# Reconstruction of a Damaged Region in Antakya with Seismic Isolation Technology

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**Abstract:** Eleven provinces along the East Anatolian fault line have been severly affected from the Pazarcık M7.7 and Elbistan M7.6 earthquakes which occured in Kahramanmaraş, Türkiye on February 6, 2023. Many buildings in these provinces were totally collapsed. However, it is observed that several buildings located in the vicinity of the collapsed buildings which received adequate engineering services either sustained controlled damage or did not receive any damage at all in accordance with their design target. It is clearly observed that bearing soil conditions have a significant effect on the level of damage to buildings during these earthquakes. Most of the buildings that were destroyed or severely damaged during these earthquakes were built on very weak soil such as alluvium. However, it is another fact that the centers of the cities were located on soft soil near rivers or plains having agricultural value. In this case, it is clear that the first attempt to be made is to reconstruct the cities where they used to be. It is also of great importance that the city center of Antakya, which is known to have an important value in terms of the Middle East history and the history of religions is included in the UNESCO World Heritage List. Hence, the city has to be reconstructed in the place where it is used to be. Considering the importance of the methods to be developed using high technology to increase the earthquake performance for the construction of the city center, a pilot study is conducted by choosing an existing zone with 9 apartment blocks at the city center. For this purpose, a block in Antakya General Şükrü Kanatlı Quarter with 9 buildings consisting of 5 and 8 floors is chosen as the pilot project region. A method has been developed to reconstruct these 9 structures in the region with seismic isolation. The foundation, insulator and plinth floors of the pilot region are designed as a single monolithic base and separate residential blocks placed on it. Basement floor consists of parking lots and shops. This study offers an economical solution that is safe against earthquakes, solves the parking problem of the blocks, and enables using infrastructure services of the central region of the city by preserving the current location and silhouette of the region, seismically protected with advanced technology.

**Keywords:** Seismic Isolation Technology, Earthquake Performance, Kahramanmaraş Earthquake, Antakya

# 1 Introduction

## 1.1 Brief History

Antakya is the center of Hatay province near Syrian border in southeast Türkiye. Its history goes back thousands of years and it is an important city that has hosted many civilizations. Antakya's 2500+ year history is among the most eventful, brilliant and tragic in a region where such histories are commonplace.

Seleucus I Nicator (321-281), successor to the empire of Alexander the Great, laid out a plan for this city about 300 BC. It became the capital of the Seleucid Empire stretching from Macedonia nearly to India. The empire facilitated trade, and Antioch became an important point on the Silk Road, with caravans of luxury goods bringing fabulous wealth and a scandalously sybaritic lifestyle. Remnants of this can be seen at Daphne (Harbiye).

Under the Romans, Antioch-ad-Orontes was the capital of the province of Syria with a population around 500,000. It became one of the empire's greatest cities—only Rome and Alexandria were greater—with a considerable Jewish community. Saint Peter came here to preach, and Saints Paul and Barnabas used it as their base for missionary work. Converts from the local Jewish community were many, but it was here that the saints decided to expand their mission to Gentiles as well, calling their followers Christians.

Antioch flourished under the Byzantines until in the 500s a violent earthquake ruined it, killing 200,000 people. Later overrun by the Persians, then the Arabs (700s) and the Seljuk Turks (1084), it regained importance under the Crusaders (1098) as the capital of their Principality of Antioch, but conquest by the Mamelukes in 1268 saw its utter destruction.

What the Ottomans claimed in 1516 was only a shadow of its former self, and it later declined to just a village.

After the collapse of the Ottoman Empire following World War I, Ottoman Syria, including Antakya, was placed under French Mandate government. By a plebiscite in 1939 it was returned to Türkiye along with the entire Sanjak of Alexandretta, the province now called Hatay.

Hatay province is famous for its natural beauties and rich cuisine, as well as being under the influence of different civilizations throughout history. Today, the city is called the 'Meeting Point of Civilizations'…

## 1.2 Earthquake History of Hatay Region

Hatay province is one of the most affected regions by the great earthquakes that took place in Türkiye. At least 15 of the 100 major earthquakes experienced in the last 2,000 years in Türkiye's history occurred in Hatay. In a recent study, according to the records kept from ancient times to the 1900s, the number of effective earthquakes experienced by mentioning Antakya's name is over 30. To understand the earthquake hazard in the eastern Mediterranean, we first look at the motion of the tectonic plates in the region. The relative motion of Arabian, Eurasian and African plates generates complex fault systems in Anatolia. The continental collision causes N-S compression in eastern Türkiye and transforms faults because of the westward motion of Anatolia with the additional rollback force of the Hellenic subduction. The left-lateral Dead Sea Fault Zone (DSFZ) and the East Anatolian Fault Zone (EAFZ) meet at the Maraş Triple Junction (MTJ) in eastern Türkiye. The EAFZ extends 600 km from Hatay in the southwest to Karlıova in the northeast and has about seven segments. There are also several left-lateral active strike-slip faults in the region, such as Malatya, Sürgü, Çardak, Savrun and Sarız. Furthermore, the Bitlis-Zagros Suture Zone (BZSZ) is the main thrust boundary between Eurasia and Arabian plates. According to historical records, the region suffers from destructive earthquakes.

Some important earthquakes that have occurred in the history of Antakya are listed below in chronological order.

- February 22, 115 Antakya Earthquake: The earthquake that occurred in 115 destroyed a significant part of Antakya and caused a great disaster.
- September 458 Antakya Earthquake: It is stated that approximately 80,000 people died.
- 525 Antakya Earthquake: This earthquake destroyed the historical city Antakya to a great extent. According to historical records approximately 250,000 people died.
- 17 September 1091: Fortress walls and 90 villages were demolished.
- May 29, 1169 Amik Plain Earthquake: It caused great destruction in Antakya and Bakras castle.
- 1822 İskenderun Earthquake: Many houses were damaged along with the last remains of Seleukeia Pieria.
- April 1872 Amik Lake Earthquake: While there were 3000 houses in total in the city, 1960 houses were destroyed in the earthquake.
- February 6, 2023 Earthquakes: In two major earthquakes with magnitudes of 7.8 and 7.5, more than 50,000 loss of life was experienced in Türkiye only.

