Proceedings of the 8th World Congress on Civil, Structural, and Environmental Engineering (CSEE'23)
Lisbon, Portugal – March 29 – 31, 2023
Paper No. ICSECT 146
DOI: 10.11159/icsect23.146

Investigation of the Separation Distance for Preventing Seismic Effects on Reinforced Concrete Buildings

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Abstract **-** In this paper, the importance of leaving a separation (earthquake joint) distance in the design against structural movements and the damages caused by earthquakes were examined. Possible collision and pounding scenarios between adjacent buildings that can occur through various combinations were presented by the help of figures. The consequences that may arise if necessary precautions are not taken were explained. Two adjacent buildings with different story heights and dynamic characteristics were modelled separately with ETABS software in accordance with Turkish Seismic Code (TBDY-18). In addition, earthquake analysis was performed. The building models consisted of two adjacent blocks. During the design reinforced concrete columns with beam slab system were modelled as structural members. Reinforced concrete columns and beams were implemented to the system as frame elements. It was clearly seen that the results obtained with the empirical formulas specified in the regulations and the results of the detailed analysis are not matching with each other.

Keywords**:** Seismic, Separation Distance, Reinforced Concrete, Structures

1. Introduction

The space that allows the parts of the building to move independently from each other and separates these parts from each other is expressed as "movement joint" or "separation gap" in the literature. In order to protect the structure and its elements, it is necessary to prevent damages that may occur due to various reasons by performing an extensive study and analysis. There are many structural movements, specifically earthquakes, among the elements to be considered during the design. By leaving optimal separation distances, it is possible to increase the tolerance of the structure against structural movements and to provide a safer position against many possible demolition.

Besides the destructive effects of earthquakes on the structures in different ways, structural factors can also directly affect the results of the earthquake. The geometric shape of the building, the static characteristics of the frame system, the height of the building, the number of floors, frame types, the type of building material (reinforced concrete, timber, steel), the rigidity or flexibility of the foundations and the static system, the positions of the center of rigidity and the center of gravity, and the structural details can change the effects of an earthquake. As can be seen in Fig. 1, earthquake poses a collision hazard on buildings located close to each other due to their characteristic features.

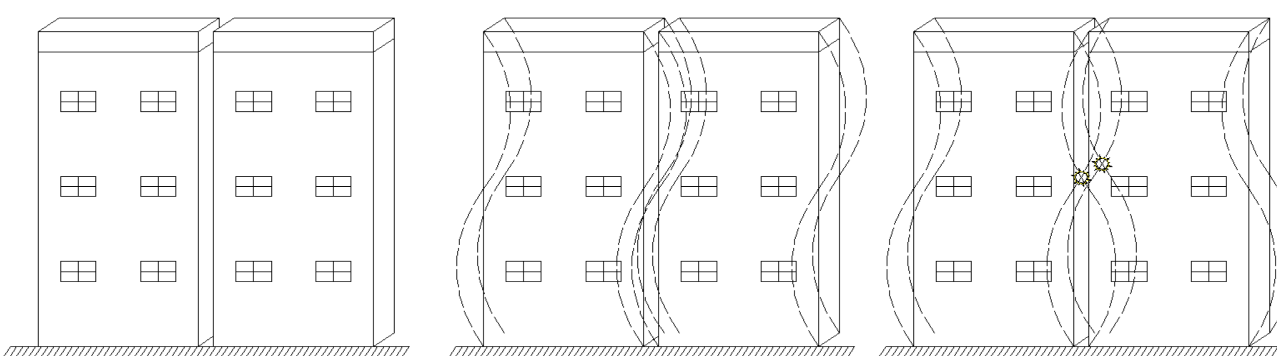

Fig. 1: Seismic interaction between adjacent buildings.

Mode shapes and periods of buildings with different dynamic characteristics such as mass and stiffness exhibit different behaviour under seismic effects. For this reason, it is possible that adjacent buildings make different displacements during the earthquake. As in Turkey, it is almost impossible to create a city layout from buildings with similar dynamic characteristics in complex city structures. For this reason, appropriate separation distances should be left between adjacent or neighbouring buildings to prevent collisions [1]. Some important studies on separation distance are given below.

