Engineering Applications
https://publish.mersin.edu.tr/index.php/enap
e-ISSN 2979-9201

Investigation of the effects of using steel cross and reinforced concrete shears earthquake performance in building

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Cite this study: Eser, M. M., & Can, H. (2022). Investigation of the effects of using steel cross and reinforced concrete shears earthquake performance in building. Engineering Applications, 1 (2), 157-162

Keywords
Reinforced concrete
Steel cross
Earthquake
Time history analysis
Finite element method

Research Article
Received: 29.09.2022
Revised: 30.10.2022
Accepted: 06.11.2022
Published: 14.11.2022

Abstract

Türkiye mostly on the seismic belt and it causes serious loss of life and property. To prevent this, quake proof structures should be developed and more research should be studied. While reinforced concrete shear walls are common in earthquake resistant buildings in Türkiye, steel usage has not spread. Reinforced concrete structures, which are well-known in project design and application used frequently. Steel structures have been used typically world-wide since the old years while different and innovative methods have been developed and new studies are continuing. Within the area of research, three different system models were designed including a reinforced concrete system without shear walls, a reinforced concrete system with a shear wall on the outermost axis and a reinforced concrete system with a steel cross on the outermost axis then examined. The analyzes are modeled in the SAP2000 program which is internationally accepted and frequently used in academic studies and it will be designed according to the Turkish Building Earthquake Code (TBDY-2018). Modeled buildings were analyzed using the equivalent earthquake load and time history calculation method.

1. Introduction

68% of all earthquakes in the world are in the Pacific belt, 21% are in the Mediterranean-Himalayan belt and the remaining 11% are in other continents. Turkey is located in the Mediterranean – Himalayan belt from these belts [1]. World earthquake map is shown in Figure 1. It is a fact that we will suffer great loss of life and property due to frequent earthquakes in the future, just as there have been many devastating earthquakes in our country in the past. According to the Turkey Earthquake Hazard Map, it is known that 92% of our country is in earthquake zones, 98% of our population lives under earthquake risk, and 98% of large industrial centers and 93% of our dams are located in earthquake zones. In the last 58 years, 58,202 citizens have lost their lives, 122,096 people have been injured, and approximately 411,465 buildings have been destroyed or severely damaged by earthquakes. As a result, it can be said that an average of 1.003 citizens die and 7,094 buildings are destroyed every year due to earthquakes [2].

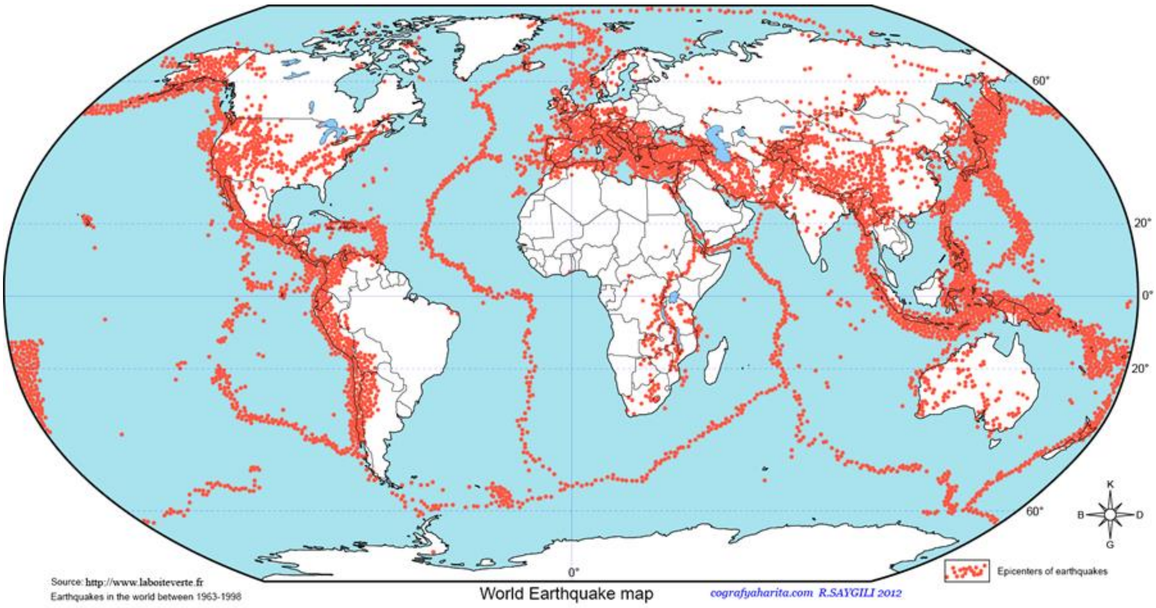


Figure 1. World Earthquake Map [3]

