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COMPARISON OF SKYSCRAPER BUILDING DESIGN: ISOLATED FOUNDATIONS VS. NON-ISOLATED FOUNDATIONS

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Abstract

As the population grows, the need for safe and comfortable places to live and work increases. Tall buildings are becoming a popular option as they enable efficient use of urban space and provide solutions to the challenges of urbanization. However, the safety of these buildings against natural hazards such as earthquakes is crucial. Engineers are putting a lot of effort into the construction and design of tall buildings, some of which have been successfully completed, while others have been halted due to design difficulties. High-rise buildings have challenged engineers' endurance due to their height and number of floors. Efforts have been made to increase the resistance of tall buildings to natural factors and the weight of the building. One of the most important factors is the building's vibration movement, which must be resistant to wind, loads on the building, and earthquakes. One way to increase the strength of the building is to use isolated foundations. This article investigates whether using an isolated foundation has an effect on the strength of tall buildings. Two 51-floor tall buildings were designed, one with an isolated foundation and one without. The differences between the buildings were evaluated in terms of earthquakes, the greatest risk for buildings. Using the ETABS program and following international standards, these two buildings were designed to withstand the forces of wind, earthquakes, and loads on the building. The loads and forces caused by earthquakes, the resistances and possible damages of both types of buildings were also evaluated.

Keywords: ETABS, earthquake, Tall building, structural analysis, isolated and non-isolated foundation.

GÖKDELEN BİNA TASARIMININ KARŞILAŞTIRILMASI: İZOLATÖRLÜ VE İZOLATÖRSÜZ TEMELLER

Öz

Nüfus arttıkça, yaşamak ve çalışmak için güvenli ve rahat yerlere olan ihtiyaç artıyor. Yüksek binalar, kentsel alanın verimli kullanımına olanak sağladığı ve kentleşmenin getirdiği zorluklara çözüm sağladığı için popüler bir seçenek haline geliyor. Ancak bu yapıların deprem gibi doğal afetlere karşı güvenliği çok önemlidir. Mühendisler, bir kısmı başarıyla tamamlanan, bir kısmı da tasarım güçlükleri nedeniyle durdurulan yüksek binaların inşası ve tasarımı için büyük çaba harcıyor. Yüksek binalar, yükseklikleri ve kat sayıları nedeniyle mühendislerin dayanıklılığını zorlamıştır. Yüksek binaların doğal etkenlere ve bina ağırlığına karşı dayanımı artırılmaya çalışılmıştır. Rüzgara, binaya binen yüklere ve depremlere dayanıklı olması gereken en önemli etkenlerden biri binanın titreşim hareketidir. Binanın sağlamlığını arttırmanın bir yolu izole temel kullanmaktır. Bu makale, izole bir temel kullanmanın yüksek binaların dayanımı üzerinde bir etkisi olup olmadığını araştırmaktadır. 51 katlı, izole temelli ve temelsiz olmak üzere iki adet yüksek bina tasarlandı. Binalar arasındaki farklar, binalar için en büyük risk olan depremler açısından değerlendirilmiştir. Bu iki bina, ETABS programı kullanılarak ve uluslararası standartlara uygun olarak rüzgar, deprem ve bina üzerindeki yüklere dayanacak şekilde tasarlanmıştır. Ayrıca depremlerin oluşturduğu yükler ve kuvvetler, her iki yapı tipinin dayanımları ve olası hasarları da değerlendirilmiştir..

Anahtar Kelimeler: ETABS, deprem, Yüksek bina, yapısal analiz, izolasyonlu ve izolasyonsuz temel.

1. Introduction

Tall buildings are structures characterized by height and the number of floors. With the increase in population and urbanization, the construction of tall buildings becomes more common. The main reason for building tall structures is the need for optimal use of urban space and the desire to locate commercial and government buildings in prime locations.

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The history of tall buildings dates back to the late 19th century when the first tall building was built in Chicago, USA for insurance services. It was 10 stories high and 42 meters high. Nowadays, tall buildings often accommodate different uses such as shopping centers, restaurants, and offices in one place. These buildings offer many benefits including on-site amenities and the ability to add unique beauty to the city.

