THE BUILDING AND THAT CAN REPRESENT THE BUILDING)	
PROVINCE:					
DISTRICT:					
QUARTER:					
AVENUE/STREET					
BUILDING NO:					
BUILDING NAME:					
SHEET NUMBER:					
LOT NUMBER:					
PARCEL NUMBER:					
NATIONAL ADDRESS DATABASE CODE:					
ESTIMATED AGE OF BUILDING:					
GEOGRAPHICAL COORDINATES:	LATITUDE:........................ LONGITUDE:........................				
BUILDING INTENDEN PURPOSE:	☐ HOUSING	☐COMMERCIAL	☐ INDUSTRIAL	☐ PUBLIC	☐ DERELICT
BUILDING TECHNICAL INFORMATION					
BEARING SYSTEM TYPE	☐ RC FRAME			☐ RC FRAME with SHEAR WALL	
NUMBER OF RELEASED STOREY					
CURRENT SITUATION AND APPEARANCE	☐ GOOD	☐ AVERAGE	☐ BAD		
SOFT STOREY / WEAK STOREY	☐ YES	☐ NO			
VERTİCAL IRREGULARITY:	☐ YES	☐ NO			
OVERHANG:	☐ YES	☐ NO			
PLAN IRREGULARITIES:	☐ YES	☐ NO			
SHORT COLUMN EFFECT:	☐ YES	☐ NO			
NEIGHBOURING FORMATION:	☐ DISCRETE	☐ ADJACENT	☐ ADJACENT at the EDGE		
POSITION OF NEIGHBOURING SLABS	☐ SAME HEIGHT LEVEL	☐ DIFFIRENT HEIGHT LEVEL			
SLOPE of SOIL:	☐ FLAT	☐ SLOPING (Tilt angle> 30⁰)			
SEISMIC ZONE:	☐ ZA	☐ ZB	☐ ZC	☐ ZD	☐ ZE
BRIEF NOTES:					

Figure 3.1. Rapid screening form for RC buildings in Simplified Methods for Determining the Regional Earthquake Risk Distribution of Buildings

When applying Simplified Methods that can be used to determine the Regional Earthquake Risk Distribution of Buildings, the hazard zone of the building is determined according to the seismic zone and soil class of the area under investigation, and the floor score is determined according to the number of floors. The structural system score is determined according to the type of structural system and the number of floors. According to the regulation, the Building Performance Score is determined by the following equation.

$$PP = TP + \sum (Oi * OPi) + YSP \quad (7)$$

The equation uses several variables: 'PP' represents the performance score, 'TP' represents the base score from Table 3.1, 'Oi' represents each adverse parameter, 'OPi' represents the adverse parameter score, and 'YSP' represents the structural system scores from Table 3.1. The adverse parameter score is determined according to the number of storeys and the Hazard Zone depending on the seismic zone and soil class as shown in Table 3.2. It should be especially noted that the Hazard Zones are not the soil classes specified in the 2007 TEC.

Table 3.1. Base Scores and Structural System Scores according to hazard zone and load bearing members.

Number of storeys	Base Scores				**Structural system Scores**	
					Load bearing members	
	Hazard zone				**Only column**	**Shear wall ± column**
	I	**II**	**III**	**IV**		
1 - 2	90	120	160	195	0	100
3	80	100	140	170	0	85
4	70	90	130	160	0	75
5	60	80	110	135	0	65
6 - 7	50	65	90	110	0	55

Table 3.2. Numerical representation of soil types.

Hazard zone	**Seismic zone in TEC 2018**	**Soil class in TEC 2018**
1	1	ZC/ZD/ZE
2	1	ZA/ZB
	2	ZC/ZD/ZE
3	2	ZA/ZB
	3	ZC/ZD/ZE
4	3	ZA/ZB
	4	All soil class

Table 3.3. Numerical representation of adverse parameters.

Parameters		**Case 1**		**Case 2**	
		Condition	Value	Condition	Value
1	Soft Storey	None	0	Exist	1
2	Overhang	None	0	Exist	1
3	Appearance	Good	0	Average (bad)	1 (2)
4	Short column	None	0	Exist	1
5	Slope	None	0	Exist	1
6	Plan irregularity	None	0	Exist	1

Table 3.4. Penalty scores of the parameters.

Number of storeys	Soft storey	Appearance	Overhang	Position of Neighbouring Slabs / Settlement of the building				Vertical Irregularity	Plan Irregularities	Short Column	Slope
				Non-levelled		Levelled					
				Middle	Edge	Middle	Edge				
1,2	-10	-10	-10	0	-10	-5	-15	-5	-5	-5	-3
3	-20	-10	-20	0	-10	-5	-15	-10	-10	-5	-3
4	-30	-15	-30	0	-10	-5	-15	-15	-10	-5	-3
5	-30	-25	-30	0	-10	-5	-15	-15	-10	-5	-3
6,7	-30	-30	-30	0	-10	-5	-15	-15	-10	-5	-3

Determination of the risky or non-risk status of the examined building is not provided directly by "Simplified Methods for Determining the Regional Earthquake Risk Distribution of Buildings". The risk priority among regions is determined solely by ranking building performance values in the evaluated region from highest to lowest. Analyzing studies from literature, the threshold score at which performance scores can differentiate between risky and non-risk is determined. In this context, Tozlu [94] addressed the declaration of a high-risk area in her master's thesis. She conducted field studies and applied the "Simplified Methods that can be used to determine the Regional Earthquake Risk Distribution of Buildings" method to rapidly screen 1613 reinforced concrete buildings in Istanbul-Beyoglu and Nigde-City Center provinces. The objective was to identify and declare certain areas as high-risk for earthquakes. Furthermore, a thorough static analysis of high-risk buildings was conducted on a sample of 121 randomly selected structures. The analysis revealed that reinforced concrete buildings with a performance score below 60 points pose a significant threat and require prioritization in the urban transformation initiative.

3.3. Improving the Existing Rapid Screening Method Under the Regulation

Based on the above mentioned problems, studies were carried out to develop the method specified by Coskun [93], based on the opinion that the rapid screening method in the regulation would not be sufficient for field applications with partial modifications to the parameters and an update to the scoring system, based on the "Simplified Methods that can be used to determine the Regional Earthquake Risk Distribution of Buildings". This method is also known as the Structure Score method and Alper ALDEMİR, who is the supervisor of this thesis is also the supervisor of the Structure Score method. In this context, reports prepared in the past, during the process of declaring risky areas within the scope of Law No. 6306 and comprehensive risky building detection analyses carried out by organizations licensed by the Ministry of Environment, Urbanization and Climate Change to conduct risky building analysis were used. With the data compiled from the aforementioned studies, the parameters included in the *"Simplified Methods that can be used to determine the Regional Earthquake Risk Distribution of Buildings"* have been evaluated with statistical methods, additional parameters have been added to the existing parameters and the method has been updated to provide applicable and accurate results in the field. In this study, in addition to other rapid screening method studies, a large database of reinforced concrete (RC) buildings with detailed seismic assessment results and photographs of buildings was created by using data provided by the Ministry of Environment, Urbanization and Climate Change. Evaluations on the accuracy of the developed method have also been carried out with the help of this database.

These parameters are included in the "Simplified Methods for Determining the Regional Earthquake Risk Distribution of Buildings" in the annex of the regulation. In the developed "Structure Score" method, the existing condition and appearance parameter has been removed. The concept of "Existing Condition and Appearance" is subjective and varies depending on individual perception. It is important to note that a visually appealing building that has undergone renovations, sheathing, and repairs may still have inadequate load carrying capacity. Thus, the use of "visual quality of the building" as a parameter in risk assessments is not recommended. Also “Age of Building” and “Effect of Construction Date” parameters has been added to studied rapid screening method.

Age of buiding: This parameter is used to find the effect of the age of the building on seismic performance.

• **Effect of construction date:** With this parameter, a correlation will be established regarding which of the earthquake codes was in force when the building under study was constructed (1975 [95], 1998 [96] and 2007 [97]TEC).

Within the scope of the study, 400 buildings for which detailed seismic assessment was performed were utilized to determine how effective these parameters are on the risk status of the buildings. The seismic hazard status of the buildings in the database was determined as a result of the detailed seismic risk assessment method given in Guidelines for the Assessment of Buildings under High Risk (GABHR) [81]. To facilitate the utilization of the estimation parameters in statistical analyses and software processes, we carried out the quantification processes illustrated in Table 3.6.

Table 3.5. Numerical representations of estimation parameters

Estimation Parametres	**Values**									
Number of storeys, N	1	2	3	4	5	6	7	8	9	9+
Seismic zone	S_{DS}* > 0.75g : 1			0.75g > $S_{DS} \geq$ 0.50g : 2			0.50g > $S_{DS} \geq$ 0.25g : 3		S_{DS} < 0.25g : 4	
Soil condition	V_{s30}** > 700m/s : 1			700 > V_{s30} > 400m/s : 2			400 > V_{s30} > 200m/s : 3		V_{s30} < 200m/s : 4	
Age of building	Any integer value									
Structural system type	RC Frame : 0			RC Frame with Shearwall :1						
Neighboring Status	Adjacent: 0			Separate: 1						
Short Column	None: : 0			Exist: : 1						
Vertical Irregularity	None: : 0			Exist: : 1						
Overhange	None: : 0			Exist: : 1						
Plan Irregularities	None: : 0			Exist: : 1						
Soft Storey	None: : 0			Exist: : 1						
Position of Neighboring Slabs	Non - levelled: 0			Levelled: 1						
Slope of Soil	Flat: 0			Slopped: 1						
Effect of Construction Date	After 2007: 1			1997-2007 : 2			1975-1997 : 3		Before 1975: 4	

The study analyzed the effectiveness of selected parameters for each building in the database for both risky and non-risky situations, calculating the marginal effect of each parameter. The statistical method, Ordinary Least Squares Regression Analysis (OLS), was used in this context and rapid screening scores were derived from the obtained results.

Table 3.6. Penalty Scores for Parameters

Number of storey	Penalty scores
1	-5
2	-6
3	-7
4	-7
5	-10
6	-12
7	-14
8	-17
9	-19
9+	-17 - 2 x (N - 8)

Seismic zone	Representation Value	Penalty scores
$S_{DS} \geq 0{,}75g$	1	-30
$0{,}50g \leq S_{DS} < 0{,}75g$	2	-15
$0{,}25g \leq S_{DS} < 0{,}50g$	3	0
$S_{DS} < 0{,}25g$	4	15

Soil Type	Representation Value	Penalty scores
Vs_{30}>700 m/s	1	-1
700> Vs_{30}>400 m/s	2	-3
400>Vs_{30} >200m/s	3	-5
Vs_{30} < 200m/s	4	-7

Age of building	Penalty scores
	(Age of building) x -0,166

Structural system type	Representation Value	Penalty Scores
RC Frame	0	55
RC Frame with Shearwall	1	75

Vertical Irregularity	Representation Value	Penalty Scores
Exist	1	-15
None	0	0

Overhange	Representation Value	Penalty Scores
Exist	1	-15
None	0	0

Neighboring Status	Representation Value	Penalty Scores
Seperate	1	21
Adjacent	0	0

Position of Neighboring Slabs	Representation Value	Penalty scores
Non - levelled	1	0
Levelled	0	-28

Slope of Soil	Representation Value	Penalty Scores
Flat	0	0
Slopped	1	-20

Short Column	Representation Value	Penalty Scores
Exist	1	-39
None	0	0

Plan Irregularities	Representation Value	Penalty Scores
Exist	1	-33
None	0	0

Soft Storey	Representation Value	Penalty Scores
Exist	1	-10
None	0	0

Effect of Construction Date	Representation Value	Penalty Scores
After 2007	1	30
Between 2007 and 1997	2	25
Between 1997 and 1975	3	-15
Before 1975	4	-20

3.4. Determination of the Performance of the Applied Rapid Screening Method and Validation with Damaged Building Database

In the second stage of the three-stage filtering method we propose in our study, it is preferred to use the existing Structure Score method instead of proposing a new rapid screening method. The Structure Score method utilises the existing parameters in the "Simplified Methods that can be used to determine the Regional Earthquake Risk Distribution of Buildings" method, but has removed some input parameters and added new input parameters. It completely changed the scoring system and developed the rapid screening method included in the legislation. Before directly using the Structure Score method for the preferred filtering method, which is the subject of our study, the performance of this method was statistically evaluated and then validated by directly applying it to buildings that damaged in earthquakes.

3.4.1 Determining the Statistical Dependencies of The Parameters Used in the Updated Rapid Screening Method by using Discriminant Analysis

In this part of the study, the effects of the selected parameters on each other in the rapid screening method with updated input parameters are analysed. In order to realise this purpose, the discriminant analysis is used. Discriminant analysis, which is also defined as discriminant function analysis, makes discrimination according to the characteristics of the parameters used in the classification of the examined data. To explain in more detail, Discriminant analysis is used to check whether the selected parameters of a given database can be classified, determine the differences between the different selected parameters, show the variance explained by the selected parameters with the dependent variable, examine the order of priority of the selected parameters in the classification according to the dependent variable, and finally identify parameters that can be ignored (of low importance).

When the studies of the discriminant method on the damage parameters of damaged buildings examined, the articles published by Askan in 2002 [98] and Askan and Yüceman in 2010 [21] are existed. In these studies, a database was created using the parameters of the buildings damaged in 1992 Erzincan, 1995 Dinar and 1999 Düzce earthquakes, and while applying the discriminant analysis technique on these data, the effects of parameters such as number of storeys, soft storey, heavy overhang, density ratio and storey regularity factor on the damage of buildings were investigated.

While applying the Discreterminant Analysis to the Structure Score method, the database created by Coşkun while developing the method [20] was first obtained. There are 402 reinforced concrete buildings in this database and these buildings have been predetermined to be classified as risky and non-risky by detailed analyses.

Seismic zone, Soil condition, Age of building, Structural system type, Neighboring Status, Short Column, Vertical Irregularity, Overhange, Plan Irregularities, Soft Storey, Position of Neighboring Slabs, Slope of Soil, Effect of Construction Date parameters, which are the input parameters of the Structure Score method, were determined as discrimination parameters in the discriminant analysis. Risky - Non-Risk situations were determined as the separation group of the discriminant analysis. Accordingly, a discriminant analysis was performed with 402 buildings in the database.

The success percentage of the decomposition groups formed after the analysis is given in Table 3.7. Here, when risk assessment is performed with the Structure Score method using all these input parameters, it is concluded that the riskiness status can be grouped correctly at a rate of 85,6%. The standardised coefficients of the discriminant function after the analysis are shown in Table 3.8. When these coefficients are interpreted, it is seen that the importance of the parameters Neighboring Slabs, Effect of Construction Date, Short Column, Plan Irregularities parametreas are more important than other variables in discriminating the seismic risk status of reinforced concrete structures.

Table 3.7. Results of Discriminant Analysis of Buildings in the Database

			Discriminant Analysis Grouping	
			0	1
Detailed Analysis Grouping	**Quantity**	0	**175**	26
		1	32	**169**
	(%) Percentage	0	**87.1**	12.9
		1	15.9	**84.1**
In total, 85.6% correct grouping was obtained.				

0: Non-Risky 1: Risky

Table 3.8. Standardised Coefficients of the Discriminant Function for buildings in the database

Position of Neighboring Slabs	0.605
Neighboring Status	0.564
Short Column	0.490
Plan Irregularities	0.449
Slope of Soil	0.287
Vertical Irregularity	0.280
Age of Building	-0.232
Effect of Construction Date	-0.227
Soil Condition	-0.209
Number of Stories	0.196
Structural System Type	-0.160
Overhange	-0.139
Soft Storey	0.097

After the development of the proposed rapid screening method, the data risk estimates of the proposed method for the underlying reinforced concrete buildings were determined. The developed rapid screening method was used to predict the seismic risks of "risky" and "non-risky" buildings. The comparison of these predictions with the results obtained by detailed seismic assessments (risky building detection analysis) resulted in an error rate of around 17%. It is important to note that the database used for this validation is the same as the one used during the method's development. To prevent over-convergence, a new test database comprising 143 reinforced concrete structures situated in diverse seismic zones was established. The developed method analysed in this database, revealing that the rapid-screening approach could estimate with a margin of error of 19% during the checks. The obtained results are shown in Table 3.9 and Table 3.10 below.

Table 3.9 Validation with the database used in method development processes. (402 buildings)

Risk Status	**Number of buildings** Prediction Correct - Incorrect	**Error Rate (%)**
Risky	150 – 51	25,37
Non-risky	184 – 17	8,46
TOTAL	334 – 68	**16,92**

Table 3.10. Validation with subsequently created database. (143 buildings)

Risk Status	Number of buildings Prediction Correct - Incorrect	Error Rate (%)
Risky	84 – 23	21,50
Non-risky	33 – 5	13,16
TOTAL	117 – 28	**19,31**

3.4.2 Determining the Statistical Dependencies of The Parameters Used in the Updated Rapid Screening Method by using Damaged Building Database

In addition to the verification processes mentioned above, this study also aims to test the accuracy of the method by utilizing buildings damaged in earthquakes. In this context, a new database containing the parameters in the rapid screening method was created using information and photographs of buildings that were severly damaged and slightly damaged in the 2019 Silivri (Istanbul) and 2020 Elazığ earthquakes. The database contains a total of 320 buildings, 150 from Istanbul (65 severly damaged and 85 slightly damaged - undamaged) and 170 from Elazığ (110 severly damaged and 60 slightly damaged - undamaged).

During the evaluation of this database, it is evaluated that the method predicts correctly if the severly damaged buildings are estimated as "Risky" and slightly damaged - undamaged buildings are estimated as "Non-risky", while in the opposite cases, method predicts incorrectly. In the validation of the method by using damaged structure databese, the ground acceleration (S_{DS}) value that the structures were exposed to in the earthquake is taken into consideration in determining the seismic zone parameter (Silivri: 0.08 g, Elazıg: 0.20 g). Based on this, S_{DS} < 0.25g value is obtained for both earthquakes and each structure received +15 points. With these studies, it is determined that the rapid scanning method is able to perform accurate prediction with an error rate of 24% for the damaged buildings in the Silivri Earthquake and 24.12% for the damaged buildings in the Elazıg earthquake. When both databases are evaluated together, it is found that the rapid screening method evaluated yielded 24.06% correct predictions. The results are shown in Table 3.11, 3.12 and 3.12 below.

Table 3.11. Verification by using Silivri (Istanbul) Earthquake damaged building database (150 building)

Risk Status	**Number of buildings** Prediction Risky – Non - Risky	**Error Rate (%)**
Severely Damaged (65)	50 – 15	23,07
Slightly Damaged- Undamaged (85)	21 – 64	24,70
Correct Prediction: 114	Inaccurate prediction: 36	**24,00**

Table 3.12. Verification by using Elazıg Earthquake damaged building database (170 building)

Risk Status	**Number of buildings** Prediction Risky – Non - Risky	**Error Rate (%)**
Severely Damaged (110)	83 – 27	24,54
Slightly Damaged- Undamaged (60)	14 – 46	23,33
Correct Prediction: 129	Inaccurate prediction: 41	**24,12**

Table 3.13. Verification by using both databases (320 building)

Risk Status	**Number of buildings** Prediction Risky – Non - Risky	**Error Rate (%)**
Severely Damaged (175)	133 – 42	24,00
Slightly Damaged- Undamaged (145)	35 – 110	24,14
Correct Prediction: 243	Inaccurate prediction: 77	**24,06**

4. BUILDING MATERIAL - MECHANICAL PROPERTIES DETECTION

The third step of the filtering method will involve examining the material durability and the existing durability of the building. At this stage, we propose that the process step be completed according to a value we call the Building Axial Load Ratio. In order to determine the Building Axial Load Ratio (ALR), it is first necessary to estimate the approximate total weight of the building. In order to achieve this, we multiply the volumes of the building frame elements (slab-beam, column, curtain) which we have determined through our survey work by the unit volume weight of concrete (2.4 ton/m^3) and then calculate the element weights. Similarly, wall weights are calculated by multiplying the volumes of the walls in the building by the unit volume weight of the wall material used. Subsequently, the building weight is proportioned to the "total cross-sectional area" value of the vertical structural system elements on the ground floor. The impact on the structural system elements is then calculated in megapascals (Mpa). This value is sometimes referred to as the "Building Axial Load Ratio" (ALR). At the decision stage, the Axial Load Ratio determined for the building is compared with the concrete compressive strength value obtained by coring. If the Axial Load Ratio is calculated more than 20% of the concrete compressive strength, the building subject to inspection will receive “-1” point in this step. If the Axial Load Ratio is calculated less than 20% of the concrete compressive strength, the building subject to inspection will receive “+1” point in this step.

In the development of this approach, the condition in Article 7.3.1.2 of the Turkish Building Earthquake Code, which is related to column cross-sections, was utilised. *"The gross cross-sectional area of the column shall satisfy the condition Ac ≥ Ndm /(0.40 fck), where Ndm is the largest of the axial compressive forces calculated under G (fixed load) and Q (live load) vertical loads and the common effect of earthquake effect E under G + Q + E, taking into account the live load reduction coefficients defined for live loads in TS 498."*

$$\mathrm{Ac} = \frac{Ndm}{0{,}40\, fck} \tag{8}$$

In this provision; Ac corresponds to cross-sectional area of the column or shear zone, Ndm corresponds to the largest of the axial compressive forces calculated under the joint effect of vertical loads and earthquake loads (taking into account the live load reduction coefficients defined for live loads in TS 498 [99] and f_{ck} corresponds to the characteristic cylinder compressive strength of concrete. When this equation is adapted for Building Axial Load Rating using design loads, the following form is obtained:

$$0{,}40\ fck = \frac{Ndm}{Ac} \tag{9}$$

The design loads in the aforementioned legislation article are defined as "characteristic loads multiplied by load factors". In order to convert the characteristic loads determined by calculations into design loads, dead loads are increased by 40% and live loads by 60%. In the modelling process of residential buildings, it is known that the dead weights and live loads have close values. From this point of view, it can be concluded that the design loads in the buildings, which are the target of our study, are the characteristic loads increased by 50%. The equation specified above in Equation:8 has been transformed easier and more applicable in our study and compared with whether the characteristic concrete compressive strength exceeds 20% of the Building Axial Load Ratio value.

$$\begin{aligned} &0{,}20\ fck > \frac{Ncharacteristic}{Ac} \quad \Rightarrow \text{Criteria Safe} \\ &0{,}20\ fck \leq \frac{Ncharacteristic}{Ac} \quad \Rightarrow \text{Criteria Unsafe} \end{aligned} \tag{10}$$

5. APPLICATION OF THE THREE STAGE FILTERING METHOD

The three-stage filtering method to be developed in our thesis consists of Evaluation of Building Demand and Design Capacity, Rapid Screening Score Assessment and Building Material Mechanical Properties Detection. Retrofitting scoring is performed by giving scores of “-1”, “0” and “1” for each stage. For each of the three stages, buildings with moderate damage with a total score of 2 and above are considered to be retrofittable. For moderately damaged buildings with a score below 2, it is understood that their retrofitting is not within economic limits, or it is assessed that these buildings are not technically suitable for retrofitting.

In the Three Stage Filtering Method application, the necessary information is collected by going to the location of the Moderately Damaged building. In the field study, the geographical coordinates of the building are first determined, and soil class is learned for these coordinates and the year of construction of the building is determined. With observational studies, the ground slope, the number of storeys, the presence of overhang and if exist in which directions (X, Y, both) are examined. The presence of short column, the presence of soft storey, the presence of irregularities in the plan and the presence of vertical irregularities are examined. The adjacent or seperate layout of the building with the neighboring buildings is examined and if it is adjacent, the same-different floor levels with the neighboring building are determined. It is also determined whether there is a shearwall in the structural system of the building. After the observational studies are completed, a survey of the building is prepared. In this process, the average storey heights and slab thicknesses of the building are determined, the plan dimensions are measured, the positions of the structural system elements and walls are plotted on the drawings, the number of axes for both directions (X and Y) are determined, if overhang exist, the amount of overhang is measured for both directions. After this stage, element-based damage conditions for beams, columns, shearwalls and walls are determined and each element group classiffied as undamaged, slightly damaged, moderately damaged and severely damaged. Finally, cores are taken from the building to determine the existing concrete compressive strength and the field study is completed.

DATA COLLECTION FORM FOR THREE STAGE FILTERING			
PHOTOGRAPH	Form No:	Date: ... / ... / 20....	
	Latitude:	.... , ...	
	Longtitude:	.... , ...	
	Address:		

Soil Type:	Slope of Soil:	Number of Storeys:
A ☐ B ☐ C ☐ D ☐ E ☐	Flat ☐ Slopped ☐	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8+ ☐

Building Construction Year	Building Age	Load Bearing Type
....	....	RC Frame ☐ RC Frame with Shearwall ☐

Soft Storey	Short Column	Plan Irregularities	Vertical Irragularity
Exist ☐ None ☐	Exist ☐ None ☐	Exist ☐ None ☐	Exist ☐ None ☐

Neighboring Formation	Position of Neighboring Slabs	Overhange
Seperate ☐ Adjacent ☐ ⟹	Same ☐ Levelled ☐	Exist ☐ X: .... m ☐ Y: .... m None ☐

Plan Lenght	Plan Width	Number of Axes
X: .... m	Y: .... m	X: .... Y: ....

System Elements, Damage Status			
Partition Walls	Beams	Columns	Shearwalls
☐ Undamaged	☐ Undamaged	☐ Undamaged	☐ Undamaged
☐ Slightly damaged	☐ Slightly damaged	☐ Slightly damaged	☐ Slightly damaged
☐ Moderately damaged	☐ Moderately damaged	☐ Moderately damaged	☐ Moderately damaged
☐ Severely damaged	☐ Severely damaged	☐ Severely damaged	☐ Severely damaged

Comments:

Figure 5.1. Three Stage Filtering Method, Data Collection Form

5.1. Evaluation of Building Demand and Design Capacity Stage

In the Evaluation of Building Demand and Design Capacity stage, the periods of the building that survived the earthquake with moderate damage are determined in the undamaged and component damaged state. Then, the field spectrum generated by the earthquake at the building location is estimated. The estimated field spectrum and the design spectrum specified in the regulations in force when the building is constructed are plotted together on the same graph. The period values in the undamaged and damaged conditions previously determined for the investigated building are processed on the field spectrum graph and Spactral Acceleration (S_a) values are determined for two different cases.

