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Pounding Response between RC Buildings with Equal Heights and Different Dynamic Characteristics Considering Seismic Zone 1 of Turkey

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Abstract

Interactions between inadequately separated neighboring buildings have been repeatedly observed during earthquakes. These interactions may result in substantial damage or even total destruction of colliding structures during strong ground motions. This study focuses on investigation of pounding response between RC buildings with equal heights and different dynamic characteristics considering Seismic Zone 1 of Turkey. A collision between buildings is represented by a pounding model commonly used in the literature, which is a nonlinear elastic spring (Hertz model). In this study, the considered ground motion records are scaled according to design spectrum given for Seismic Zone 1 in Turkish Earthquake Code 2007 (TEC–2007). Neighboring buildings are modelled as a three-dimensional beam-column system which is a widely constructed building type in Turkey. Pounding analyses of the neighboring buildings are performed in time domain by aid of SAP2000 program. Pounding forces obtained from the analyses are used to investigate the pounding response between buildings RC buildings with equal heights and different dynamic characteristics considering Seismic Zone 1 of Turkey. The results presented in this study represents that gap values defined in TEC–2007 are insufficient.

Keywords: Pounding response, Hertz model, earthquake ground motions, TEC–2007.

1. Derece Deprem Bölgesinde, Aynı Yüksekliklere ve Farklı Dinamik Özelliklere Sahip Betonarme Binalar Arasındaki Çarpışma Davranışı

Öz

Son meydana gelen depremlerde, aralarında yetersiz derz boşlukları bulunan komşu binaların birbirlerinden etkilendikleri gözlemlenmiştir. Bu etkileşim, çarpışan binaların büyük depremler sırasında ciddi zarar görmelerine veya tamamen yıkılmalarına sebep olabilir. Bu çalışmada, Türkiye'nin birinci deprem bölgesinde, eşit yüksekliklere ve farklı dinamik karakteristiklere sahip komşu betonarme binaların çarpışma davranışları incelenmiştir. Binalar arasındaki çarpışma, literatürde sıkça kullanılan lineer olmayan elastik yay (Hertz modeli) çarpışma modeli ile temsil edilmiştir. Bu çalışmada, ivme kayıtları Türk Deprem Yönetmeliğinde (TDY−2007) birinci derece deprem bölgesi için verilen tasarım spektrumuna göre ölçeklendirilmiştir. Komşu binalar, Türkiye'de çok sık kullanılan üç boyutlu kolon kiriş sistemi olarak modellenmiştir. Komşu binaların çarpışma analizleri SAP2000 program kullanılarak zaman tanım alanında analiz yöntemiyle gerçekleştirilmiştir. Birinci derece deprem bölgesinde, eşit yüksekliklere ve farklı dinamik karakteristiklere sahip komşu betonarme binaların çarpışma analizleri neticesinde çarpışma kuvvetleri elde edilmiştir. Bu çalışmanın sonucunda, TDY–2007'de tanımlanan derz miktarlarının yetersiz olduğu anlaşılmıştır.

Anahtar Kelimeler: Çarpışma davranışı, Hertz Modeli, deprem yer hareketleri, TDY–2007

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1. Introduction

Recent studies have reported that pounding effects due to the relative displacements of adjacent buildings having different dynamic characteristics should not be neglected [1-8]. However, there is still not enough gap between adjacent buildings because of many reasons such as unplanned urbanization, to enable designers plan and design buildings one by one. The adjacent buildings with different dynamic characteristics experience different displacements during the earthquake. Therefore, the buildings should have sufficient gap. Otherwise, the buildings can be exposed to collision.

This study focuses on investigation of pounding response between RC buildings with equal heights and different dynamic characteristics considering Seismic Zone 1 defined in TEC–2007 [9].