The construction and design of tall buildings are complex and require careful attention to the various forces acting on them, such as gravity and wind. One of the most challenging factors is the earthquake force. The height of the building, wind energy, its impact, and the type of foundation all play an important role in ensuring the building's stability against earthquakes and wind rigidity. Therefore, one of the important factors in the design of a tall building is the design of the building's foundation. Foundations are very important in the stability of the building in terms of bearing the full load of the building and also transferring the forces produced in the building to the ground. In addition, because foundations are the point of connection between the building and the ground, they also introduce the force of the earthquake to the building during an earthquake, and also the Wind force, which enters the building is transferred to the ground through the foundations. Naimi, S. & Peker, Ö. (2022),Therefore, foundations are a very important member in transferring power from the building to the ground and vice versa from the ground to the building. The most important of these forces is the force of the earthquake, which enters the building from the ground by creating vibrations in the building and destroys the building. The most destructive force is the force of the earthquake, and for this reason, scientists sought to change the foundations to control this force. In general, by controlling the vibration in the building, destruction can be prevented. The best option that scientists have been able to use to control the vibration caused by an earthquake is isolated foundations. Isolate foundations repel force with their elastic properties. isolate foundations prevent almost 90% of building destruction and increase the life of the building. The first 33-story tall building with an isolated foundation was built in the United States, . Kasalanati 2017 ,but as the number of floors increases, the design becomes more challenging.

The purpose of this article is to analyze the difference between two buildings with isolated foundations and non-isolated foundations and to examine the design and performance of these structures against earthquakes. The analysis will be based on relevant literature and studies Celikag, M. & Naimi, S. 2010.

2. Location and Features of the Building

This study focuses on a 51-story residential building located in the city of Istanbul. The building measures 42 meters by 32 meters, with an area of approximately 1344 square meters and a height of 163.5 meters. It was designed on two models: an isolated foundation and a non-isolated foundation, using building codes and standards such as ASCE , IBC, ACI, ASTM, FEMA and Uniform building codes. Steel Buildings 2016, ACI 318M-08, ASCE/SEI 7-16, A 615/A 615M – 04a, FEMA P-2082-1/ 2020, FEMA P-749 / 2010, IBC 2009, UBC 1&2. The article aims to analyze the design and performance of both models of the building against earthquakes. The research will evaluate the forces and loads caused by earthquakes, and the effect of these forces on the building's isolated and non-isolated foundations, to determine the building's strength and potential damages. The building designed in the ETABS program shows 2D and 3D models of the building in Figure 1 and Figure 2; the details are in Table 1.

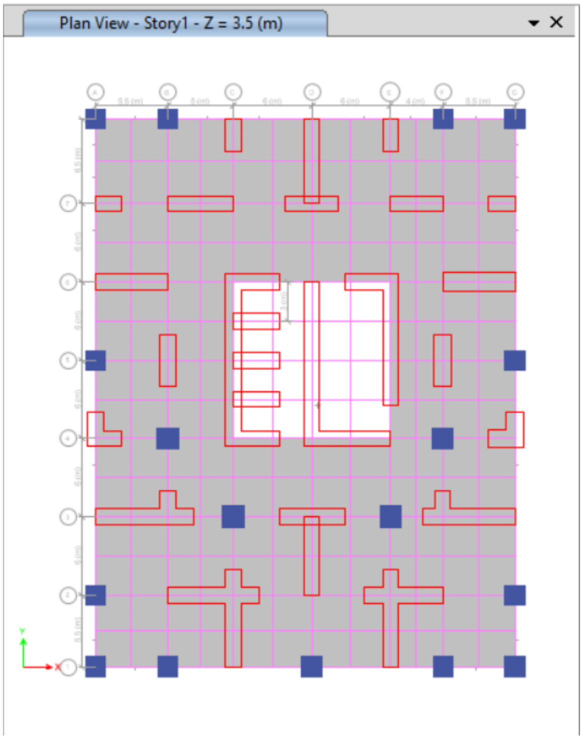

Figure.1: Two-dimensional design of the building

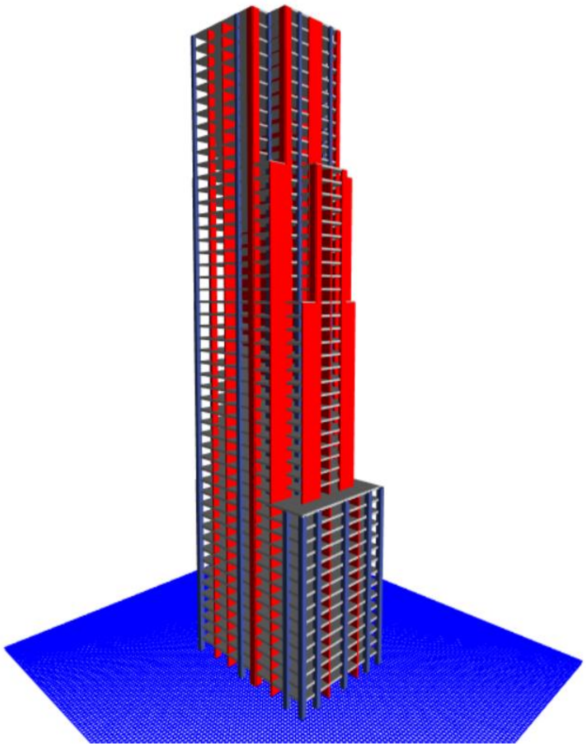

Figure.2: Three-dimensional model of the building

Table1: Building features

Building height	163,5 meter	Shear wall	70cm, 60cm, 55cm, 50cm
Area	42 x 42	Location	İstanbul
Ceiling type	Flat slab	Building foundation	Two Isolated and non-isolated types
Zone factor	0.4	Loads and forces	live load, dead load, super load, wind, earthquake
Soil type	SD	Beam	none
column	1x1m , 1.2x1.2m , 1.3x1.3m , 1.5x1.5m , 1.7x1.7m		