In the rapidly developing world, while the needs of humanity are increasing, new designs and models have been sought. Our choice of materials and design methods that we can use when designing buildings is quite wide and increasing. This increase offers new options while solving space and volume in architecture. This provides architectural diversity. Since it is important that the building models to be designed are constructable, the development of construction techniques leads to new designs.

In the buildings built in our country, importance is given to aesthetics and architecture as well as to the economic and robustness of the building. Since our country is in an earthquake zone, one of the most important forces affecting our buildings is earthquake. Earthquake is a reality for our country and we engineers need to do various researches and studies for this. In this study, it is aimed to compare the performances of reinforced concrete (RC) shears used in large areas in our country and steel cross against earthquakes. In addition, it is aimed to expand the scope of the study and to find detailed results for wider data by taking the placement of both reinforced concrete shears and steel cross to be used instead of shear walls in different places

Reinforced concrete shear wall structures are used very frequently in our country and in the world. In addition, different studies have been carried out on reinforced concrete. Steel plate structures have been widely used in the United States, Canada and Japan since the 1970s, and these structures have not suffered serious damage as a result of earthquakes [4]. Common strengthening methods are based on two basic approaches. The first of these is to strengthen the structure by adding steel diagonal elements or shear walls, and the other is to increase the strength of structural elements such as column beams in reinforced concrete structures or to increase the performance of the structure by strengthening the column-beam junctions [5]. In similar studies, it has been observed that the reinforcement area decreases in reinforced concrete sections when steel cross is used. In addition, when calculating the approximate costs of the structures, he concluded that the cost is 3.09% more economical if steel cross is used [6].

2. Material and Method

In order to ensure that the reinforced concrete buildings, which are used extensively in our country, are reliably strong, some regulations are used while static calculations are made. TBDY-2018 is the regulation that should be taken as a basis in order to determine earthquake forces and to build resistant structures in Turkey [7]. Earthquake forces can be determined by dynamic analysis, taking into account ground accelerations and the mass, stiffness and damping properties of the structure [8]. Earthquake forces cannot be taken as a constant load for every structure and situation because they are not a certain force. Many approaches and methods have been developed on the subject.

Two of the three most commonly used methods were used in this study. The methods that are considered to be used are the equivalent earthquake load method and the calculation method in the time history. Equivalent earthquake load method is based on the first mode of the building and it is accepted that the earthquake forces acting on the floors are proportional to the floor mass and the height of the floor from the foundation. Since the mass of the building is taken into account in the calculation of the vibration period and the distribution of the earthquake load, this method can be considered as a dynamic method based on the first degree of freedom of the building [9]. The purpose of the calculation method in the time history is to integrate the equation of motion of the system step by step, taking into account the nonlinear behavior of the carrier system. During the analysis, the displacement, plastic deformation and internal forces occurring in the system at each time increment and the maximum values of these magnitudes corresponding to the earthquake demand are calculated [10]. In this method, according to (TBDY-2018), at least 11 earthquake records should be used and the two perpendicular horizontal components of these acceleration records should be simultaneously acted on in the direction of the X and Y principal axes of the carrier system. In addition, a maximum of three acceleration records from the same earthquake should be used [7-11]. 11 different earthquake records were selected to analyze with the calculation method in the time history. These records were taken from the Earth motion database of the Pacific Earthquake Engineering Research Center (PEER) and scaled [12].

3. Modeling of The Structure

Our structure has been designed in accordance with the TBDY-2018 regulation, considering that C30/37 class concrete, B420C class reinforcement and S355 class steel cross are used. The foundation is not included in the calculations and the columns at the ground level are defined as built-in. Calculations and analyzes have gained worldwide reliability and the widely used Structural Analysis Program (SAP2000) is used [13]. The location where the building is thought to be was chosen in Eyüp district of Istanbul province and is shown in Figure 2. Ground class is determined as ZB.