In TEC–2007, there are two cases for minimum separation between adjacent buildings. In the first case, minimum value gap is 30mm up to 6m height. In the case is increased by a minimum of 10mm for each 3m height increment. In the second case, minimum value of gap is calculated by

$$d = \alpha.\sqrt{\Delta_{i1}^2 + \Delta_{i2}^2} \tag{1}$$

where Δ_{i1} and Δ_{i2} are the lateral displacements of buildings 1 and 2 relative to the ground at level i which are calculated by using response spectrum analyses of the buildings, respectively. α is a coefficient which depends on ductility ratios (R) of adjacent buildings and can be given by

$$\alpha = \begin{cases} R/4 & \textit{if all floor levels of adjacent buildings are same elevations} \\ R/2 & \textit{if any floor levels of adjacent buildings are not same elevations} \end{cases} \tag{2}$$

The biggest one of the two cases is taken into consideration in this study.

A collision between buildings is represented by a pounding model commonly used in the literature, which is a nonlinear elastic spring (Hertz model). In this study, the considered ground motion records are scaled according to design spectrum given for Seismic Zone 1 defined in TEC–2007. Neighboring buildings are modelled as a three-dimensional beam-column system which is a widely constructed building type in Turkey. Pounding analyses of the neighboring buildings are performed in time domain by aid of SAP2000 program [10]. Pounding forces obtained from the analyses are used to investigate the pounding response between buildings RC buildings with equal heights and different dynamic characteristics considering Seismic Zone 1.

2. Modelling of Collision between Adjacent Buildings

Pounding between adjacent buildings is simulated using the nonlinear elastic spring (Hertz model) shown in Figure 1. The force transmits from one structure to another by means of the nonlinear spring only when contact occurs. The force-deformation relationship of the gap element is given by

$$f_G(t)= \begin{cases} k_G\left[u(t)\text{-}d\right] & if \quad u(t)>d \\ 0 & if \quad u(t)\le d \end{cases} \tag{3}$$

where k_G is the nonlinear spring constant in the gap element. The constant is taken into consideration as 1,130,000kN/m for concrete-to-concrete impacts based on numerical simulation performed by Jankowski [6]. $u(t)$ is defined as $u_i(t)$-$u_j(t)$ if $u_i(t)$ and $u_j(t)$ are the displacements in the same direction of adjacent buildings. d is the initial gap between adjacent buildings.

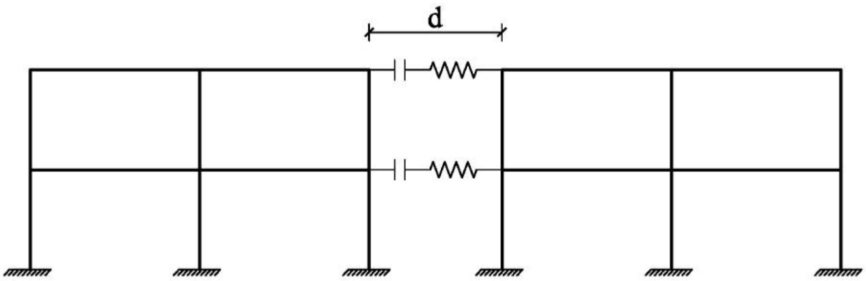


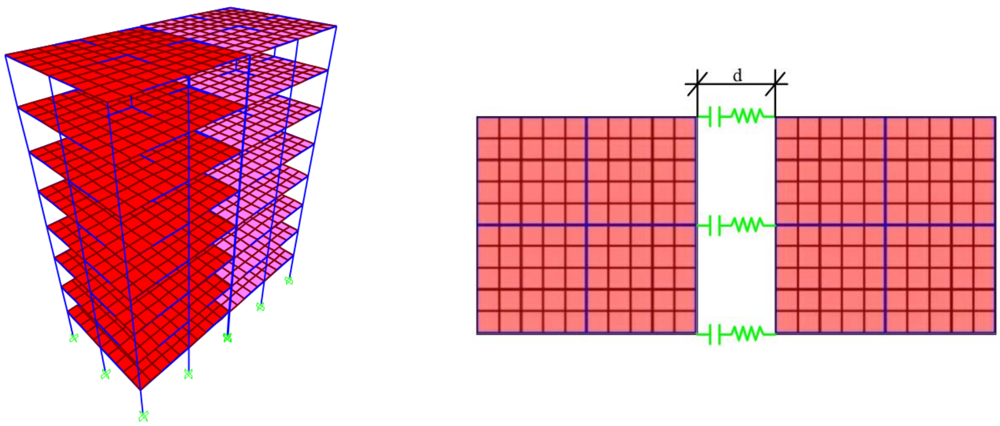
Figure 1. Pounding model (Hertz model)