2.1. Dimensions and Details of the Building

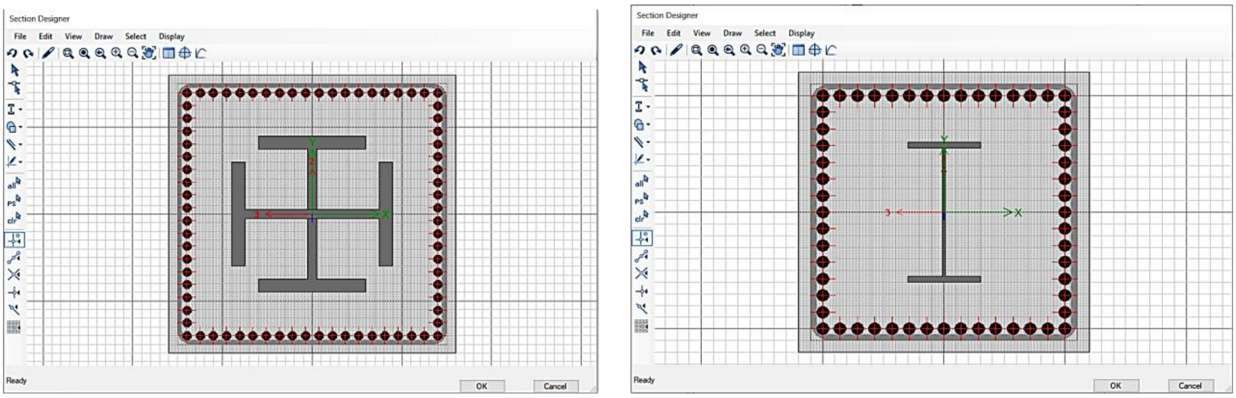

Figure. 3: (a) Sub view of composite columns used in the building with cross I shape steel **(b)** Sub view of composite columns used in the building with I shape steel

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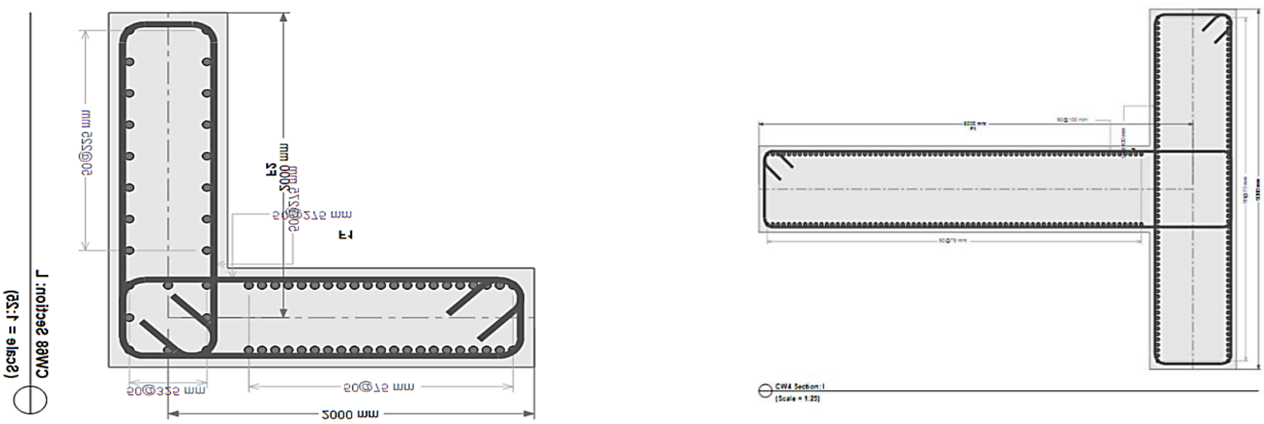

(a) **(b)**

Figure.4: (a) Sub view of T shape shear wall **(b)** Sub view of T shape shear wall

The ceiling of the building is designed as a flat slab, with a thickness of 47 cm, in accordance with international codes and standards. This thickness is calculated based on the dimensions of the building and the load-bearing capacity of the structure. The foundation of the building is also designed and analyzed in two ways: a non-isolated foundation and an isolated foundation. These designs will be discussed in further detail in other sections of the article.