The collision analysis of three adjacent buildings without leaving any gaps to prevent transfer of seismic effects was carried out in [2]. In their research, they concluded that the effects of collisions that occur as a result of structural movements during an earthquake are more severe in lighter buildings [3]. The significance of pounding effects due to the devastating effects of the 1985 Mexico City earthquake was investigated in [4]. In their study on the investigation of earthquake damage, it was determined that almost half of the structures were exposed to the negative consequences of pounding effects. They also stated that this earthquake is the seismic movement, in which the collision damage is most common. It was also stated that collisions occurred in 15 % of the collapsed structures and 40 % of the damaged buildings in this earthquake. The use of local connectors in order to reduce the effects of collision between adjacent buildings during earthquakes was researched in [5]. It has been observed that connecting the buildings at the top floor level prevents possible collisions. It has also been stated that by placing local connectors at floor levels between adjacent buildings, the impact of earthquakes can be reduced. The seismic impact of a low-rise building and a mid-rise building was investigated in [6]. Shaking table tests were performed on building models. According to their test results, the increase in kinetic energy during collisions was evaluated. [7] investigated earthquake-induced effects between adjacent structures, soil-structure interaction problems, and methods for reducing earthquake-induced forces. Based on the results of the Mexico City earthquake, a study was conducted which investigated how Taipei would respond to a similar seismic hazard [7]. As a result of their study, it has been determined that the city is vulnerable earthquake risk, and 708 (30%) of 2359 multi-story buildings built without sufficient distance in the city have smaller separation distances than necessary. In a research on the Loma Prieta earthquake, it was stated that there were many collision cases as a result of the earthquake [8]. During the investigations, they found out that 21 of the 38 structures suffered major structural damage due to the impact. In a study investigating the consequences of the Christchurch earthquake, it was stated that 22% of the buildings examined had impact effects and 6% had serious damage [9]. It has been stated that modern buildings face the risk of collision when constructed with rigid and hard materials that allow force transfer across building separations, and this risk can be reduced by using compression flanges placed in a building. They have concluded that most destructive results occur in masonry buildings. In the next section numerical example and the results are presented.

2. Numerical Example

2.1. Structural Model

The adjacent two-block building, which has different story heights and dynamic characteristics, was modelled separately with the ETABS program according to the Turkish earthquake standards [10] and earthquake analysis was performed. By the help of the analysis were made by considering the story displacements and the relative story drifts. In addition the amount of space that should be left to prevent collisions under possible earthquakes was investigated. In adjacent two buildings, the joint gap between the buildings is arranged in such a way that there is no collision according to the displacements found as a result of the earthquake analysis. The 3 story structural model used in this study for block A is shown in the right part of Fig. 2. On the other hand 4-story building model for block B is presented in left part of Fig. 2. Block B is placed in an antisymmetric way on the plan.

Fig. 2: Building Models of Block A & B.

2.2. Material Properties

The concrete and steel materials are chosen with respect to the Turkish Earthquake Standards. Mechanical properties of the materials are shown in Table 1.

Table 1: Mechanical Properties of the Materials.

Material	**Unit Weight (kN/m^3)**	**Unit Mass (kg/m^3)**	**Modulus of Elasticity (MPa)**	**Poisson Ratio**
Steel	0	0	200000	0.3
Concrete	25	2550	32000	0.2

2.3. Application of Dilatation between Block A & B

The two blocks are shown in Fig. 3 as a floor plan. The joint distance to be left between the buildings modelled separately from each other will be determined according to the analysis. Appropriate dilatation system is aimed by examining floor drifts and maximum displacements.