## 2 Features of the Region

### 2.1 Geology, Topography and Geomorphology

The intense tectonic feature in Antakya and its surroundings caused different soil characteristics to emerge in a short distance. These soils are classified as weakest, weak, less solid, moderately sound and solid soils according to their reactions in a possible earthquake.

The graben area and the fill areas along the streams are the weak and weakest soils. In a possible earthquake, soil amplification, liquefaction, rupture, settlement and landslides are the soils where the shake will be felt the most. Bedrock horst areas in the east and west of the Graben consist of less solid, moderately sound and solid soils. Due to the soil properties, the intensity of a possible earthquake will be less felt than the weak and weakest soils. Moderately solid and solid soils are located on the western slope of Habibineccar Mountain.

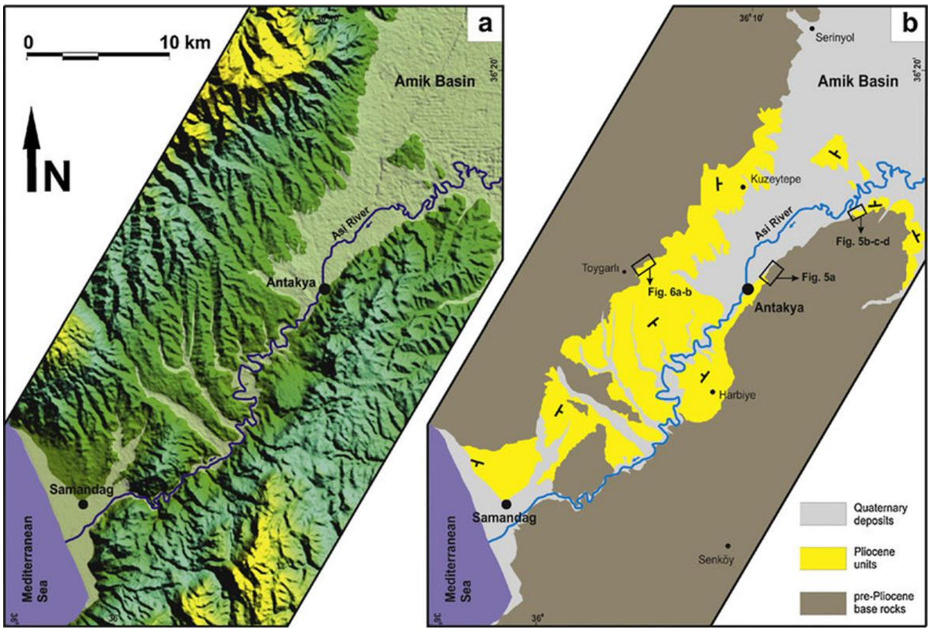


**Fig. 1.** Evoluation of the northern Dead Sea Fault Zone in southern Turkey [1].

During Miocene times, the Arabian and Anatolian plates collided, forming a foreland basin associated with flexurally controlled normal faulting. During the Late Miocene there was a transition from extension to transtension (oblique extension). The Neotectonic Hatay Graben formed during the Plio-Quaternary in a transtensional setting. In the light of modern and ancient comparisons, it is suggested that contemporaneous strain was compartmentalized into large-scale normal faults on the graben margins and mainly small-scale strike-slip faults near the graben axis. Overall, the graben reflects Plio-Quaternary westward tectonic escape from a collision zone towards the east to a pre- or syn-collisional zone to the west in the Mediterranean Sea [2].