2.2. Earthquake Design of Buildings

The first factor to consider in the earthquake-proof design of a building is the zone in which the building is located. This is because the intensity and frequency of earthquakes vary in different regions.

This building, which is located in the city of Istanbul, is designed and analyzed according to the 0.4 districts according to the zoning of the city of Istanbul. As per the map, the building is designed to withstand earthquakes in this zone by using the ETABS program. Olbak, M. & Naimi, S. (2016) The program takes into account the location of Istanbul, the number of earthquakes in the area, and the characteristics of the ground on which the building is built to design the structure's resistance to real earthquakes. IBC 2003, It is important to note that data on earthquakes and zone Factor 0.4 is inserted into the program during the design process and show in Figure 5. The design process also involves adjusting the building for earthquake resistance by using relevant literature and studies such as UBC1997, Karolya.ZalKa 2013, ACI 421.3R-15 W.F. Chen and J.Y. Richard Liew. p. cm.2002, https://tdth.afad.gov.tr.

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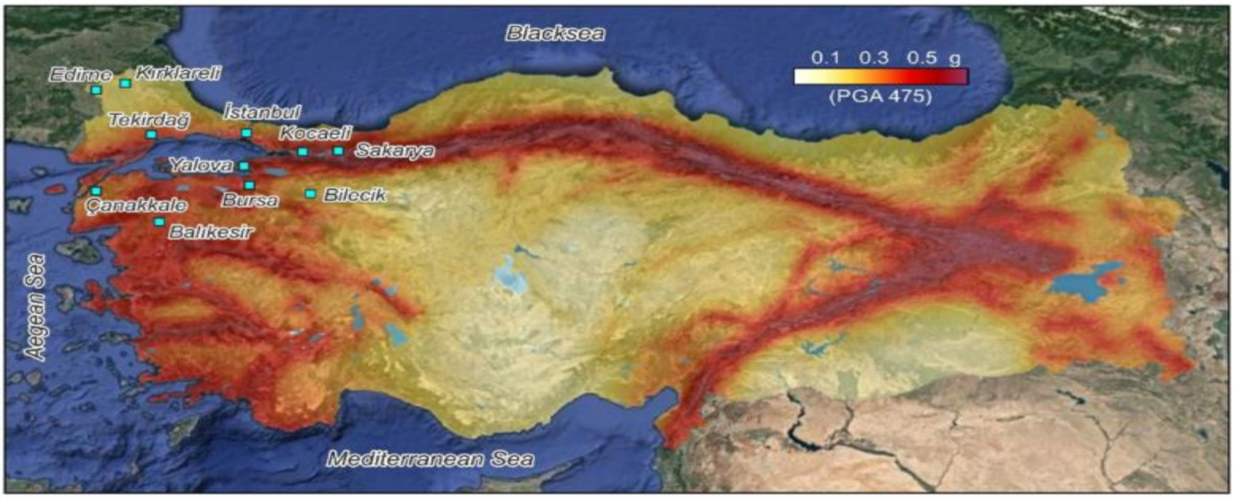

3. Earthquake Setting in ETABS Program

In the design process, all necessary data, including detailed data on earthquakes, wind, dead and live loads, and super load, must be entered into the program for accurate analysis. In the ETABS program, in addition to modeling the building, must set an earthquake in the program to check the building's resistance value. It can be said that the most important part of the design of a building is to adjust the earthquake to check the resistance of the building. To set the earthquake in the program, the required data must be entered into the program step by step, the last step which is shown in Figure 6, is the time history and the response spectrum, which were set in the previous steps, are matched together that the program can adjust the earthquake for the building.