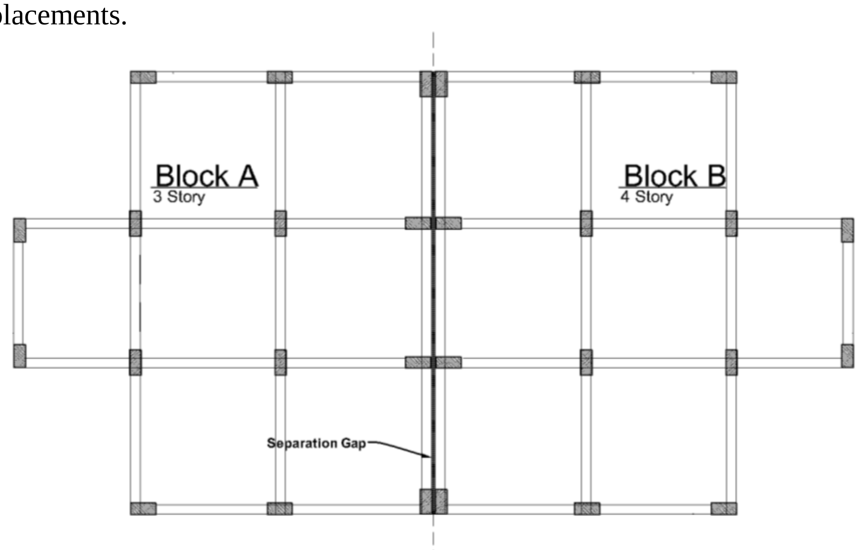

Fig. 3: Plan View of Blocks A and B.

2.4. Earthquake Spectra

While defining the horizontal elastic design acceleration spectrum, the horizontal elastic design spectral Sae (T) for an investigated earthquake ground motion level are defined by the expression given below. Here, S_{DS} and the design spectral acceleration coefficients and T is the natural vibration period. T_A and T_B are the control (corner) and T_L is the long-period or transition period. The horizontal design spectrums of the earthquake used in this study is in Fig. 4.

$$
\begin{aligned}
Sae(T) &= \left(0.4 + 0.6\frac{T}{TA}\right)SDS \qquad (0 \leq T \leq TA) \\
Sae(T) &= SDS \qquad (TA \leq T \leq TB) \\
Sae(T) &= \left(\frac{SD1}{T}\right) \qquad (TB \leq T \leq TL) \\
Sae(T) &= \left(\frac{SD1\,TL}{T}\right) \qquad (TL \leq T)
\end{aligned}
\tag{1}
$$

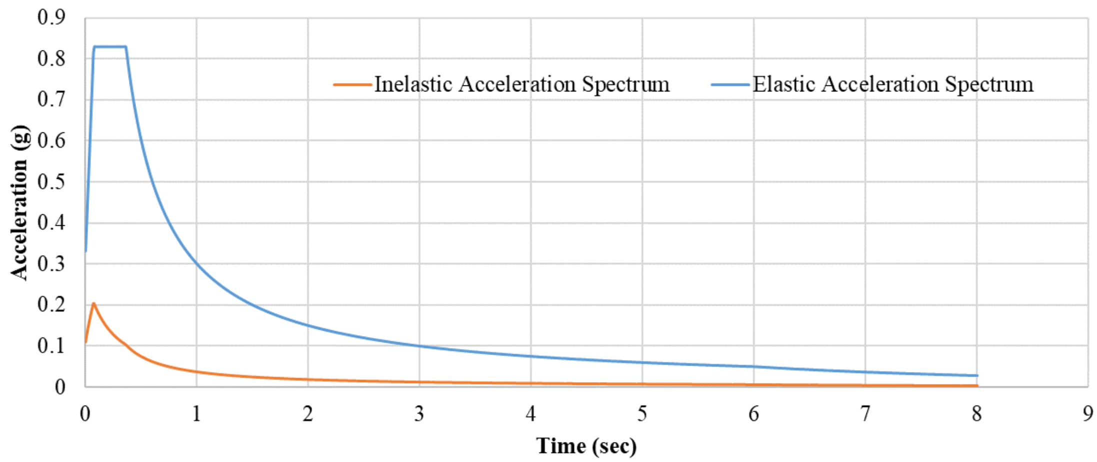

Fig. 4: Horizontal Acceleration Design spectrum.

The corner periods T_A and T_B are obtained as 0.103 s and 0.517 s in a respective way. Long period T_L is obtained as 6 s. The results of the analysis is given in the next section.