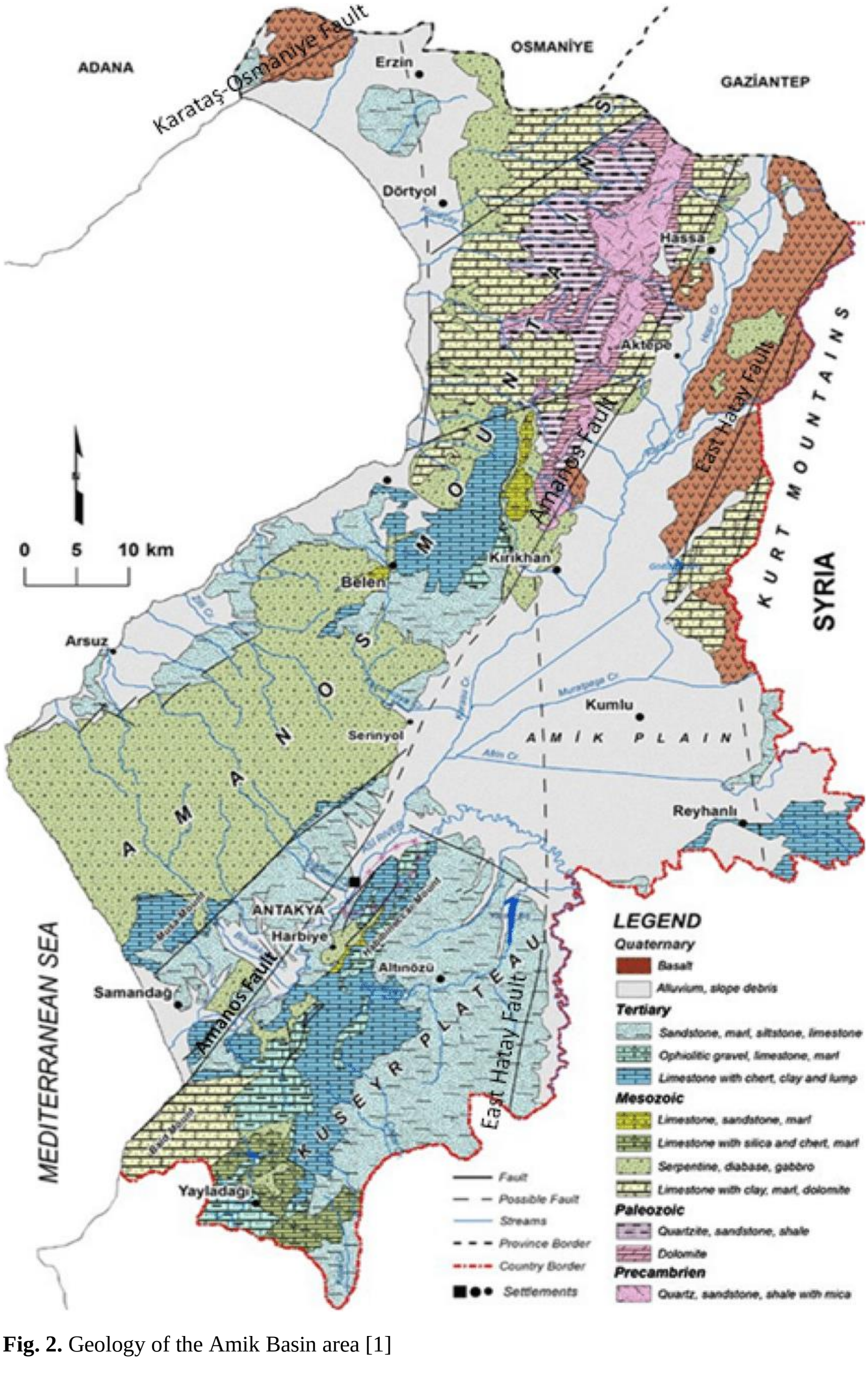


**Fig. 2.** Geology of the Amik Basin area [1]

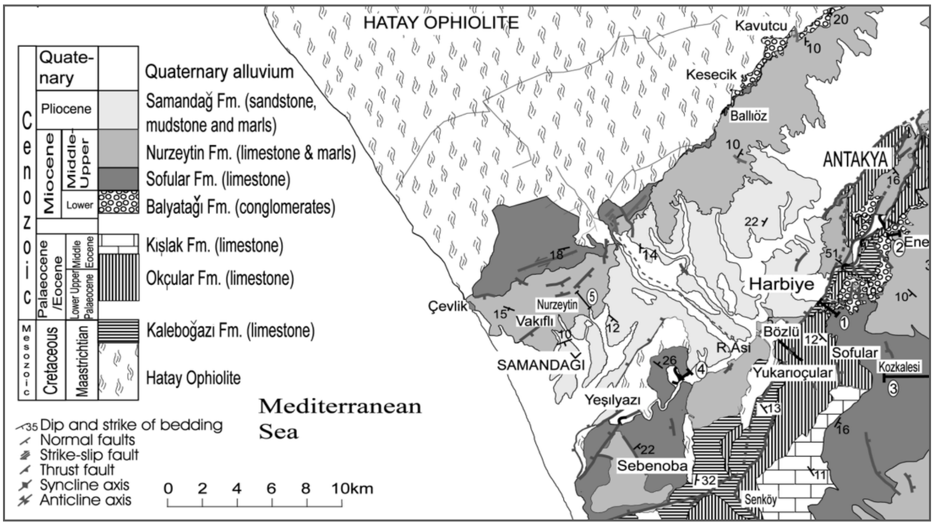


**Fig. 3.** Geology-lithology map of Antakya [3]

## 2.2 Effect of Geomorphology on Settlement

Geomorphological structure of a region has an important effect on the selection of the settlement areas of cities. Unplanned urbanization is an inevitable problem in cities that are formed without considering the geomorphological structure of the city. However, it is another fact that the centers of the main cities were located generally on soft soil near rivers or plains having agricultural value and easy to settlement. The most brutal example of this settlement situation is the city of Antakya (Fig. 4 and 5). The city is located on a water-saturated alluvial layer, which is completely weak and has limited load bearing capacity. It is clearly observed that bearing soil conditions have a significant effect on the level of damage to buildings during these earthquakes.

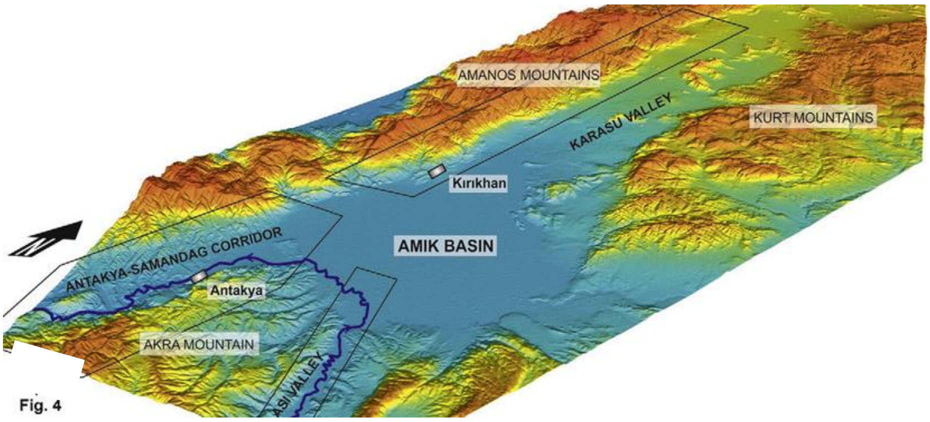


**Fig. 4.** 3-D digital topographical model of the Amik Basin area [1]

## 2.3 Tectonics of the Hatay Region

The Hatay region is located at the northeastern corner of the Mediterranean Sea and lies in an intersection domain between the East Anatolian Fault Zone (EAFZ), the Dead Sea Fault Zone (DSFZ), and the Cyprus Arc and its on-land extension (Figure 5). This domain accommodates the relative motions of Arabia/Anatolia, Africa/Arabia, and Anatolia/Africa.

