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POUNDING OF ADJACENT RC BUILDINGS DURING SEISMIC LOADS

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ABSTRACT: *Turkey is in high seismic risk zone. On a possible earthquake, adjacent buildings which are not separated from each other properly are under pounding risk. Although gap size requirements are given in Turkish Earthquake Code (TEC), in Turkey, adjacent buildings are still been constructing with insufficient gap sizes. In this paper; results of pounding and effects of pounding to structural elements of buildings are studied. Stress analyses are made on frame models for different impact points and analysis results are discussed. It is concluded that pounding forces are not completely absorbable because of their high values but their effects on structure can be reduced by placing elastic materials between adjacent buildings or by reinforcing structural systems with cast-in-place reinforced concrete (RC) walls.*

Keywords: *Adjacent building, pounding (impact), seismic load, gap*

SİSMİK YÜKLER ESNASINDA BİTİŞİK BETONARME YAPILARIN ÇARPIŞMASI

ÖZET: *Türkiye yüksek sismik risk içeren bir bölgede yer almaktadır. Olası bir depremde, aralarında herhangi bir boşluk olmayan bitişik binalar çarpışma riski taşırlar. Türkiye Deprem Yönetmeliğinde gerekli bina aralıkları belirlenmiş olmasına rağmen, yeterli aralığına sahip olmayan bitişik binalar halen inşa edilmektedir. Bu çalışmada; çarpışmanın sonuçları ve çarpışmanın incelenen binalara ait yapı elemanları üzerindeki etkisi çalışılmıştır. Çerçeve modellerinde, farklı darbe noktaları için gerilme analizleri yapılmış ve sonuçlar tartışılmıştır. Sonuç olarak, çarpışma kuvvetlerinin çok büyük olmalarından dolayı tamamen absorbe edilemediği fakat bitişik binalar arasına elastik malzemeler konulmasıyla veya yapısal sistemin yerinde döküm betonarme perdelerle güçlendirilmesiyle azaltılabildiği görülmüştür.*

Anahtar kelimeler: *Bitişik binalar, Çarpışma, Sismik yük, aralık (boşluk)*

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I. INTRODUCTION

During earthquakes buildings make displacements and deformations for damping earthquake forces. As a reason of this, structural elements can be damaged or whole structure can be collapsed. Character of these displacements and deformations is very complex and it is a functions of many variables from ground acceleration to rigidity center of the structure. If adjacent buildings are not separated properly from each other, a pounding case can be possible on an earthquake and buildings can be damaged even if they are well designed and constructed (Fig. 1.).

Figure 1. *Pounding damage of adjacent buildings (Izmit-Gölcük).*

Many studies were made about structural pounding. Muthukumar S. and DesRoches R. studied Stereo-mechanical, Linear spring, Kelvin, Hertz contact models and presented a model with non-linear damping which is based on Hertz contact model [1]. AbdelRaheem S.E. used three types of ground acceleration records for obtaining seismic pounding behavior of adjacent buildings [2]. Westermo B.D. presented a method for preventing pounding damages of adjacent buildings by using dampers which are placed between joints of adjacent buildings [3]. Maison B.F. and Kasai K. analyzed pounding of adjacent multi-degree-of-freedom structures by classifying pounding types and made calculations of pounding cases at different floor levels [4].

Anagnostopoulos S.A. modeled four adjacent single-degree-of-freedom structures and studied pounding behavior [5]. In another study of Anagnostopoulos S.A., five ground acceleration records are used and variables which change character of pounding are studied [6]. Garcia D.L. studied critical separation distances between adjacent buildings [7]. Matsagar V.A. and Jangid R.S. presented a method for damping pounding forces by using viscoelastic dampers [8].

Fourty two percent (42%) of total surface area and %51 of industrial complex area of Turkey is in 1st degree seismic zone. According to the Turkey Seismic Zone Map, peak ground acceleration of 1st degree seismic zone is assumed 0,40g. Many destructive earthquakes were occurred in Turkey as expected (Fig. 2).