3. Results of the Analysis

The minimum separation distance to be left between the two blocks was determined as 99 mm as shown in Table 2. It is foreseen that the dilatation range to be selected above 99 mm will provide safety between blocks against maximum displacement movements and prevent possible collisions. In order to accept a value above the resulting displacements, this separation distance will be chosen as 100 mm in the next sections. The depiction of the blocks according to the expected floor displacement will be as given in Fig. 5.

Table 2: Total Displacements in Y Direction.

Story	Story Level (m)	Block A	Block B	$\sum u$
		Displacement Y-Direction (mm)	Displacement Y-Direction (mm)	
Foundation	0	0	0	0
First	3	14	15	29
Second	6	33	36	69
Third	9	45	54	99
Fourth	12	-	63	-

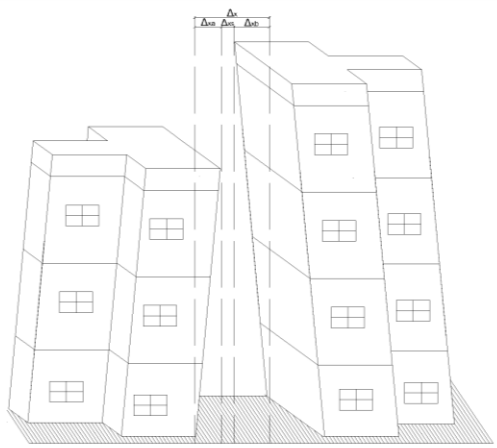

Fig. 5: Expected Floor Displacements of the Blocks.

The total displacements in X direction is presented in Table 3. When Table 3 is examined, it can be predicted that there is a risk of collision between the two blocks. And in case of different oscillations in the X direction, they will move away from each other in this direction and cause building damage at the roof connection points, especially due to the different number of floors. The analysis results of the modelled buildings show that, it is necessary to take precautions between these two blocks so that the floor displacements in the Y direction do not cause a collision. Considering the negative consequences that may arise, one of the most suitable methods is to use a dilatation profile (separation distance) between two buildings as depicted in Fig. 6.

Table 3: Total Displacements in X Direction.

Story	Story Level (m)	Block A	Block B	$\sum u$
		Displacement X-Direction (mm)	Displacement X-Direction (mm)	
Foundation	0	0	0	0
First	3	14	15	29
Second	6	33	36	69
Third	9	45	53	98
Fourth	12	-	63	-

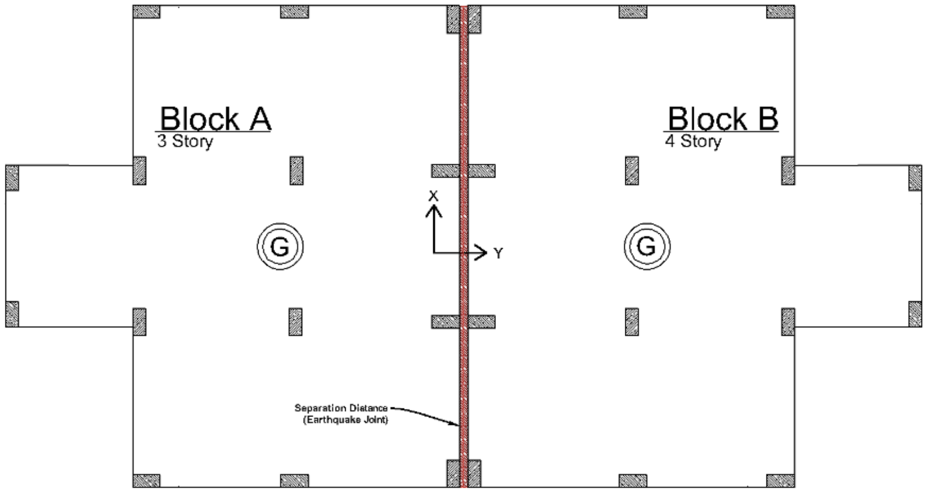

Fig. 6: Plan View of the Buildings.