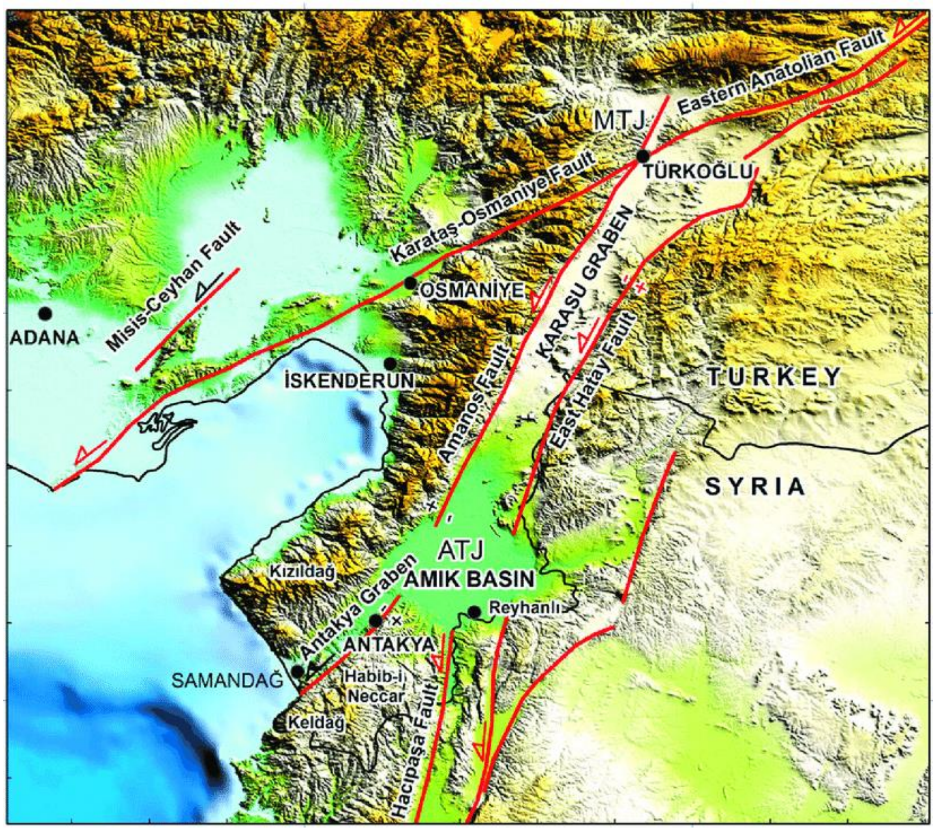


**Fig. 5.** A digital elevation model for Hatay and its surroundings, showing the major active faults and the morphotectonic units [4].

Active deformation in the eastern Mediterranean region, particularly in Anatolia, has occurred as a result of continental collision between the Afro-Arabian and Eurasian plates since the Late Miocene, following closure of the Neotethys oceanic basin at a collisional boundary corresponding to the Bitlis suture.

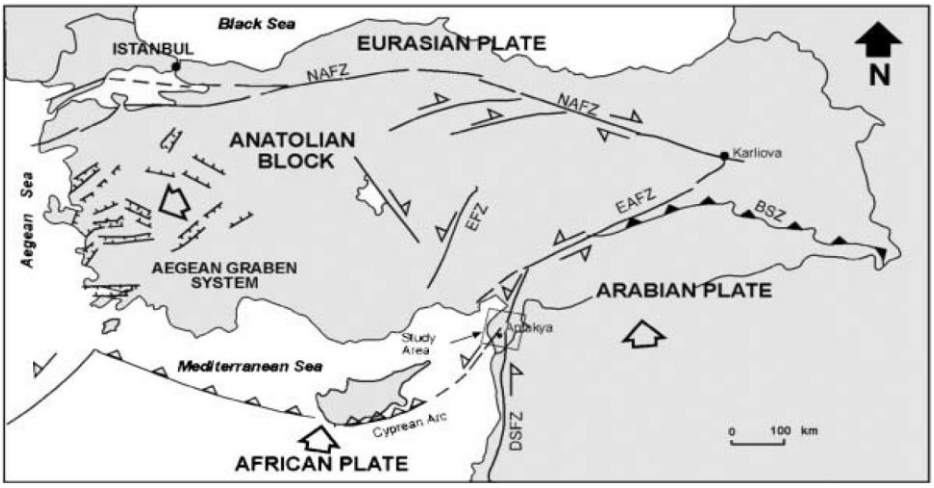


**Fig. 6.** Sketch map of the eastern Mediterranean tectonic framework

# 3 Rebuilding of the Cities After Disaster

## 3.1 The Fundamental Concept of City and Urbanism After Disaster

Cities are unique formations formed by the combination of different physical, social and psychological layers. The transition of people to a settled life, the provision of urban memory and continuity have caused them to establish a bond of belonging with the place where they live and to claim the place they live in.

All kinds of physical components, which are the space of the individual and urban life of the people of the city, are an important part of the life of the people. Therefore, any change made in the city affects the bond of the people living in that city with the city. However, the complete change in the location, plan and silhouette of the city causes the people who lived in that city or who somehow find their way to live in that city to break their bond with the past and their culture.

Two different ways can be followed for the rebuilding of cities after the earthquake: Leaving the old city and establishing a new city in a place where there is low earthquake risk, or to rebuild the city where it is already located.