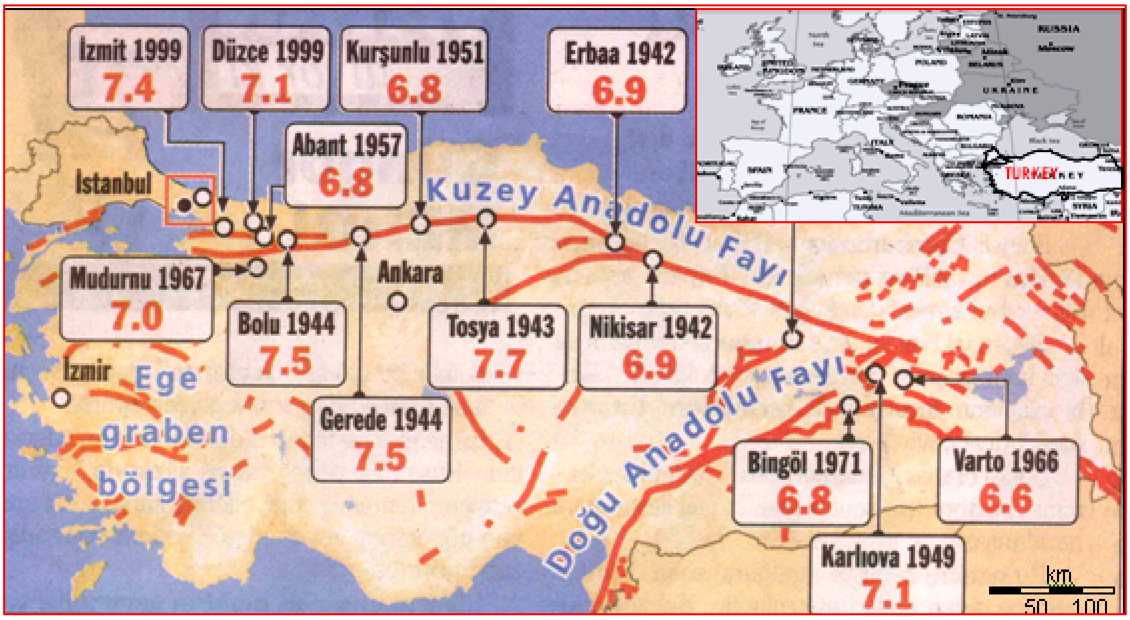


Figure 2. *Destructive earthquakes which are happened in Turkey.*

In Izmit (1999) earthquake, 17480 life losses, 73342 damaged buildings, in Duzce (1999) earthquake, 763 life losses, 35519 damaged buildings and in Erzincan (1939) earthquake 32968 life losses, 116720 damaged buildings are reported. These data show that; in Turkey, mistakes can be made in design and construction stages of buildings which are constructed before.

In this study effect of pounding and structural elements of adjacent buildings are studied according to seismic zone and number of stories.

II. EFFECT OF SEISMIC LOAD TO ADJACENT BUILDING

Building of adjacent structures with insufficient gap distances is one of the most critical mistake. In TEC [9], calculation methods of min. gap distance between adjacent buildings are given. However adjacent buildings are still been constructing without considering gap distances (Fig. 3.)

Figure 3. *Existing different floor level adjacent buildings in Eskişehir.*

The photograph which is presented in Fig. 3 is taken from one of the most important streets of Eskisehir (Turkey). Eskisehir, which is an important city, is located on the West of Turkey. Its surface area is 13652 km^2 and the city has a population of 482793. Three adjacent 8 stories buildings are seen in Fig. 3 and it can be easily seen that these buildings are not separated from each other. In Table 1, proper separation distances are calculated for these three buildings according to methods presented in both TEC and EC8 [9,10].

Table 1. *Proper separation distances for adjacent buildings in Fig. 3*

Separation (cm)	TEC	EC8
Building 1 – Building 2	45.24	16.97
Building 2 – Building 3	22.62	16.97

Table 1 proves that buildings are built improperly according to both TEC and EC8. In Turkey, many streets are formed by such adjacent buildings with improper separations between them. It must be considered that even adjacent buildings are designed and constructed properly, during a possible earthquake they can collide to each other and they can be heavily damaged because of high pounding forces.

Pounding forces are function of pounding masses. During earthquake, buildings hit to each other with very high forces because of their large masses. Engineers must realize that structural pounding is a serious hazard and it must be considered during design and construction of buildings. In a statistical study which is made in Eskisehir (Turkey), main streets are examined and graphs of adjacent building cases are drawn (Fig. 4).

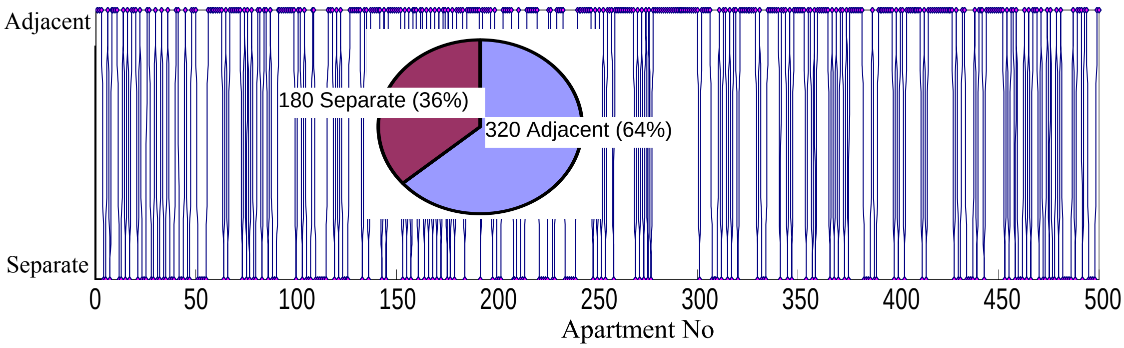
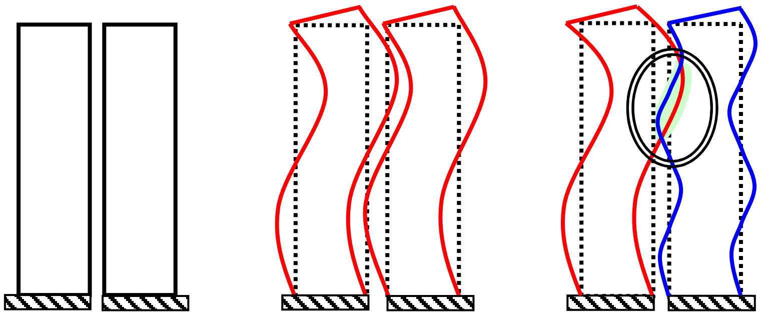


Figure 4. *Adjacent building cases of Eskisehir's important streets.*

In Fig. 4, a graph which indicates adjacent building cases is can be. Important streets of Eskisehir are examined and adjacent building cases are noted. In vertical axis, "Separate" indicates that there's no adjacent building near the building which is read from horizontal axis, "Adjacent" indicates that there's one or more adjacent buildings near the mentioned building. According to the graph it is given in Fig. 4, 64% of the observed buildings has adjacent buildings near them and 36% of them is separated from each other. This means that %64 of buildings in Eskisehir is under pounding risk. Adjacent building cases in these main streets of Eskisehir (Turkey) can be taken as a general model of Turkey.