3. Numerical Application

In this study, it is investigated pounding response between RC buildings with equal heights and different dynamic characteristics considering Seismic Zone 1 of Turkey. Seven finite element models are used to investigate the earthquake-induced pounding response of RC buildings. Model 1, Model 2, Model 3, Model 4, Model 5, Model 6, Model 7 have 2-stories, 3-stories, 4-stories, 5-stories, 6-stories, 7-stories, 8-stories, respectively. Gap values between adjacent buildings at all models are calculated according to TEC–2007 and given in Table 1. All seven models have two bays in X and Y–directions. The bay widths are 5.0m. Three–dimensional and plan views of a sample model are shown in Figure 2.

Table 1. Gap sizes according to TEC-2007

The gap sizes (cm)						
Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
3.0	4.0	5.0	6.0	7.0	8.0	9.0



a) Three–dimensional view **b)** Plan view

Figure 2. Three-dimensional and plan view of the buildings

The building on the right is heavier than the building on the left. The story heights in all models are 3.0m. The concrete is considered as C25 (f_{ck} = 25MPa). The Young's modulus and the weight per unit volume of concrete are 30×10^6kN/m^2 and 25kN/m^3, respectively. All column sections of building on the right is 100cm×100cm. Information about column sections of the building on the left is given in Table 2. In addition, the slab thickness at the buildings is 12cm and all beam sections are 25cm×50cm.

Loads are determined according to TS 498 [11]. In addition to the self-weight, a dead load of 1.5kN/m^2 is applied to all floors. The service live load is 2.0kN/m^2 on the normal floors, whereas the load is 1.5kN/m^2 on the roof floor. In addition, a wall load of 6.25kN/m is applied to the related beams.

Table 2. Column sections of the building on the left

	Column Sections of Left Building (cmxcm)											
Stories	**Model 1**				**Model 2**				**Model 3**			
	SC 1	**SC 2**	**SC 3**	**SC 4**	**SC 1**	**SC 2**	**SC 3**	**SC 4**	**SC 1**	**SC 2**	**SC 3**	**SC 4**
Ground	30×30	30×30	30×30	35×35	35×35	35×35	35×35	40×40	35×35	35×35	35×35	40×40
1	30×30	30×30	30×30	30×30	30×30	30×30	30×30	35×35	35×35	35×35	35×35	40×40
2					30×30	30×30	30×30	30×30	30×30	30×30	30×30	35×35
3									30×30	30×30	30×30	30×30
4												
5												
6												
7												
Stories	**Model 4**				**Model 5**				**Model 6**			
	SC 1	**SC 2**	**SC 3**	**SC 4**	**SC 1**	**SC 2**	**SC 3**	**SC 4**	**SC 1**	**SC 2**	**SC 3**	**SC 4**
Ground	35×35	35×35	35×35	40×40	35×35	35×35	40×40	45×45	40×40	40×40	40×40	45×45
1	35×35	35×35	35×35	40×40	35×35	35×35	35×35	40×40	35×35	35×35	40×40	45×45
2	35×35	35×35	35×35	40×40	35×35	35×35	35×35	40×40	35×35	35×35	35×35	40×40
3	30×30	30×30	30×30	35×35	35×35	35×35	35×35	40×40	35×35	35×35	35×35	40×40
4	30×30	30×30	30×30	30×30	30×30	30×30	30×30	35×35	35×35	35×35	35×35	40×40
5					30×30	30×30	30×30	30×30	30×30	30×30	30×30	35×35
6									30×30	30×30	30×30	30×30
7												
Stories	**Model 7**											
	SC 1	**SC 2**	**SC 3**	**SC 4**								
Ground	40×40	40×40	40×40	45×45								
1	40×40	40×40	40×40	45×45								
2	35×35	35×35	40×40	45×45								
3	35×35	35×35	35×35	40×40								
4	35×35	35×35	35×35	40×40								
5	35×35	35×35	35×35	40×40								
6	30×30	30×30	30×30	35×35								
7	30×30	30×30	30×30	30×30								

In this study, the ground motion records are obtained from the PEER Strong Motion Database [12]. The considered ground motion records are scaled according to design spectrum given for local soil classes defined in TEC–2007 for Seismic Zone 1. Figure 3 shows the scaled ground motion records and their elastic acceleration spectrums.