Until today – with a few exceptions – cities have been rebuilt in their old locations after the earthquake. There are many reasons for this approach. These are briefly:

- Each region has a central location and cities were established in this central location. Changing it affects other connected cities as well, and there is a huge economic cost to change it.
- The necessity of re-establishing the transportation network to the city is a very important criterion.

- No matter how much destruction a city has seen, it is still a plus value that a significant part of the city has not been destroyed. Renovating the entire city is an expensive solution.
- The fact that the infrastructure is less damaged and usable compared to the buildings is an important reason for savings.
- People living in a city own property there and they have a commitment to that place. Therefore, they will not want to change it.
- People's commitment to their cities, and the sense of protecting their cultural assets are an important factor in front of many factors.

For these reasons, on-site reconstruction should be considered as the most important criterion in the rebuilding of the cities that were severely damaged after the earthquake. The creation of planned, robust, durable, sustainable and more livable cities is one of the most important factors in the treatment of the psychological and social destruction experienced by the people of the city after the earthquake.

### 3.2 Rebuilding of Antakya After Disaster

Antakya has been under the influence of different civilizations throughout its history and has a rich cultural heritage. There are many historical buildings and monuments in the city. These are very important for many different societies and religious. Only the historical and cultural background of the city of Antakya necessitates it to be rebuilt after the earthquake. It is necessary to bring the spirit of historical monuments back to the city without deteriorating. For this reason, it is a duty of humanity to revive the historical spirit of Antakya in the same place, even after the earthquake.

It is also of great importance that the city center of Antakya, which is known to have an important value in terms of the Middle East history and the history of religions is included in the UNESCO World Heritage List. Hence, the city has to be reconstructed in the place where it is used to be. For this reason, in the new planning of Antakya, going to the revival of the city is the most logical solution.

As a matter of fact, Antakya was almost completely destroyed 3 times in great earthquakes throughout history and was rebuilt in its old place.

It is very important that the methods to be applied for the rebuilding of the city have gained the trust of the people living there. For this reason, methods that have been tried but have not been proven successful and that are looked with suspicious should not be applied. The success of seismic isolation implementations in many hospitals in the region – despite all the erection mistakes – has been adopted by the public and even legendary. Considering that the two main reasons for the destruction of the city of Antakya in the earthquake are weak soil and poor construction quality, it is essential to implement a method that will eliminate these two factors at the same time. The method to be applied must also be appropriate for the re-planning of the city. In other words, the reorganization of the city in terms of planning should be considered as a good opportunity while it is being rebuilt.

# 4 Proposed Rebuilding Model for Antakya

## 4.1 Proposed Methodology: Implementation on the Basis of Plot (Block)

It is a reality that the city of Antakya be rebuilt where it is now. Based on this fact, a safe method should be applied in order to develop the current city plan of Antakya by considering contemporary criteria, but by preserving the basic elements and characteristics of the city.

A proposal methodology has been developed by applying seismic isolation technology on the basis of city blocks for reconstruction. It is a fact that the system, which has been implemented on a smaller scale in some countries in the past, can not be applied in the whole city, but in high-risk areas with very poor ground conditions in the center and in the reconstruction of important public and cultural (historical) structures.

The solution proposal to be implemented is expected to meet the following criteria:

- It should be adaptable to the pre-earthquake existing plan of the city.
- It should protect private and public property rights in the city.
- It is important to ensure that the city's existing – undamaged – infrastructure is used and meet the current regulatory needs (parking, fire, infrastructure, etc.).
- The general silhouette and character of the city should be preserved.
- It should also be applicable in historical areas of the city.
- It should be applicable on the weak ground on which the city is established.
- It should also be suitable for solving the city's parking, infrastructure and similar problems.
- It should be ensured that the number of independent units of the owners is maintained.
- It should be possible to build jointly with the Citizen-Government partnership model.

Considering the importance of the method to be developed using high technology to increase the earthquake performance for the construction of the city center, a pilot study is conducted by choosing an existing zone with 9 apartment blocks at the city center near Asi River with 5 and 8 floors is chosen as the pilot project city block. A method has been developed to reconstruct of these buildings in the block with seismic isolation technique. The foundation, isolators and plinth floors of the pilot block are designed as a single monolithic base and separate residential blocks are placed on it. Basement floor consists of parking, technical units and storages. This study offers an economical solution that is safe against earthquakes, solves the parking problem of the region, and enables using infrastructure services of the central region of the city by preserving the current location and silhouette of the region, seismically protected with advanced technology. This method can be applied to the historical monuments preservation and restoration implementation works.

### 4.2 Pilot Region

A pilot area is chosen to represent the region by being centrally located and one of the most influenced areas by earthquakes. Antakya Atatürk Avenue, being the busiest and most well-known part of the city, is an area with numerous buildings that suffered damage due to earthquakes. For this purpose, a block no 1992 in Antakya General Şükrü Kanatlı Quarter on Atatürk Avenue with 9 buildings.


**Fig. 7.** Plan View of the block no 1992 before and after earthquake. [5]

## 5 Structural Analyses of the Proposed System

### 5.1 General Approach

The seismic isolation approach relies on incorporating technological devices between the foundation and superstructure to enhance the structure's energy dissipation capability and flexibility. By implementing an isolation system, the structure can effectively absorb a portion of the earthquake energy, thereby mitigating the seismic forces transmitted to the superstructure. This is achieved by increasing the dominant periods of the structure [6]. The aim of this study is to investigate the performance of friction pendulum isolators for a block of buildings having different number of floors.

Isolators are placed between the two foundation layers in the form of a grid consisting of equal intervals in both directions, regardless of the column formation in the superstructure. The column loads acting from the top structural system are transfer to the insulators by the upper foundation layer.

Seismic isolators are placed between the lower and upper foundation layers. The upper foundation also forms the floor level of the basement floor. Four of the buildings have a total of 5 floors, while the remaining five buildings are designed with 8 floors above the isolator level (Fig. 8).