III. CHARACTERISTICS OF POUNDING

Structural poundings happen because of swaying of adjacent buildings with different mode shapes and periods under seismic loads which are not separated from each other properly (Fig. 5). During earthquakes, structure's mass and rigidity affect seismic behavior. It is nearly impossible to construct a building which has similar seismic behavior to another building.



(a) **(b)** **(c)**

a) Before earthquake, **b)** Similar seismic behavior, **c)** Different seismic behavior

Figure 5. *Seismic behavior of adjacent buildings.*

Poundings may occur because of structural irregularities. For example eccentricity between mass and rigidity centers cause torsion in the structure (Fig. 6a). If pounding building is regular, an impact surface can be formed between two adjacent buildings (Fig. 6b). In some cases this situation is better than the situation that is seen in Fig. 6a.

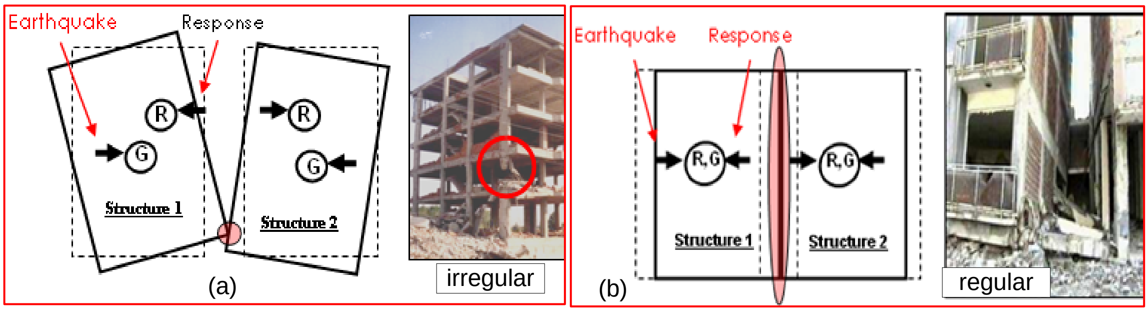


Figure 6. *Pounding of regular adjacent buildings.*

Also buildings may collide to each other because of liquefaction. This case is not considered while calculating separation distances. Otherwise, separation distance between two adjacent buildings must be equal to the height of the highiest one (Fig. 7).

Figure 7. *Liquefaction effect.*

Different modal behavior of two adjacent buildings cause different pounding types. This makes pounding more complex. In dynamical analysis of structures, buildings are modeled by forming lumped masses at floor levels. Pounding models of Single-Degree-of-Freedom (SDOF) and Multi-Degree-Freedom (MDOF) systems are given in Fig. 8.

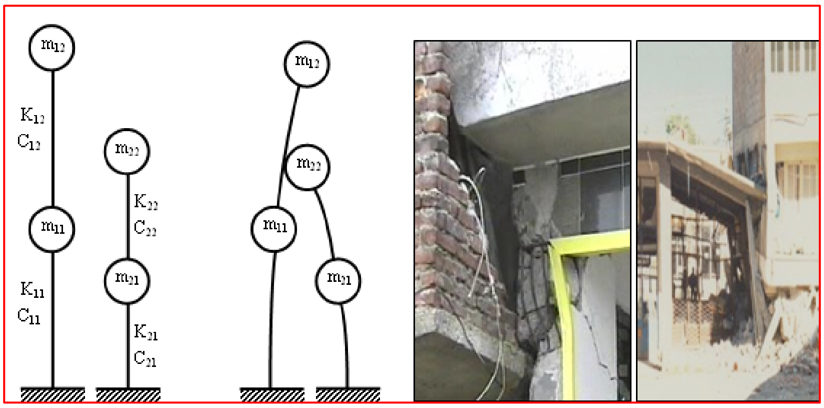
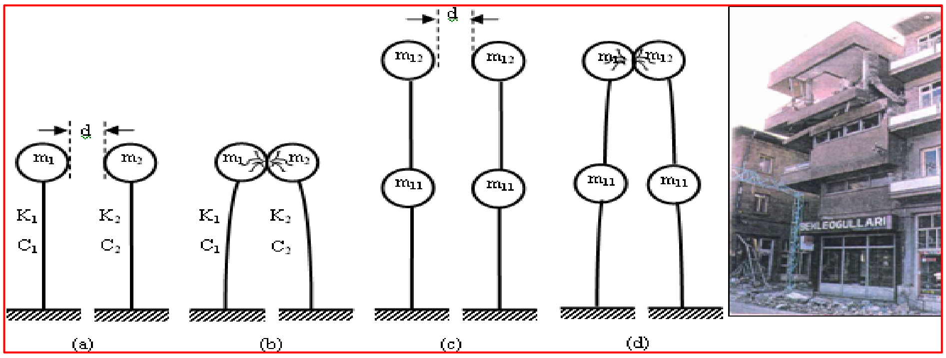


Figure 8. *Pounding at different floor heights.*

However floor heighiest of adjacent buildings are not always the same. So, collisions may occur at different levels (Fig. 9)



a) Before pounding (SDOF), **b)** Pounding case (SDOF), **c)** Before pounding (MDOF), **d)** Pounding case (MDOF)

Figure 9. *Pounding model of adjacent buildings at floor levels.*

Structural behavior can change due to impact point in the pounding case. For analyzing structural pounding effects for different contact points a solid frame model is generated by SAP2000 (Structural Analysis Program) [11]. This 2-storey frame has three 40 cm x 60 cm columns and these columns are connected with 30 cm x 50 cm beams which have 4 m. span. All frame elements are generated by using 10 cm x 10 cm x 10 cm solid cubes for high precision. In calculations, it is assumed that a 100 kN pounding force applied to solid frame at second floor level and 1/2, 1/3, 2/3 of floor height (Fig. 10). Stress values are given on color scales in terms of kN/m^2.