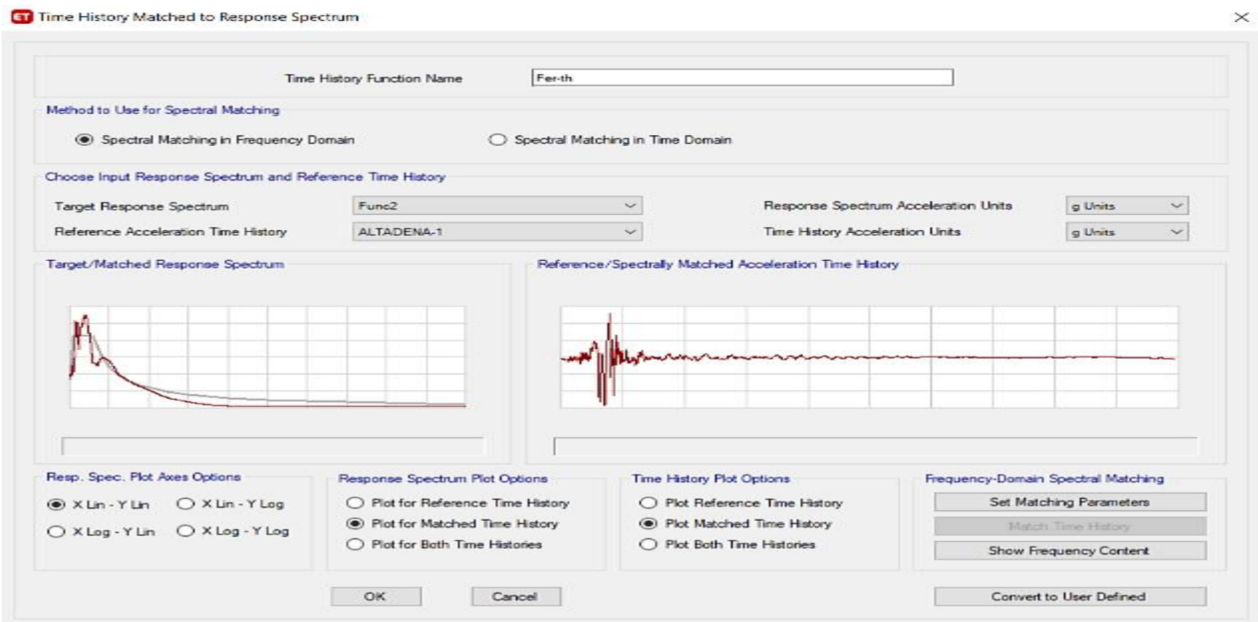

Figure 6: Spectral matching

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4. Isolation Design

As previously discussed, the main objective of this study is to investigate and compare buildings with isolated foundations to those without. In the preceding section, the building was designed with a non-isolated foundation, and all the seismic components and models of the building were analyzed and evaluated. In terms of isolated foundations, there are two types: those with metal-core isolators, known as LRBs show in Figure 7, and those without, known as HDRBs show in Figure 8 . HDRBs are less commonly used due to their high damping characteristics. This research will analyze the performance of the building using both LRB and HDRB isolators, and compared with non-isolated foundation and research studies, such as, Farzad Naeim Editor and James M. Kelly 1999, SEISMIC ISOLATION AND PROTECTIVE SYSTEMS 2010 and will be reviewed to analyze the performance of the building against earthquakes.images took from https://structurae.net/en/products-services/lasto-hdrb-high-damping-rubber-bearings.

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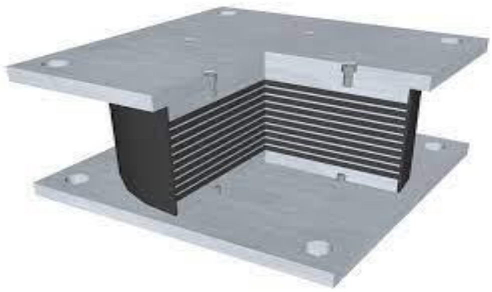

Figure 7: HDRB isolated

Figure 8: HDRB isolated

5. Rubber isolated design for isolated foundations

There are various methods for designing rubber isolators, and in this study, the Kelly and Farzad methods are primarily used. In addition to these methods, international codes are also applied to various aspects of the design, such as, Naimi, S. & Tufan, T. (2021), ASCE/SEI 7-10 /2010, Manufacturing Engineer's Reference Book / 1993, ACI 350.3-06 /2007, UBC 1997 6th edition, Bungale S. Taranath, Ph.D, 2010, Karolya.ZalKa 2013, A 955/A 955M – 01/ 2001, Sharad Manohar and Suhasini Madhekar 2015, G. R. Reddy · Hari Prasad Muruva · Ajit Kumar Verma 2019, W.F. Chen and J.Y. Richard Liew. p. cm.2002, Frederick S. Merritt 1994, Roger L 1999, R. Lagos, R. Boroschek, R. Retamales , M. Lafontaine , K. Friskel and A. Kasalanati 2017.

Zone details required factors

Sections

for Seismic Zone factor 4 = 0.4 ubc97 (8.1)
Soil type = SD ubc97 (8.2)
Seismic source type of the area = B (8.3)
Seismic coefficient = 0.64 Nv , Nv =1 so Cv = 0.64*1=0.64 (8.4)
Seismic coefficient = 0.44 Na , Na =1 ie Ca = 0.44*1=0.44 (8.5)
Na, near source factor 10 km = 1 (8.6)
Nv , near source factor 10km = 1 (8.7)
W= maximum structure weight in a column=40000 (8.8)
Shear stress of rubber = 100% = 1 (8.9)

Table 2: ASCE 7-10 damping coefficient and effective damping, ASCE/SEI 7-10, 2010

Damping coefficient, BD or BM	
effective damping, βD or βM	**BD or BM factor**
≤2	0.8
5	1.0
10	1.2
20	1.5
30	1.7
40	1.9
≥50	2.0

Effective damping for this earthquake is assumed to be between 5% and 10%, and 10% design for this:

βd = 10% so BD= 1.2 (8.10)

Effective damping = 10% =1 Use for U1, U2, U3.