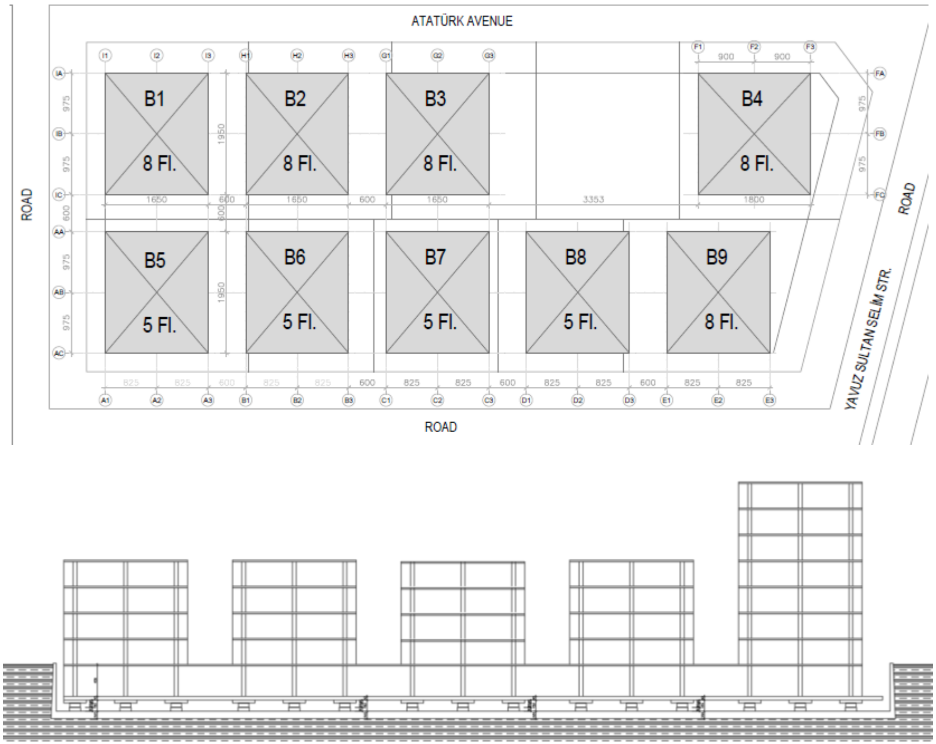


**Fig. 8.** The Plan and Section of the Block no 1992

## 5.2 Earthquake Loading and Analysis

While Design Basis Earthquake (DBE) was used for the evaluation of the base reactions, peak floor accelerations and inter-storey drift ratios, Maximum Considered Earthquake (MCE) was used for the evaluation of isolation system displacement. Nonlinear Time History Analysis (NTHA) was used to investigate the performance of seismic isolation under horizontal and vertical seismic forces.

Analysis was performed by selecting 11 ground motions having 2 horizontal and 1 vertical acceleration components. These 11 ground motions were selected by taking shear wave velocity (Vs30), type of mechanism, fault distances and soil conditions into consideration. Time-histories were scaled based on the target spectrum prepared in accordance with TBEC2018 for DBE and MCE separately. Directivity effects were considered in preparing target spectra given in Fig. 9 for DBE and MCE.

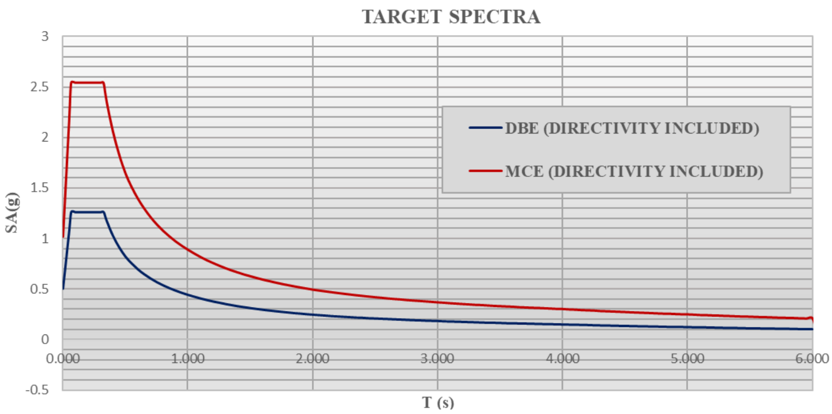


**Fig. 9.** Target Spectra for DBE and MCE

Matched and mean matched spectras for DBE and MCE are given in Fig. 10 and 11.