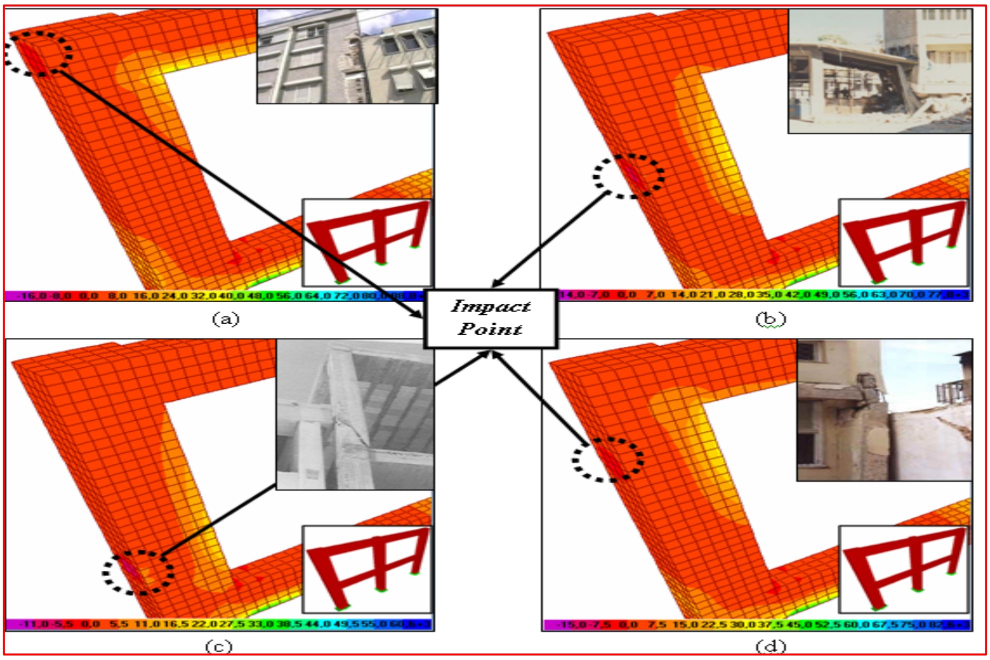


Figure 10. a) *Pounding at floor level,* ***b)*** *Pounding at 1/2 of floor height,* ***c)*** *Pounding at 1/3 of floor height,* ***d)*** *Pounding at 2/3 of floor height.*

It can be seen from Fig. 10 a if impact point is at floor level, column – beam connections carry maximum pounding stresses. Column–beam connection behavior is more rigid than any structural elements span. In this case, pounding energy is directly transferred to all frame elements by joints and all columns in frame show resistance to bending effect of pounding force. Fig. 10 b shows that impact point is in the middle of the column span. In this case, maximum pounding stress is carried by column span. Pounding element must transfer the pounding energy to other frame elements by joints. However this is almost impossible. Structural elements which are subjected to pounding forces are generally too weak to carry destructive pounding loads. If the impact point is on the column span, possible conclusion of pounding is failure of mentioned structural element. Pounding at 1/3 (Fig. 10 c) and 2/3 (Fig. 10 d) of floor height have better results than pounding at 1/2 of floor height. Strength of these parts of a column span is higher than middle part because of better reinforcement detailing at these parts of column.

VI. RESPONSE ACCELERATION GRAPHS of BIG EARTHQUAKE IN TURKEY

Three important earthquakes are used for calculations. These are Sakarya (1999), Duzce (1999) and Bingöl (2003). Five percent damping ratio is assumed for simulating reinforced concrete behavior. In Sakarya (1999) earthquake which is the most important of these three earthquakes max. ground acceleration was 0.62 g. Ground acceleration, velocity and displacement graphs are given in Fig. 11.