Damping coefficient according to Table 1.2 = 1.2 (8.11)

Rubber details

Table 3: Manufacturing Engineers Manual, stiffness and elastic modulus, Manufacturing Engineer's Reference Book 1993

Hardness (IRHD ±2)	Young's modulus E0 (MN m^{-2})	shear modulus G (MN m^{-2})	K**	bulk modulus E∞ (MN m^{-2})
30	0.92	0.30	0.93	1000
35	1.18	0.37	0.89	1000
40	1.50	0.45	0.85	1000
45	1.80	0.54	0.80	1000
50	2.20	0.64	0.73	1030
55	3.25	0.81	0.64	1090
60	4.45	1.06	0.57	1150
65	5.85	1.37	0.54	1210
70	7.35	1.73	0.53	1270
75	9.40	2.22	0.52	1330

Choose a hardness of 75 due to the weight of the structure, therefore

Weight of the building on the Ceiling maximum value = 31838 KN (8.12)

Young's Modulus E0 = 9.40 Mpa (8.13)

Compression properties = 0.52 (8.14)

Heap Modulus, Eꝏ = 1330 (8.15)

REPLACEMENT DESIGN:

Td = Design time = 2.5 N/mm^2 (Mga) (8.16)

DD = 0.3313 (8.17)

Bearing effective hardness:

$$k_{eff} = \frac{w}{g}\left(\frac{2\pi}{TD}\right)^2 = \frac{31838}{9.81}\left(\frac{2\pi}{2.5}\right)^2 = 20500.12 \quad (8.18)$$

Energy consumed per cycle:

$W_D = 2\pi\, k_{eff} D_D^2 \beta d = 1413.77$ (8.19)

Force at design characteristic strength:

$Q = \frac{WD}{4Dd} = \frac{1413.77}{4*0.3313} = 1066.83$ (8.20)

Pre-yield hardness of rubber:

Kpre = 17279.99 (8.21)

Initial elastic stiffness of rubber:

Post Yield stiffness non-linear value used for U2, U3 ratio

$K_{post} = \frac{Kpre}{Kin} = \frac{17279.99}{172799.99} = 0.099 \cong 0.1$ (8.22)

Yield displacement (distance from end j):

Dy = 0.0068597 (8.23)

The new value of Q using Dy:

$Q_2 = \frac{WD}{4(DD - Dy)} = \frac{1413.77}{4(0.3313 - 0.0068597)} = 1089.39$ (8.24)

So the hardness of the lead core is:

$K_{c2} = \frac{Q2}{DD} = \frac{1089.39}{0.3313} = 3288.23$ (8.25)

K pre 2 = keff – Rc2 = 20500.12 – 3288.23 = 17211.89 (8.26)

lead core area

$A_{LC} = \frac{Q}{Fy*10^3} = \frac{1089.39}{10*10^3} = 0.109\ m^2 = 109 mm^2$ (8.27)

lead core diameter:

$D_L = \sqrt{\frac{4Alc}{\pi}} = \sqrt{\frac{4*0.109}{\pi}} = 0.3725m$ (8.28)

Total rubber thickness :

$tr = \frac{DD}{\gamma} = \frac{0.3313}{1} = 0.3313$ (8.29)

Lead rubber bearing area

$A_{LRB} = \frac{K\ pre\ 2(tr)}{G} = \frac{17211.89*0.3313}{2.22} = 2.5686 m^2$ (8.30)

LRB Diameter :

DLRB = 1.80 m (8.31)

Horizontal stiffness:

$K_H = \frac{G*ALRB}{tr} = \frac{G*ALRB}{tr} = 17211.87$ (8.32)

Consider the horizontal time period:

$\omega = \frac{W}{KH} = \frac{31838}{17211.87} = 1.85$ (8.33)

Bearing diameter = 1.80m (8.34)

Single layer rubber thickness:

$t_0 = \frac{DLRB}{4S} = \frac{1.80}{4*13.94} = 0.03228m = 32.28mm = 33mm$ (8.35)

Total rubber thickness :

Tt = 0.37 m (8.36)

Thickness of shim plate Tp:

Tp = 14.3mm (8.37)

Bottom + rubber total thickness :

$h = 0.484$ m (8.38)

Lead to tip steel plate Cover thickness: 160mm

Total thickness of LRB:

$Ht = 2 * 160 + 484 = 0.804$ m (8.39)

moment of inertia of LRB:

$I = \pi b4/64 = \pi 1.84/64 = 0.515$ (8.40)

6. Isolate Setting in Application

As outlined, all relevant factors have been considered in the design process. The area of the rubber and the amount and height of the steel required for the design have been calculated. Using these values, the isolated foundation program can be used to design and add the isolated system to the structure. As can be seen in Figure 9, the calculated values are inputted into the program.