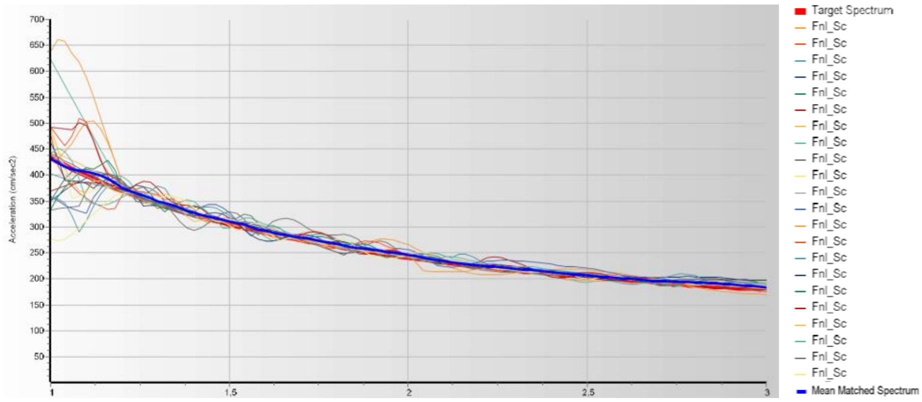


**Fig. 10.** Mean Matched Spectrum for DBE

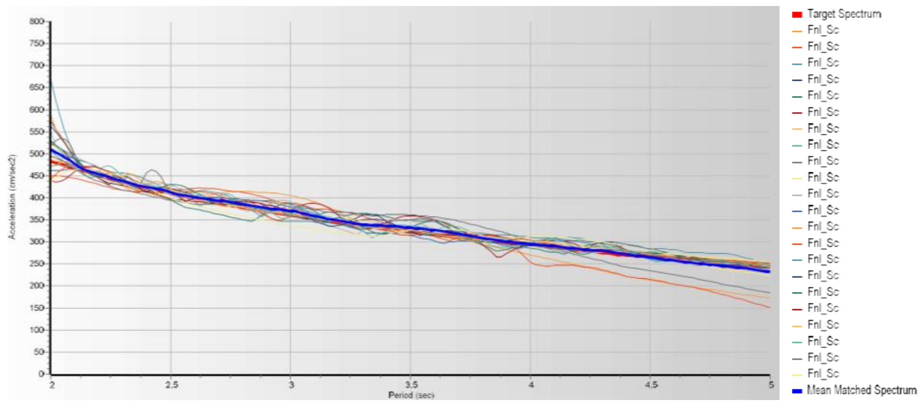


**Fig. 11.** Mean Matched Spectrum for MCE

### 5.3 Seismic Isolation System Design

The friction pendulum isolators possess two key mechanical characteristics: the radius of curvature (R) and the coefficient of friction (μ). The effective stiffness, R and μ of isolators are determined in accordance with Turkish Building Earthquake Code 2018 (TBEC2018). For this particular analysis, the nominal parameters for friction isolator were selected as 6 meters and 0.055, for R and μ, respectively.

The evaluation of various performance indicators was conducted using different boundary conditions. For the assessment of base reactions, peak floor accelerations, and inter-storey drift ratios under the Design Basis Earthquake (DBE) level earthquake, upper boundary conditions were utilized. Conversely, for evaluating the displacement of the system under the Maximum Considered Earthquake (MCE) level earthquake, lower boundary conditions were employed. The nonlinear nominal characteristics of the isolators used in these calculations are; TD= 2.55 sec, TM= 4.20 sec, DM= 88 cm, R= 6 m, and μ (nominal)= 0.055.

### 5.4 Structural Analysis

In this study, four parameters are evaluated to specify the behavior of the isolated structure underground motions such as; Isolation System Displacement, Base Shear Values, Inter-Storey Drift Ratio and Peak Floor Accelerations. Non-linear time history analysis was carried out to evaluate these behaviors.

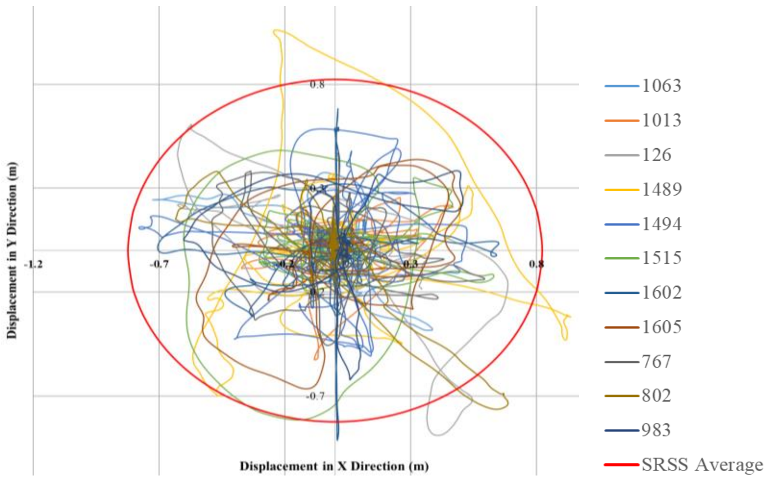


**Fig. 12.** Isolation System Displacement

**Isolation System Displacement**

The analysis of 11 ground motion records indicates that the mean displacement is 85 cm, which is found to be in accordance with the target design requirements. The results of this analysis, including the data from all selected 11 ground motions, have been illustrated and are visually represented in Fig. 12.

## Base Shear

Based on the results obtained from the Nonlinear Time History Analysis (NTHA), the base shear of the structure is determined to be below 15%. This finding implies that the lateral force applied at the base of the building during seismic events is within acceptable limits relative to the overall weight of the structure.

**Table 1.** Base Shear Values

| GM # | Base Shear | |
|---|---|---|
| 126 | 68613 kN | 16.92 % |
| 767 | 63890 kN | 15.76 % |
| 802 | 58011 kN | 14.31 % |
| 821 | 58267 kN | 14.37 % |
| 1004 | 60040 kN | 14.81 % |
| 1013 | 65627 kN | 16.19 % |
| 1063 | 59537 kN | 14.69 % |
| 1493 | 59835 kN | 14.76 % |
| 1515 | 57872 kN | 14.28 % |
| 1546 | 55522 kN | 13.70 % |
| 1605 | 59327 kN | 14.63 % |
| **Average** | **60595 kN** | **14.95 %** |

## Inter-Storey Drift Ratio

Based on the results obtained from the Nonlinear Time History Analysis (NTHA), the inter-storey drift ratios for 11 ground motion records are determined to be below 0.01 which requires the conditions in TBEC2018. The inter-storey drift ratios for selected 11 ground motion records are presented in Fig. 13 for 5 level and 8 level buildings.