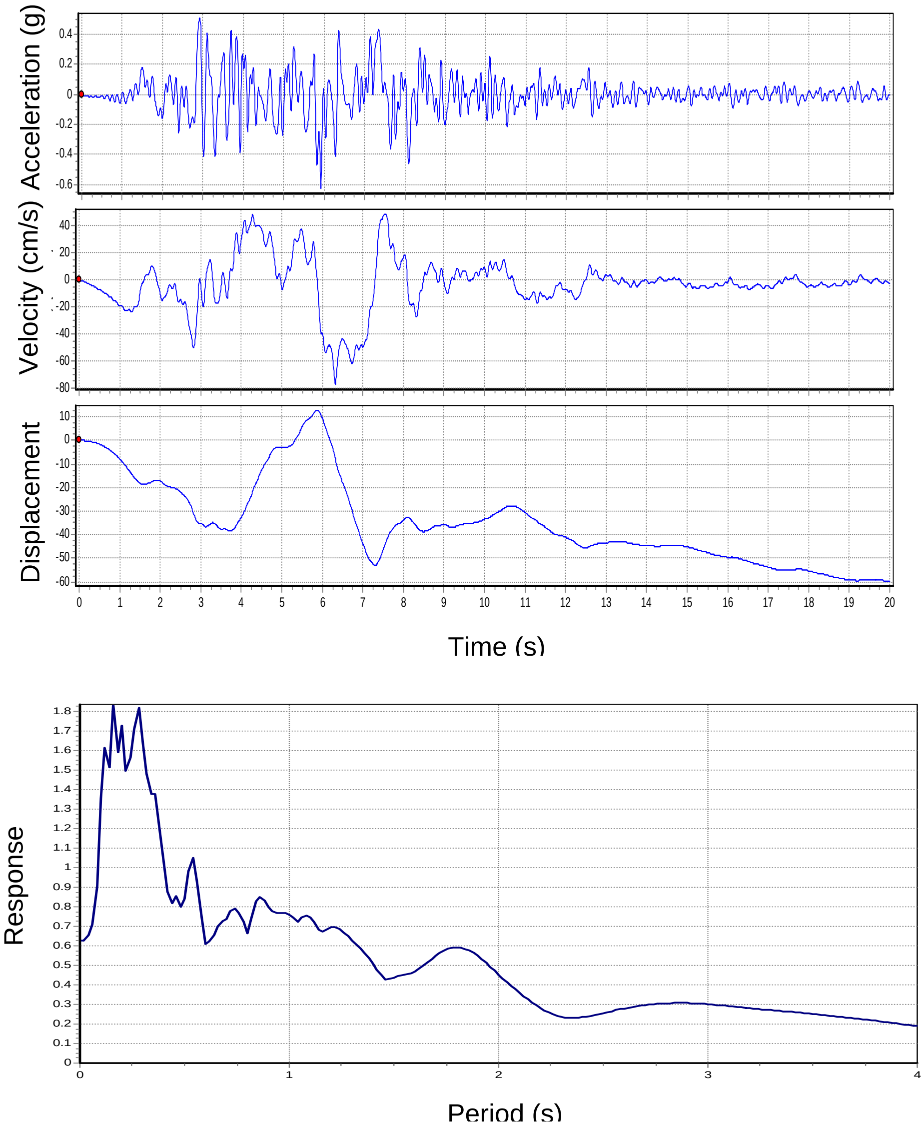


Figure 11. *Response acceleration graphs of Sakarya (1999) earthquake.*

Peak ground acceleration value of Duzce (1999) earthquake is 0.82g. Graphs of this earthquake are given in Fig. 12.