If the examined building suffered moderate damage even though it is subjected to acceleration demands less than the design spectrum, it will be concluded that there are problems in the structural system and/or material strength of the building. In this case, the building will receive a negative score. In other cases, if it is determined that the building suffered moderate damage even at acceleration demands close to the designed values, a positive conclusion will be made about the structural system and/or material strengths of the building. In this case, the building will receive positive score.

The Demand - Design Spectrum Ratio (DDSR) parameter has been defined in order to provide a mathematical basis for the mentioned issues. The Demand - Design Spectrum Ratio (DDSR) is the normalized numerical integration of the areas under the Demand - Design spectra. In this study, the Trapezoidal Rule is used to determine the integral domain. If the DDSR value is calculated as 0.5 and lower, the building is given a score of "-1" for the Building Demand and Design Capacity section. $0.5 < DDSR < 0.75$ is given a score of "0" and $DDSR \geq 0.75$ is given a score of "+1". The details of these calculations are shown in Figure 5.2.

To summarise, in this filtering step, the spectral values of the building during the design phase and the earthquake spectral acceleration were utilised. In addition, the undamaged building period and post-damage period values were also determined. The main purpose of the DDSR calculation is to compare the design acceleration values of the earthquake that damaged the building with the spectral acceleration values of the earthquake that occurred. DDSR value above 0.75 leads to the conclusion that the moderately damaged building was exposed to a relatively higher force than the forces predicted to be exposed during the design period. Despite this situation, the fact that the building survived the earthquake with moderate damage provides a "+1" score for the building in the scoring. DDSR value below 0.50 indicates that the building with moderate damage suffered moderate damage despite being exposed to much lower forces compared to those predicted at the time of design. This situation causes the building to receive a score of "-1" in the scoring. DDSR value between 0.50 and 0.75 indicates that the building was exposed to earthquake forces close to the design earthquake and a score of "0" is given for this situation.

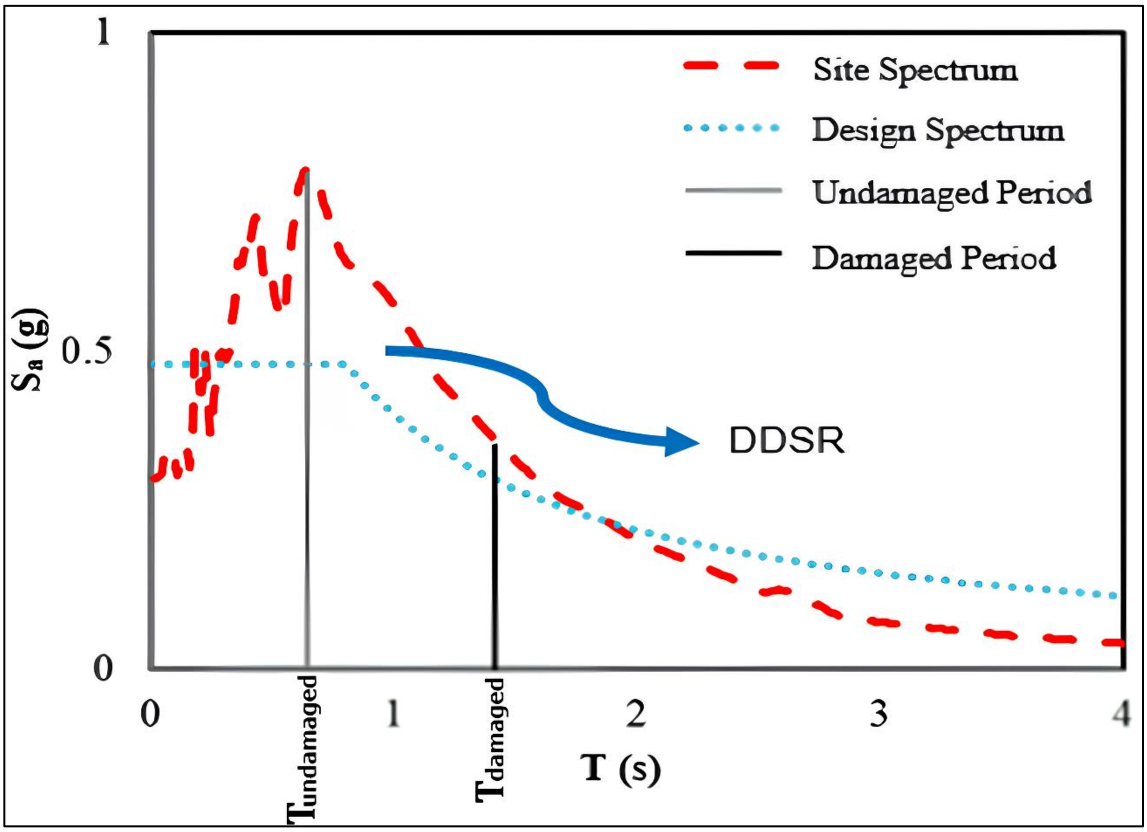


Figure 5.2. Determination of the Demand - Design Spectrum based on the estimated site spectrum and determined period values

5.2. Rapid Screening Score (Structure Score) Assessment Stage

At this stage, the Structure Score of the building will be obtained by using the Rapid Screening method detailed in the third section. If this calculated score corresponds to a value greater than zero, at this stage a positive opinion is reached about the structural system of the building. Accordingly, a score of "+1" is given for the building examined in the Rapid Screening Score Assessment step. If the score of the examined building is determined as a value less than -50, these buildings are considered risky in terms of structural system and a score of "-1" is given for these buildings. For other buildings "0" point is given.

Number of storeys	1	2	3	4
				√
	5	6	7	8
Seismic zone:	1	2	3	4
	√			
Soil Type	ZA	ZB	ZC	ZD - ZE
			√	
Building Age	After 2007	1998-2007	1975-1998	Before 1975
40			√	
Load Bearing Type	RC Frame	RC Frame with Shearwall	**STRUCTURE SCORE**	
		√	**2**	
Neighboring Formation	Seperate	Adjacent		
		√		
Vertical Irragularity	Exist	None		
		√		
Overhange	Exist	None		
		√		
Plan Irregularities	Exist	None		
		√		
Short Column	Exist	None		
		√		
Position of Neighboring Slabs	Same	Levelled		
	√			
Soft Storey	Exist	None		
	√			
Slope of Soil	Flat	Slopping		
	√			

Figure 5.3. An example of rapid screening scoring

5.3. Buildings' Material - Mechanical Properties Detection Stage

In the last step of the developed method, it is completed by determining the Axial Load Ratio (ALR) of the building calculated based on the approximate total weight of the building and comparing this ratio with the concrete compressive strength. In order to calculate the weights of the building elements, we calculated the slab-beam, column and curtain volumes of the investigated building. We multiplied the total element volumes by the unit volume weight of concrete and calculated the weights of the reinforced concrete elements. When calculating the weights of the walls, we approximated the wall thicknesses and the areas covered by the walls and multiplied them by the unit volume weight of the wall material. Then, we determined the cross-sectional areas of the vertical structural system elements (columns and shear walls, if any) on the ground floor of the building. We divided the building weight by the cross-sectional area of the ground floor structural system elements and determined the Building Axial Load Ratio (ALR).

In the Building Material - Mechanical Properties Detection stage, the Axial Load Ratio determined for the building is compared with the concrete compressive strength value of the building. At the scoring stage, if the Axial Load Ratio is calculated to be more than 20 per cent of the concrete compressive strength, the inspected building will receive a score of '-1' at this step. Conversely, if the Axial Load Ratio is calculated to be less than 20% of the concrete compressive strength, the building under examination will receive '+1' point in this step.

5.4. Conclusion and Summary

A three-stage filtering method is developed to determine the retrofitting potential of moderately damaged buildings. As described above, field studies of the building are completed, and filtering scores are determined for each stage. After all stages are completed, moderately damaged buildings with an assessment score of 2 and above are considered to be retrofittable. For moderately damaged buildings with a score below 2, it is decided that retrofitting these buildings would be uneconomical or technically inappropriate. A summary of the filtering scores is shown in Table 5.1.

Table 5.1. Summary of the filtering scores

STAGES	POINT
1. Stage: Evaluation of Building Demand and Design Capacity Stage	
The Demand - Design Spectrum Ratio < 0,50:	-1
0,5 < The Demand - Design Spectrum Ratio < 0,75:	0
The Demand - Design Spectrum Ratio > 0,75:	1
2. Stage: Rapid Screening Score Assessment	
Structure Score < -50:	-1
-50 < Structure Score < 0:	0
Structure Score > 0:	1
3. Stage: Building Material - Mechanical Properties Detection	
Building Axial Load Ratio > 0,20 x fck:	-1
Building Axial Load Ratio ≤ 0,20 x fck:	1

The scoring system, developed within the scope of the methodology, evaluates the technical suitability of buildings for retrofitting, as well as the economic viability of such retrofitting in light of engineering science and experience. The scores assigned in the filtering steps are determined with this purpose in mind. In the initial stage of the filtering algorithm, the impact of the earthquake on the building is assessed. The seismic effects experienced by a moderately damaged building are then compared with the effects predicted in the original design, allowing for an evaluation of the building's earthquake resistance. In the second step of the filtering method, the Structure Score is determined and the physical properties of the building are evaluated. In the final step, the Building Axial Load Ratio is determined. This ratio is used to assess whether the concrete compressive strength of the building meets the minimum limits set forth in the regulation. Buildings that do not meet this limit are deemed unsafe even when subjected to vertical loads. This step is of particular significance in the scoring system, as it serves as a crucial determinant of suitability for retrofitting, irrespective of the scores assigned in other steps. If the Building Axial Load Ratio value does not meet the prescribed conditions, the filtered building is deemed unsuitable for retrofitting.

6. VALIDATION OF THE THREE STAGE FILTERING METHOD

In order to determine whether the developed filtering method gives accurate results, among the buildings that were determined as moderately damaged in past earthquakes, the buildings with detailed seismic analysis are identified and the information of these buildings is used. In the verification of the method, 15 buildings that were moderately damaged in the January 24, 2020 Elazıg earthquake and October 30, 2020 Izmir - Samos earthquakes and whose performance analysis - risky building analysis reports are used.

Filtering scores were determined for each building by applying a three-stage filtering method. Afterwards, the performance analysis - risky building analysis reports are examined and the economic cost for the retrofitting requirements of these buildings are determined. In detailed seismic analyses, it is envisaged to increase the capacity of each column and shearwall elements with insufficient capacity by reinforcing them with FRP (Fiber Reinforced Polymers). In order to determine the cost of reinforcement with FRP, the unit prices of KTB.80.2002: Single Layer Reinforcement using Carbon Fiber Fabrics. in the unit price tables of the Ministry of Culture and Tourism were used. During the application, the possibility of loss of carbon fiber boards is also taken into consideration and 10% loss is added to the required material calculation.

In buildings with high storey drift, it is envisaged to limit the storey drift by adding retrofitting shear walls. At this point, past retrofitting experiences were utilized to determine how much retrofitting shear wall would be sufficient for the building. In determining the economic cost of adding reinforcing walls, the amount of concrete and reinforcement required for a reinforcing wall of 0.25 m x 1.00 m is determined approximately and the economic cost of a 0.25 x 1.00 m reinforcing wall is calculated using the poses in the unit price schedule of the Ministry of Environment, Urbanization and Climate Change. *(15.150.1005: Pouring of ready-mixed concrete, including concrete transportation in C 25/30 compressive strength class, produced or purchased at the concrete batching plant and pumped by concrete pump; 15.160.1003: Ø 8- Ø 12 mm ribbed concrete steel bars, cutting, bending and replacing the bars)*. By using calculated prices, the total cost of the retrofitting shearwall required to limit the building drift is calculated. At this point, only the concrete and reinforcement costs of the retrofitting shear wall were taken into consideration, and all other cost items during the retrofitting phase were ignored.

In determining the economic feasibility of retrofitting a building, if the cost of retrofitting is 40% or more of the new building construction cost, it is determined that retrofitting is not economical. The total cost of retrofitting is determined as the total cost of FRP application and the cost of building a retrofit curtain, if any. In determining the construction cost of the new building, the square meter unit prices in the "Communiqué on Building Approximate Unit Costs to be Used in the Calculation of Architectural and Engineering Service Fees for the Year 2024" is used and the construction cost of the new building is calculated by multiplying the total square meters of the building subject to examination by the approximate unit costs.

In the validation phase, the retrofit cost determined for each building is compared with the new building construction cost. Buildings with retrofitting costs of 40% or more of the new building construction cost are considered as uneconomical to retrofit. Other buildings are considered as suitable for retrofitting. At this point, the buildings whose retrofitting suitability is determined by the filtering score are compared with the economic suitability assessments. If the retrofitting cost is 40% or less of the new building construction cost for buildings with a filtering score of 2 and above, the filtering method is found to be correct for this building. For buildings with a filtering score below 2, if the retrofitting cost is above 40% of the new building construction cost, then the filtering method for this building is correct. For other cases, the filtering method makes an incorrect determination. The performance of the Three Stage Filtering Method is evaluated for 15 buildings with the specified validation method.

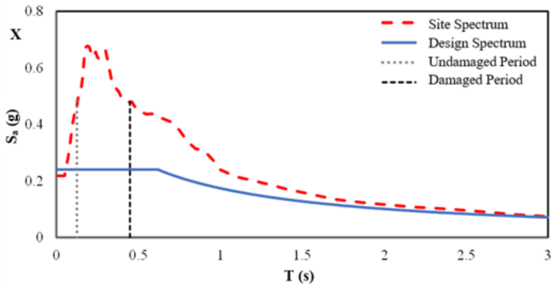
6.1. Building #1

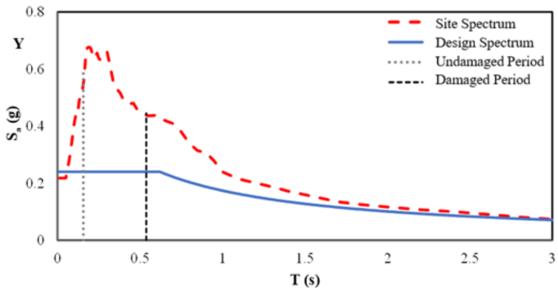
On January 24, 2020, Elazığ-Sivrice earthquake caused moderate damage to the building. The soil class of the examined building is determined as ZC. After the coring process, the average concrete compressive strength is determined as 18.5 MPa. In addition, ribbed steel bar reinforcement (B420c) with a yield strength of 420 N/mm^2 is used as the building material for the structural system. According to the Communiqué on the Approximate Unit Costs of Building to be used in the Calculation of Architectural and Engineering Service Costs, the building is classified as Class III Group B building.

6.1.1. Implementation of the three-stage evaluation score for Building #1

Figur.1. Photographs of Building #1

Building #1: Evaluation of Building Demand and Design Capacity





Building #1 DDSR
(a) X direction, (b) Y direction

Period and DDSR for Building #1

	Period (s)	DDST
$T_{x,\ undamaged}$	0.125	1,00
$T_{x,\ damaged}$	0.449	
$T_{y,\ undamaged}$	0.156	1,00
$T_{y,\ damaged}$	0.538	

DDSR: The Demand- Design Spectrum Ratio

Building #1: Structure Score Assessment

Number of storeys	1	2	3	4
				√
	5	6	7	8
Seismic zone:	1	2	3	4
	√			
Soil Type	ZA	ZB	ZC	ZD - ZE
			√	
Building Age	After 2007	1998-2007	1975-1998	Before 1975
40			√	
Load Bearing Type	RC Frame	RC Frame with Shearwall	STRUCTURE SCORE	
		√	2	
Neighboring Formation	Seperate	Adjacent		
		√		
Vertical Irragularity	Exist	None		
		√		
Overhange	Exist	None		
		√		
Plan Irregularities	Exist	None		
		√		
Short Column	Exist	None		
		√		
Position of Neighboring Slabs	Same	Levelled		
	√			
Soft Storey	Exist	None		
	√			
Slope of Soil	Flat	Slopping		
	√			

Building #1: Material-Mechanical Properties Detection

Slab weight (ton):	427,8 ton
Column weight (ton):	208,42 ton
Shearwall weight (ton):	0.00 ton
Partition wall weight (ton):	583,59 ton
Total building weight(ton):	1219,81 ton
Cross-sectional area of vertical load bearing system elements at ground floor (m^2):	8,98 m^2
Average concrete compressive strength (MPa):	18,5 MPa

$$\text{Building Axial Load Ratio: } \frac{1219{,}81}{8{,}98} = 135{,}83 \text{ ton/m}^2 = 1{,}35 \text{ MPa}$$

$$0{,}20 \times f_{ck}: \quad 0{,}20 \times 18{,}5 = 3{,}70 \text{ MPa}$$

$$\text{Building Axial Load Ratio} = \mathbf{1{,}35\ MPa < 3{,}70\ MPa} = 0{,}20 \times f_{ck}$$

Figure 6.2. Calculation of three-stage evaluation score for Building #1

6.1.2. Summary of the three-stage evaluation score for Building #1

Table 6.1. Determination of the three-stage filtering score for Building #1

THREE STAGE FILTERING STEPS		POINT
1. Stage: Evaluation of Building Demand and Design Capacity Stage		
The Demand - Design Spectrum Ratio for X direction	1,00	**+ 1**
The Demand - Design Spectrum Ratio for Y direction	1,00	
DDSR > 0,75		
2. Stage: Rapid Screening Score Assessment		
Structure Score	+2	**+1**
Structure Score > 0		
3. Stage: Building Material - Mechanical Properties Detection		
Building Axial Load Ratio (MPa)	1,30	**+1**
0,20 x f_{ck} (MPa)	2,48	
Building Axial Load Ratio < 0,20 x f_{ck}		
TOTAL FILTERING POINT		**+3**

Since the filtering score for **Building #1** is above 2 point, retrofitting for investigated buildings is determined as **appropriate** according to the developed method.

6.1.3 Retrofit Cost vs. New Building Construction Cost for Building #1

As a result of the performance analysis of Building #1, determined building has a total of 104 beams and 184 columns, and 11 of the beams and 16 of the columns have insufficient shear capacities. Storey drift values were found to be within the permissible limits. For this structure, it is determined that only the elements lacking sufficient shear capacity needed to be reinforced by using Fiber Reinforced Polymer.

Table 6.2. Determination of reconstruction and retrofitting costs for Building #1

Cost of new building construction				
Number of storey	Plan area (m^2)	Total building area (m^2)	Unit price for new building construction (TL/m^2)	New building construction cost (TL)
4	210,08	840,32	14.400,00	12.100.608,00

Retrofitting Cost of Existing Building					
Fiber Reinforced Polymer (FRP)	FRP reinforcement area (m^2)		Unit price for FRP reinforcement (TL/m^2)		FRP reinforcement cost (TL)
	361,72		6.040,31		2.184.900,93
Retrofitting Shearwalls	Concrete quantity (m^3)	Reinforcement quantity (ton)	Concrete unit price (TL/m^3)	Reinforcement unit price (TL/ton)	Retrofitting shearwalls cost (TL)
	0,00	0,00	2605.30	33.511,95	0
				Total Retrofit Cost:	2.184.900,93

$$\frac{\text{Total retrofitting cost}}{\text{New building construction cost}} = \frac{2.184.900{,}93}{12.100.608{,}00} = \mathbf{0{,}18 < 0{,}40}$$

Building #1, which scored +3 in the three-stage filtering process and is deemed eligible for retrofitting, is also identified as suitable for retrofitting following economic assessments.

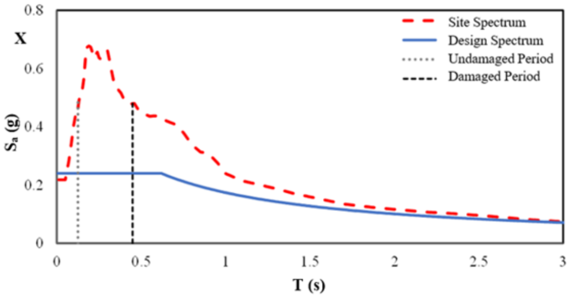
6.2. Building #2

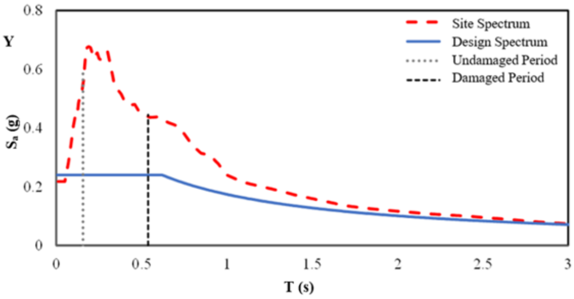
On January 24, 2020, Elazığ-Sivrice earthquake caused moderate damage to the building. The soil class of the examined building is determined as ZC. After the coring process, the average concrete compressive strength is determined as 12,40 MPa. In addition, ribbed steel bar reinforcement (B420c) with a yield strength of 420 N/mm^2 is used as the building material for the structural system. According to the Communiqué on the Approximate Unit Costs of Building to be used in the Calculation of Architectural and Engineering Service Costs, the building is classified as Class III Group B building.

6.2.1. Implementation of the three-stage evaluation score for Building #2

Figure 6.3. Photographs of Building #2

Building #2: Evaluation of Building Demand and Design Capacity





Building #2 DDSR
(a) X direction, (b) Y direction

Period and DDSR for Building #2

	Period (s)	DDST
$T_{x, undamaged}$	0.159	1,00
$T_{x, damaged}$	0.837	
$T_{y, undamaged}$	0.139	1,00
$T_{y, damaged}$	0.584	

DDSR: The Demand - Design Spectrum Ratio

Building #2: Structure Score Assessment

Number of storeys	1	2	3	4
			√	
	5	6	7	8
Seismic zone:	1	2	3	4
	√			
Soil Type	ZA	ZB	ZC	ZD - ZE
			√	
Building Age	After 2007	1998-2007	1975-1998	Before 1975
40			√	
Load Bearing Type	RC Frame	RC Frame with Shearwall	STRUCTURE SCORE	
	√		-9	
Neighboring Formation	Seperate	Adjacent		
		√		
Vertical Irragularity	Exist	None		
		√		
Overhange	Exist	None		
		√		
Plan Irregularities	Exist	None		
		√		
Short Column	Exist	None		
		√		
Position of Neighboring Slabs	Same	Levelled		
	√			
Soft Storey	Exist	None		
		√		
Slope of Soil	Flat	Slopping		
	√			

Building #2: Material- Mechanical Properties Detection

Slab weight (ton):	256,68 ton
Column weight (ton):	123,98 ton
Shearwall weight (ton):	0.00 ton
Partition wall weight (ton):	401,04 ton
Total building weight(ton):	781,69 ton
Cross-sectional area of vertical load bearing system elements at ground floor (m^2):	5,90 m^2
Average concrete compressive strength (MPa):	12,40 MPa

Building Axial Load Ratio: $\frac{781{,}69}{5{,}90} = 132{,}49 \text{ ton/m}^2 = 1{,}32 \text{ MPa}$

$0{,}20 \times f_{ck}$: $0{,}20 \times 12{,}40 = 2{,}48 \text{ MPa}$

Building Axial Load Ratio = **1,32 MPa < 2,48 MPa** = $0{,}20 \times f_{ck}$

Figure 6.4. Calculation of three-stage evaluation score for Building #2

6.2.2. Summary of the three-stage evaluation score for Building #2

Table 6.3. Determination of the three-stage filtering score for Building #2

THREE STAGE FILTERING STEPS		POINT
1. Stage: Evaluation of Building Demand and Design Capacity Stage		
The Demand - Design Spectrum Ratio for X direction	1,00	+ 1
The Demand - Design Spectrum Ratio for Y direction	1,00	
DDSR > 0,75		
2. Stage: Rapid Screening Score Assessment		
Structure Score	-9	**0**
-50 < Structure Score < 0		
3. Stage: Building Material - Mechanical Properties Detection		
Building Axial Load Ratio (MPa)	1,32	+1
0,20 x f_{ck} (MPa)	2,48	
Building Axial Load Ratio < 0,20 x f_{ck}		
TOTAL FILTERING POINT		**+2**

Since the filtering score for **Building #2** is equal to 2 point, retrofitting for investigated buildings is determined as **appropriate** according to the developed method.

6.2.3. Retrofit Cost vs. New Building Construction Cost for Building #2

As a result of the performance analysis of Building #2, determined building has a total of 45 beams and 18 of the beams have insufficient shear capacities. Storey drift values are within the permissible limits. For this structure, it is determined that only the elements lacking sufficient shear capacity needed to be reinforced by using Fiber Reinforced Polymer.

Table 6.4. Determination of reconstruction and retrofitting costs for Building #2

<table>
<tr><th colspan="5">Cost of new building construction</th></tr>
<tr><th>Number of storey</th><th>Plan area (m^2)</th><th>Total building area (m^2)</th><th>Unit price for new building construction (TL/m^2)</th><th>New building construction cost (TL)</th></tr>
<tr><td>3</td><td>285.20</td><td>1.140,80</td><td>14.400,00</td><td>16,427,520.00</td></tr>
</table>

<table>
<tr><th colspan="6">Retrofitting Cost of Existing Building</th></tr>
<tr><td rowspan="2">Fiber Reinforced Polymer (FRP)</td><td colspan="2">FRP reinforcement area (m^2)</td><td colspan="2">Unit price for FRP reinforcement (TL/m^2)</td><td>FRP reinforcement cost (TL)</td></tr>
<tr><td colspan="2">297,00</td><td colspan="2">6.040,31</td><td>1.793.972,07</td></tr>
<tr><td rowspan="2">Retrofitting Shearwalls</td><td>Concrete quantity (m^3)</td><td>Reinforcement quantity (ton)</td><td>Concrete unit price (TL/m^3)</td><td>Reinforcement unit price (TL/ton)</td><td>Retrofitting shearwalls cost (TL)</td></tr>
<tr><td>0,00</td><td>0,00</td><td>2.605,30</td><td>33.511,95</td><td>0</td></tr>
<tr><td colspan="5">Total Retrofit Cost:</td><td>1.793.972,07</td></tr>
</table>

$$\frac{\text{Total retrofitting cost}}{\text{New building construction cost}} = \frac{1.793.972,07}{16,427,520.00} = \mathbf{0,11 < 0,40}$$

Building #2, which scored +2 in the three-stage filtering process and is deemed eligible for retrofitting, is also identified as suitable for retrofitting following economic assessments.

