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Seismic Performance Evaluation of a Train Station Building Considering Earthquake-Induced Pounding Effects

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Abstract

Performance evaluation of adjacent buildings is generally performed by ignoring earthquake-induced pounding effects. Therefore, unexpected damages in adjacent buildings have occurred at the past earthquakes. The aim of this study is to evaluate seismic performance of a Train Station Building in Van during 2011 Van (Turkey) earthquake taking into account pounding effects. To this aim, three-dimensional pounding analyses of the Train Station Building are performed with SAP2000 structural analysis program. Nonlinear time history analysis of the building with and without pounding effects is conducted, and results are compared.

In the Train Station Building consisting of three blocks, spaces among the blocks were not sufficient. The building had experienced damage in 2011 Van earthquake. Shear failures were observed over the walls in blocks. However, damages to column-beam joints were observed in the middle block. Thus, seismic performance of the middle block is only evaluated by analyzing Train Station Building since any damage did not been observed in the structural elements of the other blocks. The results obtained from the analyses confirm that the experienced damages in the 2011 Van earthquakes occurred due to the pounding effects.

Key words: Seismic Performance, Earthquake-Induced Pounding Effects, 2011 Van Earthquakes

1. Introduction

While gap values between adjacent buildings mention in many standards, these gaps are omitted due to unplanned urbanization and the land conflict between landowners. Moreover, the design and analysis of the buildings are performed by ignoring the earthquake-induced pounding effects. For these reasons, impacts between adjacent, inadequately separated buildings have repeatedly been observed during earthquakes. This phenomenon referred to as earthquake-induced structural pounding may often result in substantial damage or even total destruction of colliding structures during earthquakes [1].

In recent years, many damages in structures have occurred at the past earthquakes because of insufficient gaps between adjacent buildings. Especially, significant damage of pounding occurred after 1971 San Fernando, 1994 Northridge, 1989 Loma Prieta earthquakes in United States of America; 1985 Mexico City earthquake in Mexica, 1999 Athens earthquake in Greece, 1999 Kocaeli (Izmit) and 2011 Van earthquakes in Turkey The recent investigations have reported that pounding effects due to relative displacements of neighboring buildings should not

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be ignored [1, 2-9].

There are many studies about performance evaluation of buildings using nonlinear analysis methods [10-18]. In these studies, performance evaluations of structures which are not affected by the buildings around them were performed by taking into various parameters. It can be seen from the literature review that a few works on performance evaluation of structures considering earthquake-induced pounding effects have been performed [1, 19].

The purpose of this study is to perform seismic performance of a Train Station Building in Van during 2011 Van (Turkey) earthquake due to pounding effects, and to evaluate damages on the buildings. In the Train Station Building consisting of three blocks, spaces among the blocks were not sufficient. The building had experienced damage in 2011 Van earthquakes. Shear failures were observed over the walls in Block 1 and 3. However, damages to column-beam joints were observed in Block 2 [9]. So, seismic performance of Block 2 (middle block) is only evaluated by analyzing Train Station Building since any damage did not been observed in the structural elements of the other blocks. Seismic performance of Block 2 is evaluated according to Turkish Earthquake Code [20]. Nonlinear time-history analyses of the Train Station Building considering and not considering earthquake-induced pounding effects are performed with SAP2000 structural analysis program [21].

2. Modelling of Pounding Force

Pounding between adjacent buildings is simulated using the Hertz model shown in Figure 1. The force transmits from one structure to another by means of nonlinear spring in Figure 1 only when contact occurs during earthquakes.