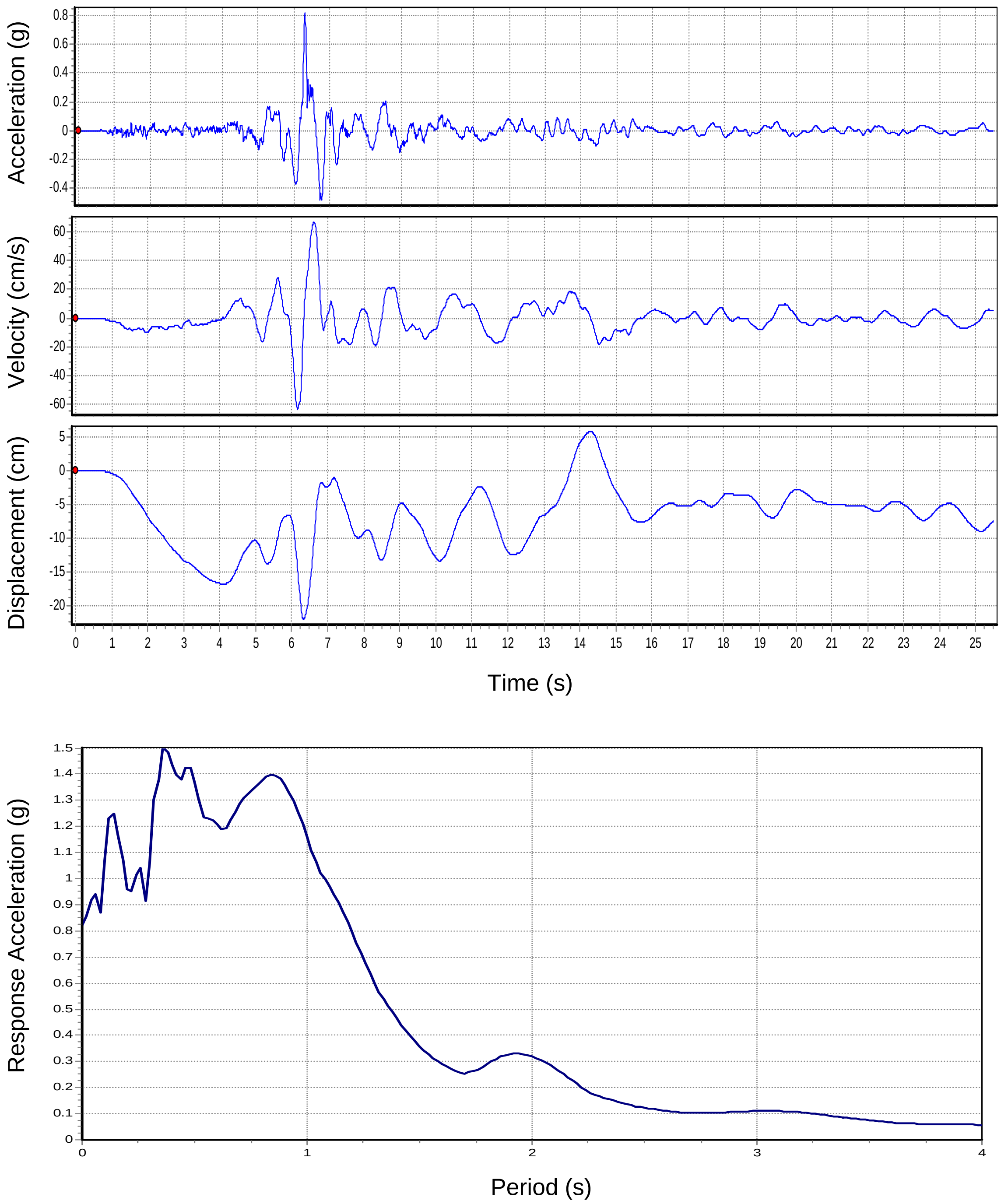


Figure 12. *Response acceleration graphs of Duzce (1999) earthquake.*

Peak ground acceleration value is 0.55g for the last earthquake. Also this earthquake caused property and life loss (Fig. 13).

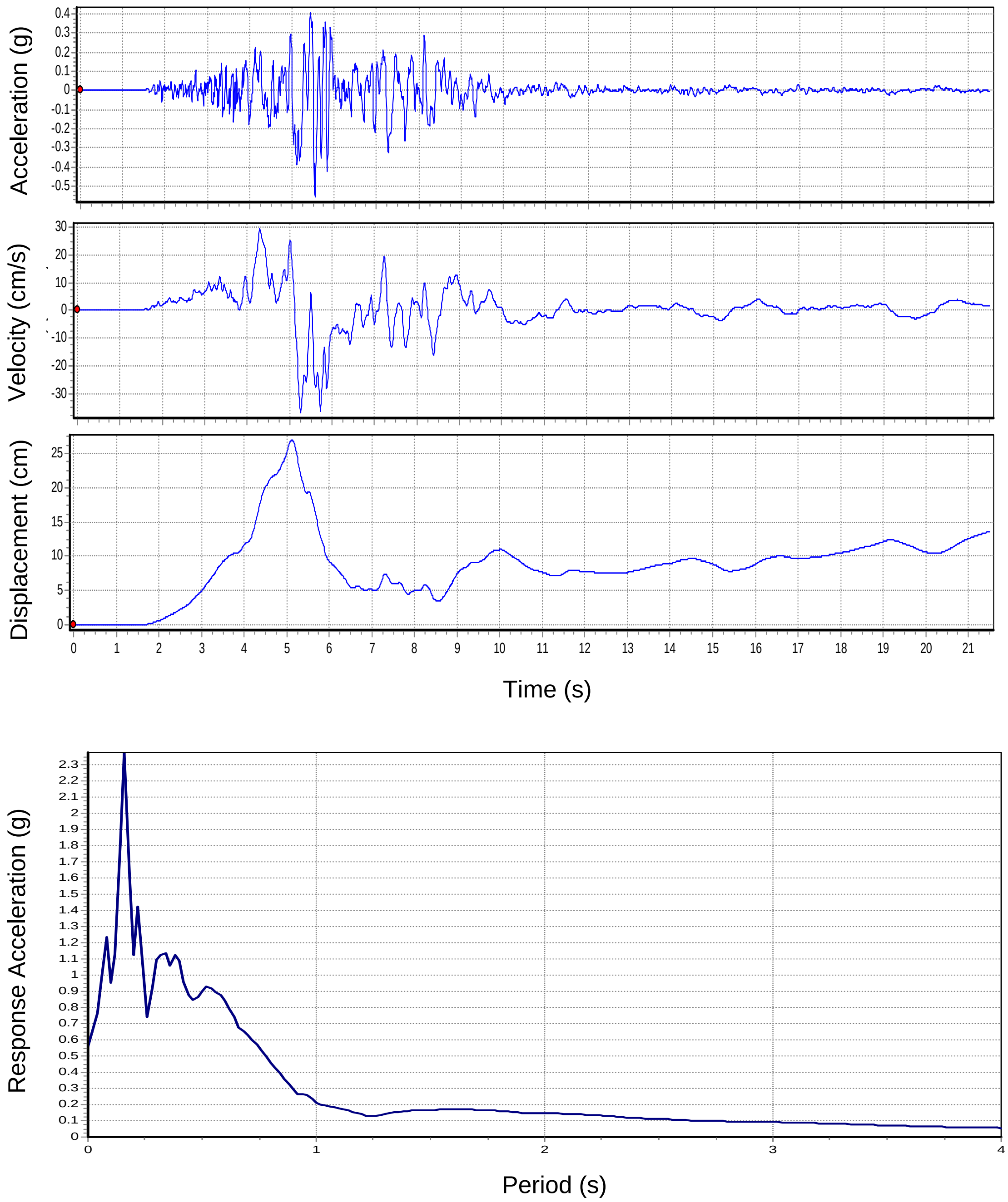
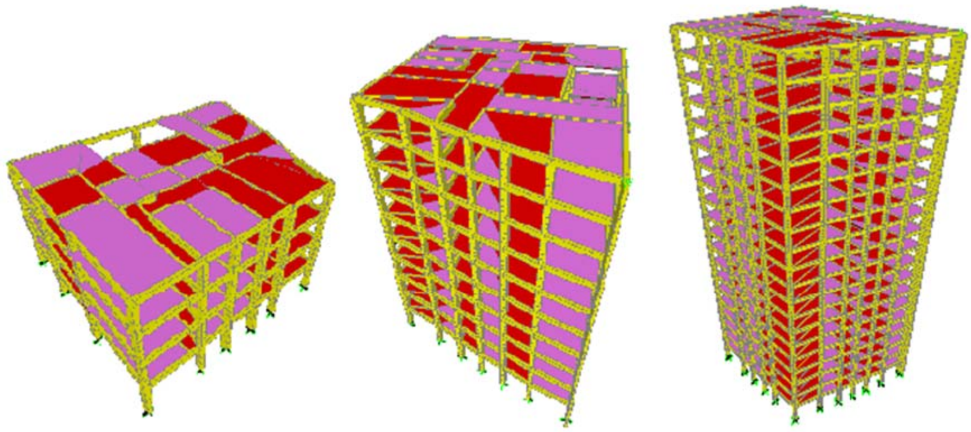