6.3. Building #3

On January 24, 2020, Elazığ-Sivrice earthquake caused moderate damage to the building. The soil class of the examined building is determined as ZC. After the coring process, the average concrete compressive strength is determined as 11,70 MPa. In addition, unribbed steel bar reinforcement (S220) with a yield strength of 2200 N/mm^2 is used in the structural system of the building. According to the Communiqué on the Approximate Unit Costs of Building to be used in the Calculation of Architectural and Engineering Service Costs, the building is classified as Class III Group A building.

6.3.1. Implementation of the three-stage evaluation score for Building #3

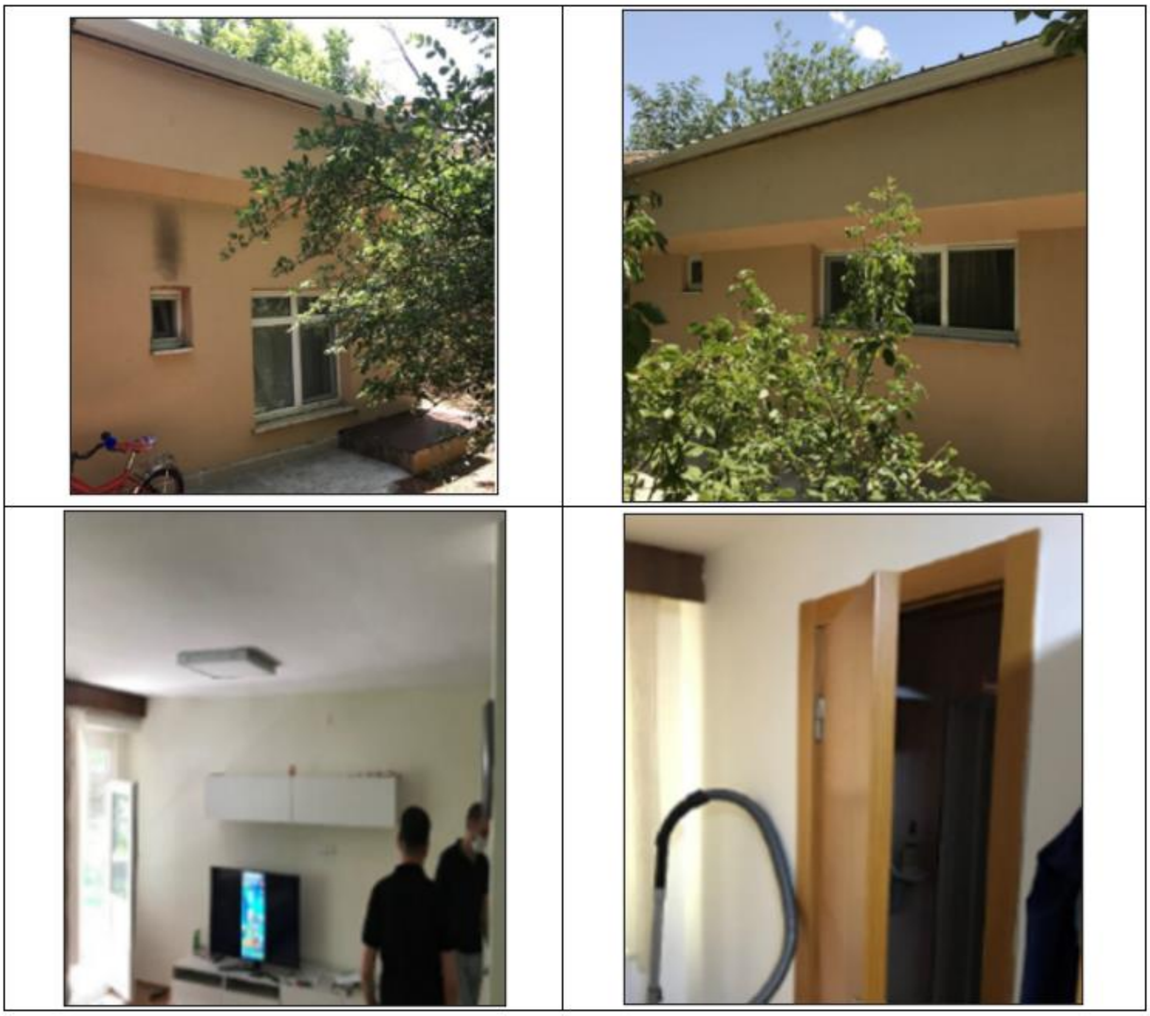
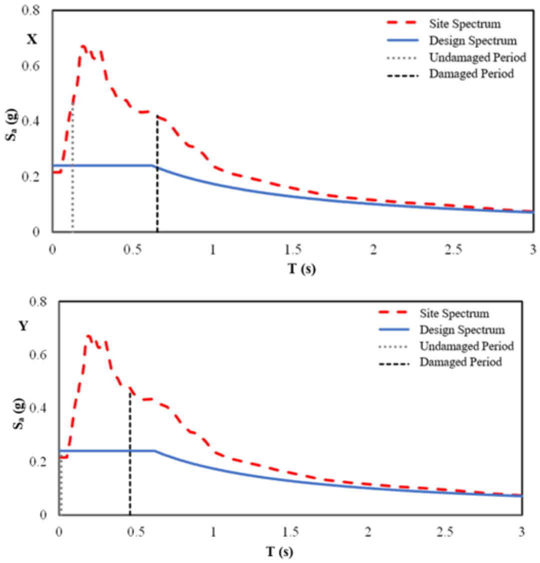


Figure 6.5. Photographs of Building #3

Building #3: Evaluation of Building Demand and Design Capacity



Building #3 DDSR
(a) X direction, (b) Y direction

Period and DDSR for Building #3

	Period (s)	DDST
$T_{x,\ undamaged}$	0.125	1,00
$T_{x,\ damaged}$	0.654	
$T_{y,\ undamaged}$	0.014	0,961
$T_{y,\ damaged}$	0.460	

DDSR: The Demand - Design Spectrum Ratio

Building #3: Structure Score Assessment

Number of storeys	1	2	3	4
	√			
	5	6	7	8
Seismic zone:	1	2	3	4
	√			
Soil Type	ZA	ZB	ZC	ZD - ZE
			√	
Building Age	After 2007	1998-2007	1975-1998	Before 1975
40			√	
Load Bearing Type	RC Frame	RC Frame with Shearwall	**STRUCTURE SCORE**	
	√		**15**	
Neighboring Formation	Seperate	Adjacent		
	√			
Vertical Irragularity	Exist	None		
		√		
Overhange	Exist	None		
		√		
Plan Irregularities	Exist	None		
		√		
Short Column	Exist	None		
		√		
Position of Neighboring Slabs	Same	Levelled		
	√			
Soft Storey	Exist	None		
		√		
Slope of Soil	Flat	Slopping		
	√			

Building #3: Material- Mechanical Properties Detection

Slab weight (ton):	47,13 ton
Column weight (ton):	23,94 ton
Shearwall weight (ton):	0.00 ton
Partition wall weight (ton):	185,59 ton
Total building weight(ton):	256,66 ton
Cross-sectional area of vertical load bearing system elements at ground floor (m^2):	2,69 m^2
Average concrete compressive strength (MPa):	11,70 MPa

Building Axial Load Ratio: $\frac{256,66}{2,69} = 95,41\ \text{ton/m}^2 = 0,95\ \text{MPa}$

$0,20 \times f_{ck}$: $0,20 \times 11,70 = 2,34\ \text{MPa}$

Building Axial Load Ratio = **0,95 MPa < 2,34 MPa** = 0,20 x fck

Figure 6.6. Calculation of three-stage evaluation score for Building #3

6.3.2. Summary of the three-stage evaluation score for Building #3

Table 6.5. Determination of the three-stage filtering score for Building #3

THREE STAGE FILTERING STEPS		POINT
1. Stage: Evaluation of Building Demand and Design Capacity Stage		
The Demand - Design Spectrum Ratio for X direction	1,00	+ 1
The Demand - Design Spectrum Ratio for Y direction	0,961	
DDSR = 0,961 > 0,75		
2. Stage: Rapid Screening Score Assessment		
Structure Score	+15	+ 1
Structure Score > 0		
3. Stage: Building Material - Mechanical Properties Detection		
Building Axial Load Ratio (MPa)	0,95	+ 1
0,20 x f_{ck} (MPa)	2,34	
Building Axial Load Ratio < 0,20 x f_{ck}		
TOTAL FILTERING POINT		+ 3

Since the filtering score for **Building #3** is above 2 point, retrofitting for investigated buildings is determined as **appropriate** according to the developed method.

6.3.3. Retrofit Cost vs. New Building Construction Cost for Building #3

As a result of the performance analysis of Building #3, determined building has a total of 18 beams and 1 of the beams have insufficient shear capacities. Storey drift values are within the permissible limits. For this structure, it is determined that only the elements lacking sufficient shear capacity needed to be reinforced by using Fiber Reinforced Polymer.

Table 6.6. Determination of reconstruction and retrofitting costs for Building #3

Cost of new building construction				
Number of storeys	Plan area (m^2)	Total building area (m^2)	Unit price for new building construction (TL/m^2)	New building construction cost (TL)
1	196,36	196,36	12.250,00	2.405.410,00

Retrofitting Cost of Existing Building					
Fiber Reinforced Polymer (FRP)	FRP reinforcement area (m^2)		Unit price for FRP reinforcement (TL/m^2)		FRP reinforcement cost (TL)
	7,83		6.040,31		47.295,63
Retrofitting Shearwalls	Concrete quantity (m^3)	Reinforcement quantity (ton)	Concrete unit price (TL/m^3)	Reinforcement unit price (TL/ton)	Retrofitting shearwalls cost (TL)
	0	0	2.605,30	33.511,95	0
				Total Retrofit Cost:	47,295.63

$$\frac{\text{Total retrofitting cost}}{\text{New building construction cost}} = \frac{47,295.63}{2.405.410,00} = 0,02 < 0,40$$

Building #3, which scored +3 in the three-stage filtering process and is deemed eligible for retrofitting, is also identified as suitable for retrofitting following economic assessments.

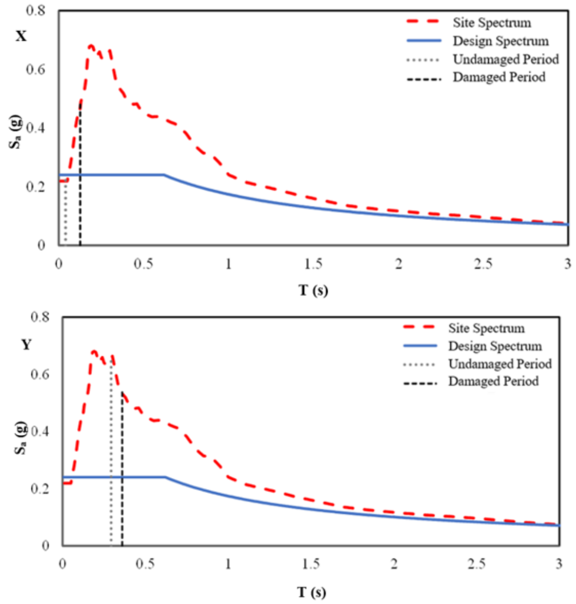
6.4. Building #4

On January 24, 2020, Elazığ-Sivrice earthquake caused moderate damage to the building. The soil class of the examined building is determined as ZC. After the coring process, the average concrete compressive strength is determined as 12,50 MPa. In addition, unribbed steel bar reinforcement (S220) with a yield strength of 2200 N/mm^2 is used as the building material for the structural system. According to the Communiqué on the Approximate Unit Costs of Building to be used in the Calculation of Architectural and Engineering Service Costs, the building is classified as Class III Group A building.

6.4.1. Implementation of the three-stage evaluation score for Building #4

Figure 6.7. Photographs of Building #4

Building #4: Evaluation of Building Demand and Design Capacity



Building #4 DDSR
(a) X direction, (b) Y direction

Period and DDSR for Building #4

	Period (s)	DDST
$T_{x, undamaged}$	0.040	0,845
$T_{x, damaged}$	0.126	
$T_{y, undamaged}$	0.293	1,00
$T_{y, damaged}$	0.360	

DDSR: The Demand - Design Spectrum Ratio

Building #4: Structure Score Assessment

Number of storeys	1	2	3	4
	√			
	5	6	7	8
Seismic zone:	1	2	3	4
	√			
Soil Type	ZA	ZB	ZC	ZD - ZE
			√	
Building Age	After 2007	1998-2007	1975-1998	Before 1975
40			√	
Load Bearing Type	RC Frame	RC Frame with Shearwall	STRUCTURE SCORE	
	√		-40	
Neighboring Formation	Seperate	Adjacent		
	√			
Vertical Irregularity	Exist	None		
	√			
Overhange	Exist	None		
		√		
Plan Irregularities	Exist	None		
		√		
Short Column	Exist	None		
	√			
Position of Neighboring Slabs	Same	Levelled		
	√			
Soft Storey	Exist	None		
		√		
Slope of Soil	Flat	Slopping		
	√			

Building #4: Material- Mechanical Properties Detection

Slab weight (ton):	129,78 ton
Column weight (ton):	75,95 ton
Shearwall weight (ton):	0.00 ton
Partition wall weight (ton):	370,89 ton
Total building weight(ton):	576,61 ton
Cross-sectional area of vertical load bearing system elements at ground floor (m^2):	4,32 m^2
Average concrete compressive strength (MPa):	12,50 MPa

$$\text{Building Axial Load Ratio: } \frac{576{,}61}{4{,}32} = 133{,}47 \text{ ton/m}^2 = 1{,}33 \text{ MPa}$$

$$0{,}20 \times f_{ck}: \quad 0{,}20 \times 12{,}50 = 2{,}50 \text{ MPa}$$

$$\text{Building Axial Load Ratio} = \mathbf{1{,}31\ MPa < 2{,}50\ MPa} = 0{,}20 \times f_{ck}$$

Figure 6.8. Calculation of three-stage evaluation score for Building #4

6.4.2. Summary of the three-stage evaluation score for Building #4

Table 6.7. Determination of the three-stage filtering score for Building #4

THREE STAGE FILTERING STEPS		POINT
1. Stage: Evaluation of Building Demand and Design Capacity Stage		
The Demand - Design Spectrum Ratio for X direction	0,845	+ 1
The Demand - Design Spectrum Ratio for Y direction	1,00	
DDSR=0,845 > 0,75		
2. Stage: Rapid Screening Score Assessment		
Structure Score	-40	**0**
-50<Structure Score < 0		
3. Stage: Building Material - Mechanical Properties Detection		
Building Axial Load Ratio (MPa)	1,33	+1
0,20 x f_{ck} (MPa)	2,50	
Building Axial Load Ratio < 0,20 x f_{ck}		
TOTAL FILTERING POINT		+2

Since the filtering score for **Building #4** is equal to 2 points, retrofitting for investigated buildings is determined as **appropriate** according to the developed method.

6.4.3. Retrofit Cost vs. New Building Construction Cost for Building #4

As a result of the performance analysis of Building #4, determined building has a total of 44 beams – 31 columns and 16 of the beams – 10 columns have insufficient shear capacities. The storey drift ratio in Y direction is determined as 0.02. For this reason, retrofitting shear walls should be added to increase the lateral stiffness in the Y direction of the examined building.

Table 6.8. Determination of reconstruction and retrofitting costs for Building #4

Cost of new building construction				
Number of storeys	Plan area (m^2)	Total building area (m^2)	Unit price for new building construction (TL/m^2)	New building construction cost (TL)
2	540,75	540,75	12.250,00	6.624.187,50

Retrofitting Cost of Existing Building					
Fiber Reinforced Polymer (FRP)	FRP reinforcement area (m^2)		Unit price for FRP reinforcement (TL/m^2)		FRP reinforcement cost (TL)
	364,32		6.040,31		2.200.605,74
Retrofitting Shearwalls	Concrete quantity (m^3)	Reinforcement quantity (ton)	Concrete unit price (TL/m^3)	Reinforcement unit price (TL/ton)	Retrofitting shearwalls cost (TL)
	53,64	0,85	2.605,30	33.511,95	168.233,45
				Total Retrofit Cost:	2.368.839,19

$$\frac{\text{Total retrofitting cost}}{\text{New building construction cost}} = \frac{2.368.839,19}{6.624.187,50} = 0,36 < 0,40$$

Building #4, which scored +2 in the three-stage filtering process and is deemed eligible for retrofitting, is also identified as suitable for retrofitting following economic assessments.

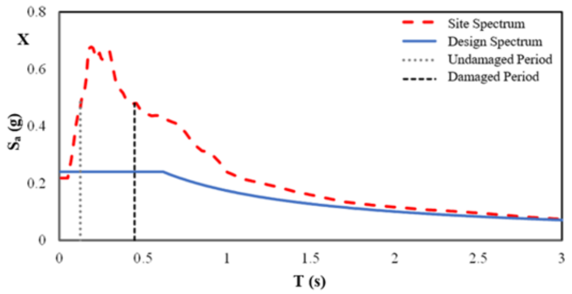
6.5. Building #5

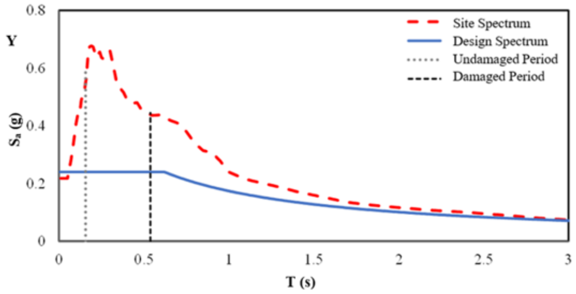
On January 24, 2020, Elazığ-Sivrice earthquake caused moderate damage to the building. The soil class of the examined building is determined as ZC. After the coring process, the average concrete compressive strength is determined as 19,20 MPa. In addition, ribbed steel bar reinforcement (S220) with a yield strength of 2200 N/mm^2 is used as the building material for the structural system. According to the Communiqué on the Approximate Unit Costs of Building to be used in the Calculation of Architectural and Engineering Service Costs, the building is classified as Class III Group A building.

6.5.1. Implementation of the three-stage evaluation score for Building #5

Figure 6.9. Photographs of Building #5

Building #5: Evaluation of Building Demand and Design Capacity





Building #5 DDSR
(a) X direction, (b) Y direction

Period and DDSR for Building #5

	Period (s)	DDST
$T_{x,\ undamaged}$	0.159	1,00
$T_{x,\ damaged}$	0.837	
$T_{y,\ undamaged}$	0.139	1,00
$T_{y,\ damaged}$	0.584	

DDSR: The Demand - Design Spectrum Ratio

Building #5: Structure Score Assessment

Number of storeys	1	2	3	4
	√			
	5	6	7	8
Seismic zone:	1	2	3	4
	√			
Soil Type	ZA	ZB	ZC	ZD - ZE
			√	
Building Age	After 2007	1998-2007	1975-1998	Before 1975
41			√	
Load Bearing Type	RC Frame	RC Frame with Shearwall	STRUCTURE SCORE	
	√		-83	
Neighboring Formation	Seperate	Adjacent		
	√			
Vertical Irragularity	Exist	None		
	√			
Overhange	Exist	None		
		√		
Plan Irregularities	Exist	None		
	√			
Short Column	Exist	None		
	√			
Position of Neighboring Slabs	Same	Levelled		
	√			
Soft Storey	Exist	None		
	√			
Slope of Soil	Flat	Slopping		
	√			

Building #5: Material- Mechanical Properties Detection

Slab weight (ton):	154,68 ton
Column weight (ton):	157,22 ton
Shearwall weight (ton):	0.00 ton
Partition wall weight (ton):	381,69 ton
Total building weight (ton):	693,59 ton
Cross-sectional area of vertical load bearing system elements at ground floor (m^2):	7,67 m^2
Average concrete compressive strength (MPa):	19,2 MPa

Building Axial Load Ratio: $\frac{639,59}{7,67} = 83,39$ ton/m^2 = 0,83 MPa

0,20 x f_{ck}: 0,20 x 19,2 = 3,84 MPa

Building Axial Load Ratio = **0,83 MPa < 3,84 MPa** = 0,20 x fck

Figure 6.10. Calculation of three-stage evaluation score for Building #5

6.5.2. Summary of the three-stage evaluation score for Building #5

Table 6.9. Determination of the three-stage filtering score for Building #5

THREE STAGE FILTERING STEPS		POINT
1. Stage: Evaluation of Building Demand and Design Capacity Stage		
The Demand - Design Spectrum Ratio for X direction	1,00	+ 1
The Demand - Design Spectrum Ratio for Y direction	1,00	
DDSR > 0,75		
2. Stage: Rapid Screening Score Assessment		
Structure Score	-83	-1
-Structure Score < -50		
3. Stage: Building Material - Mechanical Properties Detection		
Building Axial Load Ratio (MPa)	0,83	+1
0,20 x f_{ck} (MPa)	3,84	
Building Axial Load Ratio < 0,20 x f_{ck}		
TOTAL FILTERING POINT		+1

Since the filtering score for **Building #5** is below 2 points, retrofitting for investigated buildings is determined as **inappropriate** according to the developed method.

6.5.3. Retrofit Cost vs. New Building Construction Cost for Building #5

As a result of the performance analysis of Building #5, determined building has a total of 48 beams – 36 columns and 19 of the beams and 28 of columns have insufficient shear capacities. Storey drift values are within the permissible limits. For this structure, it is determined that only the elements lacking sufficient shear capacity needed to be reinforced by using Fiber Reinforced Polymer.

Table 6.10. Determination of reconstruction and retrofitting costs for Building #5

<table>
<tr><th colspan="5">Cost of new building construction</th></tr>
<tr><td>Number of storeys</td><td>Plan area (m²)</td><td>Total building area (m²)</td><td>Unit price for new building construction (TL/m²)</td><td>New building construction cost (TL)</td></tr>
<tr><td>1</td><td>644,48</td><td>644,48</td><td>12.250,00</td><td>7.894.880,00</td></tr>
</table>

<table>
<tr><th colspan="6">Retrofitting Cost of Existing Building</th></tr>
<tr><td rowspan="2">Fiber Reinforced Polymer (FRP)</td><td colspan="2">FRP reinforcement area (m²)</td><td colspan="2">Unit price for FRP reinforcement (TL/m²)</td><td>FRP reinforcement cost (TL)</td></tr>
<tr><td colspan="2">764,06</td><td colspan="2">6.040,31</td><td>4.615.159,26</td></tr>
<tr><td rowspan="2">Retrofitting Shearwalls</td><td>Concrete quantity (m³)</td><td>Reinforcement quantity (ton)</td><td>Concrete unit price (TL/m³)</td><td>Reinforcement unit price (TL/ton)</td><td>Retrofitting shearwalls cost (TL)</td></tr>
<tr><td>0</td><td>0</td><td>2.605,30</td><td>33.511,95</td><td>0</td></tr>
<tr><td colspan="5">Total Retrofit Cost:</td><td>4.615.159,26</td></tr>
</table>

$$\frac{\text{Total retrofitting cost}}{\text{New building construction cost}} = \frac{4.615.159,26}{7.894.880,00} = 0,58 > 0,40$$

Building #5, which scored +1 in the three-stage filtering process and is deemed improper for retrofitting, is also identified as **inefficient** and **unfeasible** for retrofitting following economic assessments.

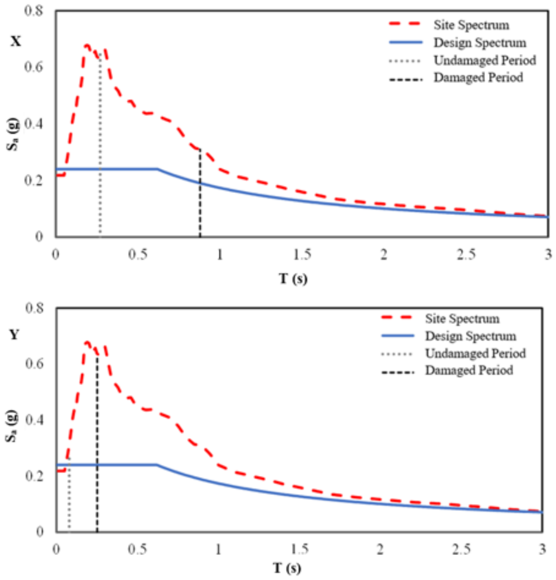
6.6. Building #6

On January 24, 2020, Elazığ-Sivrice earthquake caused moderate damage to the building. The soil class of the examined building was determined as ZC. After the coring process, the average concrete compressive strength is determined as 21,30 MPa. In addition, ribbed steel bar reinforcement (S220) with a yield strength of 2200 N/mm^2 is used as the building material for the structural system. According to the Communiqué on the Approximate Unit Costs of Building to be used in the Calculation of Architectural and Engineering Service Costs, the building is classified as Class III Group B building.