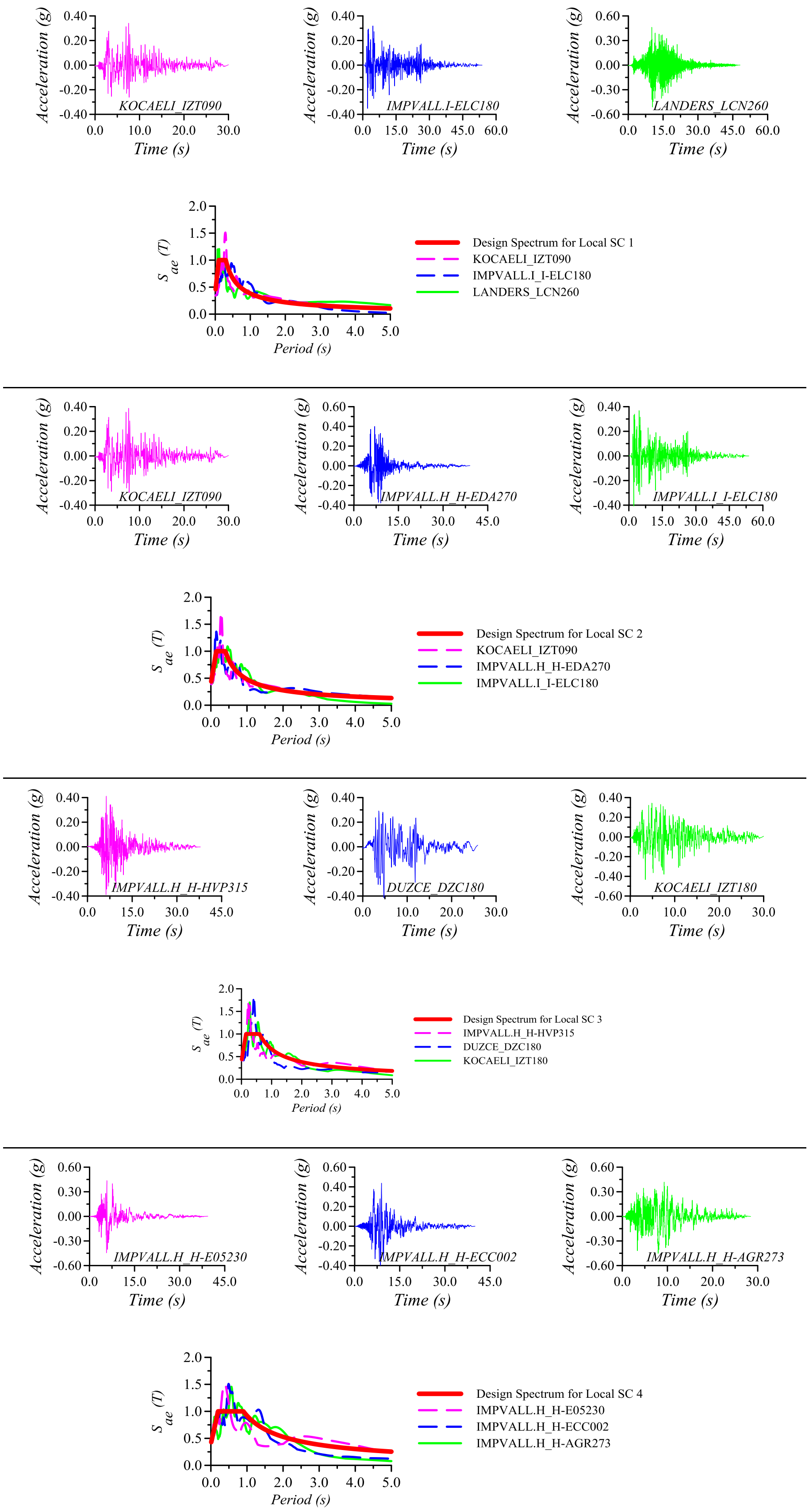


Figure 3. The scaled ground motion records and their elastic acceleration spectrums according to four local soil classes defined in TEC–2007 for Seismic Zone 1