The required earthquake joint distance was calculated and selected as 100 mm. This result was obtained by adding the maximum displacements in the same direction on the floors where the collision may occur. The displacement comparison of block A & B are shown in Fig. 7. The comparison between the required separation distance according to [10] and calculated separation distance in this paper is given in Fig. 8. Conclusions are presented in the next section.

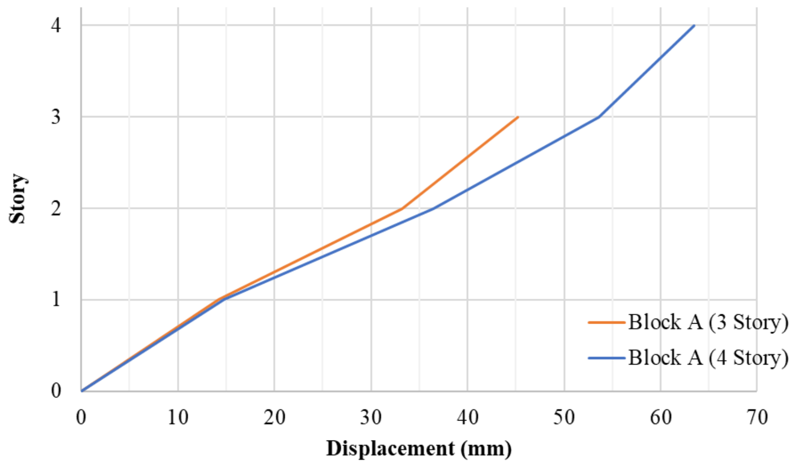

Fig. 7: Displacement Comparison between Blocks.

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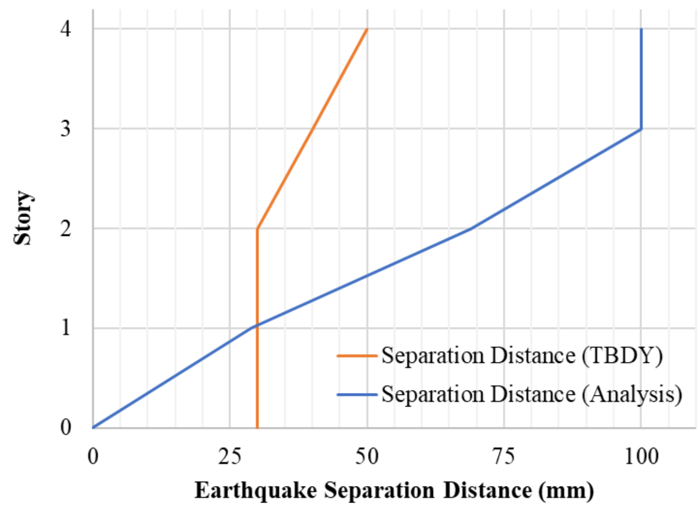

Fig. 8: Displacement Comparison with Turkish Standards.

4. Conclusion

When the earthquakes and their results are examined in detail, the danger we are in comes to light. While the losses experienced should have been a lesson, the results that emerged as a result of the earthquakes that occurred do not change and there are many losses due to these seismic events. In many earthquakes throughout history, collisions between buildings that did not have sufficient earthquake separation (joint) distance occurred. And as a result of these collisions, structures have experienced various types of damages ranging from slight damage to collapse.

In this paper separation distance obtained by summing the maximum displacements of two adjacent buildings in the same direction, is compared with the distance obtained according to the standards. And it is seen that there is a double difference between the two results. The most accurate and reliable thing to do is to perform a comprehensive research and to find the separation distance by using the data obtained from the analysis. This will help to prevent the tragic events that may occur during earthquakes and will prevent the damage of the structures. The differences of the separation distances between this study and standards are significant. Thanks to the data obtained in this study, it has been revealed that the results of the calculations for the separation distance recommended in the regulation will be insufficient and should be checked.

As a result, when constructing adjacent buildings, the earthquake separation distances given in the regulations should be carefully investigated. In addition the results obtained by analysing the displacement values of the building models should be compared thoroughly. Moreover the resulting data should be compared and the safe earthquake joint distance should be selected.

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