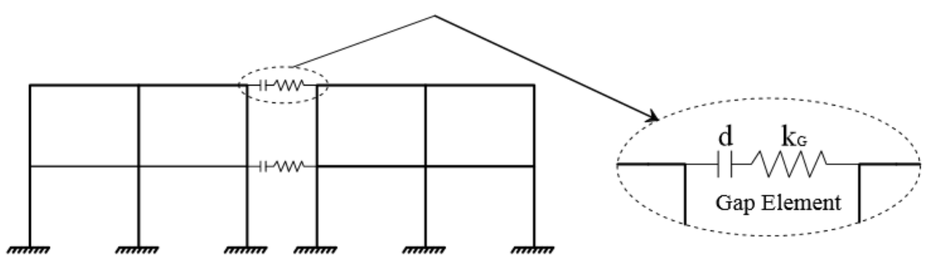


Figure 1. Pounding model (Hertz model)

The force-deformation relationship of the gap element is given by

$$f_G(t)=\begin{cases} k_G\left[u(t)\text{-}d\right] & if \quad u(t)>d \\ 0 & if \quad u(t)\leq d \end{cases} \tag{1}$$

where k_G is the nonlinear spring constant in the gap element. This constant is taken as 1,130,000kN/m for concrete-to-concrete impacts based on numerical simulation performed by Jankowski [7]. $u(t)$ 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.

3. Numerical Application

3.1. Details of Train Station Building

The Train Station Building has three blocks as shown in Figure 2. Three-dimensional views and gap elements belong to three blocks of the Train Station Building are shown in Figure 3. The total area covered by Blocks 1, 2 and 3 are 651.57m^2, 267.57m^2, and 474.41m^2, respectively.

The RC buildings were constructed in the city of Van that is located in Earthquake Zone 1. Soil class Z3 dominant throughout Van City. According to the TEC-2007, the design ground acceleration of the zone is 0.4g, and the characteristic periods (T_A and T_B) for soil class Z3 are 0.15 and 0.60 seconds. The strength of concrete which are obtained samples taken from the structure were 20MPa for the first and third blocks, 10 MPa for the second block. Moreover, steel class was obtained S220 (f_{yk}=220MPa) from examinations after the earthquake for all blocks.

In the first and third blocks, shear damages were observed over the walls. However, the structural elements of these buildings were not damaged during the earthquake. In the second block, damage at the beam-column joints and pounding damage were observed as shown in Figure 4 [9]. There was not sufficient gap between blocks. For these reasons, the second block came into contact several times to other blocks during the 2011 Van earthquakes. Therefore, performance evaluation is only performed for the second block.

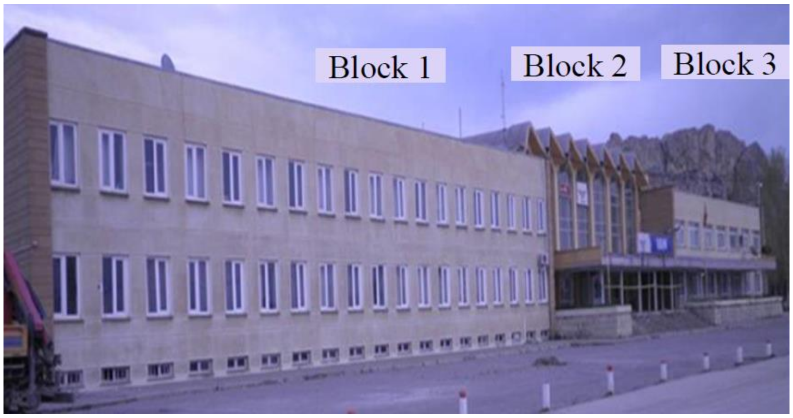


Figure 2. Train station building experienced damages in 2011 Van earthquakes [9]