4. Results

In this study, pounding analyses of adjacent RC buildings with equal heights and different dynamic characteristics considering Seismic Zone 1 of Turkey are performed in a time domain by aid of SAP2000 program.

Pounding forces obtained from the analyses are used to evaluate the pounding response of adjacent RC buildings and given in Table 3. In, the largest pounding forces are highlighted in bold. As seen from the table, the pounding forces between neighboring buildings increase in general from Model 1 to Model 7 for each local soil classes. The increase in the pounding forces is similarly seen from local soil class 1 (SC 1) to local soil class 4 (SC 4) for each pounding models. It is understood from this that as the height of the buildings increases, the pounding forces also increase. The largest pounding force occurred during the contacts is obtained as 15047kN in the Model 6 for local soil class 3 (SC 3).

Table 3. The pounding forces obtained from seven FEM models

Soil Classes	**Scaled Ground Motions**	**Pounding Forces (kN)**						
		Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
	KOCAELI_IZT090	0	0	**4273**	1865	3564	5233	5661
SC 1	IMPVALL.I_I-ELC180	**1373**	**1783**	2816	**3983**	**6162**	**7262**	**6503**
	LANDERS_LCN260	0	0	1194	1335	1858	2500	5035
	KOCAELI_IZT090	798	928	**1746**	2155	4644	6956	**8239**
SC 2	IMPVALL.H_H-EDA270	0	**2804**	1220	4209	3645	4893	5849
	IMPVALL.I_I-ELC180	**2283**	2712	1106	**4798**	**6339**	**9529**	5840
	IMPVALL.H_H-HVP315	1504	**3769**	**4538**	5018	3046	3902	6916
SC 3	DUZCE_DZC180	**3245**	2954	3310	**6862**	**7724**	10659	**9684**
	KOCAELI_IZT180	1008	3724	3837	5298	7464	**15047**	5051
	IMPVALL.H_H-E05230	**1877**	3389	**4983**	**6253**	7750	4336	8688
SC 4	IMPVALL.H_H-ECC002	0	**4288**	3760	5028	7863	7420	**8858**
	IMPVALL.H_H-AGR273	0	1665	3610	5619	**8030**	**13553**	8110

The time-histories of pounding forces on the top floor of the colliding RC buildings subjected to the scaled ground motions are presented in Figure 4. It can be seen from the figure that buildings in all models came into contact several times during the earthquakes.

According to the pounding forces given in here, it is observed that the amount of space calculated in accordance with TEC–2007 for Seismic Zone 1 and local soil classes is inadequate.