Figure 2. The location where the designed building is thought to be [2]

Our building is designed to stand without collapse under the effects of earthquakes. The cross-sectional dimensions of the building are given in Table 1.

Table 1. Cross-sectional dimensions of the structure

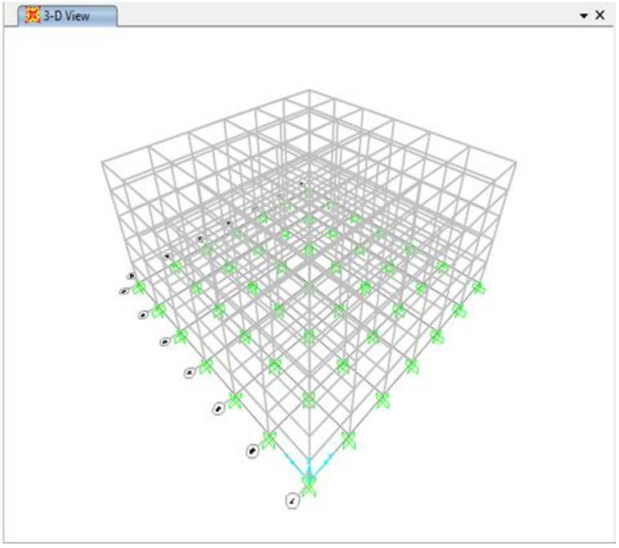
Material	Section
Column	50x50 cm
Beam	50x30 cm
Shear wall	30 cm
Slab thickness	15 cm
Steel cross	HE120A

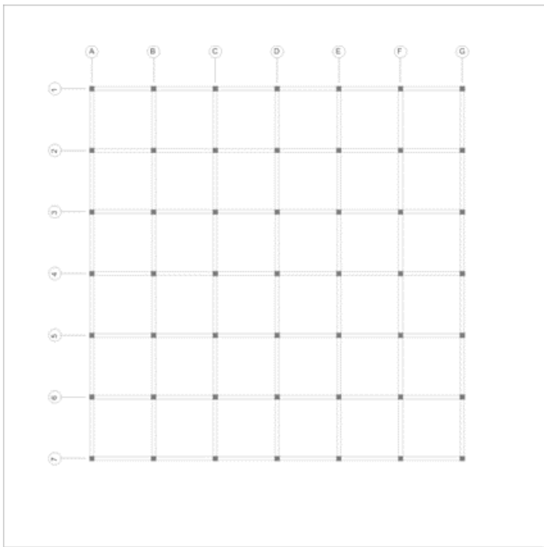
The structure is designed in a symmetrical square form in order to understand the analysis results more efficiently in terms of x and y. The floor heights are 3 meters equally on each floor and the column openings are 5 meters.

In Model 1, there are only reinforced concrete column and beam elements in the structure. Three-dimensional finite element model of the structure and two-dimensional structural system plans is shown in Figure 3.

In Model 2, there are reinforced concrete columns, beams and shear wall elements in the building. Three-dimensional finite element model of the structure and two-dimensional structural system plans is shown in Figure 4.

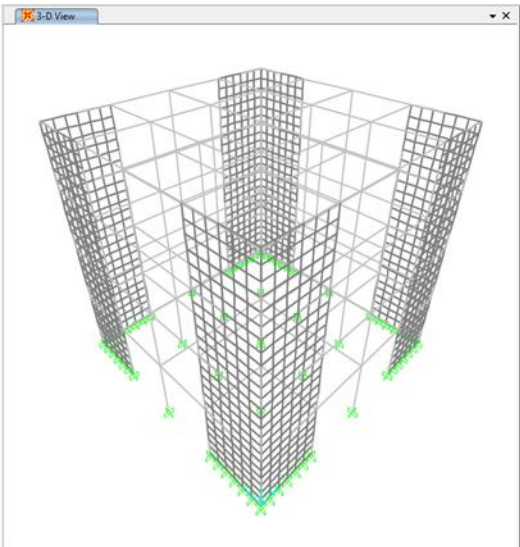
In Model 3, there are reinforced concrete columns, beams and steel cross members in the structure. Three-dimensional finite element model of the structure and two-dimensional structural system plans is shown in Figure 5.