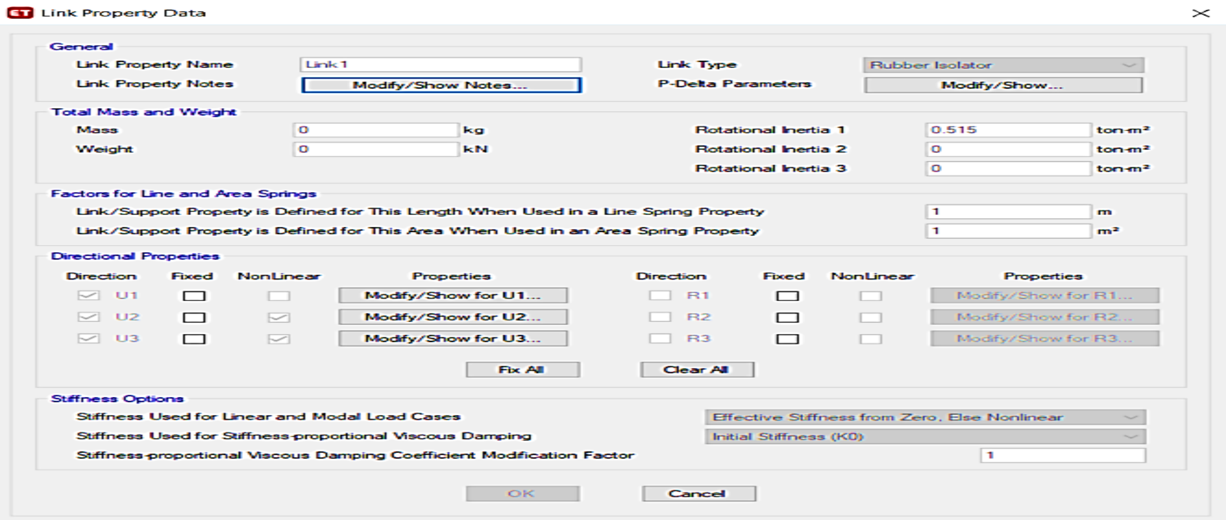

Figure 9: The values obtained from the formulas for the isolated design are entered into the ETABS program

7. Comparison of building with and without insulated foundations

In this section, the building's performance is analyzed under both isolated and non-isolated foundation conditions, with regard to the forces acting on the building. As seen in the graphs presented, the building's isolated foundation allows for better resistance to the forces acting on the building. Additionally, the stress on the building's components is reduced when compared to a non-isolated foundation. In the case of a non-isolated foundation, the columns of the building experience a significant amount of stress, and the structure is under a high level of resistive stress. This is not observed in buildings with isolated foundations. It can be concluded that an isolated foundation increases the building's strength and stability against earthquakes and other forces.

The building's high rigidity in the fixed base condition causes excessive pressure and movement in the building due to its height. This results in excessive pressure on the columns and shear walls and leads to severe damage to the building. However, in the isolated foundation case, these displacements are greatly reduced by the forces. The

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reduction in movement is especially important in a building of this height and contributes to the building's safety and longevity. The comparison and difference between the isolated foundation building and the non-isolated building can be seen in the graphics obtained from the program, as shown below Naimi, S. & Kaya, S. (2020).