Figure 13. *Response acceleration graphs of Bingöl (2003) earthquake.*

V. MODEL AND CALCULATIONS

For analyzing pounding case and building models are generated and calculated with SAP2000. Structural irregularities are formed on these 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20 storey building models for forming critical conditions (Fig. 14).



(a) **(b)** **(c)**

Figure 14. *Building models* ***a)*** *4 storey,* ***b)*** *10 storey,* ***c)*** *20 storey.*

A standard structural system form is used in models Column, beam and slab cross sections and reinforcement detailing of models are changed due to structural requirements. In calculations, special joints are defined for modelling separations between buildings (Fig. 15).

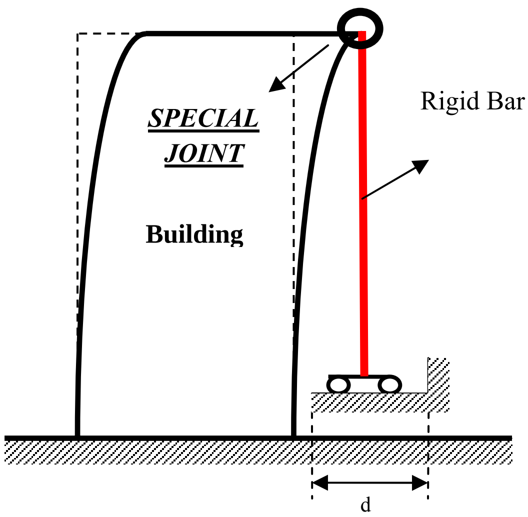


Figure 15. *Presented special joint model.*

It is assumed that buildings pounded to a rigid block for modelling are the most critical case. Average pounding forces are determined for different separation distances between building model and rigid block. TEC [2007] is used for determining lateral displacements and lateral seismic loads of building models. Pounding force – storey number graph is given in Fig. 16. Series indicate separation distances between building model and rigid block. Pounding force – storey number graphs for analyzed earthquakes are given in Fig. 16.

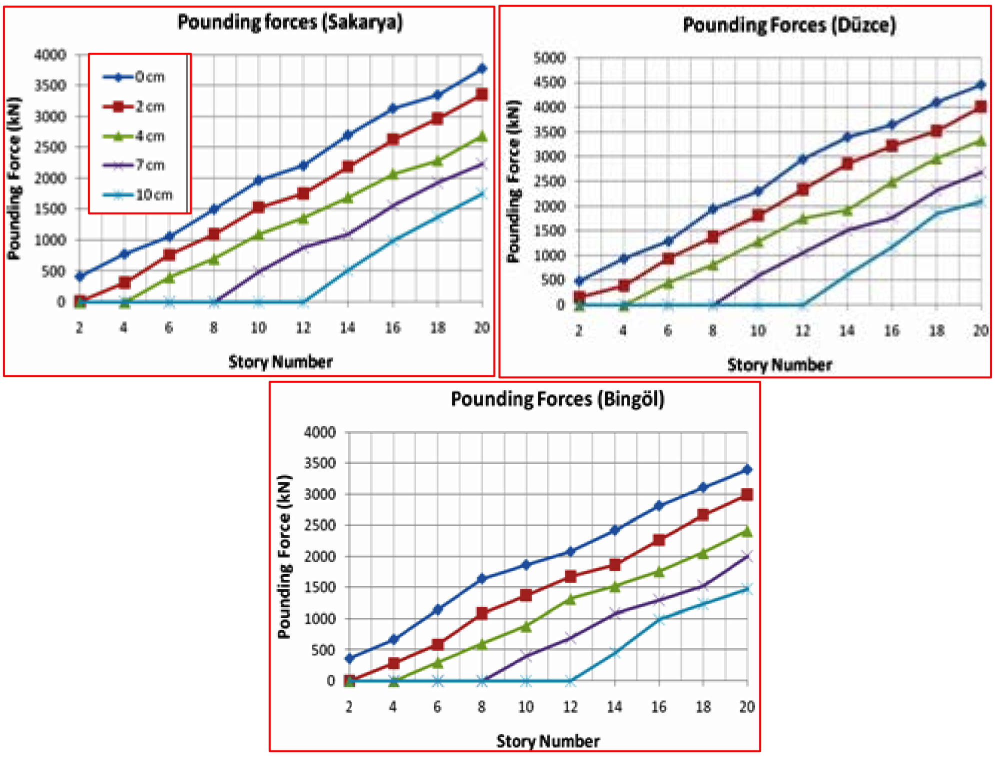


Figure 16. *Pounding forces for Sakarya, Duzce and Bingöl earthquakes.*

Pounding force graph for 0 and 10 cm gaps indicates the importance of separation distance between adjacent buildings clearly (Fig. 17).