6.6.1. Implementation of the three-stage evaluation score for Building #6

Figure 6.11. Photographs of Building #6

Building #6: Evaluation of Building Demand and Design Capacity



Building #6 DDSR
(a) X direction, (b) Y direction

Period and DDSR for Building #1

	Period (s)	DDST
$T_{x,\ undamaged}$	0.270	1,00
$T_{x,\ damaged}$	0.879	
$T_{y,\ undamaged}$	0.079	1,00
$T_{y,\ damaged}$	0.251	

DDSR: The Demand - Design Spectrum Ratio

Building #6: Structure Score Assessment

Number of storeys	1	2	3	4
			√	
	5	6	7	8
Seismic zone:	1	2	3	4
	√			
Soil Type	ZA	ZB	ZC	ZD - ZE
			√	
Building Age	After 2007	1998-2007	1975-1998	Before 1975
40			√	
Load Bearing Type	RC Frame	RC Frame with Shearwall	**STRUCTURE SCORE**	
		√	**-7**	
Neighboring Formation	Seperate	Adjacent		
	√			
Vertical Irragularity	Exist	None		
		√		
Overhange	Exist	None		
		√		
Plan Irregularities	Exist	None		
		√		
Short Column	Exist	None		
	√			
Position of Neighboring Slabs	Same	Levelled		
	√			
Soft Storey	Exist	None		
		√		
Slope of Soil	Flat	Slopping		
	√			

Building #6: Material- Mechanical Properties Detection

Slab weight (ton):	791,74 ton
Column weight (ton):	457,70 ton
Shearwall weight (ton):	0,00 ton
Partition wall weight (ton):	1428,93 ton
Total building weight(ton):	2.678,37 ton
Cross-sectional area of vertical load bearing system elements at ground floor (m^2):	16,23 m^2
Average concrete compressive strength (MPa):	21,30 MPa

Building Axial Load Ratio: $\frac{2.678,37}{16,23}$ = 165,03 ton/m^2 = 1,64 MPa

0,20 x f_{ck}: 0,20 x 21,30 = 4,26 MPa

Building Axial Load Ratio = **1,62 MPa < 4,26 MPa** = 0,20 x f_{ck}

Figure 6.12. Calculation of three-stage evaluation score for Building #6

6.6.2. Summary of the three-stage evaluation score for Building #6

Table 6.11. Determination of the three-stage filtering score for Building #6

THREE STAGE FILTERING STEPS		POINT
1. Stage: Evaluation of Building Demand and Design Capacity Stage		
The Demand - Design Spectrum Ratio for X direction	1,00	+ 1
The Demand - Design Spectrum Ratio for Y direction	1,00	
DDSR > 0,75		
2. Stage: Rapid Screening Score Assessment		
Structure Score	-7	0
-50 < Structure Score < 0		
3. Stage: Building Material - Mechanical Properties Detection		
Building Axial Load Ratio (MPa)	1,62	+1
0,20 x f_{ck} (MPa)	4,26	
Building Axial Load Ratio < 0,20 x f_{ck}		
TOTAL FILTERING POINT		+2

Since the filtering score for **Building #6** is equal to 2 point, retrofitting for investigated buildings is determined as **appropriate** according to the developed method.

6.6.3. Retrofit Cost vs. New Building Construction Cost for Building #6

As a result of the performance analysis of Building #6, determined building has a total of 138 beams – 192 column and 39 of the beams – 43 of columns have insufficient shear capacities. Storey drift values are within the permissible limits. For this structure, it is determined that only the elements lacking sufficient shear capacity needed to be reinforced by using Fiber Reinforced Polymer.

Table 6.12. Determination of reconstruction and retrofitting costs for Building #6

Cost of new building construction				
Number of storeys	Plan area (m^2)	Total building area (m^2)	Unit price for new building construction (TL/m^2)	New building construction cost (TL)
3	879,71	2.639,13	14.400,00	38.003.472,00

Retrofitting Cost of Existing Building					
Fiber Reinforced Polymer (FRP)	FRP reinforcement area (m^2)		Unit price for FRP reinforcement (TL/m^2)		FRP reinforcement cost (TL)
	1.446,94		6.040,31		8.739.966,15
Retrofitting Shearwalls	Concrete quantity (m^3)	Reinforcement quantity (ton)	Concrete unit price (TL/m^3)	Reinforcement unit price (TL/ton)	Retrofitting shearwalls cost (TL)
	0	0	2.605,30	33.511,95	0
				Total Retrofit Cost:	8.739.966,15

$$\frac{\text{Total retrofitting cost}}{\text{New building construction cost}} = \frac{8.739.966,15}{38.003.472,00} = 0,23 < 0,40$$

Building #6, which scored +2 in the three-stage filtering process and is deemed eligible for retrofitting, is also identified as **suitable** and **efficient** for retrofitting following economic assessments.

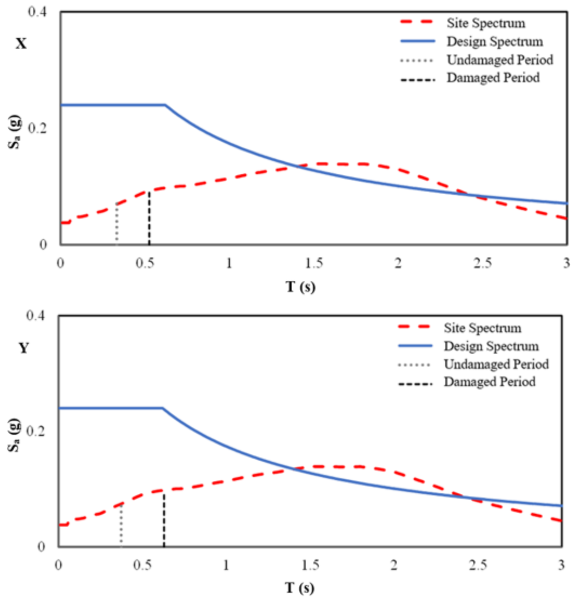
6.7. Building #7

On November 30, 2020, Sisam - Izmir earthquake caused moderate damage to the building. The soil class of the examined building is determined as ZE. After the coring process, the average concrete compressive strength is determined as 8,28 MPa. According to the Communiqué on the Approximate Unit Costs of Building to be used in the Calculation of Architectural and Engineering Service Costs, the building is classified as Class III Group B building.

6.7.1. Implementation of the three-stage evaluation score for Building #7

Figure 6.13. Photographs of Building #7

Building #7: Evaluation of Building Demand and Design Capacity



Building #7 DDSR
(a) X direction, (b) Y direction

Period and DDSR for Building #7

	Period (s)	DDST
$T_{x,\ undamaged}$	0,332	0,00
$T_{x,\ damaged}$	0,525	
$T_{y,\ undamaged}$	0,373	0,00
$T_{y,\ damaged}$	0,629	

DDSR: The Demand - Design Spectrum Ratio

Building #7: Structure Score Assessment

Number of storeys	1	2	3	4
	5	6	7	8
				√
Seismic zone:	1	2	3	4
	√			
Soil Type	ZA	ZB	ZC	ZD - ZE
				√
Building Age	After 2007	1998-2007	1975-1998	Before 1975
31			√	
Load Bearing Type	RC Frame	RC Frame with Shearwall	STRUCTURE SCORE	
		√	22	
Neighboring Formation	Seperate	Adjacent		
	√			
Vertical Irragularity	Exist	None		
		√		
Overhange	Exist	None		
		√		
Plan Irregularities	Exist	None		
		√		
Short Column	Exist	None		
		√		
Position of Neighboring Slabs	Same	Levelled		
	√			
Soft Storey	Exist	None		
		√		
Slope of Soil	Flat	Slopping		
	√			

Building #7: Material- Mechanical Properties Detection

Slab weight (ton):	887,33 ton
Column weight (ton):	310,06 ton
Shearwall weight (ton):	500,23 ton
Partition wall weight (ton):	476,25 ton
Total building weight(ton):	2.173,88 ton
Cross-sectional area of vertical load bearing system elements at ground floor (m^2):	18,76 m^2
Average concrete compressive strength (MPa):	8,28 MPa

$$\text{Building Axial Load Ratio: } \frac{2.173,88}{18,76} = 115,88 \text{ ton/m}^2 = 1,15 \text{ MPa}$$

$$0,20 \times f_{ck}: \quad 0,20 \times 8,28 = 1,66 \text{ MPa}$$

Building Axial Load Ratio = **1,14 MPa < 1,66 MPa** = 0,20 x f_{ck}

Figure 6.14. Calculation of three-stage evaluation score for Building #7

6.7.2. Summary of the three-stage evaluation score for Building #7

Table 6.13. Determination of the three-stage filtering score for Building #7

THREE STAGE FILTERING STEPS		POINT
1. Stage: Evaluation of Building Demand and Design Capacity Stage		
The Demand - Design Spectrum Ratio for X direction	0,00	-1
The Demand - Design Spectrum Ratio for Y direction	0,00	
DDSR < 0,50		
2. Stage: Rapid Screening Score Assessment		
Structure Score	22	+1
0 < Structure Score		
3. Stage: Building Material - Mechanical Properties Detection		
Building Axial Load Ratio (MPa)	1,15	+1
0,20 x f_{ck} (MPa)	1,66	
Building Axial Load Ratio < 0,20 x f_{ck}		
TOTAL FILTERING POINT		+1

Since the filtering score for **Building #7** is below 2 points, retrofitting for investigated buildings is determined as **inappropriate** according to the developed method.

6.7.3. Retrofit Cost vs. New Building Construction Cost for Building #7

In the earthquake risk analyses conducted for Building #7, it is determined that the bearing capacities of the vertical load bearing elements (columns and shear walls) of the building are exceeded in 91% and 100% for X and Y directions, respectively. In addition, the storey drift ratios of the building in X and Y directions are determined as 0,024 in both directions. For this reason, it is necessary to add reinforcing shear walls to the building for both directions during the retrofitting process.

Table 6.14. Determination of reconstruction and retrofitting costs for Building #7

Cost of new building construction				
Number of storeys	Plan area (m^2)	Total building area (m^2)	Unit price for new building construction (TL/m^2)	New building construction cost (TL)
8	369,72	2957,76	14.400,00	42.591.744,00

Retrofitting Cost of Existing Building					
Fiber Reinforced Polymer (FRP)	FRP reinforcement area (m^2)		Unit price for FRP reinforcement (TL/m^2)		FRP reinforcement cost (TL)
	4.873,17		6.040,31		29.435.457,48
Retrofitting Shearwalls	Concrete quantity (m^3)	Reinforcement quantity (ton)	Concrete unit price (TL/m^3)	Reinforcement unit price (TL/ton)	Retrofitting shearwalls cost (TL)
	1.702,84	41,73	2.605,30	33.511,95	5.834.862,73
Total Retrofit Cost:					35.270.320,21

$$\frac{\text{Total retrofitting cost}}{\text{New building construction cost}} = \frac{35.270.320{,}21}{42.591.744{,}00} = 0{,}83 > 0{,}40$$

Building #5, which scored +1 in the three-stage filtering process and is deemed improper for retrofitting, is also identified as **inefficient** and **unfeasible** for retrofitting following economic assessments.

6.8. Building #8

On November 30, 2020, Sisam - Izmir earthquake caused moderate damage to the building. The soil class of the examined building is determined as ZE. After the coring process, the average concrete compressive strength is determined as 8,05 MPa. According to the Communiqué on the Approximate Unit Costs of Building to be used in the Calculation of Architectural and Engineering Service Costs, the building is classified as Class III Group B building.

6.8.1. Implementation of the three-stage evaluation score for Building #8

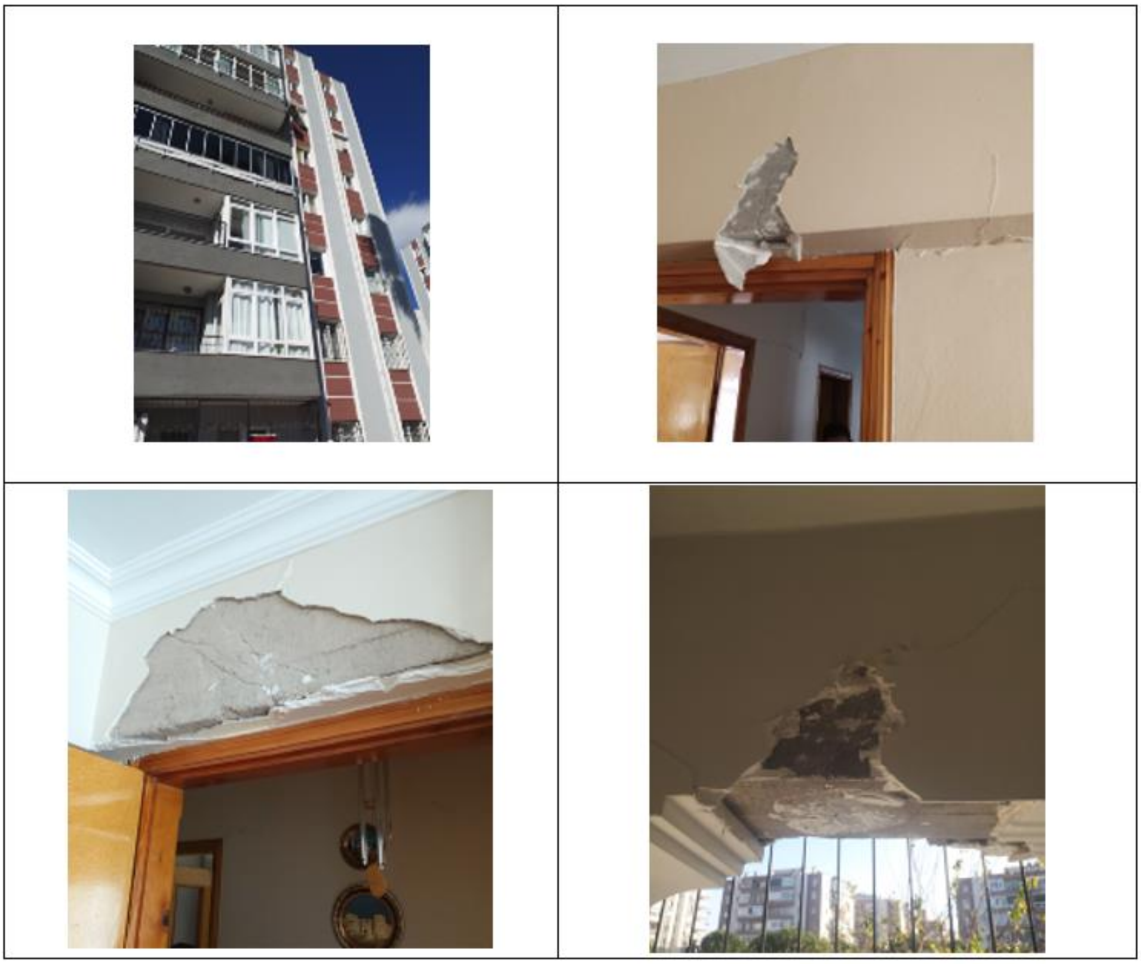
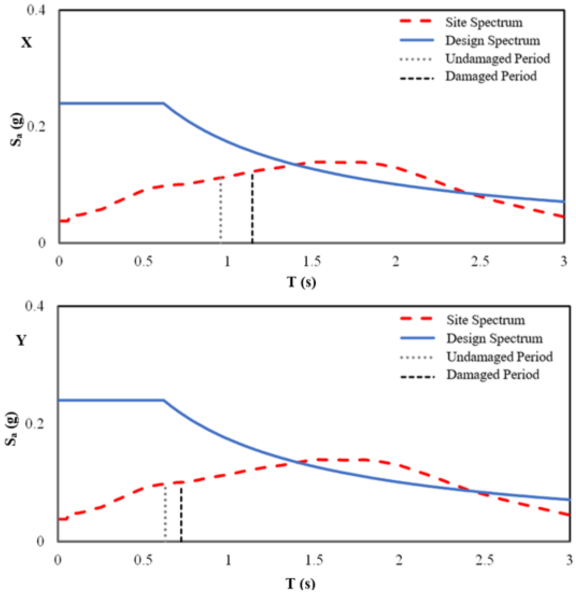


Figure 6.15. Photographs of Building #8

Building #8: Evaluation of Building Demand and Design Capacity



Building #8 DDSR
(a) X direction, (b) Y direction

Period and DDSR for Building #1

	Period (s)	DDST
$T_{x,\ undamaged}$	0.959	0,00
$T_{x,\ damaged}$	1.147	
$T_{y,\ undamaged}$	0.629	0,00
$T_{y,\ damaged}$	0.722	

DDSR: The Demand - Design Spectrum Ratio

Building #8: Structure Score Assessment

Number of storeys	1	2	3	4
	5	6	7	8
				√
Seismic zone:	1	2	3	4
	√			
Soil Type	ZA	ZB	ZC	ZD - ZE
				√
Building Age	After 2007	1998-2007	1975-1998	Before 1975
31			√	
Load Bearing Type	RC Frame	RC Frame with Shearwall	STRUCTURE SCORE	
	√		2	
Neighboring Formation	Seperate	Adjacent		
	√			
Vertical Irragularity	Exist	None		
		√		
Overhange	Exist	None		
		√		
Plan Irregularities	Exist	None		
		√		
Short Column	Exist	None		
		√		
Position of Neighboring Slabs	Same	Levelled		
	√			
Soft Storey	Exist	None		
		√		
Slope of Soil	Flat	Slopping		
	√			

Building #8: Material- Mechanical Properties Detection

Slab weight (ton):	887,33 ton
Column weight (ton):	329,20 ton
Shearwall weight (ton):	0.00 ton
Partition wall weight (ton):	1.396,74 ton
Total building weight (ton):	2.613,26 ton
Cross-sectional area of vertical load bearing system elements at ground floor (m^2):	7,76 m^2
Average concrete compressive strength (MPa):	8,05 MPa

Building Axial Load Ratio: $\frac{2.613,26}{7,76} = 336,76\ ton/m^2 = 3,36\ MPa$

$0,20 \times f_{ck}$: $0,20 \times 8,05 = 1,61\ MPa$

Building Axial Load Ratio = **3,36 MPa > 1,61 MPa** = $0,20 \times f_{ck}$

Figure 6.16. Calculation of three-stage evaluation score for Building #8

6.8.2. Summary of the three-stage evaluation score for Building #8

Table 6.15. Determination of the three-stage filtering score for Building #8

THREE STAGE FILTERING STEPS		POINT
1. Stage: Evaluation of Building Demand and Design Capacity Stage		
The Demand - Design Spectrum Ratio for X direction	0,00	**-1**
The Demand - Design Spectrum Ratio for Y direction	0,00	
DDSR < 0,50		
2. Stage: Rapid Screening Score Assessment		
Structure Score	+2	**+ 1**
0 < Structure Score		
3. Stage: Building Material - Mechanical Properties Detection		
Building Axial Load Ratio (MPa)	3,36	**-1**
0,20 x f_{ck} (MPa)	1,61	
Building Axial Load Ratio > 0,20 x f_{ck}		
TOTAL FILTERING POINT		**-1**

Since the filtering score for **Building #8** is equal to -1 and below 2 points, retrofitting for investigated buildings is determined as **inppropriate** according to the developed method.

6.8.3. Retrofit Cost vs. New Building Construction Cost for Building #8

In the earthquake risk analyses conducted for Building #7, it is determined that the bearing capacities of the vertical load bearing elements (columns and shear walls) of the building are exceeded in 99% and 100% for X and Y directions, respectively. In addition, the storey drift ratios of the building in X and Y directions are determined as 0,025 in both directions. For this reason, it is necessary to add reinforcing shear walls to the building for both directions during the retrofitting process.

Table 6.16. Determination of reconstruction and retrofitting costs for Building #8

<table>
<tr><td colspan="5">Cost of new building construction</td></tr>
<tr><td>Number of storeys</td><td>Plan area (m^2)</td><td>Total building area (m^2)</td><td>Unit price for new building construction (TL/m^2)</td><td>New building construction cost (TL)</td></tr>
<tr><td>8</td><td>369,72</td><td>2.957,76</td><td>14.400,00</td><td>42.591.744,00</td></tr>
</table>

<table>
<tr><td colspan="6">Retrofitting Cost of Existing Building</td></tr>
<tr><td rowspan="2">Fiber Reinforced Polymer (FRP)</td><td colspan="2">FRP reinforcement area (m^2)</td><td colspan="2">Unit price for FRP reinforcement (TL/m^2)</td><td>FRP reinforcement cost (TL)</td></tr>
<tr><td colspan="2">5.017,34</td><td colspan="2">6.040,31</td><td>30.306.288,98</td></tr>
<tr><td rowspan="2">Retrofitting Shearwalls</td><td>Concrete quantity (m^3)</td><td>Reinforcement quantity (ton)</td><td>Concrete unit price (TL/m^3)</td><td>Reinforcement unit price (TL/ton)</td><td>Retrofitting shearwalls cost (TL)</td></tr>
<tr><td>63,70</td><td>8,04</td><td>2.605,30</td><td>33.511,95</td><td>435.393,69</td></tr>
<tr><td colspan="5">Total Retrofit Cost:</td><td>30.741.682,66</td></tr>
</table>

$$\frac{\text{Total retrofitting cost}}{\text{New building construction cost}} = \frac{30.741.682,66}{42.591.744,00} = 0,72 < 0,40$$

Building #8, which scored -1 in the three-stage filtering process and is deemed improper for retrofitting, is also identified as **inefficient** and **unfeasible** for retrofitting following economic assessments.

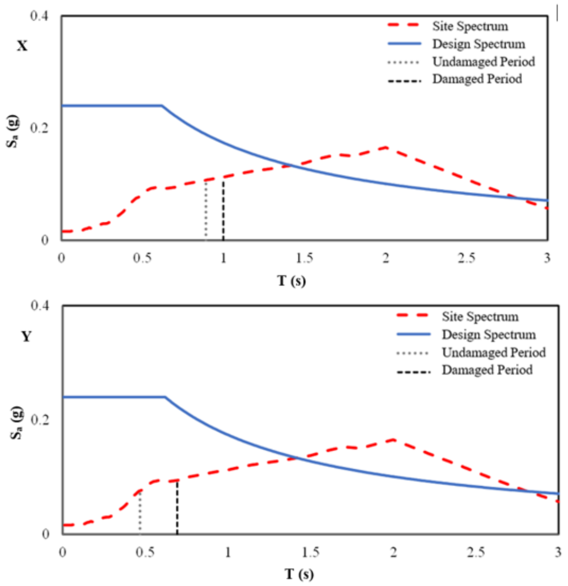
6.9. Building #9

On November 30, 2020, Sisam - Izmir earthquake caused moderate damage to the building. The soil class of the examined building is determined as ZE. After the coring process, the average concrete compressive strength is determined as 10,10 MPa. According to the Communiqué on the Approximate Unit Costs of Building to be used in the Calculation of Architectural and Engineering Service Costs, the building is classified as Class III Group B building.

6.9.1. Implementation of the three-stage evaluation score for Building #9

Figure 6.17. Photographs of Building #9

Building #9: Evaluation of Building Demand and Design Capacity



Building #9 DDSR
(a) X direction, (b) Y direction

Period and DDSR for Building #9

	Period (s)	DDST
$T_{x, undamaged}$	0.891	0,00
$T_{x, damaged}$	0.999	
$T_{y, undamaged}$	0.467	0,00
$T_{y, damaged}$	0.693	

DDSR: The Demand - Design Spectrum Ratio

Building #9: Structure Score Assessment

Number of storeys	1	2	3	4
	5	6	7	8
				√
Seismic zone:	1	2	3	4
	√			
Soil Type	ZA	ZB	ZC	ZD - ZE
				√
Building Age	After 2007	1998-2007	1975-1998	Before 1975
31			√	
Load Bearing Type	RC Frame	RC Frame with Shearwall	**STRUCTURE SCORE**	
	√		**-14**	
Neighboring Formation	Seperate	Adjacent		
	√			
Vertical Irragularity	Exist	None		
		√		
Overhange	Exist	None		
	√			
Plan Irregularities	Exist	None		
		√		
Short Column	Exist	None		
		√		
Position of Neighboring Slabs	Same	Levelled		
	√			
Soft Storey	Exist	None		
		√		
Slope of Soil	Flat	Slopping		
	√			

Building #9: Material- Mechanical Properties Detection

Slab weight (ton):	834,62 ton
Column weight (ton):	393,66 ton
Shearwall weight (ton):	0,00 ton
Partition wall weight (ton):	1530,57 ton
Total building weight (ton):	2.758,85 ton
Cross-sectional area of vertical load bearing system elements at ground floor (m^2):	8,69 m^2
Average concrete compressive strength (MPa):	10,10 MPa

Building Axial Load Ratio: $\frac{2.758,85}{8,69} = 317,47\ ton/m^2 = 3,16\ MPa$

$0,20 \times f_{ck}$: $0,20 \times 10,10 = 2,02\ MPa$

Building Axial Load Ratio = **3,16 MPa > 2,02 MPa** = $0,20 \times f_{ck}$

Figure 6.18. Calculation of three-stage evaluation score for Building #9

6.9.2. Summary of the three-stage evaluation score for Building #9

Table 6.17. Determination of the three-stage filtering score for Building #9

THREE STAGE FILTERING STEPS		POINT
1. Stage: Evaluation of Building Demand and Design Capacity Stage		
The Demand - Design Spectrum Ratio for X direction	0,00	**-1**
The Demand - Design Spectrum Ratio for Y direction	0,00	
DDSR < 0,50		
2. Stage: Rapid Screening Score Assessment		
Structure Score	-14	**0**
-50 < Structure Score < 0		
3. Stage: Building Material - Mechanical Properties Detection		
Building Axial Load Ratio (MPa)	3,16	**-1**
0,20 x f_{ck} (MPa)	2,02	
Building Axial Load Ratio < 0,20 x f_{ck}		
TOTAL FILTERING POINT		**-2**

Since the filtering score for **Building #9** is equal to -2 and below +2 points, retrofitting for investigated buildings is determined as **inappropriate** according to the developed method.

6.9.3. Retrofit Cost vs. New Building Construction Cost for Building #9

In the earthquake risk analyses conducted for Building #9, it is determined that the bearing capacities of the vertical load bearing elements (columns and shear walls) of the building are exceeded in 100% and 100% for X and Y directions, respectively. In addition, the storey drift ratios of the building in X and Y directions are determined as 0,027 in both directions. For this reason, it is necessary to add reinforcing shear walls to the building for both directions during the retrofitting process.