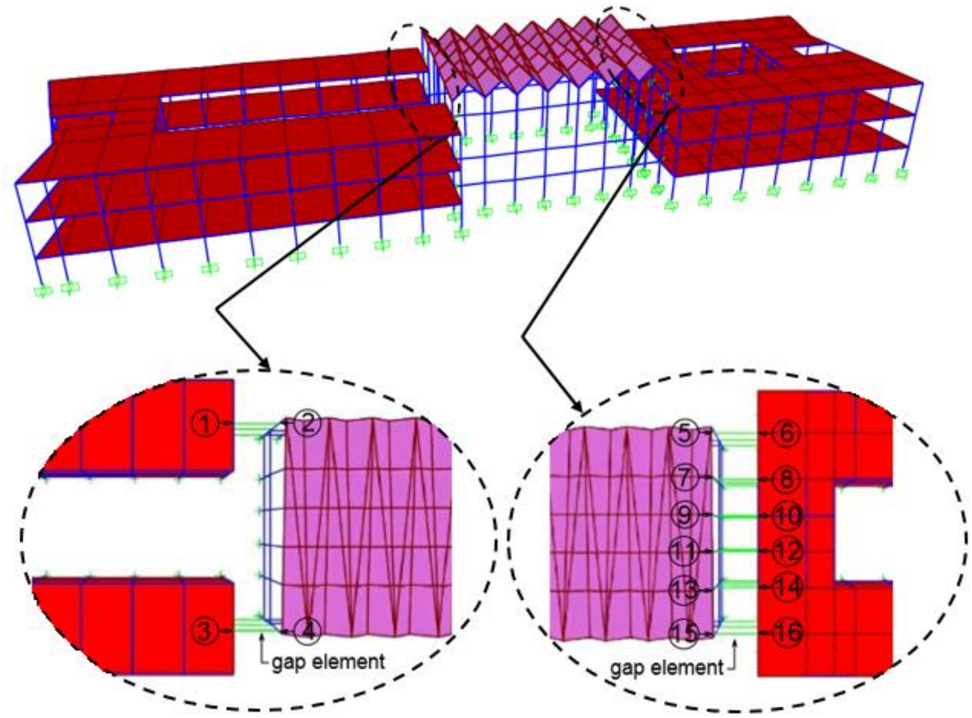


Figure 3. Three dimensional view of blocks and pounding model in the Train Station Building

Figure 4. Damage to column-beam joints and walls in the second block [9]

3.2. Seismic performance analysis of the train station building

In design and analysis of structures, realist assumptions should be practiced for obtain accurate results and represent existing behaviors of structures. These assumptions are generally very complex and require a detailed knowledge of the structures, but it must be applied to achieve realistic results. The performance evaluation of adjacent buildings is generally performed by ignoring the earthquake-induced pounding effects. Therefore, unexpected damages in the adjacent buildings have occurred at the past earthquakes. The seismic performances of adjacent buildings are evaluated by using nonlinear time history analysis in order to investigate the pounding effects on seismic performances of adjacent buildings.

In this study, seismic performance of the Train Station Building at Van city with and without considering earthquake-induced pounding effects is investigated and compared with each other. The nonlinear time-history analyses of the Train Station Building are performed with SAP2000 structural analysis program [21]. The North-South (N-S) component of October 23, 2011 Van Earthquake ground motion given in Fig. 5 is used in the nonlinear time history analysis of Train Station Building with and without the pounding effect. Since interaction between the blocks of the building occurred in one-direction during the Van earthquake, the earthquake ground motion is implemented to contact direction of the building in the analyses.

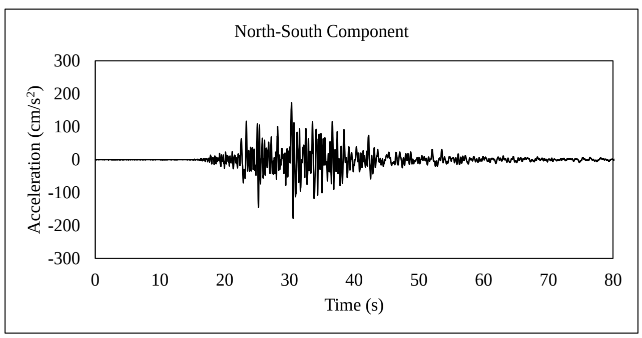


Figure 5. N-S components of ground acceleration of Van Earthquake

To observe the effect of pounding, nonlinear time-history analysis of Block 2 is only performed for seismic performance evaluation not considering earthquake-induced pounding effects, firstly. Then, nonlinear time-history analysis of the Train Station Building considering earthquake-induced pounding effects is performed, and the pounding forces are obtained. Thus, seismic performance of Block 2 without pounding case is compared with that of pounding case.