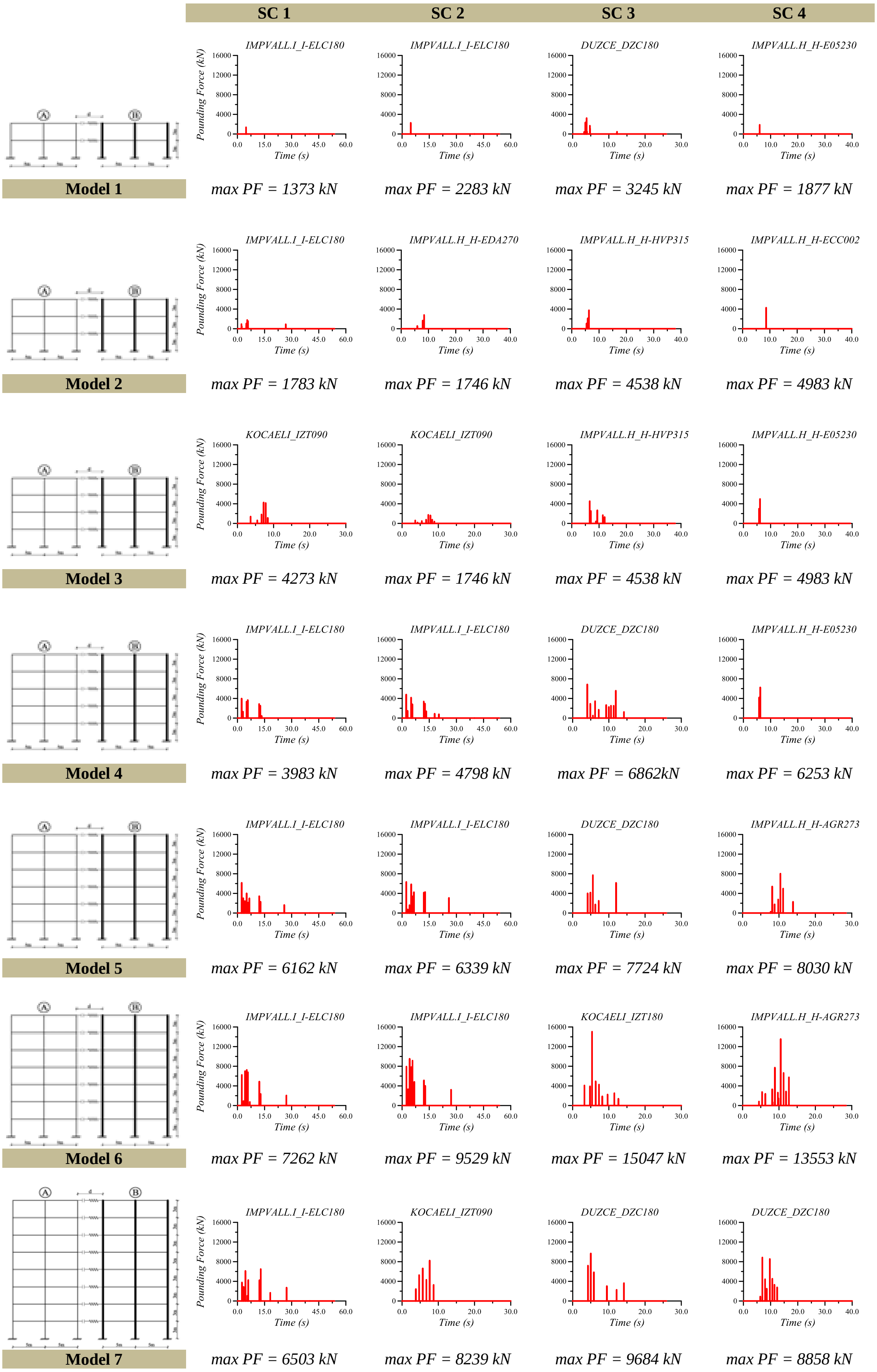


Figure 4. The time-histories of pounding forces at the top floor of the colliding RC buildings.

5. Discussion and Conclusion

In this study, it is investigated pounding response between RC buildings with equal heights and different dynamic characteristics considering Seismic Zone 1 of Turkey. A collision between buildings is represented by a pounding model commonly used in the literature, which is a nonlinear elastic spring (Hertz model). The considered ground motion records are scaled according to design spectrum given for Seismic Zone 1 in TEC–2007. Neighboring buildings are modelled as a three-dimensional beam-column system which is a widely constructed building type in Turkey. Pounding analyses of the neighboring buildings are performed in time domain by aid of SAP2000 program.

It can be seen from the presented results that as the story height increases, the pounding forces increases. Similarly, the pounding forces increases from SC 1 to SC 4 for each pounding models. In addition, it is observed that the amount of space calculated in accordance with TEC–2007 for Seismic Zone 1 and local soil classes is inadequate.

These results indicate that neighboring buildings may be subject to unexpected damages due to earthquakes if there is not enough space between them.

6. Acknowledgment

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