Table 6.18. Determination of reconstruction and retrofitting costs for Building #9

Cost of new building construction				
Number of storeys	Plan area (m^2)	Total building area (m^2)	Unit price for new building construction (TL/m^2)	New building construction cost (TL)
8	347,76	2.782,08	14.400,00	40.061.952,00

Retrofitting Cost of Existing Building					
Fiber Reinforced Polymer (FRP)	FRP reinforcement area (m^2)		Unit price for FRP reinforcement (TL/m^2)		FRP reinforcement cost (TL)
	5.171,65		6.040,31		31.238.369,21
Retrofitting Shearwalls	Concrete quantity (m^3)	Reinforcement quantity (ton)	Concrete unit price (TL/m^3)	Reinforcement unit price (TL/ton)	Retrofitting shearwalls cost (TL)
	75,26	9,50	2.605,30	33.511,95	499.358,03
				Total Retrofit Cost:	31.737.727,24

$$\frac{\text{Total retrofitting cost}}{\text{New building construction cost}} = \frac{31.737.727{,}24}{40.061.952{,}00} = \mathbf{0{,}79 > 0{,}40}$$

Building #9, which scored -1 in the three-stage filtering process and is deemed improper for retrofitting, is also identified as **inefficient** and **unfeasible** for retrofitting following economic assessments.

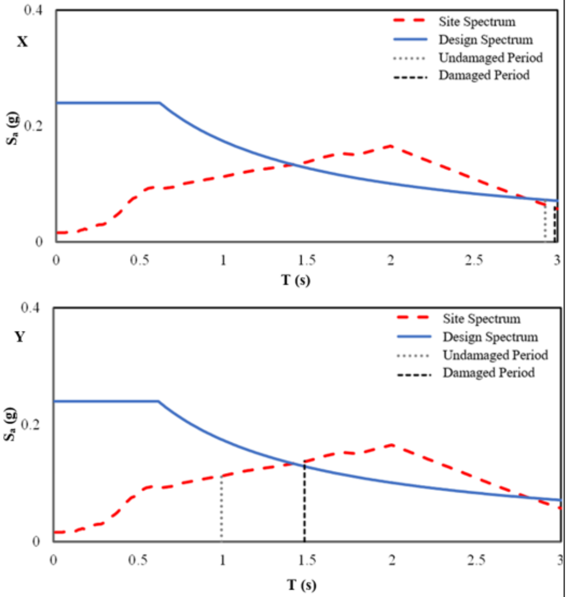
6.10. Building #10

On November 30, 2020, Sisam - Izmir earthquake caused moderate damage to the building. The soil class of the examined building is determined as ZD. After the coring process, the average concrete compressive strength is determined as 3,78 MPa. In addition, ribbed steel bar reinforcement (B420c) with a yield strength of 420 N/mm^2 is used as the building material for the structural system. According to the Communiqué on the Approximate Unit Costs of Building to be used in the Calculation of Architectural and Engineering Service Costs, the building is classified as Class III Group B building.

6.10.1. Implementation of the three-stage evaluation score for Building #10

Figure 6.19. Photographs of Building #10

Building #10: Evaluation of Building Demand and Design Capacity



Building #10 DDSR
(a) X direction, (b) Y direction

Period and DDSR for Building #10

	Period (s)	DDST
$T_{x,\ undamaged}$	2.941	**0,00**
$T_{x,\ damaged}$	2.998	
$T_{y,\ undamaged}$	1.118	**0,154**
$T_{y,\ damaged}$	1.562	

DDSR: The Demand - Design Spectrum Ratio

Building #10: Structure Score Assessment

Number of storeys	1	2	3	4
				√
	5	6	7	8
Seismic zone:	1	2	3	4
	√			
Soil Type	ZA	ZB	ZC	ZD - ZE
				√
Building Age	After 2007	1998-2007	1975-1998	Before 1975
25			√	
Load Bearing Type	RC Frame	RC Frame with Shearwall	**STRUCTURE SCORE**	
	√		**-49**	
Neighboring Formation	Seperate	Adjacent		
		√		
Vertical Irragularity	Exist	None		
	√			
Overhange	Exist	None		
	√			
Plan Irregularities	Exist	None		
		√		
Short Column	Exist	None		
		√		
Position of Neighboring Slabs	Same	Levelled		
	√			
Soft Storey	Exist	None		
	√			
Slope of Soil	Flat	Slopping		
	√			

Building #10: Material- Mechanical Properties Detection

Slab weight (ton):	164,57 ton
Column weight (ton):	64,81 ton
Shearwall weight (ton):	0,00 ton
Partition wall weight (ton):	308,82 ton
Total building weight (ton):	538,20 ton
Cross-sectional area of vertical load bearing system elements at ground floor (m^2):	2,91 m^2
Average concrete compressive strength (MPa):	3,78 MPa

Building Axial Load Ratio: $\frac{538,20}{2,91} = 184,95 \text{ ton/m}^2 = 1,84 \text{ MPa}$

$0,20 \times f_{ck}$: $0,20 \times 3,78 = 0,76$ MPa

Building Axial Load Ratio = **1,81 MPa > 0,76 MPa** = $0,20 \times f_{ck}$

Figure 6.20. Calculation of three-stage evaluation score for Building #10

6.10.2. Summary of the three-stage evaluation score for Building #10

Table 6.19. Determination of the three-stage filtering score for Building #10

THREE STAGE FILTERING STEPS		POINT
1. Stage: Evaluation of Building Demand and Design Capacity Stage		
The Demand - Design Spectrum Ratio for X direction	0,00	**-1**
The Demand - Design Spectrum Ratio for Y direction	0,154	
DDSR < 0,50		
2. Stage: Rapid Screening Score Assessment		
Structure Score	-49	**0**
-50 < Structure Score < 0		
3. Stage: Building Material - Mechanical Properties Detection		
Building Axial Load Ratio (MPa)	1,84	**-1**
0,20 x f_{ck} (MPa)	0,76	
Building Axial Load Ratio > 0,20 x f_{ck}		
TOTAL FILTERING POINT		**-2**

Since the filtering score for **Building #10** is equal to -2 below 2 points, retrofitting for investigated buildings is determined as **inppropriate** according to the developed method.

6.10.3. Retrofit Cost vs. New Building Construction Cost for Building #10

In the earthquake risk analyses conducted for Building #10, it is determined that the bearing capacities of the vertical load bearing elements (columns and shear walls) of the building are exceeded in 100 % and 100% for X and Y directions, respectively. In addition, the storey drift ratios of the building in X and Y directions are determined as 0,034 in both directions. For this reason, it is necessary to add reinforcing shear walls to the building for both directions during the retrofitting process.

Table 6.20. Determination of reconstruction and retrofitting costs for Building #10

Cost of new building construction				
Number of storeys	Plan area (m^2)	Total building area (m^2)	Unit price for new building construction (TL/m^2)	New building construction cost (TL)
4	171,43	685,72	14.400,00	9.874.368,00

Retrofitting Cost of Existing Building			
Fiber Reinforced Polymer (FRP)	FRP reinforcement area (m^2)	Unit price for FRP reinforcement (TL/m^2)	FRP reinforcement cost (TL)
	1.044,74	6.040,31	6.310.553,47

Retrofitting Shearwalls	Concrete quantity (m^3)	Reinforcement quantity (ton)	Concrete unit price (TL/m^3)	Reinforcement unit price (TL/ton)	Retrofitting shearwalls cost (TL)
	19,26	2,43	2.605,30	33.511,95	131.612,12
				Total Retrofit Cost:	6.442.165,59

$$\frac{\text{Total retrofitting cost}}{\text{New building construction cost}} = \frac{6.442.165,59}{9.874.368,00} = 0,65 > 0,40$$

Building #10, which scored -2 in the three-stage filtering process and is deemed improper for retrofitting, is also identified as **inefficient** and **unfeasible** for retrofitting following economic assessments.

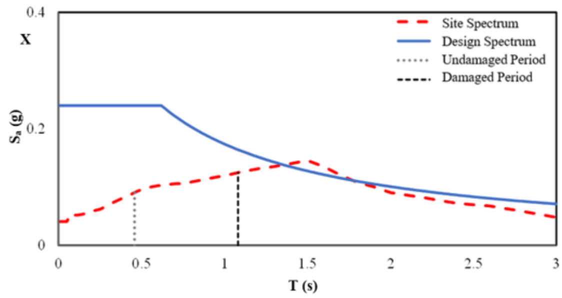
6.11. Building #11

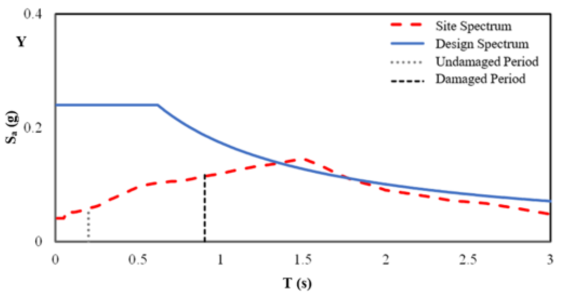
On November 30, 2020, Sisam - Izmir earthquake caused moderate damage to the building. The soil class of the examined building is determined as ZE. After the coring process, the average concrete compressive strength is determined as 8,31 MPa. According to the Communiqué on the Approximate Unit Costs of Building to be used in the Calculation of Architectural and Engineering Service Costs, the building is classified as Class III Group B building.

6.11.1. Implementation of the three-stage evaluation score for Building #11

Figure 6.21. Photographs of Building #11

Building #11: Evaluation of Building Demand and Design Capacity





Building #11 DDSR
(a) X direction, (b) Y direction

Period and DDSR for Building #11

	Period (s)	**DDST**
$T_{x,\ undamaged}$	0.458	0,00
$T_{x,\ damaged}$	1.082	
$T_{y,\ undamaged}$	0.200	0,00
$T_{y,\ damaged}$	0.905	

DDSR: The Demand - Design Spectrum Ratio

Building #11: Structure Score Assessment

Number of storeys	1	2	3	4
				√
	5	6	7	8
Seismic zone:	1	2	3	4
	√			
Soil Type	ZA	ZB	ZC	ZD - ZE
				√
Building Age	After 2007	1998-2007	1975-1998	Before 1975
45			√	
Load Bearing Type	RC Frame	RC Frame with Shearwall	**STRUCTURE SCORE**	
	√		**-31**	
Neighboring Formation	Seperate	Adjacent		
	√			
Vertical Irregularity	Exist	None		
	√			
Overhange	Exist	None		
	√			
Plan Irregularities	Exist	None		
		√		
Short Column	Exist	None		
		√		
Position of Neighboring Slabs	Same	Levelled		
	√			
Soft Storey	Exist	None		
	√			
Slope of Soil	Flat	Slopping		
	√			

Building #11: Material- Mechanical Properties Detection

Slab weight (ton):	136,8 ton
Column weight (ton):	56,18 ton
Shearwall weight (ton):	0,00 ton
Partition wall weight (ton):	369,73 ton
Total building weight (ton):	562,71 ton
Cross-sectional area of vertical load bearing system elements at ground floor (m^2):	2,28 m^2
Average concrete compressive strength (MPa):	8,31 MPa

$$\text{Building Axial Load Ratio: } \frac{562{,}71}{2{,}28} = 246{,}80 \text{ ton/m}^2 = 2{,}46 \text{ MPa}$$

$$0{,}20 \times f_{ck}: \quad 0{,}20 \times 8{,}31 = 1{,}66 \text{ MPa}$$

Building Axial Load Ratio = **2,46 MPa > 1,66 MPa** = $0{,}20 \times f_{ck}$

Figure 6.22. Calculation of three-stage evaluation score for Building #11

6.11.2. Summary of the three-stage evaluation score for Building #11

Table 6.21. Determination of the three-stage filtering score for Building #11

THREE STAGE FILTERING STEPS		POINT
1. Stage: Evaluation of Building Demand and Design Capacity Stage		
The Demand - Design Spectrum Ratio for X direction	0,00	**-1**
The Demand - Design Spectrum Ratio for Y direction	0,00	
DDSR < 0,50		
2. Stage: Rapid Screening Score Assessment		
Structure Score	-31	0
-50 < Structure Score < 0		
3. Stage: Building Material - Mechanical Properties Detection		
Building Axial Load Ratio (MPa)	2,46	**-1**
0,20 x f_{ck} (MPa)	1,66	
Building Axial Load Ratio > 0,20 x f_{ck}		
TOTAL FILTERING POINT		**-2**

Since the filtering score for **Building #11** is equal to -2 and below 2 points, retrofitting for investigated buildings is determined as **inppropriate** according to the developed method.

6.11.3. Retrofit Cost vs. New Building Construction Cost for Building #11

In the earthquake risk analyses conducted for Building #11, it is determined that the bearing capacities of the vertical load bearing elements (columns and shear walls) of the building are exceeded in 100% and 100% for X and Y directions, respectively. In addition, the storey drift ratios of the building in X and Y directions are determined as 0,032 in both directions. For this reason, it is necessary to add reinforcing shear walls to the building for both directions during the retrofitting process.

Table 6.22. Determination of and retrofitting costs for Building #11

Cost of new building construction				
Number of storeys	Plan area (m^2)	Total building area (m^2)	Unit price for new building construction (TL/m^2)	New building construction cost (TL)
4	142.50	570,00	14.400,00	8.208.000,00

Retrofitting Cost of Existing Building			
Fiber Reinforced Polymer (FRP)	FRP reinforcement area (m^2)	Unit price for FRP reinforcement (TL/m^2)	FRP reinforcement cost (TL)
	945.47	6.040,31	5.710.931,90

Retrofitting Shearwalls	Concrete quantity (m^3)	Reinforcement quantity (ton)	Concrete unit price (TL/m^3)	Reinforcement unit price (TL/ton)	Retrofitting shearwalls cost (TL)
	17,76	2,24	2.605,30	33.511,95	121.336,90
				Total Retrofit Cost:	5.832.268,79

$$\frac{\text{Total retrofitting cost}}{\text{New building construction cost}} = \frac{5.832.268{,}79}{8.208.000{,}00} = \mathbf{0{,}71 > 0{,}40}$$

Building #11, which scored -2 in the three-stage filtering process and is deemed improper for retrofitting, is also identified as **inefficient** and **unfeasible** for retrofitting following economic assessments.

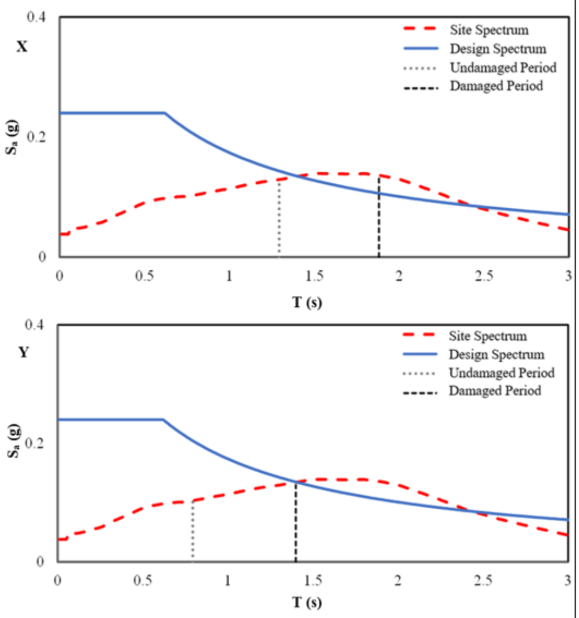
6.12. Building #12

On November 30, 2020, Sisam - Izmir earthquake caused moderate damage to the building. The soil class of the examined building is determined as ZE. After the coring process, the average concrete compressive strength is determined as 10,29 MPa. According to the Communiqué on the Approximate Unit Costs of Building to be used in the Calculation of Architectural and Engineering Service Costs, the building is classified as Class III Group B building.

6.12.1. Implementation of the three-stage evaluation score for Building #12

Figure 6.23. Photographs of Building #12

Building #12: Evaluation of Building Demand and Design Capacity



Building #12 DDSR
(a) X direction, (b) Y direction

Period and DDSR for Building #12

	Period (s)	DDST
$T_{x, undamaged}$	1.293	0,821
$T_{x, damaged}$	1.881	
$T_{y, undamaged}$	0.794	0,00
$T_{y, damaged}$	1.399	

DDSR: The Demand - Design Spectrum Ratio

Building #12: Structure Score Assessment

Number of storeys	1	2	3	4
	5	6	7	8
				√
Seismic zone:	1	2	3	4
	√			
Soil Type	ZA	ZB	ZC	ZD - ZE
				√
Building Age	After 2007	1998-2007	1975-1998	Before 1975
34			√	
Load Bearing Type	RC Frame	RC Frame with Shearwall	STRUCTURE SCORE	
		√	-22	
Neighboring Formation	Seperate	Adjacent		
	√			
Vertical Irragularity	Exist	None		
		√		
Overhange	Exist	None		
		√		
Plan Irregularities	Exist	None		
	√			
Short Column	Exist	None		
		√		
Position of Neighboring Slabs	Same	Levelled		
	√			
Soft Storey	Exist	None		
	√			
Slope of Soil	Flat	Slopping		
	√			

Building #12: Material- Mechanical Properties Detection

Slab weight (ton):	1380 ton
Column weight (ton):	358,74 ton
Shearwall weight (ton):	176,70 ton
Partition wall weight (ton):	1.542,07 ton
Total building weight (ton):	3.457,51 ton
Cross-sectional area of vertical load bearing system elements at ground floor (m^2):	11,50 m^2
Average concrete compressive strength (MPa):	10,29 MPa

Building Axial Load Ratio: $\frac{3.457,51}{11,50} = 326,74 \text{ ton/m}^2 = 3,27 \text{ MPa}$

$0,20 \times f_{ck}$: $0,20 \times 10,29 = 2,09 \text{ MPa}$

Building Axial Load Ratio = **3,27 MPa > 2,09 MPa** = $0,20 \times f_{ck}$

Figure 6.24. Calculation of three-stage evaluation score for Building #12

6.12.2. Summary of the three-stage evaluation score for Building #12

Table 6.23. Determination of the three-stage filtering score for Building #12

THREE STAGE FILTERING STEPS		POINT
1. Stage: Evaluation of Building Demand and Design Capacity Stage		
The Demand - Design Spectrum Ratio for X direction	1,00	**-1**
The Demand - Design Spectrum Ratio for Y direction	1,00	
DDSR Y < 0,50		
2. Stage: Rapid Screening Score Assessment		
Structure Score	-22	0
-50 < Structure Score < 0		
3. Stage: Building Material - Mechanical Properties Detection		
Building Axial Load Ratio (MPa)	3,27	**-1**
0,20 x f_{ck} (MPa)	2,09	
Building Axial Load Ratio > 0,20 x f_{ck}		
TOTAL FILTERING POINT		**-2**

Since the filtering score for **Building #12** is below 2 points, retrofitting for investigated buildings is determined as **inappropriate** according to the developed method.

6.12.3. Retrofit Cost vs. New Building Construction Cost for Building #12

In the earthquake risk analyses conducted for Building #12, it is determined that the bearing capacities of the vertical load bearing elements (columns and shear walls) of the building are exceeded in 100% and 100% for X and Y directions, respectively. In addition, the storey drift ratios of the building in X and Y directions are determined as 0,03 in both directions. For this reason, it is necessary to add reinforcing shear walls to the building for both directions during the retrofitting process.

Table 6.24. Determination of reconstruction and retrofitting costs for Building #12

Cost of new building construction				
Number of storeys	Plan area (m^2)	Total building area (m^2)	Unit price for new building construction (TL/m^2)	New building construction cost (TL)
8	575,00	4.600,00	14.400,00	66.240.000,00

Retrofitting Cost of Existing Building			
Fiber Reinforced Polymer (FRP)	FRP reinforcement area (m^2)	Unit price for FRP reinforcement (TL/m^2)	FRP reinforcement cost (TL)
	4.131,78	6.040,31	24.957.232,05

Retrofitting Shearwalls	Concrete quantity (m^3)	Reinforcement quantity (ton)	Concrete unit price (TL/m^3)	Reinforcement unit price (TL/ton)	Retrofitting shearwalls cost (TL)
	856,68	42.80	2.605,30	33.511,95	3.666.219,86
				Total Retrofit Cost:	28.623.451,92

$$\frac{\text{Total retrofitting cost}}{\text{New building construction cost}} = \frac{28.623.451,92}{66.240.000,00} = 0,43 > 0,40$$

Building #12, which scored -2 point in the three-stage filtering process and is deemed improper for retrofitting, is also identified as **inefficient** and **unfeasible** for retrofitting following economic assessments.

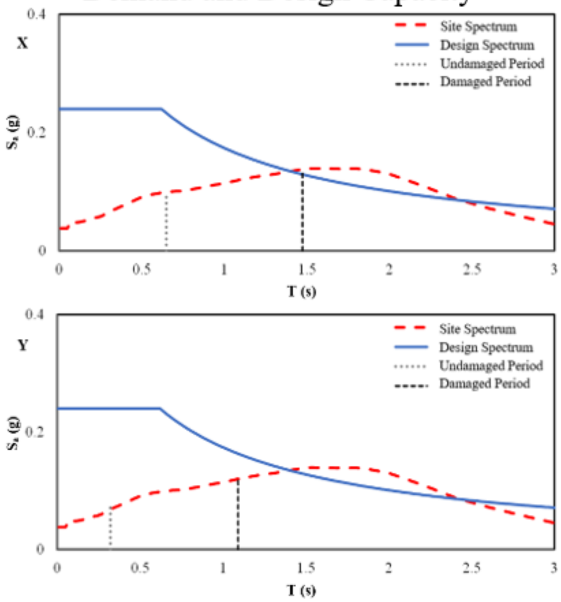
6.13. Building #13

On November 30, 2020, Sisam - Izmir earthquake caused moderate damage to the building. The soil class of the examined building is determined as ZE. After the coring process, the average concrete compressive strength is determined as 9,76 MPa. According to the Communiqué on the Approximate Unit Costs of Building to be used in the Calculation of Architectural and Engineering Service Costs, the building is classified as Class III Group B building.

6.13.1. Implementation of the three-stage evaluation score for Building #14

Figure 6.25. Photographs of Building #13

Building #13: Evaluation of Building Demand and Design Capacity



Building #13 DDSR
(a) X direction, (b) Y direction

Period and DDSR for Building #13

	Period (s)	DDST
$T_{x,\ undamaged}$	0.649	0,098
$T_{x,\ damaged}$	1.473	
$T_{y,\ undamaged}$	0.321	0,00
$T_{y,\ damaged}$	1.091	

DDSR: The Demand - Design Spectrum Ratio

Building #13: Structure Score Assessment

Number of storeys	1	2	3	4
	5	6	7	8
				√
Seismic zone:	1	2	3	4
	√			
Soil Type	ZA	ZB	ZC	ZD - ZE
				√
Building Age	After 2007	1998-2007	1975-1998	Before 1975
34			√	
Load Bearing Type	RC Frame	RC Frame with Shearwall	STRUCTURE SCORE	
		√	12	
Neighboring Formation	Seperate	Adjacent		
	√			
Vertical Irragularity	Exist	None		
		√		
Overhange	Exist	None		
		√		
Plan Irregularities	Exist	None		
		√		
Short Column	Exist	None		
		√		
Position of Neighboring Slabs	Same	Levelled		
	√			
Soft Storey	Exist	None		
	√			
Slope of Soil	Flat	Slopping		
	√			

Building #13: Material- Mechanical Properties Detection

Slab weight (ton):	526,65 ton
Column weight (ton):	85,53 ton
Shearwall weight (ton):	47,19 ton
Partition wall weight (ton):	610,49 ton
Total building weight (ton):	1.269,86 ton
Cross-sectional area of vertical load bearing system elements at ground floor (m^2):	2,96 m^2
Average concrete compressive strength (MPa):	9,76 MPa

Building Axial Load Ratio: $\frac{1.269,86}{2,96} = 429,01\ ton/m^2 = 4,29\ MPa$

$0,20 \times f_{ck}: 0,20 \times 9,76 = 1,95\ MPa$

Building Axial Load Ratio = **4,29 MPa > 1,95 MPa** = $0,20 \times f_{ck}$

Figure 6.26. Calculation of three-stage evaluation score for Building #13

6.13.2. Summary of the three-stage evaluation score for Building #13

Table 6.25. Determination of the three-stage filtering score for Building #13

THREE STAGE FILTERING STEPS		POINT
1. Stage: Evaluation of Building Demand and Design Capacity Stage		
The Demand - Design Spectrum Ratio for X direction	0,098	**-1**
The Demand - Design Spectrum Ratio for Y direction	0,00	
DDSR Y < 0,50		
2. Stage: Rapid Screening Score Assessment		
Structure Score	+12	**+1**
-50 < Structure Score < 0		
3. Stage: Building Material - Mechanical Properties Detection		
Building Axial Load Ratio (MPa)	4,29	**-1**
0,20 x f_{ck} (MPa)	1,95	
Building Axial Load Ratio > 0,20 x f_{ck}		
TOTAL FILTERING POINT		**-1**

Since the filtering score for **Building #13** is below 2 points, retrofitting for investigated buildings is determined as **inappropriate** according to the developed method.

6.13.3. Retrofit Cost vs. New Building Construction Cost for Building #13

In the earthquake risk analyses conducted for Building #12, it is determined that the bearing capacities of the vertical load bearing elements (columns and shear walls) of the building are exceeded in 100% and 100% for X and Y directions, respectively. In addition, the storey drift ratios of the building in X and Y directions are determined as 0,042 in both directions. For this reason, it is necessary to add reinforcing shear walls to the building for both directions during the retrofitting process.