It is seen from Fig. 6 that the plastic hinges occurred at contact direction of the Block 2 after the nonlinear time history analysis. It is shown from Fig. 6a that the plastic hinges are obtained without considering earthquake-induced pounding effects. Moreover, the plastic hinges which are obtained by considering earthquake-induced pounding effects are presented in Fig. 6b. According to the results given by Figure 6, plastic hinges are concentrated at the zone of potential impacts due to earthquake-induced pounding.

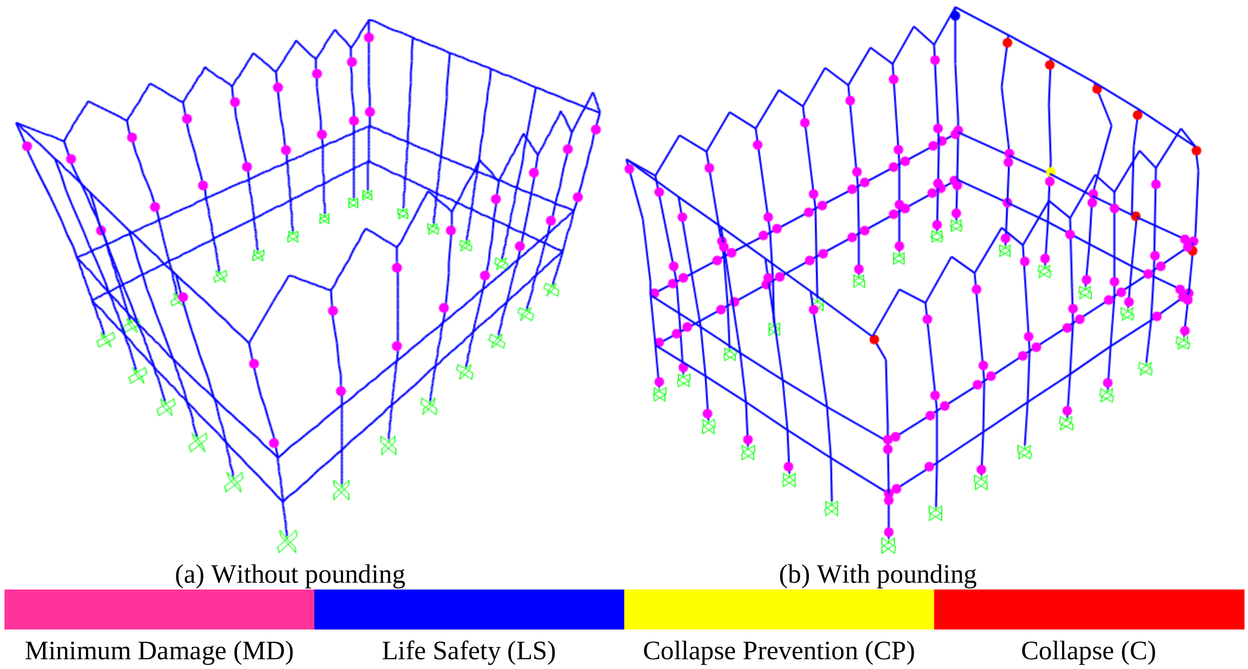
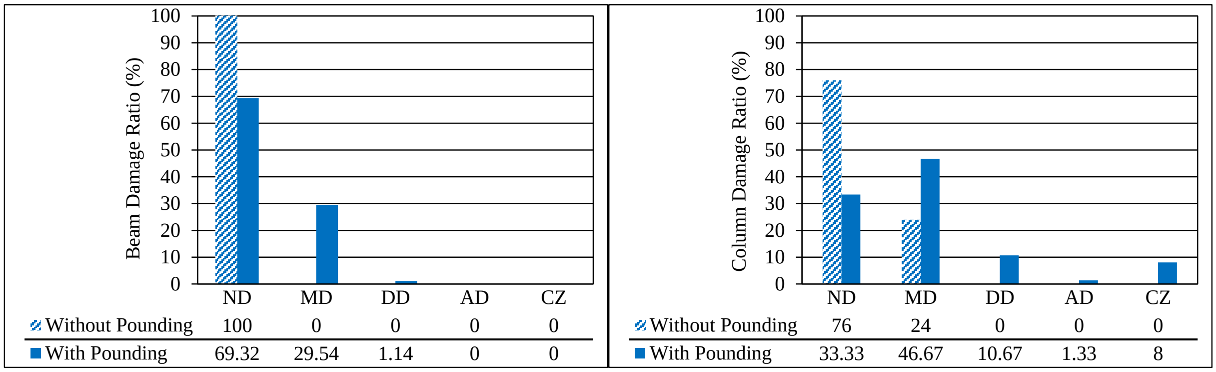