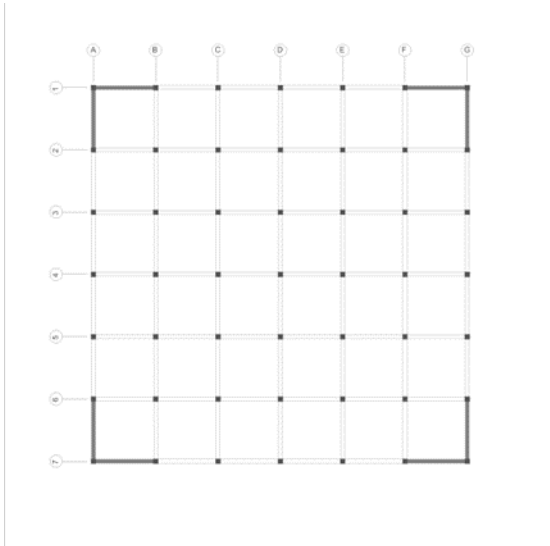




(a) (b)

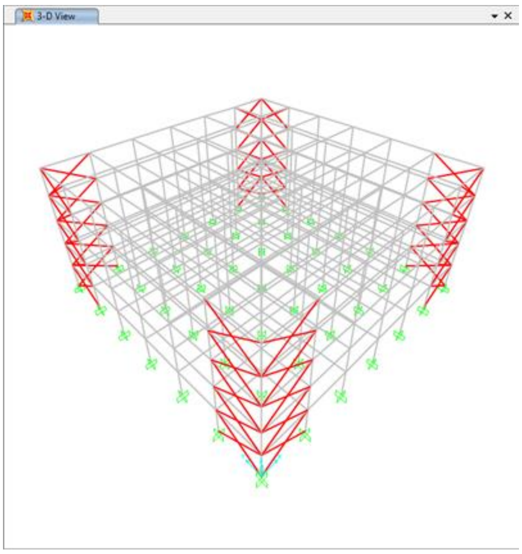
Figure 3. Model 1's (a) three-dimensional finite element model and (b) two-dimensional carrier system plan

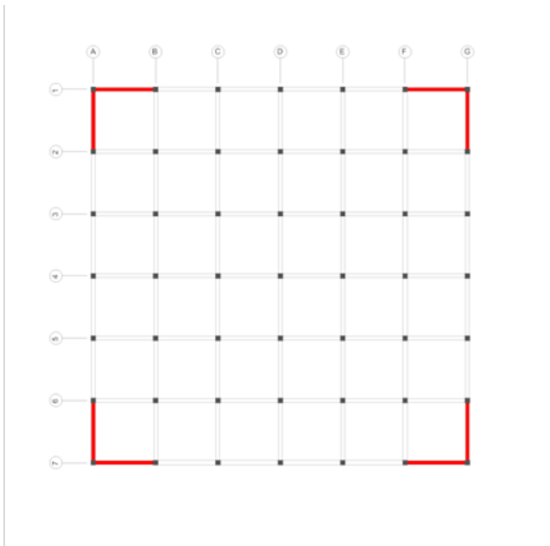




(a) (b)

Figure 4. Model 2's (a) three-dimensional finite element model and (b) two-dimensional carrier system plan





(a) (b)

Figure 5. Model 3's (a) three-dimensional finite element model and (b) two-dimensional carrier system plan

4. Results

The period values obtained as a result of the analysis of our structure is shown in Figure 6. Since the first two modes of our structure are symmetrical, the first modes are equal in the x and y directions, and the third mode is torsion.