Table 6.26 Determination of reconstruction and retrofitting costs for Building #13

Cost of new building construction				
Number of storeys	Plan area (m^2)	Total building area (m^2)	Unit price for new building construction (TL/m^2)	New building construction cost (TL)
8	220,00	1.760,00	14.400,00	25.344.000,00

Retrofitting Cost of Existing Building			
Fiber Reinforced Polymer (FRP)	FRP reinforcement area (m^2)	Unit price for FRP reinforcement (TL/m^2)	FRP reinforcement cost (TL)
	4.062,08	6.040,31	24.536.222,44

Retrofitting Shearwalls	Concrete quantity (m^3)	Reinforcement quantity (ton)	Concrete unit price (TL/m^3)	Reinforcement unit price (TL/ton)	Retrofitting shearwalls cost (TL)
	350,32	16,48	2.605,30	33.511,95	1.464.965,63
				Total Retrofit Cost:	26.001.188,08

$$\frac{\text{Total retrofitting cost}}{\text{New building construction cost}} = \frac{26.001.188{,}08}{25.344.000{,}00} = 1{,}02 > 0{,}40$$

Building #13, which scored -1 in the three-stage filtering process and is deemed improper for retrofitting, is also identified as **inefficient** and **unfeasible** for retrofitting following economic assessments.

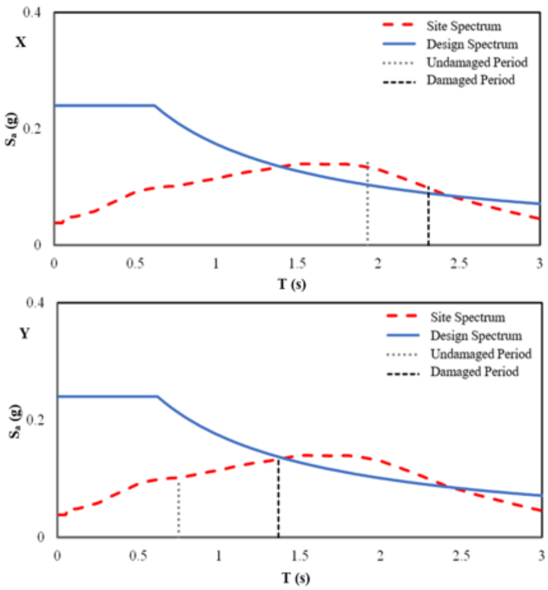
6.14. Building #14

On November 30, 2020, Sisam - Izmir earthquake caused moderate damage to the building. The soil class of the examined building is determined as ZE. After the coring process, the average concrete compressive strength is determined as 9,76 MPa. According to the Communiqué on the Approximate Unit Costs of Building to be used in the Calculation of Architectural and Engineering Service Costs, the building is classified as Class III Group B building.

6.14.1. Implementation of the three-stage evaluation score for Building #14

Figure 6.27. Photographs of Building #14

Building #14: Evaluation of Building Demand and Design Capacity



Building #14 DDSR
(a) X direction, (b) Y direction

Period and DDSR for Building #14

	Period (s)	DDST
$T_{x,\ undamaged}$	1.935	1,00
$T_{x,\ damaged}$	2.312	
$T_{y,\ undamaged}$	0.751	0,00
$T_{y,\ damaged}$	1.368	

DDSR: The Demand - Design Spectrum Ratio

Building #14: Structure Score Assessment

Number of storeys	1	2	3	4
	5	6	7	8
				√
Seismic zone:	1	2	3	4
	√			
Soil Type	ZA	ZB	ZC	ZD - ZE
				√
Building Age	After 2007	1998-2007	1975-1998	Before 1975
34			√	
Load Bearing Type	RC Frame	RC Frame with Shearwall	STRUCTURE SCORE	
		√	12	
Neighboring Formation	Seperate	Adjacent		
	√			
Vertical Irragularity	Exist	None		
		√		
Overhange	Exist	None		
		√		
Plan Irregularities	Exist	None		
		√		
Short Column	Exist	None		
		√		
Position of Neighboring Slabs	Same	Levelled		
	√			
Soft Storey	Exist	None		
	√			
Slope of Soil	Flat	Slopping		
	√			

Building #14: Material- Mechanical Properties Detection

Slab weight (ton):	2.073,6 ton
Column weight (ton):	47,52 ton
Shearwall weight (ton):	454,9 ton
Partition wall weight (ton):	2.838,24 ton
Total building weight (ton):	5.414,26 ton
Cross-sectional area of vertical load bearing system elements at ground floor (m^2):	8,37 m^2
Average concrete compressive strength (MPa):	9,76 MPa

$$\text{Building Axial Load Ratio: } \frac{5.414{,}26}{8{,}37} = 646{,}86 \text{ ton/m}^2 = 6{,}44 \text{ MPa}$$

$$0{,}20 \times f_{ck}: 0{,}20 \times 9{,}76 = 1{,}95 \text{ MPa}$$

Building Axial Load Ratio = **6,44 MPa > 1,95 MPa** = 0,20 x f_{ck}

Figure 6.28. Calculation of three-stage evaluation score for Building #14

6.14.2. Summary of the three-stage evaluation score for Building #14

Table 6.27. Determination of the three-stage filtering score for Building #14

THREE STAGE FILTERING STEPS		POINT
1. Stage: Evaluation of Building Demand and Design Capacity Stage		
The Demand - Design Spectrum Ratio for X direction	1,00	**-1**
The Demand - Design Spectrum Ratio for Y direction	0,00	
DDSR Y < 0,50		
2. Stage: Rapid Screening Score Assessment		
Structure Score	+12	**+1**
-50 < Structure Score < 0		
3. Stage: Building Material - Mechanical Properties Detection		
Building Axial Load Ratio (MPa)	6,44	**-1**
0,20 x f_{ck} (MPa)	1,95	
Building Axial Load Ratio > 0,20 x f_{ck}		
TOTAL FILTERING POINT		**-1**

Since the filtering score for **Building #14** is below 2 points, retrofitting for investigated buildings is determined as **inappropriate** according to the developed method.

6.14.3. Retrofit Cost vs. New Building Construction Cost for Building #14

In the earthquake risk analyses conducted for Building #14, it is determined that the bearing capacities of the vertical load bearing elements (columns and shear walls) of the building are exceeded in 55% and 42% for X and Y directions, respectively. In addition, the storey drift ratios of the building in X and Y directions are determined as 0,056 in both directions. For this reason, it is necessary to add reinforcing shear walls to the building for both directions during the retrofitting process.

Table 6.28. Determination of reconstruction and retrofitting costs for Building #14

Cost of new building construction				
Number of storeys	Plan area (m^2)	Total building area (m^2)	Unit price for new building construction (TL/m^2)	New building construction cost (TL)
12	720,00	8.640,00	14.400,00	124.416.000,00

Retrofitting Cost of Existing Building			
Fiber Reinforced Polymer (FRP)	FRP reinforcement area (m^2)	Unit price for FRP reinforcement (TL/m^2)	FRP reinforcement cost (TL)
	4.062,08	6.040,31	24.536.222,44

Retrofitting Shearwalls	Concrete quantity (m^3)	Reinforcement quantity (ton)	Concrete unit price (TL/m^3)	Reinforcement unit price (TL/ton)	Retrofitting shearwalls cost (TL)
	1.733,91	106,91	2.605,30	33.511,95	8.100.118,30
				Total Retrofit Cost:	32.636.340,74

$$\frac{\text{Total retrofitting cost}}{\text{New building construction cost}} = \frac{53.099088{,}47}{77.760.000{,}00} = 0{,}26 < 0{,}40$$

Building #14, which scored -1 in the three-stage filtering process and is deemed improper for retrofitting, is identified as **efficient** and **feasible** for retrofitting following economic assessments.

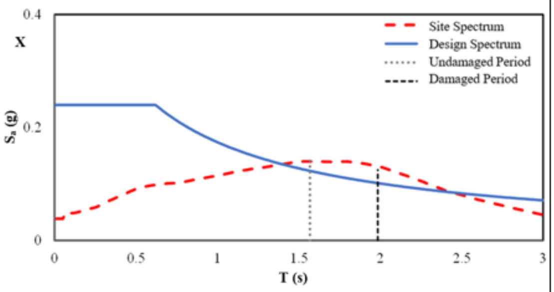
6.15. Building #15

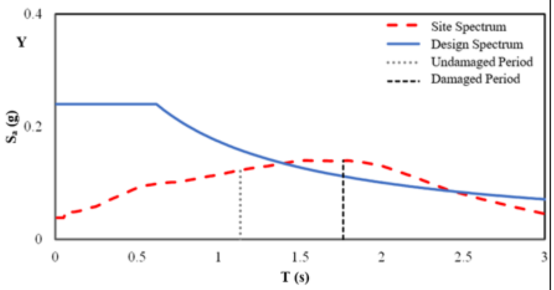
On November 30, 2020, Sisam - Izmir earthquake caused moderate damage to the building. The soil class of the examined building is determined as ZE. After the coring process, the average concrete compressive strength is determined as 13,62 MPa. According to the Communiqué on the Approximate Unit Costs of Building to be used in the Calculation of Architectural and Engineering Service Costs, the building is classified as Class III Group B building.

6.15.1. Implementation of the three-stage evaluation score for Building #15

Figure 6.29. Photographs of Building #15

Building #15: Evaluation of Building Demand and Design Capacity





Building #15 DDSR
(a) X direction, (b) Y direction

Period and DDSR for Building #15

	Period (s)	DDST
$T_{x,\ undamaged}$	1.568	1,00
$T_{x,\ damaged}$	1.985	
$T_{y,\ undamaged}$	1.134	0,606
$T_{y,\ damaged}$	1.765	

DDSR: The Demand - Design Spectrum Ratio

Building #15: Structure Score Assessment

Number of storeys	1	2	3	4
	5	6	7	8
				√
Seismic zone:	1	2	3	4
	√			
Soil Type	ZA	ZB	ZC	ZD - ZE
				√
Building Age	After 2007	1998-2007	1975-1998	Before 1975
34			√	
Load Bearing Type	RC Frame	RC Frame with Shearwall	STRUCTURE SCORE	
		√	-19	
Neighboring Formation	Seperate	Adjacent		
	√			
Vertical Irragularity	Exist	None		
	√			
Overhange	Exist	None		
	√			
Plan Irregularities	Exist	None		
		√		
Short Column	Exist	None		
		√		
Position of Neighboring Slabs	Same	Levelled		
	√			
Soft Storey	Exist	None		
	√			
Slope of Soil	Flat	Slopping		
	√			

Building #15: Material- Mechanical Properties Detection

Slab weight (ton):	889,92 ton
Column weight (ton):	580,94 ton
Shearwall weight (ton):	0,00 ton
Partition wall weight (ton):	1.481,40 ton
Total building weight (ton):	2.952,26 ton
Cross-sectional area of vertical load bearing system elements at ground floor (m^2):	10,68 m^2
Average concrete compressive strength (MPa):	13,62 MPa

$$\text{Building Axial Load Ratio: } \frac{2{,}952{,}26}{10{,}68} = 276{,}43 \text{ ton/m}^2 = 2{,}75 \text{ MPa}$$

$$0{,}20 \times f_{ck}: \quad 0{,}20 \times 13{,}62 = 2{,}72 \text{ MPa}$$

Building Axial Load Ratio = **2,75 MPa > 2,72 MPa** = 0,20 x f_{ck}

Figure 6.30. Calculation of three-stage evaluation score for Building #15

6.15.2. Summary of the three-stage evaluation score for Building #15

Table 6.29. Determination of the three-stage filtering score for Building #15

THREE STAGE FILTERING STEPS		POINT
1. Stage: Evaluation of Building Demand and Design Capacity Stage		
The Demand - Design Spectrum Ratio for X direction	1,00	**0**
The Demand - Design Spectrum Ratio for Y direction	0,606	
0,50 < DDSR Y < 0,75		
2. Stage: Rapid Screening Score Assessment		
Structure Score	-19	**0**
Structure Score > 0		
3. Stage: Building Material - Mechanical Properties Detection		
Building Axial Load Ratio (MPa)	2,75	**-1**
0,20 x f_{ck} (MPa)	2,72	
Building Axial Load Ratio > 0,20 x f_{ck}		
TOTAL FILTERING POINT		**-1**

Since the filtering score for **Building #15** is below 2 points, retrofitting for investigated buildings is determined as **inappropriate** according to the developed method.

6.15.3. Retrofit Cost vs. New Building Construction Cost for Building #15

In the earthquake risk analyses conducted for Building #15, it is determined that the bearing capacities of the vertical load bearing elements (columns and shear walls) of the building are exceeded in 75% and 87% for X and Y directions, respectively. In addition, the storey drift ratios of the building in X and Y directions are determined as 0,08 in both directions. For this reason, it is necessary to add reinforcing shear walls to the building for both directions during the retrofitting process.

Table 6.30. Determination of reconstruction and retrofitting costs for Building #15

Cost of new building construction				
Number of storeys	Plan area (m^2)	Total building area (m^2)	Unit price for new building construction (TL/m^2)	New building construction cost (TL)
10	296,64	2.966,40	14.400,00	42.716.160,00

Retrofitting Cost of Existing Building			
Fiber Reinforced Polymer (FRP)	FRP reinforcement area (m^2)	Unit price for FRP reinforcement (TL/m^2)	FRP reinforcement cost (TL)
	4.062,08	6.040,31	8.100.118,30

Retrofitting Shearwalls	Concrete quantity (m^3)	Reinforcement quantity (ton)	Concrete unit price (TL/m^3)	Reinforcement unit price (TL/ton)	Retrofitting shearwalls cost (TL)
	1.733,91	106,91	2.605,30	33.511,95	8.100.118,30
				Total Retrofit Cost:	32.636.340,74

$$\frac{\text{Total retrofitting cost}}{\text{New building construction cost}} = \frac{32.636.340,74}{42.716.160,00} = 0,76 > 0,40$$

Building #15, which scored -1 in the three-stage filtering process and is deemed improper for retrofitting, is also identified as **inefficient** and **unfeasible** for retrofitting following economic assessments.

6.16. Obatained Results

In the last part of the study, the developed method is tested on reinforced concrete buildings that suffered moderate damage after the Elazıg and Samos - Izmir earthquakes. For 15 buildings subjected to three-stage filtration, the suitability of retrofitting is evaluated according to the developed method. These 15 buildings were selected from different building classes, with different number of storeys, with and without sherwalls, which were moderately damaged in two recent earthquakes. In this way, according to the three-stage filtration method, it is determined whether the buildings would be suitable for retrofitting or not. Subsequently, the retrofitting costs for each building were approximated in terms of increasing the element bearing capacity and controlling the story drift. This value is compared with the cost of constructing a new building with the same area. If the retrofitting cost is below 40% of the new building construction cost, retrofitting is considered economically feasible for this building. At higher retrofitting costs, retrofitting is considered uneconomical.

In the procedures carried out to determine whether the three-stage evaluation method gives correct results or not, all of the 5 buildings determined as "APPROPRIATE for RETROFITTIN" according to the method have been determined as "EFFICIENT for RETROFITTIN". According to the method, 9 out of 10 buildings whose retrofitting is determined as "INAPPROPRIATE FOR RETROFITTIN" were determined as "UNEFFICIENT FOR RETROFITTIN ". From this point of view, it is determined that the three-stage filtration method developed gave accurate results with an error rate of 6.6%.

Table 6.31. Summary table for validation data

	Three Stage Filtering		Retrofit - Reconstruction Comparison		COMPLIANCE
	Filtering score	Result	Retrofit Cost vs. Reconstruction Cost	Result	
Building #1	+3	Retrofittable	< %40	Feasible	Eligible
Building #2	+2	Retrofittable	< %40	Feasible	Eligible
Building #3	+3	Retrofittable	< %40	Feasible	Eligible
Building #4	+2	Retrofittable	< %40	Feasible	Eligible
Building #5	+1	Not Retrofittable	> %40	Not Feasible	Eligible
Building #6	+2	Retrofittable	< %40	Feasible	Eligible
Building #7	+1	Not Retrofittable	> %40	Not Feasible	Eligible
Building #8	-1	Not Retrofittable	> %40	Not Feasible	Eligible
Building #9	-2	Not Retrofittable	> %40	Not Feasible	Eligible
Building #10	-2	Not Retrofittable	> %40	Not Feasible	Eligible
Building #11	-2	Not Retrofittable	> %40	Not Feasible	Eligible
Building #12	-2	Not Retrofittable	> %40	Not Feasible	Eligible
Building #13	-1	Not Retrofittable	> %40	Not Feasible	Eligible
Building #14	-1	Not Retrofittable	< %40	Feasible	Not Eligible
Building #15	-1	Not Retrofittable	> %40	Not Feasible	Eligible

7. SUMMARY and CONCLUSION of THREE-STAGE FILTERING METHOD

Within the scope of this study, a methodology has been developed to assess the technical feasibility and economic feasibility of retrofitting buildings with moderate damage. This is the first time such a methodology for moderately damaged buildings has been proposed in the literature reviewed.

The focus of our study is on buildings with moderate damage. In order to determine the performance loss of damaged structural elements according to the damage level, Stiffness Reduction Factors are determined by utilizing experimental data and other studies in the literature. Then, period estimation studies were carried out for undamaged and damaged buildings. Period estimation equations were derived by Nonlinear Regression analysis, but it was understood that the period values could not be determined with sufficient accuracy with these derived equations, after which a machine learning network was developed and Fundamental Vibration Period values could be determined with high accuracy for both undamaged and damaged conditions of the buildings. In addition, the values predicted by the developed machine learning network were compared with acceleration records taken from moderately damaged buildings in an earthquake, and it was proved that the developed network reached the accurate results with real field data. In this way, the Fundamental Vibration Period of the moderately damaged building before and after the damage could be determined without detailed modeling. Then, in order to determine the effect of the earthquake on the location of the building, Ground Motion Models in the literature were utilized and the earthquake records measured at the seismograph stations were applicated to the building location. By using the data obtained as a result of the studies, the Building Demand and Design Capacity Stage, the first stage of the three-stage assessment method is completed. In the second step of the filtering, the Structure Score which is a rapid screening method developed by A.Aldemir - O.Coskun was adopted. Discriminant Analysis was applied on the input parameters of the method developed within the scope of this study and the suitability of the method for real-life use was investigated by creating a database of severly damaged - slightly damaged buildings in earthquakes. In the last step of the filtering process, the concept of Building Axial Load Ratio was derived within the scope of this study, and the compressive strength of the concrete used in the building compared with the building's ultimate loads. In the developed filtering steps, scores are proposed for each of the three steps and it is concluded that buildings above the limit value are suitable for retrofitting and buildings below the limit value are not suitable for retrofitting. Finally, the method was applied to the buildings that had sustained moderate damage in the earthquake and compared with the reconstruction costs of these buildings. The results demonstrated that the method provides accurate results.

After earthquakes, simple repair is sufficient for slightly damaged structures and destruction of heavyly damaged buildings without wasting time is mandatory. In buildings that are determined as moderately damaged, the subject should be examined in detail. The age of the building, the material quality of the building, the nonconformities in the first design of the building directly affect whether the buildings are suitable for retrofitting or whether the retrofitting process will be fisibil. For the reasons mentioned above, there is a need for an assessment of whether moderately damaged buildings can be retrofitted or not. The method we propose in this study is intended to meet this requirement.

During the development of the method, after establishing the infrastructure with numerical and statistical methods, field studies were carried out for each step in order to determine the applicability of the filterin method in real life. The Fundamental Vibration Period values determined by the developed machine learning network and tested on moderately damaged buildings, the predictions of the GMM models were verified with seismograph station records and the Structure Score method was tested on earthquake-exposed buildings. Finally, the proposed three-stage filtering method is applied to earthquake-damaged buildings and its results are validated by comparing with new building construction costs. As a result, it is proved by field studies that, this method gives accurate results in real life. Within the scope of this study, the "Damage Assessment" database and "Risky Building" database of the Ministry of Environment, Urbanization and Climate Change were actively utilized.

It is possible to apply this method after the earthquake and use it to categorize moderately damaged buildings in terms of retrofitability. After the field application of the developed method in a future earthquake, the performance of the method will be evaluated with a larger database and it will be possible to improve the method based on these data. If the authority responsible for damage assessment deems it appropriate to apply this method for categorizing buildings with moderate damage, mobile software can be developed to collect input parameters with mobile devices in order to accelerate the data collection process. In addition, after extensive field studies, generalizations can be made for input parameters that will take time in the data collection process, thus making it possible to apply the method faster.