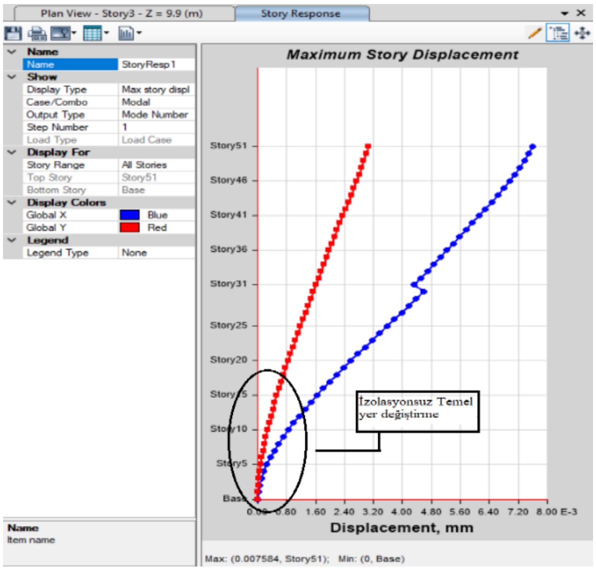

Figure. 10: Foundation d isplacement without isolated

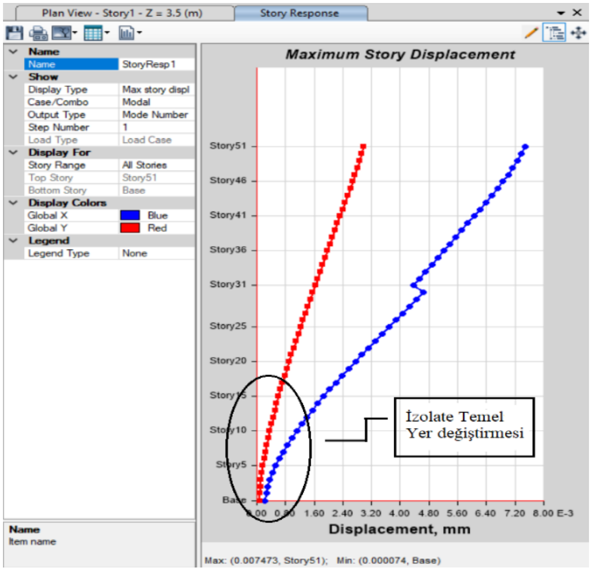

Figure. 11: Isolate foundation displacement

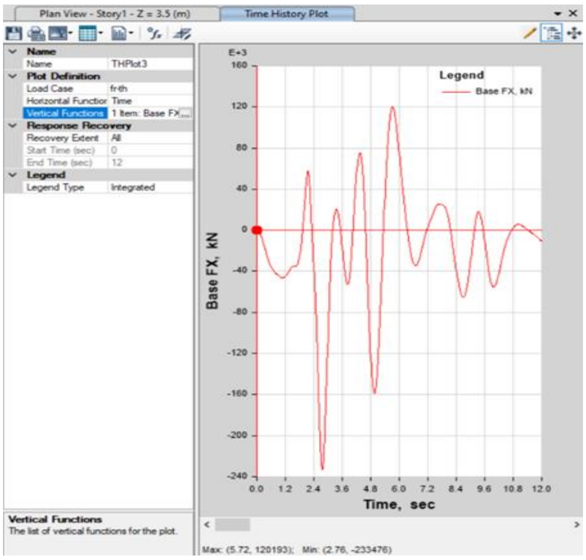

Figure. 12: Basic Time History without isolated

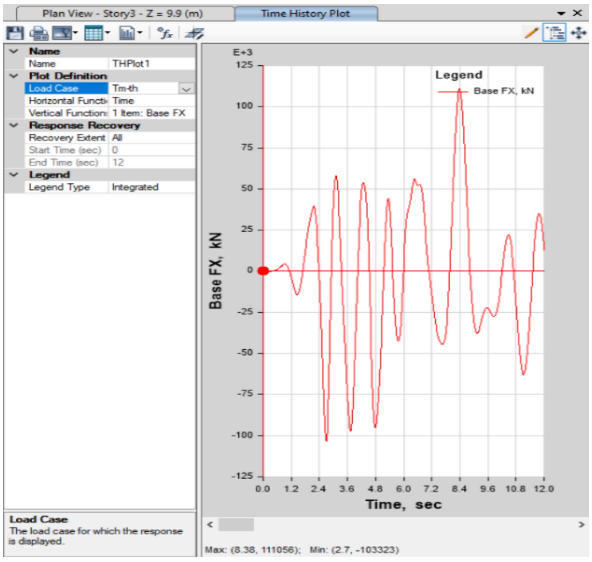

Figure. 13: Basic Time History with isolation

Conclusion

During this research, two buildings, one with an isolated foundation and the other without, were designed and compared, with the only difference being their foundations. The analysis of the first building without isolation, using the data obtained from the ETABS program, revealed a significant amount of stress and pressure on the columns and the overall structure. The penetration of earthquake and wind forces into the building resulted in a low level of strength, and the likelihood of collapse in the event of an earthquake was very high, leading to the potential destruction of the building.

On the other hand, when the isolated foundation was designed and installed in a building with the same structural elements and a number of floors, the building's resistance to earthquake and wind forces greatly improved. As can be seen in the graphical representations, the building with an isolated foundation is able to better withstand these forces.

The statistics and the analysis of damage in buildings with and without isolated foundations reveal a significant difference. Buildings with isolated foundations have a much greater level of strength, ultimately reducing damage and increasing the safety and longevity of the building.

In conclusion, this research highlights the benefits of buildings with isolated foundations in terms of safety and damage reduction. Engineers will continue to strive towards reducing these factors, thus it is likely that isolated foundations will gradually replace traditional foundations in all engineering buildings and structures. Isolated foundations have been mainly used in tall buildings but they will also be used in low-rise buildings. As human tries to find ways to live a comfortable life, the invention of isolated foundations has paved the way for a better and safer living environment. Despite their widespread use in low-rise buildings, their use in tall buildings is still limited. However, as more and more research is conducted on the benefits of isolated foundations, we can expect to see an increasing use of isolated foundations in tall buildings in the future.

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