Figure 6. The plastic hinges distribution occurred at x-direction of Block 2 after the nonlinear time history analysis

The damage zones of beams and columns for contact direction of Block 2 are presented in Fig. 7 for without and with pounding case. In the case where pounding is not taken into account, it is shown from Fig. 7b that there was no damage in 57 columns (%76), minimum damage occurred in the 18 columns (%24). Also, there was not happen distinctive damage, advanced damage and collapse in the columns. According to the results given by Fig. 7a, damage did not occur in the beams.

In the case where pounding is taken into account, it can be seen from the results of the nonlinear time history analysis in the contact direction (Fig. 7a) that there was no damage in 61 beams (%69.32), minimum damage happened in 26 beams (%29.54), and distinctive damage happened in 1 beam (%1.14). Advanced damage and collapse did not occur in beams. It is shown from Fig. 7b that there was no damage in 25 columns (%33.33), minimum damage happened in 35 columns (%46.67), distinctive damage happened in 8 columns (%10.67), advanced damage occurred in 1 column (%1.33), and 6 columns (%8) collapsed.

According to TEC-2007, whereas a train station building under maximum earthquake must be satisfied life safety (LS) performance level, the structure under design earthquake must be satisfied immediate occupancy (IO). When the damage zones of structural elements which are determined performance evaluation of the train station building using nonlinear time history analysis are investigated, Block 2 is in the immediate occupancy (IO) performance level for the case where pounding is not taken into account. However, performance level of Block 2 is determined as collapse (C) for the case where pounding is taken into account.



(a) (b)

Figure 7. Damage zones of (a) beams and (b) columns through the x direction of the block 2 obtained from nonlinear time history analysis

Conclusions

In this study, seismic performance of a Train Station Building in Van during 2011 Van (Turkey) earthquakes taking into account pounding effects is investigated and evaluated damages on the buildings. It can be reached the following conclusions:

- In the case where pounding is not taken into account, the second block satisfies the expected performance level, i.e. Immediate Occupancy (IO) according to the TEC-2007. In the present case, there is no damage in all beams.

- In the case where pounding is taken into account, the second block does not satisfy the expected performance level, i.e. Immediate Occupancy (IO) according to the TEC-2007, since performance level of block 2 is determined as Collapse (C) under Van Earthquake loads.

Finally, earthquake-induced pounding effects should be considered in design and analysis of adjacent structures. Otherwise, unexpected damages may be occurred at the contacts of neighboring buildings due to earthquakes such as the Train Station Building in Van city during 2011 Van (Turkey) earthquakes.

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