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9. APPENDICES

APPENDIX A– VBA .NET ALGORITHM

```
Imports SAP2000v1
Imports Microsoft.Office.Interop
Public Class Form1
    Private excelFileName1 As String
    Private outputfolder As String
    Private xlApp As Excel.Application
    Private xlWorkBook As Excel.Workbook
    Public Baslangic As DateTime
    Public Bitis2 As DateTime
    Public Bitis As DateTime
    Private Sure As TimeSpan
    Private Sure2 As TimeSpan
    Private xlworksheet As Excel.Worksheet  'Main
    Private xlworksheet2 As Excel.Worksheet 'Results
    Public Func As Excel.WorksheetFunction
    Private Sub Button1_Click(sender As Object, e As EventArgs) Handles Button1.Click

        Baslangic = DateTime.Now

        Form2.Show()
        'Dim myURL As String
        'myURL = "https://1drv.ms/t/s!AuRsLLiEX02cgTAbIadl8gq13d1G?e=nkJpWI"
        'Dim WinHttpReq As Object
        'WinHttpReq = CreateObject("WinHttp.WinHttpRequest.5.1")
        'WinHttpReq.Open("GET", myURL, False)
        'WinHttpReq.Send()
        'Dim gethtmlfromurl As String
        'gethtmlfromurl = Mid(WinHttpReq.ResponseText, 1, 255)
        'If InStr(1, gethtmlfromurl, "msapplication") = 0 Then
        'Else
        '    Exit Sub
        'End If

        'Dim ogren As Double
        Dim z As Double
        'For z = 1 To 10
        '    ogren = Rnd()
        'Next

        Dim AnalyzeType As String
        If Me.ComboBox1.SelectedIndex = -1 Then
            AnalyzeType = "Both"
        Else
            AnalyzeType = Me.ComboBox1.SelectedItem
        End If

        'Bina Tipi = Perde & Cerceve
        Dim BinaTipi As String
        If AnalyzeType = "Both" Then
            If Rnd() <= 0.5 Then
                BinaTipi = "Cerceve"
            Else
                BinaTipi = "Perde"
            End If
        ElseIf AnalyzeType = "Moment Frame" Then
```

```
    BinaTipi = "Cerceve"
ElseIf AnalyzeType = "Shear Wall" Then
    BinaTipi = "Perde"
End If

Dim NumberOfBuilding As Double
If Me.TextBox1.Text = String.Empty Then
    NumberOfBuilding = 1
Else
    NumberOfBuilding = CDbl(Me.TextBox1.Text)
End If

Dim i, j, k As Double
Dim RandomDongusuSayisi, RNDSayisi As Double
If Me.TextBox4.Text = String.Empty Then
    RandomDongusuSayisi = 0
Else
    RandomDongusuSayisi = CDbl(Me.TextBox1.Text)
End If
For i = 1 To RandomDongusuSayisi
    RNDSayisi = Rnd()
Next i
xlworksheet2.Range("A1:XFD50000").Clear()
xlworksheet2.Activate()
xlworksheet2.Range("A1").Activate()
'=======================
Dim fck_1_9_toplam, fck_1_9 As Double
For z = 1 To NumberOfBuilding
    For i = 1 To 1000
        If xlworksheet.Cells(2 + i, "D").value Is Nothing Then Exit For
        fck_1_9_toplam = i
    Next i
    Dim fck_1_9_data(fck_1_9_toplam) As Double
    For i = 1 To fck_1_9_toplam
        fck_1_9_data(i) = xlworksheet.Cells(2 + i, "D").value
    Next i
    fck_1_9 = fck_1_9_data(CInt(Int((fck_1_9_toplam * Rnd()) + 1)))
    '=======================
    Dim fck_10ustu_toplam, fck_10ustu As Double
    For i = 1 To 1000
        If xlworksheet.Cells(2 + i, "E").value Is Nothing Then Exit For
        fck_10ustu_toplam = i
    Next i
    Dim fck_10ustu_data(fck_10ustu_toplam) As Double
    For i = 1 To fck_10ustu_toplam
        fck_10ustu_data(i) = xlworksheet.Cells(2 + i, "E").value
    Next i
    fck_10ustu = fck_10ustu_data(CInt(Int((fck_10ustu_toplam * Rnd()) + 1)))
    '=======================
    Dim fck_bolmeduvar_toplam, fck_bolmeduvar As Double
    For i = 1 To 1000
        If xlworksheet.Cells(2 + i, "F").value Is Nothing Then Exit For
        fck_bolmeduvar_toplam = i
    Next i
    Dim fck_bolmeduvar_data(fck_bolmeduvar_toplam) As Double
    For i = 1 To fck_bolmeduvar_toplam
        fck_bolmeduvar_data(i) = xlworksheet.Cells(2 + i, "F").value
    Next i
    fck_bolmeduvar = fck_bolmeduvar_data(CInt(Int((fck_bolmeduvar_toplam * Rnd()) + 1)))
    '=======================
```

```
Dim dbeton_toplam, dbeton As Double
For i = 1 To 10000
   If xlworksheet.Cells(2 + i, "W").value Is Nothing Then Exit For
   dbeton_toplam = i
Next i
Dim dbeton_data(dbeton_toplam) As Double
For i = 1 To dbeton_toplam
   dbeton_data(i) = xlworksheet.Cells(2 + i, "W").value
Next i
dbeton = dbeton_data(CInt(Int((dbeton_toplam * Rnd()) + 1)))
'=======================
Dim dduvar_toplam, dduvar As Double
For i = 1 To 10000
   If xlworksheet.Cells(2 + i, "X").value Is Nothing Then Exit For
   dduvar_toplam = i
Next i
Dim dduvar_data(dduvar_toplam) As Double
For i = 1 To dduvar_toplam
   dduvar_data(i) = xlworksheet.Cells(2 + i, "X").value
Next i
dduvar = dduvar_data(CInt(Int((dduvar_toplam * Rnd()) + 1)))
'=======================
Dim kolonmultiplier1_toplam As Double
For i = 1 To 10000
   If xlworksheet.Cells(2 + i, "Y").value Is Nothing Then Exit For
   kolonmultiplier1_toplam = i
Next i
Dim kolonmultiplier1_data(kolonmultiplier1_toplam) As Double
For i = 1 To kolonmultiplier1_toplam
   kolonmultiplier1_data(i) = xlworksheet.Cells(2 + i, "Y").value
Next i
''=======================
'Dim kolonmultiplier2_toplam As Double
'For i = 1 To 10000
'    If xlworksheet.Cells(2 + i, "Z").value Is Nothing Then Exit For
'    kolonmultiplier2_toplam = i
'Next i
'Dim kolonmultiplier2_data(kolonmultiplier2_toplam) As Double
'For i = 1 To kolonmultiplier2_toplam
'    kolonmultiplier2_data(i) = xlworksheet.Cells(2 + i, "Z").value
'Next i
''=======================
'Dim kolonmultiplier3_toplam As Double
'For i = 1 To 10000
'    If xlworksheet.Cells(2 + i, "AA").value Is Nothing Then Exit For
'    kolonmultiplier3_toplam = i
'Next i
'Dim kolonmultiplier3_data(kolonmultiplier3_toplam) As Double
'For i = 1 To kolonmultiplier3_toplam
'    kolonmultiplier3_data(i) = xlworksheet.Cells(2 + i, "AA").value
'Next i
''=======================
Dim kirismultiplier1_toplam As Double
For i = 1 To 10000
   If xlworksheet.Cells(2 + i, "Z").value Is Nothing Then Exit For
   kirismultiplier1_toplam = i
Next i
Dim kirismultiplier1_data(kirismultiplier1_toplam) As Double
For i = 1 To kirismultiplier1_toplam
   kirismultiplier1_data(i) = xlworksheet.Cells(2 + i, "AB").value
```

```
Next i
''=======================
'Dim kirismultiplier2_toplam As Double
'For i = 1 To 10000
'   If xlworksheet.Cells(2 + i, "AC").value Is Nothing Then Exit For
'   kirismultiplier2_toplam = i
'Next i
'Dim kirismultiplier2_data(kirismultiplier2_toplam) As Double
'For i = 1 To kirismultiplier2_toplam
'   kirismultiplier2_data(i) = xlworksheet.Cells(2 + i, "AC").value
'Next i
''=======================
'Dim kirismultiplier3_toplam As Double
'For i = 1 To 10000
'   If xlworksheet.Cells(2 + i, "AD").value Is Nothing Then Exit For
'   kirismultiplier3_toplam = i
'Next i
'Dim kirismultiplier3_data(kirismultiplier3_toplam) As Double
'For i = 1 To kirismultiplier3_toplam
'   kirismultiplier3_data(i) = xlworksheet.Cells(2 + i, "AD").value
'Next i
''=======================
Dim xperdemultiplier1_toplam As Double
For i = 1 To 10000
   If xlworksheet.Cells(2 + i, "AA").value Is Nothing Then Exit For
   xperdemultiplier1_toplam = i
Next i
Dim xperdemultiplier1_data(xperdemultiplier1_toplam) As Double
For i = 1 To xperdemultiplier1_toplam
   xperdemultiplier1_data(i) = xlworksheet.Cells(2 + i, "AE").value
Next i
''=======================
'Dim xperdemultiplier2_toplam As Double
'For i = 1 To 10000
'   If xlworksheet.Cells(2 + i, "AF").value Is Nothing Then Exit For
'   xperdemultiplier2_toplam = i
'Next i
'Dim xperdemultiplier2_data(xperdemultiplier2_toplam) As Double
'For i = 1 To xperdemultiplier2_toplam
'   xperdemultiplier2_data(i) = xlworksheet.Cells(2 + i, "AF").value
'Next i
''=======================
'Dim xperdemultiplier3_toplam As Double
'For i = 1 To 10000
'   If xlworksheet.Cells(2 + i, "AG").value Is Nothing Then Exit For
'   xperdemultiplier3_toplam = i
'Next i
'Dim xperdemultiplier3_data(xperdemultiplier3_toplam) As Double
'For i = 1 To kirismultiplier3_toplam
'   xperdemultiplier3_data(i) = xlworksheet.Cells(2 + i, "AG").value
'Next i
''=======================
Dim yperdemultiplier1_toplam As Double
For i = 1 To 10000
   If xlworksheet.Cells(2 + i, "AB").value Is Nothing Then Exit For
   yperdemultiplier1_toplam = i
Next i
Dim yperdemultiplier1_data(yperdemultiplier1_toplam) As Double
For i = 1 To yperdemultiplier1_toplam
   yperdemultiplier1_data(i) = xlworksheet.Cells(2 + i, "AH").value
```

```
Next i
''========================
'Dim yperdemultiplier2_toplam As Double
'For i = 1 To 10000
'   If xlworksheet.Cells(2 + i, "AI").value Is Nothing Then Exit For
'   yperdemultiplier2_toplam = i
'Next i
'Dim yperdemultiplier2_data(yperdemultiplier2_toplam) As Double
'For i = 1 To yperdemultiplier2_toplam
'   yperdemultiplier2_data(i) = xlworksheet.Cells(2 + i, "AI").value
'Next i
''========================
'Dim yperdemultiplier3_toplam As Double
'For i = 1 To 10000
'   If xlworksheet.Cells(2 + i, "AJ").value Is Nothing Then Exit For
'   yperdemultiplier3_toplam = i
'Next i
'Dim yperdemultiplier3_data(yperdemultiplier3_toplam) As Double
'For i = 1 To kirismultiplier3_toplam
'   yperdemultiplier3_data(i) = xlworksheet.Cells(2 + i, "AJ").value
'Next i
''========================
Dim bolmeduvarmultiplier1_toplam As Double
For i = 1 To 10000
   If xlworksheet.Cells(2 + i, "AC").value Is Nothing Then Exit For
   bolmeduvarmultiplier1_toplam = i
Next i
Dim bolmeduvarmultiplier1_data(bolmeduvarmultiplier1_toplam) As Double
For i = 1 To bolmeduvarmultiplier1_toplam
   bolmeduvarmultiplier1_data(i) = xlworksheet.Cells(2 + i, "AK").value
Next i
''========================
'Dim bolmeduvarmultiplier2_toplam As Double
'For i = 1 To 10000
'   If xlworksheet.Cells(2 + i, "AL").value Is Nothing Then Exit For
'   bolmeduvarmultiplier2_toplam = i
'Next i
'Dim bolmeduvarmultiplier2_data(bolmeduvarmultiplier2_toplam) As Double
'For i = 1 To bolmeduvarmultiplier2_toplam
'   bolmeduvarmultiplier2_data(i) = xlworksheet.Cells(2 + i, "AL").value
'Next i
''========================
'Dim bolmeduvarmultiplier3_toplam As Double
'For i = 1 To 10000
'   If xlworksheet.Cells(2 + i, "AM").value Is Nothing Then Exit For
'   bolmeduvarmultiplier3_toplam = i
'Next i
'Dim bolmeduvarmultiplier3_data(bolmeduvarmultiplier3_toplam) As Double
'For i = 1 To bolmeduvarmultiplier3_toplam
'   bolmeduvarmultiplier3_data(i) = xlworksheet.Cells(2 + i, "AM").value
'Next i
''========================
Dim ToplamKatSayisi As Double
For i = 1 To 10000
   If xlworksheet.Cells(2 + i, "B").value Is Nothing Then Exit For
   ToplamKatSayisi = i
Next i
Dim KatSayisi As Integer = CInt(Int((ToplamKatSayisi * Rnd()) + 1))
'Kat sayisi secildikten sonra multiplierlari ekliyoruz:
Dim AtananKolonMultiplierlari(KatSayisi) As Double
```

```
Dim AtananKirisMultiplierlari(KatSayisi) As Double
Dim AtananXPerdeMultiplierlari(KatSayisi) As Double
Dim AtananYPerdeMultiplierlari(KatSayisi) As Double
Dim AtananBolmeDuvarMultiplierlari(KatSayisi) As Double
'Degerler hepsinde tek deger alinacak.Revizyon yapiyoruz:
Dim kolonm1, kirism1, xperdem1, yperdem1, bolmed1 As Double
kolonm1 = kolonmultiplier1_data((CInt(Int((kolonmultiplier1_toplam * Rnd()) + 1))))
kirism1 = kirismultiplier1_data((CInt(Int((kirismultiplier1_toplam * Rnd()) + 1))))
xperdem1 = xperdemultiplier1_data((CInt(Int((xperdemultiplier1_toplam * Rnd()) + 1))))
yperdem1 = yperdemultiplier1_data((CInt(Int((yperdemultiplier1_toplam * Rnd()) + 1))))
bolmed1 = bolmeduvarmultiplier1_data((CInt(Int((bolmeduvarmultiplier1_toplam * Rnd()) + 1))))
For i = 1 To KatSayisi
  'If i = 1 Then
  AtananKolonMultiplierlari(i) = kolonm1
    AtananKirisMultiplierlari(i) = kirism1
    AtananXPerdeMultiplierlari(i) = xperdem1
    AtananYPerdeMultiplierlari(i) = yperdem1
    AtananBolmeDuvarMultiplierlari(i) = bolmed1
  'ElseIf i = 2 Then
  '   AtananKolonMultiplierlari(i) = kolonmultiplier2_data((CInt(Int((kolonmultiplier2_toplam *
Rnd()) + 1))))
  '   AtananKirisMultiplierlari(i) = kirismultiplier2_data((CInt(Int((kirismultiplier2_toplam * Rnd())
+ 1))))
  '   AtananXPerdeMultiplierlari(i) = xperdemultiplier2_data((CInt(Int((xperdemultiplier2_toplam *
Rnd()) + 1))))
  '   AtananYPerdeMultiplierlari(i) = yperdemultiplier2_data((CInt(Int((yperdemultiplier2_toplam *
Rnd()) + 1))))
  '   AtananBolmeDuvarMultiplierlari(i) =
bolmeduvarmultiplier2_data((CInt(Int((bolmeduvarmultiplier2_toplam * Rnd()) + 1))))
  'Else
  '   AtananKolonMultiplierlari(i) = kolonmultiplier3_data((CInt(Int((kolonmultiplier3_toplam *
Rnd()) + 1))))
  '   AtananKirisMultiplierlari(i) = kirismultiplier3_data((CInt(Int((kirismultiplier3_toplam * Rnd())
+ 1))))
  '   AtananXPerdeMultiplierlari(i) = xperdemultiplier3_data((CInt(Int((xperdemultiplier3_toplam *
Rnd()) + 1))))
  '   AtananYPerdeMultiplierlari(i) = yperdemultiplier3_data((CInt(Int((yperdemultiplier3_toplam *
Rnd()) + 1))))
  '   AtananBolmeDuvarMultiplierlari(i) =
bolmeduvarmultiplier3_data((CInt(Int((bolmeduvarmultiplier3_toplam * Rnd()) + 1))))
  'End If
Next i
'Kattakiler kastediliyor
Dim ToplamPerdeDuvarSayisiX, ToplamPerdeDuvarSayisiY, ToplamKolonSayisi,
ToplamBolmeDuvarSayisiX, ToplamBolmeDuvarSayisiY As Double
Dim ToplamPerdeDuvarSayisiXAlani(KatSayisi), ToplamPerdeDuvarSayisiYAlani(KatSayisi),
ToplamKolonSayisiAlani(KatSayisi), ToplamBolmeDuvarSayisiAlaniX(KatSayisi),
ToplamBolmeDuvarSayisiAlaniY(KatSayisi) As Double
Dim KatYuksekligi(KatSayisi) As Double
Dim IlkKatSayisi, UstKatSayisi As Double
For i = 1 To 10
  If xlworksheet.Cells(3 + i, "C").value Is Nothing Then Exit For
  IlkKatSayisi = i
Next i
Dim IlkKatYukseklikleri(IlkKatSayisi) As Double
For i = 1 To IlkKatSayisi
  IlkKatYukseklikleri(i) = xlworksheet.Cells(3 + i, "C").value
Next i
For i = 1 To 10
  If xlworksheet.Cells(15 + i, "C").value Is Nothing Then Exit For
```

```
    UstKatSayisi = i
  Next i
  Dim UstKatYukseklikleri(UstKatSayisi) As Double
  For i = 1 To UstKatSayisi
    UstKatYukseklikleri(i) = xlworksheet.Cells(15 + i, "C").value
  Next i
  KatYuksekligi(0) = 0
  For i = 1 To KatSayisi
    If i = 1 Then
      KatYuksekligi(i) = IlkKatYukseklikleri(CInt(Int((IlkKatSayisi * Rnd()) + 1)))
    Else
      KatYuksekligi(i) = UstKatYukseklikleri(CInt(Int((UstKatSayisi * Rnd()) + 1)))
      If KatYuksekligi(i) > KatYuksekligi(i - 1) Then
        KatYuksekligi(i) = KatYuksekligi(i - 1)
      End If
    End If
  Next i
  'Ust kisimda herbir katin yuksekligini bulduk.
  'Simdi SAP2000 datasi olarak girmek icin z koordinatini hesaplayacagiz.
  For i = 1 To KatSayisi
    KatYuksekligi(i) = KatYuksekligi(i) + KatYuksekligi(i - 1)
  Next i
  '===========================
  Dim ToplamDosemeKalinligiSayisi As Double
  For i = 1 To 1000
    If xlworksheet.Cells(2 + i, "Q").value Is Nothing Then Exit For
    ToplamDosemeKalinligiSayisi = i
  Next i
  Dim DosemeKalinliklari(ToplamDosemeKalinligiSayisi) As Double
  For i = 1 To ToplamDosemeKalinligiSayisi
    DosemeKalinliklari(i) = xlworksheet.Cells(2 + i, "Q").value
  Next i
  Dim KatDosemeKalinliklari(KatSayisi) As Double
  For i = 1 To KatSayisi
    If i = 1 Then
  KatDosemeKalinliklari(i) = DosemeKalinliklari(CInt(Int((ToplamDosemeKalinligiSayisi * Rnd()) +
1)))
    Else
  KatDosemeKalinliklari(i) = DosemeKalinliklari(CInt(Int((ToplamDosemeKalinligiSayisi * Rnd()) +
1)))
      If KatDosemeKalinliklari(i) > KatDosemeKalinliklari(i - 1) Then
        KatDosemeKalinliklari(i) = KatDosemeKalinliklari(i - 1)
      End If
    End If
  Next i
  '===========================
  Dim ToplamBolmeDuvarKalinligiSayisi As Double
  For i = 1 To 1000
    If xlworksheet.Cells(2 + i, "V").value Is Nothing Then Exit For
    ToplamBolmeDuvarKalinligiSayisi = i
  Next i
  Dim BolmeDuvarKalinliklari(ToplamBolmeDuvarKalinligiSayisi) As Double
  For i = 1 To ToplamBolmeDuvarKalinligiSayisi
    BolmeDuvarKalinliklari(i) = xlworksheet.Cells(2 + i, "V").value
  Next i
  Dim KatBolmeDuvarKalinliklari(KatSayisi) As Double
  For i = 1 To KatSayisi
    If i = 1 Then
      KatBolmeDuvarKalinliklari(i) =
BolmeDuvarKalinliklari(CInt(Int((ToplamBolmeDuvarKalinligiSayisi * Rnd()) + 1)))
```

```
         Else
            KatBolmeDuvarKalinliklari(i) =
BolmeDuvarKalinliklari(CInt(Int((ToplamBolmeDuvarKalinligiSayisi * Rnd()) + 1)))
            If KatBolmeDuvarKalinliklari(i) > KatBolmeDuvarKalinliklari(i - 1) Then
               KatBolmeDuvarKalinliklari(i) = KatBolmeDuvarKalinliklari(i - 1)
            End If
         End If
      Next i
      '===========================
      Dim ToplamPerdeDuvarKalinligiSayisi As Double
      For i = 1 To 1000
         If xlworksheet.Cells(2 + i, "H").value Is Nothing Then Exit For
         ToplamPerdeDuvarKalinligiSayisi = i
      Next i
      Dim PerdeDuvarKalinliklari(ToplamPerdeDuvarKalinligiSayisi) As Double
      For i = 1 To ToplamPerdeDuvarKalinligiSayisi
         PerdeDuvarKalinliklari(i) = xlworksheet.Cells(2 + i, "V").value
      Next i
      Dim XYonuKatPerdeDuvarKalinliklari(KatSayisi) As Double
      For i = 1 To KatSayisi
         If i = 1 Then
            XYonuKatPerdeDuvarKalinliklari(i) =
BolmeDuvarKalinliklari(CInt(Int((ToplamPerdeDuvarKalinligiSayisi * Rnd()) + 1)))
         Else
            XYonuKatPerdeDuvarKalinliklari(i) =
BolmeDuvarKalinliklari(CInt(Int((ToplamPerdeDuvarKalinligiSayisi * Rnd()) + 1)))
            If XYonuKatPerdeDuvarKalinliklari(i) > XYonuKatPerdeDuvarKalinliklari(i - 1) Then
             XYonuKatPerdeDuvarKalinliklari(i) = XYonuKatPerdeDuvarKalinliklari(i - 1)
            End If
         End If
      Next i
      Dim YYonuKatPerdeDuvarKalinliklari(KatSayisi) As Double
      For i = 1 To KatSayisi
         If i = 1 Then
            YYonuKatPerdeDuvarKalinliklari(i) =
BolmeDuvarKalinliklari(CInt(Int((ToplamPerdeDuvarKalinligiSayisi * Rnd()) + 1)))
         Else
            YYonuKatPerdeDuvarKalinliklari(i) =
BolmeDuvarKalinliklari(CInt(Int((ToplamPerdeDuvarKalinligiSayisi * Rnd()) + 1)))
            If YYonuKatPerdeDuvarKalinliklari(i) > YYonuKatPerdeDuvarKalinliklari(i - 1) Then
            YYonuKatPerdeDuvarKalinliklari(i) = YYonuKatPerdeDuvarKalinliklari(i - 1)
            End If
         End If
      Next i
      '===========================
      Dim ToplamCikmaOraniSayisi As Double
      For i = 1 To 1000
         If xlworksheet.Cells(2 + i, "N").value Is Nothing Then Exit For
         ToplamCikmaOraniSayisi = i
      Next i
      Dim CikmaOrani(ToplamCikmaOraniSayisi) As Double
      For i = 1 To ToplamCikmaOraniSayisi
         CikmaOrani(i) = xlworksheet.Cells(2 + i, "N").value
      Next i
      Dim BinaCikmaOrani As Double
      BinaCikmaOrani = CikmaOrani(CInt(Int((ToplamCikmaOraniSayisi * Rnd()) + 1)))
      '===========================
      Dim ToplamXYonuUzunluguSayisi As Double
      For i = 1 To 1000
         If xlworksheet.Cells(2 + i, "O").value Is Nothing Then Exit For
```

```
    ToplamXYonuUzunluguSayisi = i
Next i
Dim XYonuUzunluklari(ToplamXYonuUzunluguSayisi) As Double
For i = 1 To ToplamXYonuUzunluguSayisi
    XYonuUzunluklari(i) = xlworksheet.Cells(2 + i, "O").value
Next i
Dim XYonuUzunlugu As Double
XYonuUzunlugu = XYonuUzunluklari(CInt(Int((ToplamXYonuUzunluguSayisi * Rnd()) + 1)))
'==========================
Dim ToplamYYonuUzunluguSayisi As Double
For i = 1 To 1000
    If xlworksheet.Cells(2 + i, "P").value Is Nothing Then Exit For
    ToplamYYonuUzunluguSayisi = i
Next i
Dim YYonuUzunluklari(ToplamYYonuUzunluguSayisi) As Double
For i = 1 To ToplamYYonuUzunluguSayisi
    YYonuUzunluklari(i) = xlworksheet.Cells(2 + i, "P").value
Next i
Dim YYonuUzunlugu As Double
YYonuUzunlugu = YYonuUzunluklari(CInt(Int((ToplamYYonuUzunluguSayisi * Rnd()) + 1)))
'=========================
Dim ToplamXYonuPerdeDuvarSayisi As Double
For i = 1 To 1000
    If xlworksheet.Cells(2 + i, "R").value Is Nothing Then Exit For
    ToplamXYonuPerdeDuvarSayisi = i
Next i
Dim XYonuPerdeDuvarSayilari(ToplamXYonuPerdeDuvarSayisi) As Double
For i = 1 To ToplamXYonuPerdeDuvarSayisi
    XYonuPerdeDuvarSayilari(i) = xlworksheet.Cells(2 + i, "R").value
Next i
Dim XYonuPerdeDuvarSayisi As Double
If BinaTipi = "Cerceve" Then
    XYonuPerdeDuvarSayisi = 0
Else
    XYonuPerdeDuvarSayisi = XYonuPerdeDuvarSayilari(CInt(Int((ToplamXYonuPerdeDuvarSayisi
* Rnd()) + 1)))
End If
'==========================
Dim ToplamYYonuPerdeDuvarSayisi As Double
For i = 1 To 1000
    If xlworksheet.Cells(2 + i, "S").value Is Nothing Then Exit For
    ToplamYYonuPerdeDuvarSayisi = i
Next i
Dim YYonuPerdeDuvarSayilari(ToplamYYonuPerdeDuvarSayisi) As Double
For i = 1 To ToplamYYonuPerdeDuvarSayisi
    YYonuPerdeDuvarSayilari(i) = xlworksheet.Cells(2 + i, "S").value
Next i
Dim YYonuPerdeDuvarSayisi As Double
If BinaTipi = "Cerceve" Then
    YYonuPerdeDuvarSayisi = 0
Else
    YYonuPerdeDuvarSayisi = YYonuPerdeDuvarSayilari(CInt(Int((ToplamYYonuPerdeDuvarSayisi
* Rnd()) + 1)))
End If
'==========================
Dim MinAxisDistance As Double
If Me.TextBox1.Text = String.Empty Then
    MinAxisDistance = 3
Else
    MinAxisDistance = CDbl(Me.TextBox1.Text)
```

```
        End If
        '===========================
        Dim Sayac As Double = 0
        '===========================
        Dim ToplamXAksiSayisi As Double
        For i = 1 To 1000
            If xlworksheet.Cells(2 + i, "T").value Is Nothing Then Exit For
            If XYonuUzunlugu / xlworksheet.Cells(2 + i, "T").value > MinAxisDistance Then
                Sayac = Sayac + 1
                ToplamXAksiSayisi = Sayac
            End If
        Next i
        Dim XAksiSayilari(ToplamXAksiSayisi) As Double
        Sayac = 0
        For i = 1 To ToplamXAksiSayisi
            XAksiSayilari(i) = xlworksheet.Cells(2 + i, "T").value
            If XYonuUzunlugu / xlworksheet.Cells(2 + i, "T").value > MinAxisDistance Then
                Sayac = Sayac + 1
                XAksiSayilari(Sayac) = xlworksheet.Cells(2 + i, "T").value
            End If
        Next i
        Dim XAksiSayisi As Double
        XAksiSayisi = XAksiSayilari(CInt(Int((ToplamXAksiSayisi * Rnd()) + 1)))
        '===========================
        Sayac = 0
        Dim ToplamYAksiSayisi As Double
        For i = 1 To 1000
            If xlworksheet.Cells(2 + i, "U").value Is Nothing Then Exit For
            If YYonuUzunlugu / xlworksheet.Cells(2 + i, "U").value < MinAxisDistance Then
                Sayac = Sayac + 1
                ToplamYAksiSayisi = Sayac
            End If
        Next i
        Dim YAksiSayilari(ToplamYAksiSayisi) As Double
        Sayac = 0
        For i = 1 To ToplamYAksiSayisi
            YAksiSayilari(i) = xlworksheet.Cells(2 + i, "U").value