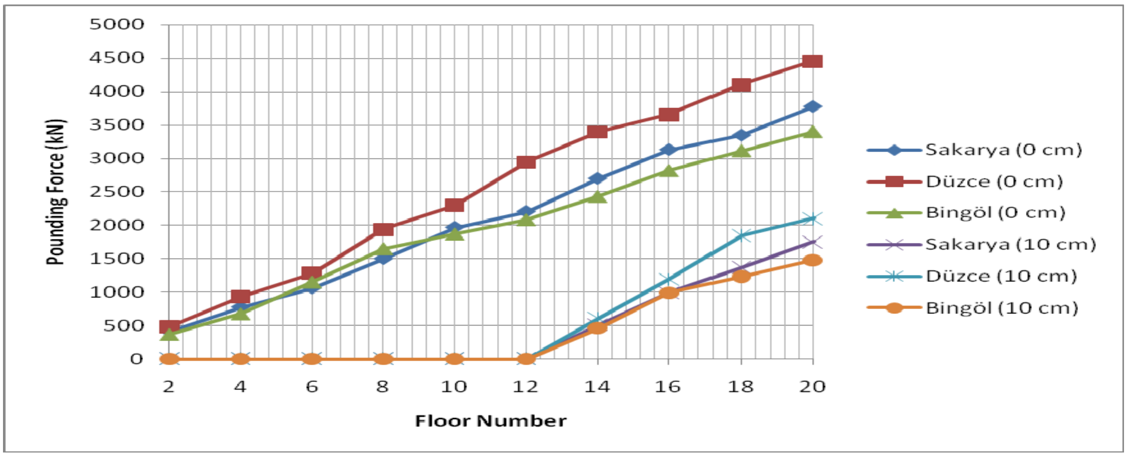


Figure 17. *Comparison of pounding forces.*

It can be seen from Fig. 17 that (for all earthquake records examined in this study) separation distances between buildings decrease pounding forces by a considerable ratio (about 50%). According to the graph that is given in Fig. 17, a 20-storey building pounds to its adjacent rigid block with a force about 3750 kN, if there is no separation between building and rigid block. But if there's 10 cm gap between them, pounding force decreases to 1650 kN. These numerical data show that how gaps between adjacent buildings are important. As mentioned above, this graph shows pounding force of buildings which collide to a rigid block. But, during an earthquake, two adjacent buildings may sway in opposite directions and in this case pounding effects will be more destructive (Fig. 18).

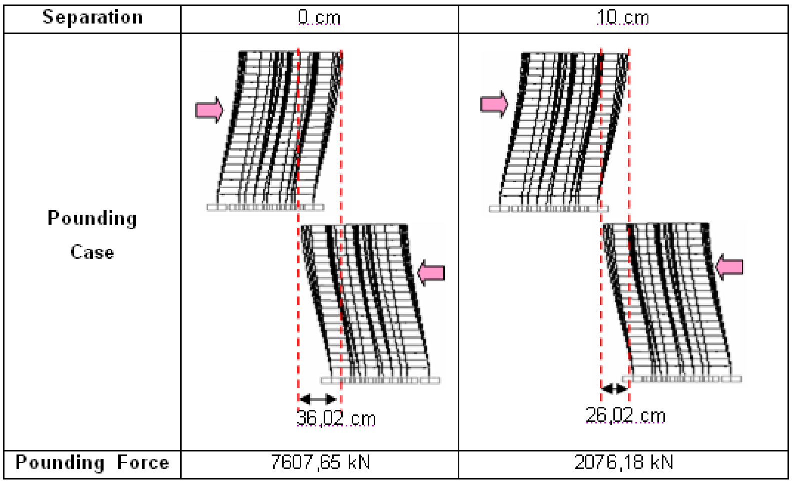


Figure 18. *Pounding forces of adjacent two 20-storey adjacent buildings.*

It is assumed that if a building shows response equal to the other adjacent buildings pounding force, determination of pounding forces can be possible for this case. Pounding forces of two adjacent 20-storey buildings are given in Fig. 18 for 0 cm and 10 cm separation distances. It is assumed that, those 20-storey buildings sway in opposite directions and they have equal periods. It can be seen from Fig. 18, that needed separation distance for these buildings is at least 36.02 cm. Fig. 18 also shows positive effect of gap. ten cm separation distance is not enough for these two buildings, however but results of pounding will be better than no separation case. Pounding forces and pounding cases depends on seismic character of earthquake as well. By considering all of these cases, the most critical case must be considered for constructing safe buildings.

VI. CONCLUSIONS

As presented in graphs, pounding force of buildings is very high. Absorbing of these high forces by structural elements and whole structure is nearly impossible. Constructing separated buildings is the best way of preventing structural poundings. However if adjacent buildings must be constructed for any reason, these structures must be separated with gaps as given in codes. In calculations it can be seen that 10 cm gap size decreases pounding force of two 20-storey buildings by %73 if it is compared to 0 cm separation case between them. In this paper, it is concluded that constructing adjacent buildings with equal floor heights and separation distances reduces the effects of pounding considerably. Existing adjacent buildings which are not properly separated from each other can be protected from effects of pounding by placing elastic materials between them. Also limiting lateral displacements of existing adjacent buildings with cast-in-place RC walls is an effective method for preventing structural poundings. These precautions can not always isolate adjacent buildings completely from pounding but it can help in damping of pounding energy.

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