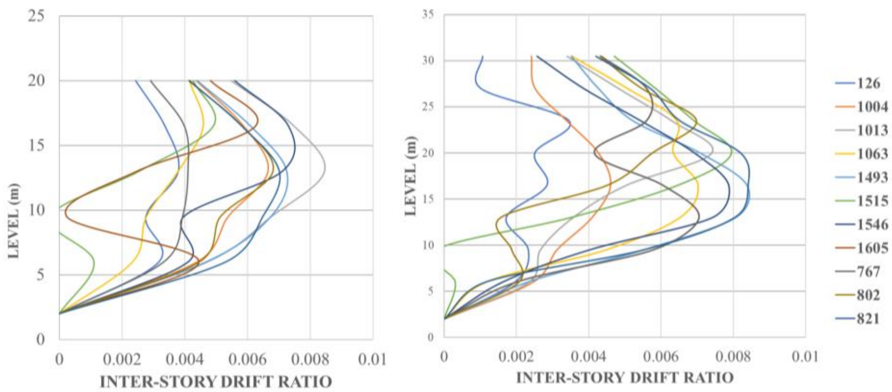


**Fig. 13.** Inter-Storey Drift Ratios for 5 and 8 Level Buildings

**Peak Floor Accelerations**

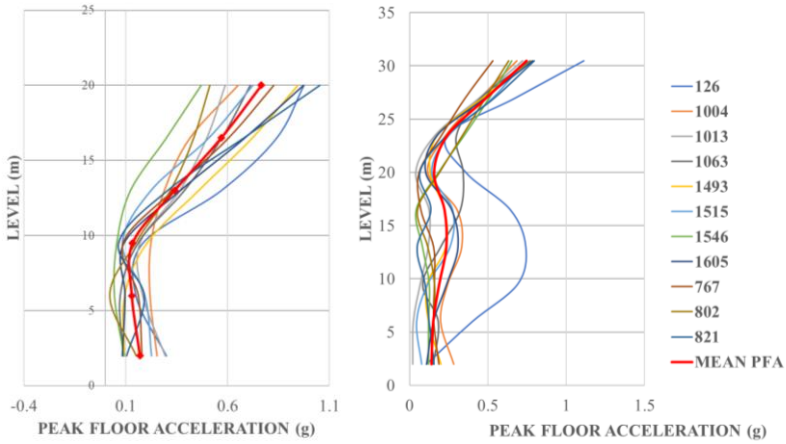


**Fig. 14.** Peak Floor Accelerations for 5 and 8 Level Buildings

For the basement, ground floor, and first floors: The mean peak floor acceleration remains below 0.3 g. This indicates that these lower levels of the structure experience relatively lower floor accelerations, which is favorable for structural integrity and the safety of occupants.

For the highest two floors: While the mean peak floor acceleration increases to 0.55 g for 5 storey building, the acceleration value reaches to 0.8g for 8 storey building. This indicates that the uppermost floors of the building experience higher accelerations during seismic events compared to the lower levels.

## 6 Possible Implementation Problems

Like any system, the proposed system may not be perfect. However, it is up to us to optimize it. Obstacles identified in this study and possible problems are given below:

- Seismic isolator devices are technological products. For this reason, one should be very careful in implementation and a serious control mechanism should be established under the coordination of the government to ensure this.
- It should be considered that rebuilding of the whole city by using seismic isolation devices may extend the construction duration. So, we propose partial implementation of this system.
- Incorporating a seismic isolation system can be an effective solution, particularly for short and mid-rise structures, to mitigate the impact of higher accelerations on the upper floors.

- The production of seismic isolators may not be sufficient for a mass application. Resources should be well analyzed and a time-spread application should be considered.
- The loss of property owners should be considered in the first place in all the work to be done. Therefore, a special study should be done.
- For the application in historical buildings, a team of experts should definitely be worked on. Sometimes the historical building foundations cannot be touched and it may be necessary to suspend them and bear on isolators.

## 7 Conclusions

In this paper the effect and the results of the 7.8 and 7.5 Mw magnitude earthquakes that occurred on February 6, 2023 on the structures in Antakya has been evaluated. Numerous buildings in the region have suffered severe damage, necessitating the reconstruction of the city to meet the housing needs of the people. Despite being located in an area with the highest earthquake risk, the most appropriate solu-tion is seen to be rebuilding the city in the same location with the aid of suitable engineering services to construct earthquake-resistant buildings. The buildings that remained undamaged or minor damage during the earthquake serve as evidence for this claim.

In the proposed new design, the nine structures will have a shared basement floor and will be equipped with seismic isolator devices to enhance their resistance to seismic events. It is envisaged that the new residential buildings to be built on the insulated base foundation will have a high-quality structural system with a controlled engineering application.

With this technological method, the people of Antakya will also feel the confidence of living in a safe house. This method can be considered as a continuation of the ‘urban transformation process’ that has been successfully carried out in our country in recent years.

To ensure seismic resistance in areas with high seismic risk, it is essential to minimize inter-storey drift ratios and floor accelerations in structures. This will enhance the building's ability to withstand seismic forces and reduce the risk of structural damage during earthquakes.

The enhancement of structure flexibility results in a reduction of floor acceleration; however, it leads to an increase in storey drift ratios, consequently posing a risk to non-structural elements which might suffer damage during seismic events. Conversely, augmenting the stiffness of the structure resolves the issue of inter-storey drift ratios; nonetheless, it gives rise to amplified floor accelerations and diminishes the seismic resistance capacity of the structure. Indeed, employing base isolation systems in buildings presents a practical solution to address the mentioned dilemma [7].

Additionally, implementing seismic isolation devices allows the construction of new buildings without disturbing the old texture of the city. Designing each 9 structures by using seismic isolation devices separately results in each building moving differently and the basement floors will be very inconvenient to use. Designing all structures together with a common basement floor and common devices provides seismic resilience to the buildings.

The fact that this seismic isolation application to be made in weak soil conditions will be applied on a large common mat foundation system without the need for soil improvement also minimizes the risk of liquefaction. In this system, there is no need for ground improvement, which will provide significant time and economic savings.

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