            If YYonuUzunlugu / xlworksheet.Cells(2 + i, "U").value < MinAxisDistance Then
                Sayac = Sayac + 1
                YAksiSayilari(Sayac) = xlworksheet.Cells(2 + i, "U").value
            End If
        Next i
        Dim YAksiSayisi As Double
        YAksiSayisi = YAksiSayilari(CInt(Int((ToplamYAksiSayisi * Rnd()) + 1)))
        '===========================
        Dim XAksiAraligi, YAksiAraligi As Double
        XAksiAraligi = XYonuUzunlugu / XAksiSayisi
        YAksiAraligi = YYonuUzunlugu / YAksiSayisi
        'Bolme Duvar Sayilari
        ToplamBolmeDuvarSayisiX = XAksiSayisi * (YAksiSayisi + 1) - XYonuPerdeDuvarSayisi
        ToplamBolmeDuvarSayisiY = YAksiSayisi * (XAksiSayisi + 1) - YYonuPerdeDuvarSayisi
        'BolmeDuvarAlanlarini yazdiriyoruz:
        For i = 1 To KatSayisi
            ToplamBolmeDuvarSayisiAlaniX(i) = KatBolmeDuvarKalinliklari(i) *
ToplamBolmeDuvarSayisiX * XAksiAraligi
            ToplamBolmeDuvarSayisiAlaniY(i) = KatBolmeDuvarKalinliklari(i) *
ToplamBolmeDuvarSayisiY * YAksiAraligi
        Next i
        Dim CikmaYonu As String
            If Rnd() <= 0.5 Then
```

```
        CikmaYonu = "X"
      Else
        CikmaYonu = "Y"
      End If
      Dim ToplamNoktaSayisi As Double
      If BinaCikmaOrani = 0 Then
        ToplamNoktaSayisi = (XAksiSayisi + 1) * (YAksiSayisi + 1)
      Else
        If CikmaYonu = "X" Then
       ToplamNoktaSayisi = (XAksiSayisi + 1) * (YAksiSayisi + 1) + (XAksiSayisi + 1)
        ElseIf CikmaYonu = "Y" Then
       ToplamNoktaSayisi = (XAksiSayisi + 1) * (YAksiSayisi + 1) + (YAksiSayisi + 1)
        End If
      End If
      'Dim j, k As Double
      Dim BinaToplamNoktaSayisi As Double
      Dim NoktaBilgileri(300000, 5) As Double
      Sayac = 0
      For k = 1 To KatSayisi + 1
        For j = 1 To YAksiSayisi + 1
          For i = 1 To XAksiSayisi + 1
            Sayac = Sayac + 1
            NoktaBilgileri(Sayac, 1) = (i - 1) * XAksiAraligi
            NoktaBilgileri(Sayac, 2) = (j - 1) * YAksiAraligi
            NoktaBilgileri(Sayac, 3) = KatYuksekligi(k - 1)
          Next i
        Next j
      Next k
      BinaToplamNoktaSayisi = Sayac
      'Cikmanin Uzunlugunu buluyoruz
      'X'e paralel ise
      Dim CikmaGenisligi As Double
      If CikmaYonu = "X" Then
        CikmaGenisligi = XYonuUzunlugu * YYonuUzunlugu * BinaCikmaOrani / YYonuUzunlugu /
2
      ElseIf CikmaYonu = "Y" Then
        CikmaGenisligi = XYonuUzunlugu * YYonuUzunlugu * BinaCikmaOrani / XYonuUzunlugu /
2
      End If
      '50000 fazla
      If CikmaYonu = "X" Then
        For k = 2 To KatSayisi + 1
          Sayac = 50000 + (XAksiSayisi + 1) * (YAksiSayisi + 1) * (k - 1)
          For i = 1 To XAksiSayisi + 1
            Sayac = Sayac + 1
            NoktaBilgileri(Sayac, 1) = (i - 1) * XAksiAraligi
            NoktaBilgileri(Sayac, 2) = -CikmaGenisligi
            NoktaBilgileri(Sayac, 3) = KatYuksekligi(k - 1)
            NoktaBilgileri(Sayac + (XAksiSayisi + 1) * YAksiSayisi, 1) = (i - 1) * XAksiAraligi
            NoktaBilgileri(Sayac + (XAksiSayisi + 1) * YAksiSayisi, 2) = YYonuUzunlugu +
CikmaGenisligi
            NoktaBilgileri(Sayac + (XAksiSayisi + 1) * YAksiSayisi, 3) = KatYuksekligi(k - 1)
          Next i
        Next k
      ElseIf CikmaYonu = "Y" Then
        For k = 2 To KatSayisi + 1
          Sayac = 50000 + (XAksiSayisi + 1) * (YAksiSayisi + 1) * (k - 1)
          For j = 1 To YAksiSayisi + 1
            Sayac = Sayac + 1 + (i - 1) * (XAksiSayisi + 1)
            NoktaBilgileri(Sayac, 1) = -CikmaGenisligi
```

```
            NoktaBilgileri(Sayac, 2) = (j - 1) * YAksiAraligi
            NoktaBilgileri(Sayac, 3) = KatYuksekligi(k - 1)
            NoktaBilgileri(Sayac + XAksiSayisi, 1) = XYonuUzunlugu + CikmaGenisligi
            NoktaBilgileri(Sayac + XAksiSayisi, 2) = (j - 1) * YAksiAraligi
            NoktaBilgileri(Sayac + XAksiSayisi, 3) = KatYuksekligi(k - 1)
        Next j
    Next k
End If
Dim KirisGenisligiSayisi, KirisYuksekligiSayisi As Double
For i = 1 To 1000
    If xlworksheet.Cells(2 + i, "K").value Is Nothing Then Exit For
    KirisGenisligiSayisi = i
Next i
Dim KirisGenislikleri(KirisGenisligiSayisi) As Double
For i = 1 To KirisGenisligiSayisi
    KirisGenislikleri(i) = xlworksheet.Cells(2 + i, "K").value
Next i
For j = 1 To 1000
    If xlworksheet.Cells(2 + j, "L").value Is Nothing Then Exit For
    KirisYuksekligiSayisi = j
Next j
Dim KirisYukseklikleri(KirisYuksekligiSayisi) As Double
For j = 1 To KirisYuksekligiSayisi
    KirisYukseklikleri(j) = xlworksheet.Cells(2 + j, "L").value
Next j
'================
Dim KolonUzunKenarSayisi, KolonKisaKenarSayisi As Double
For i = 1 To 1000
    If xlworksheet.Cells(2 + i, "I").value Is Nothing Then Exit For
    KolonUzunKenarSayisi = i
Next i
Dim KolonUzunKenarlari(KolonUzunKenarSayisi) As Double

For i = 1 To KolonUzunKenarSayisi
    KolonUzunKenarlari(i) = xlworksheet.Cells(2 + i, "I").value
Next i
For i = 1 To 1000
    If xlworksheet.Cells(2 + i, "J").value Is Nothing Then Exit For
    KolonKisaKenarSayisi = i
Next i
Dim KolonKisaKenarlari(KolonKisaKenarSayisi) As Double
For i = 1 To KolonKisaKenarSayisi
    KolonKisaKenarlari(i) = xlworksheet.Cells(2 + i, "J").value
Next i
'================
Dim KolonBilgileri((XAksiSayisi + 1) * (YAksiSayisi + 1), 2 + KatSayisi * 2)
' ,1 => Perdeden dolayi kolon yok=0, kolon var=1
' ,2 =>
' ,3 => Kolon X Genisligi
' ,4 => Kolon Y Genisligi
For i = 1 To (XAksiSayisi + 1) * (YAksiSayisi + 1)
    KolonBilgileri(i, 1) = 1
Next i
Dim Sayi As Integer
Dim XYonuPerdeBilgileri(XAksiSayisi * (YAksiSayisi + 1), 3) As Double
' ,1 Perde var=1 Perde Yok=0
' ,2 Perdenin İlk Nokta Numarasi
' ,3 Perdenin İkinci Nokta Numarasi
' ,4
' ,5
```

```
' ,6
For i = 1 To (XAksiSayisi) * (YAksiSayisi + 1)
   XYonuPerdeBilgileri(i, 1) = 0
   'Sayi = Int(i / XAksiSayisi) * (XAksiSayisi + 1) + i Mod (XAksiSayisi + 1)
   If i Mod XAksiSayisi = 0 Then
      Sayi = i + Int(i / (XAksiSayisi)) - 1
   Else
      Sayi = i + Int(i / (XAksiSayisi))
   End If
   XYonuPerdeBilgileri(i, 2) = Sayi
   XYonuPerdeBilgileri(i, 3) = Sayi + 1
Next i
Dim YYonuPerdeBilgileri(YAksiSayisi * (XAksiSayisi + 1), 3) As Double
' ,1 Perde var=1 Perde Yok=0
' ,2 Perdenin İlk Nokta Numarasi
' ,3 Perdenin İkinci Nokta Numarasi
For i = 1 To (YAksiSayisi) * (XAksiSayisi + 1)
   YYonuPerdeBilgileri(i, 1) = 0
   YYonuPerdeBilgileri(i, 2) = i
   YYonuPerdeBilgileri(i, 3) = i + XAksiSayisi + 1
Next i
Sayac = 0
'CInt(Int((ToplamYYonuPerdeDuvarSayisi * Rnd()) + 1)))
Do Until Sayac = XYonuPerdeDuvarSayisi
   For i = 1 To (XAksiSayisi) * (YAksiSayisi + 1)

      'Rnd <0.5 Perde var >=0.5 Perde yok
      If Rnd() < 0.5 And XYonuPerdeBilgileri(i, 1) = 0 Then
         If Sayac = XYonuPerdeDuvarSayisi Then Exit For
         XYonuPerdeBilgileri(i, 1) = 1
         Sayac = Sayac + 1

         'Sayi = Int(i / XAksiSayisi) * (XAksiSayisi + 1) + i Mod (XAksiSayisi + 1)

         If i Mod XAksiSayisi = 0 Then
            Sayi = i + Int(i / (XAksiSayisi)) - 1
         Else
            Sayi = i + Int(i / (XAksiSayisi))
         End If
         KolonBilgileri(Sayi, 1) = 0
         KolonBilgileri(Sayi + 1, 1) = 0
      End If
   Next i
Loop
Sayac = 0

Do Until Sayac = YYonuPerdeDuvarSayisi
   For i = 1 To (YAksiSayisi) * (XAksiSayisi + 1)
      'Rnd <0.5 Perde var >=0.5 Perde yok
      If Rnd() < 0.5 And YYonuPerdeBilgileri(i, 1) = 0 Then
         If Sayac = YYonuPerdeDuvarSayisi Then Exit For
         YYonuPerdeBilgileri(i, 1) = 1
         Sayac = Sayac + 1
         KolonBilgileri(i, 1) = 0
         KolonBilgileri(i + XAksiSayisi + 1, 1) = 0
      End If
   Next i
Loop
Dim KirisBilgileriX((XAksiSayisi) * (YAksiSayisi + 1) * KatSayisi, 5) As Double
```

```
            ' ,1 => 0=kiris yok 1=kiris var
            ' ,2 => i noktasi
            ' ,3 => j noktasi
            ' ,4 => Genislik
            ' ,5 => Yukseklik
            For j = 1 To KatSayisi
               For i = 1 To (XAksiSayisi) * (YAksiSayisi + 1)
                  KirisBilgileriX(i + (XAksiSayisi) * (YAksiSayisi + 1) * (j - 1), 1) = 1
                  If i Mod XAksiSayisi = 0 Then
                     Sayi = i + Int(i / (XAksiSayisi)) - 1
                  Else
                     Sayi = i + Int(i / (XAksiSayisi))
                  End If
                  KirisBilgileriX(i + (XAksiSayisi) * (YAksiSayisi + 1) * (j - 1), 2) = Sayi + (XAksiSayisi + 1)
* (YAksiSayisi + 1) * j
                  KirisBilgileriX(i + (XAksiSayisi) * (YAksiSayisi + 1) * (j - 1), 3) = Sayi + 1 + (XAksiSayisi
+ 1) * (YAksiSayisi + 1) * j
                  If XYonuPerdeBilgileri(i, 1) = 1 Then
                     KirisBilgileriX(i + (XAksiSayisi) * (YAksiSayisi + 1) * (j - 1), 1) = 0
                  End If
               Next i
            Next j
            Dim KirisBilgileriY((YAksiSayisi) * (XAksiSayisi + 1) * KatSayisi, 5) As Double
            ' ,1 => 0=kiris yok 1=kiris var
            ' ,2 => i noktasi
            ' ,3 => j noktasi
            ' ,4 => Genislik
            ' ,5 => Yukseklik

            For j = 1 To KatSayisi
               For i = 1 To (YAksiSayisi) * (XAksiSayisi + 1)
                  KirisBilgileriY(i + (XAksiSayisi + 1) * (YAksiSayisi) * (j - 1), 1) = 1
                  'Sayi = Int(i / XAksiSayisi) * (XAksiSayisi + 1) + i Mod (XAksiSayisi + 1)
                  KirisBilgileriY(i + (XAksiSayisi + 1) * (YAksiSayisi) * (j - 1), 2) = i + (XAksiSayisi + 1) *
(YAksiSayisi + 1) * j
                  KirisBilgileriY(i + (XAksiSayisi + 1) * (YAksiSayisi) * (j - 1), 3) = i + XAksiSayisi + 1 +
(XAksiSayisi + 1) * (YAksiSayisi + 1) * j
                  If YYonuPerdeBilgileri(i, 1) = 1 Then
                     KirisBilgileriY(i + (XAksiSayisi + 1) * (YAksiSayisi) * (j - 1), 1) = 0
                  End If
               Next i
            Next j

            Dim SecilenKirisYuksekligi, SecilenKirisGenisligi As Double

            For j = 1 To KatSayisi
               For i = 1 To YAksiSayisi + 1
                  SecilenKirisYuksekligi = KirisYukseklikleri(CInt(Int((KirisYukseklikSayisi * Rnd()) + 1)))
                  SecilenKirisGenisligi = KirisGenislikleri(CInt(Int((KirisGenisligiSayisi * Rnd()) + 1)))
                  For k = 1 To XAksiSayisi
                     KirisBilgileriX(k + (i - 1) * XAksiSayisi + (XAksiSayisi) * (YAksiSayisi + 1) * (j - 1), 4) =
SecilenKirisYuksekligi
                     KirisBilgileriX(k + (i - 1) * XAksiSayisi + (XAksiSayisi) * (YAksiSayisi + 1) * (j - 1), 5) =
SecilenKirisGenisligi
                  Next k
               Next i
            Next j

            For j = 1 To KatSayisi
               For i = 1 To XAksiSayisi + 1
```

```
            SecilenKirisYuksekligi = KirisYukseklikleri(CInt(Int((KirisYuksekligiSayisi * Rnd()) + 1)))
            SecilenKirisGenisligi = KirisGenislikleri(CInt(Int((KirisGenisligiSayisi * Rnd()) + 1)))
            For k = 1 To YAksiSayisi
              KirisBilgileriY((k - 1) * (XAksiSayisi + 1) + i + (YAksiSayisi) * (XAksiSayisi + 1) * (j -
1), 4) = SecilenKirisYuksekligi
              KirisBilgileriY((k - 1) * (XAksiSayisi + 1) + i + (YAksiSayisi) * (XAksiSayisi + 1) * (j -
1), 5) = SecilenKirisGenisligi
            Next k
          Next i
        Next j
        Sayi = Rnd()
        For i = 1 To (YAksiSayisi + 1) * (XAksiSayisi + 1)
          For j = 1 To KatSayisi
            If KolonBilgileri(i, 1) = 1 Then
              If j = 1 Then
                If Sayi <= 0.5 Then
            KolonBilgileri(i, 3) = KolonKisaKenarlari(CInt(Int((KolonKisaKenarSayisi * Rnd()) + 1)))
            KolonBilgileri(i, 4) = KolonUzunKenarlari(CInt(Int((KolonUzunKenarSayisi * Rnd()) + 1)))
                Else
             KolonBilgileri(i, 3) = KolonUzunKenarlari(CInt(Int((KolonUzunKenarSayisi * Rnd()) + 1)))
             KolonBilgileri(i, 4) = KolonKisaKenarlari(CInt(Int((KolonKisaKenarSayisi * Rnd()) + 1)))
                End If
              Else
                If Sayi <= 0.5 Then
                  KolonBilgileri(i, 1 + 2 * j) = KolonKisaKenarlari(CInt(Int((KolonKisaKenarSayisi *
Rnd()) + 1)))
                  If KolonBilgileri(i, 1 + 2 * j) > KolonBilgileri(i, 1 + 2 * j - 2) Then KolonBilgileri(i, 1
+ 2 * j) = KolonBilgileri(i, 1 + 2 * j - 2)
                  KolonBilgileri(i, 2 + 2 * j) = KolonUzunKenarlari(CInt(Int((KolonUzunKenarSayisi *
Rnd()) + 1)))
                  If KolonBilgileri(i, 2 + 2 * j) > KolonBilgileri(i, 2 + 2 * j - 2) Then KolonBilgileri(i, 2
+ 2 * j) = KolonBilgileri(i, 2 + 2 * j - 2)
                Else
                  KolonBilgileri(i, 1 + 2 * j) = KolonUzunKenarlari(CInt(Int((KolonUzunKenarSayisi *
Rnd()) + 1)))
                  If KolonBilgileri(i, 3 + 2 * j) > KolonBilgileri(i, 1 + 2 * j - 2) Then KolonBilgileri(i, 1
+ 2 * j) = KolonBilgileri(i, 1 + 2 * j - 2)
                  KolonBilgileri(i, 2 + 2 * j) = KolonKisaKenarlari(CInt(Int((KolonKisaKenarSayisi *
Rnd()) + 1)))
                  If KolonBilgileri(i, 2 + 2 * j) > KolonBilgileri(i, 2 + 2 * j - 2) Then KolonBilgileri(i, 2
+ 2 * j) = KolonBilgileri(i, 2 + 2 * j - 2)
                End If
              End If
            End If
          Next j
        Next i
        Dim Parameter1 As Double
        Dim SatirNumarası, KolonNumarasi As Double
        KolonNumarasi = 0
        For Parameter1 = 1 To 2
          Dim NumberResults As Long
          Dim Obj() As String
          Dim Elm() As String
          Dim PointElm() As String
          Dim LoadCase() As String
          Dim StepType() As String
          Dim StepNum() As Double
          Dim F11() As Double
          Dim F22() As Double
          Dim F12() As Double
```

```
Dim FMax() As Double
Dim FMin() As Double
Dim FAngle() As Double
Dim FVM() As Double
Dim M11() As Double
Dim M22() As Double
Dim M12() As Double
Dim MMax() As Double
Dim MMin() As Double
Dim MAngle() As Double
Dim V13() As Double
Dim V23() As Double
Dim VMax() As Double
Dim VAngle() As Double

'set the following flag to True to attach to an existing instance of the program
'otherwise a new instance of the program will be started

Dim AttachToInstance As Boolean
AttachToInstance = False

'set the following flag to True to manually specify the path to SAP2000.exe
'this allows for a connection to a version of SAP2000 other than the latest installation
'otherwise the latest installed version of SAP2000 will be launched
Dim SpecifyPath As Boolean

SpecifyPath = False

'if the above flag is set to True, specify the path to SAP2000 below
Dim ProgramPath As String

'ProgramPath = "C:\Program Files\Computers and Structures\SAP2000 22\SAP2000.exe"
'full path to the model
'set it to the desired path of your model

Dim ModelDirectory As String = "C:\CSiAPIexample"

Try
   System.IO.Directory.CreateDirectory(ModelDirectory)
Catch ex As Exception
   MsgBox("Could not create directory: " + ModelDirectory)
End Try

Dim ModelName As String = "API_1-001.sdb"
Dim ModelPath As String = ModelDirectory + System.IO.Path.DirectorySeparatorChar +
ModelName
'dimension the SapObject as cOAPI type
Dim mySapObject As cOAPI
mySapObject = Nothing
'Use ret to check if functions return successfully (ret = 0) or fail (ret = nonzero)
Dim ret As Integer
ret = -1
'create API helper object
Dim myHelper As cHelper

Try
   myHelper = New Helper
Catch ex As Exception
   MsgBox("Cannot create an instance of the Helper object")
End Try
```

```
        If AttachToInstance Then
            'attach to a running instance of SAP2000

            Try
                'get the active SapObject
                mySapObject = myHelper.GetObject("CSI.SAP2000.API.SapObject")
            Catch ex As Exception
                MsgBox("No running instance of the program found or failed to attach.")
                Return
            End Try
        Else
            If SpecifyPath Then
                Try
                    'create an instance of the SapObject from the specified path
                    mySapObject = myHelper.CreateObject(ProgramPath)
                Catch ex As Exception
                    MsgBox("Cannot start a new instance of the program from " + ProgramPath)
                    Return
                End Try
            Else
                Try
                    'create an instance of the SapObject from the latest installed SAP2000
                    mySapObject = myHelper.CreateObjectProgID("CSI.SAP2000.API.SapObject")
                Catch ex As Exception
                    MsgBox("Cannot start a new instance of the program.")
                    Return
                End Try
            End If
            'start SAP2000 application
            ret = mySapObject.ApplicationStart()
        End If
        'Get a reference to cSapModel to access all API classes and functions
        Dim mySapModel As cSapModel
        mySapModel = mySapObject.SapModel
        'initialize model
        ret = mySapModel.InitializeNewModel()
        'create new blank model
        ret = mySapModel.File.NewBlank()
        'switch to k-ft units
        ret = mySapModel.SetPresentUnits(eUnits.kN_m_C)
        'add new load pattern
        ret = mySapModel.LoadPatterns.Add("G", eLoadPatternType.Dead, 1)
        ret = mySapModel.LoadPatterns.Add("Q", eLoadPatternType.Live, 0)
        ''change mass source name from MSSSRC1 to MyMassSource
        'ret = mySapModel.SourceMass.ChangeName("MSSSRC1", "MyMassSource")
        'set mass source
        Dim MyLoadPat(1) As String
        Dim MySF(1) As Double
        MyLoadPat(0) = "G"
        MyLoadPat(1) = "Q"
        MySF(0) = 1
        MySF(1) = 0.3
        'add a new mass source and make it the default mass source
        'LoadPat(0) = "DEAD"
        'SF(0) = 1.25
        ret = mySapModel.SourceMass.SetMassSource("MSSSRC1", True, True, True, True, 2,
MyLoadPat, MySF)
        If KatSayisi < 10 Then
            ret = mySapModel.PropMaterial.SetMaterial("C" & CStr(fck_1_9), eMatType.Concrete)
```

```
            'assign isotropic mechanical properties to material
            'ACI 318-14 19.2.2.1(b) => Elastisite Modulu
            ret = mySapModel.PropMaterial.SetMPIsotropic("C" & CStr(fck_1_9), 5000 *
Math.Sqrt(fck_1_9) * 1000, 0.2, 0.0000055)
            'assign material property weight per unit volume
            ret = mySapModel.PropMaterial.SetWeightAndMass("C" & CStr(fck_1_9), 1, dbeton)
            'assign other properties
            ret = mySapModel.PropMaterial.SetOConcrete_1("C" & CStr(fck_1_9), fck_1_9 * 1000,
False, 0, 1, 2, 0.0022, 0.0052, -0.1)
        Else
            ret = mySapModel.PropMaterial.SetMaterial("C" & CStr(fck_10ustu), eMatType.Concrete)
            'assign isotropic mechanical properties to material
            'ACI 318-14 19.2.2.1(b) => Elastisite Modulu
            ret = mySapModel.PropMaterial.SetMPIsotropic("C" & CStr(fck_10ustu), 5000 *
Math.Sqrt(fck_10ustu) * 1000, 0.2, 0.0000055)
            'assign material property weight per unit volume
            ret = mySapModel.PropMaterial.SetWeightAndMass("C" & CStr(fck_10ustu), 1, dbeton)
            'assign other properties
            ret = mySapModel.PropMaterial.SetOConcrete_1("C" & CStr(fck_10ustu), fck_10ustu *
1000, False, 0, 1, 2, 0.0022, 0.0052, -0.1)
        End If
        ret = mySapModel.PropMaterial.SetMaterial("Masonry", eMatType.Concrete)
        'assign isotropic mechanical properties to material
        'ACI 318-14 19.2.2.1(b) => Elastisite Modulu
        ret = mySapModel.PropMaterial.SetMPIsotropic("Masonry", 750 * fck_bolmeduvar * 1000,
0.25, 0.0000117)
        'assign material property weight per unit volume
        ret = mySapModel.PropMaterial.SetWeightAndMass("Masonry", 1, dduvar)
        ''define rectangular frame section property
        'ret = mySapModel.PropFrame.SetRectangle("COLUMN", "CONC", bcolumn, bcolumn)
        'set new area property
        If KatSayisi < 10 Then
            For i = 1 To ToplamDosemeKalinligiSayisi
                ret = mySapModel.PropArea.SetShell_1("D" & CStr(DosemeKalinliklari(i)), 1, True, "C"
& CStr(fck_1_9), 0, DosemeKalinliklari(i), DosemeKalinliklari(i), 3)
            Next i
        Else
            For i = 1 To ToplamDosemeKalinligiSayisi
                ret = mySapModel.PropArea.SetShell_1("D" & CStr(DosemeKalinliklari(i)), 1, True, "C"
& CStr(fck_10ustu), 0, DosemeKalinliklari(i), DosemeKalinliklari(i), 3)
            Next i
        End If
        Dim ShellValue(9) As Double
        For i = 0 To 9
            ShellValue(i) = 1
        Next i
        If Parameter1 = 1 Then
            For i = 1 To ToplamBolmeDuvarKalinligiSayisi
                ret =mySapModel.PropArea.SetShell_1("B" & CStr(BolmeDuvarKalinliklari(i)), 1, True,
"Masonry", 0, BolmeDuvarKalinliklari(i), BolmeDuvarKalinliklari(i))
            Next i
            'Multiplierli bolme duvarlari ekliyoruz:
        ElseIf Parameter1 = 2 Then
            For j = 1 To KatSayisi
                'If KatSayisi < 10 Then
                For i = 1 To ToplamBolmeDuvarKalinligiSayisi
                    ret = mySapModel.PropArea.SetShell_1("B" & CStr(BolmeDuvarKalinliklari(i)) & "_"
& CStr(AtananBolmeDuvarMultiplierlari(j)) & "_" & "Kat" & CStr(j), 1, True, "Masonry", 0,
BolmeDuvarKalinliklari(i), BolmeDuvarKalinliklari(i))
                    'f22,m11,m22
```

```
                    ShellValue(1) = AtananBolmeDuvarMultiplierlari(j)
                    ShellValue(3) = AtananBolmeDuvarMultiplierlari(j)
                    ShellValue(4) = AtananBolmeDuvarMultiplierlari(j)
                    ret = mySapModel.PropArea.SetModifiers("B" & CStr(BolmeDuvarKalinliklari(i)) &
"_" & CStr(AtananBolmeDuvarMultiplierlari(j)) & "_" & "Kat" & CStr(j), ShellValue)
                Next i
                'Else
                '   For i = 1 To ToplamBolmeDuvarKalinligiSayisi
                '       ret = mySapModel.PropArea.SetShell_1("B" & CStr(BolmeDuvarKalinliklari(i)) &
"_" & CStr(AtananBolmeDuvarMultiplierlari(j)) & "_" & "Kat" & CStr(j), 1, True, "C" & CStr(fck_10ustu),
0, BolmeDuvarKalinliklari(i), BolmeDuvarKalinliklari(i))
                '       'f22,m11,m22
                '       ShellValue(1) = AtananBolmeDuvarMultiplierlari(j)
                '       ShellValue(3) = AtananBolmeDuvarMultiplierlari(j)
                '       ShellValue(4) = AtananBolmeDuvarMultiplierlari(j)
                '       ret = mySapModel.PropArea.SetModifiers("B" & CStr(BolmeDuvarKalinliklari(i)) &
"_" & CStr(AtananBolmeDuvarMultiplierlari(j)) & "_" & "Kat" & CStr(j), ShellValue)
                '   Next i
```