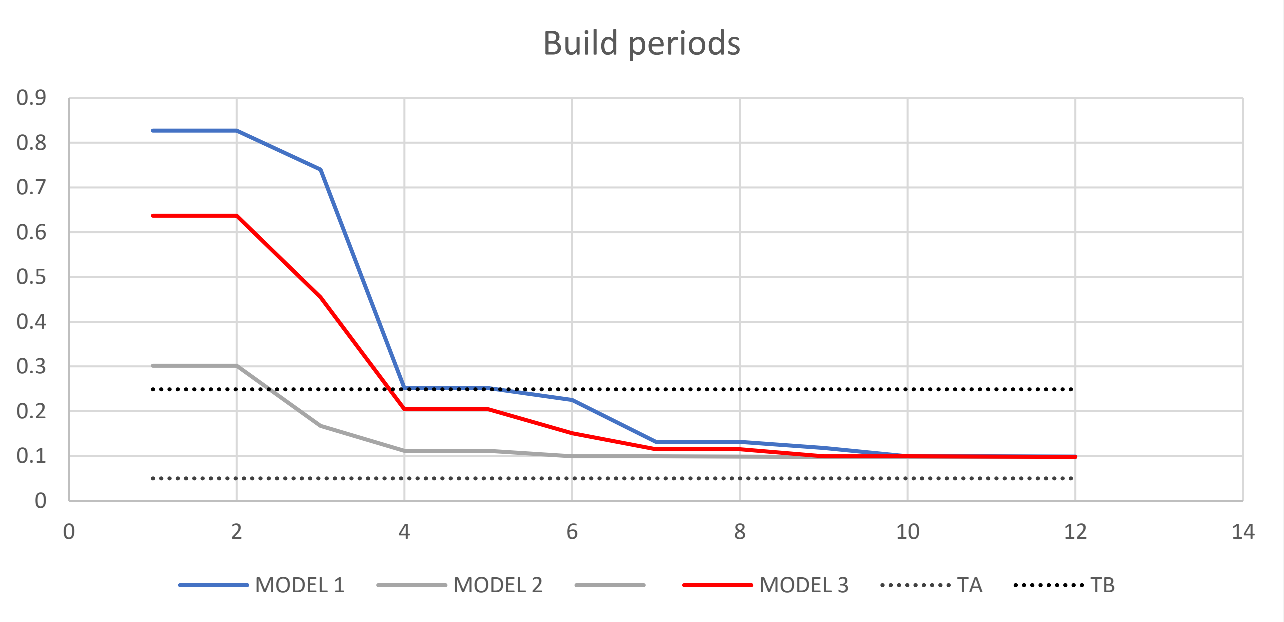


Figure 6. Modes of analyzed systems

Base shear forces determined as a result of 11 different earthquake records of the building are given in Table 2. In the model, in which steel cross elements are used instead of reinforced concrete walls, decreases in base shear walls forces are observed.

Table 2. Base shear forces determined as a result of 11 different earthquake records of the building

Models	Fx + (kN)	Fx - (kN)	Fy + (kN)	Fy - (kN)
Model 1	734.98	703.56	1030.9	1263.65
Model 2	4164.33	4153.07	4397.34	4520.31
Model 3	1724.63	1802.44	1826.72	1930.43

As a result of 11 different earthquake recordings of the building, the section effects affecting the corner column at the ground level are given in Table 3.

Table 3. Section effects of the building determined as a result of 11 different earthquake records

Models	P + (kN)	P – (kN)	V2 + (kN)	V2 - (kN)	V3 + (kN)	V3 - (kN)	M2 + (kNm)	M2 - (kNm)	M3 + (kNm)	M3 - (kNm)
Model 1	937.49	937.49	15.82	16.62	28.06	22.48	62.02	49.93	32.23	33.20
Model 2	937.50	937.51	14.69	14.99	15.23	15.12	31.98	31.81	30.64	31.21
Model 3	937.50	937.50	29.52	27.98	31.60	29.39	64.48	60.76	61.98	57.68

5. Conclusion and Discussion

As a result of the limited research and analysis, the reinforced concrete system model without shear walls, the system model with reinforced concrete shear wall, and the system models in which steel cross are used instead of shear walls in reinforced concrete structures have been examined. The analyzes made give us many parameters and provide data that can lead to many researches. As a result of the data obtained from the analyzes, it is seen that there are situations where steel can better meet the earthquake effects in structures in systems where steel cross is used instead of shear wall in reinforced concrete buildings. By developing these models and similar models, the structures can be strengthened against earthquakes by using steel elements in reinforced concrete structures. As a result, more earthquake resistant buildings can be constructed. The results obtained in this study are not yet completely finished and will be developed.

Acknowledgement

This study was partly presented at the 4th Advance Engineering Days [14]. We would like to thank Res. Asst. Fezayil Sunca for sharing his knowledge in building design and analysis.

Funding

This research received no external funding.

Author contributions

Muhammed Mustafa Eser: Investigation, Visualization, Analysis, Writing **Hüsnü Can:** Examination Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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