Evaluation of Seismic Pounding between two Adjacent Reinforced Concrete Buildings from Albanian Practice

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ABSTRACT

Seismic pounding is the colliding action between two adjacent structures that occurs during earthquake vibrations. Due to insufficient separation gap between buildings that own different dynamic characteristics, structural damages to both structural and non-structural elements are magnified during the impact of buildings. Since a country like Albania is considered to have moderate-size seismicity, it is important to provide and check the necessary separation distance to avoid the impact between structures. A parametrical approach is followed up in this study to evaluate the sufficient seismic gap in the middle of two existent Reinforced Concrete (RC) structures. Ten pairs of structural models are analyzed in Sap2000 by using the Equivalent Static Force Method (ESFM). The change of structural parameters such as concrete grade, seismic zone factor and story height are inspected to study the influence they have in the separation gap between the structures. At the end, a comparison with a similar study is done and conclusions, as well as recommendations for further studies are generalized.

Keywords: *Seismic Pounding, Separation Gap, Sap2000, Adjacent Buildings, Eurocode, Static Analysis*

INTRODUCTION

Pounding phenomenon occurs during the vibration and the existence of small gaps between the existing structures. Buildings are very often constructed close to one another, as the example of residential structure complexes or in highly populated cities, due to the high price for land usage. So, for this reason, buildings have often been found to collide with each other during the response to earthquake ground motions. The insufficient gap is not only a result of the high cost of the land, but also because the past seismic code provisions did not provide specific guides to calculate the most probable minimum building separation needed to prevent impact [1].

Albania is a developing country, and more buildings are being constructed and land usage limitation has started to be a present issue. Due to this, structures are built very close to each other and sometimes without providing the safe separation distance in-between. Moreover, it is categorized as a moderate seismic country, being one of the most active seismic zones in Europe. Since buildings are prone to frequent earthquake ground motions seismic, pounding is a phenomenon that occurs whenever the safety separation distance between adjacent buildings is not provided.

Pounding has been observed in global earthquakes including here the Alaskan seismic motion of 1964, the San Fernando earthquake of 1971, the Mexico City earthquake of 1985, the Chi-Chi earthquake of 1999, the Bhuj earthquake of 2001, Chuetsu-Oki Japan earthquake of 2007. [2] In Europe, pounding has been observed during the L'Aquila earthquake of 2009, during the earthquake in Athens, in 1999, etc. [3] In Albania, the latest severe earthquake was the one that happened in November 2019, in Durres. [4]

Pounding or hammering effect has been observed between adjacent structures during the site investigations after the Durres earthquake and the main reason is the inadequate seismic gap [5].

Several works, experiments and research have been carried out to understand the occurrence this phenomenon analytically and numerically. Namboothiri has made a generalising summary on the concept of seismic pounding by quoting that the main cause for the pounding effect is the lack of enough gap distance in between the adjacent structures [6]. Raheem, states in his study that pounding can be an issue to the closely built buildings if a seismic excitation occurs because floor accelerations and inter-story deflections are significantly amplified, threatening the functionality of the structure [7]. Different mitigation methods are introduced, but the simplest one is the provision of enough separation gap between buildings through codes and standards.

CODE RECOMMENDATIONS FOR SEISMIC SEPARATION GAP

The square root of the sum of squares (SRSS) and the absolute sum method are the most elementary formulae and they are implemented in seismic codes such as IBC, *International Building Code*. In some other codes the heights of adjacent buildings are taken into consideration while calculating the separation gap. According to Federal Emergency Management Agency (FEMA 356), minimum seismic gap for adjacent buildings is calculated with the SRSS formula. The value of the separation gap should be less than 4% of the height of the level under consideration above grade at the position where the potential pounding might occur. The Egyptian code of practice and the Eurocode 8 employ formula of the square root of the sum of squares (SRSS). [8] The Indian Standard IS 1893:2016 states that the seismic gap between two adjacent structures is equal to the response reduction factor (which in Eurocode 8 is denoted by letter “q”) times the sum of floor displacements u_i and u_j of the buildings. The default value of the reduction factor in Eurocode 8 for R/C ductile buildings is equal to 6, while in the Albanian Earthquake Resistant Design Regulations 1989, the reduction factor is 5 [9]. During the past 50 years, most of structures in Albania have been designed according to Albanian national code. The code was lastly updated in 1989 and it is still in force (KTP-89), as due to Albanian legislation in the construction field, the construction of buildings still must have to follow the KTPs (Albanian Technical Codes) [10].

STRUCTURAL MODELING

In order to observe seismic pounding between adjacent reinforced concrete buildings, G+11 and G+7 bare framed building models are selected and designed. Buildings which are modeled are two symmetric eleven story and seven story RC residential buildings with equal story height. Both buildings are designed as 2D frame models with fixed supports at the ground level (Figure 1). Sap2000 v.16.0.0 is utilized to run the linear static analyses.

For this study, a parametric approach is followed, where the systems of structures are analyzed in three general cases. The variables considered to evaluate the separation gap (SG) are the concrete class, seismic zone factor and story height. In the first case, three distinct concrete classes (C) are considered as follows, C20/25, C25/30 and C30/37. For two other cases C is taken as C25/30. While, for the second case, the influence of the seismic zone factor (Z) on separation gap is taken into consideration. The selected factors are 0.30, 0.25, 0.20 and 0.15. The seismic zone for the first and the third case is taken as 0.25, as Korca is rated as an active seismic zone in Albania. Lastly, for the third case, the change of SG with the story height is observed, where three different story levels 2.8m, 3.0m and 3.5m are chosen. The height (H) of every column is the vertical floor to floor distance. The heights of each story are the same in both structures. For the first and the second case, the heights are 3.0 m.

Two representative R/C frames of structures are modelled in Sap2000 by using the technical plans of the buildings. Frames consist of columns with (40 cm x 40 cm) dimensions and beams with (35 cm x 30 cm) dimensions. The number of bays in y direction for the 11-th story frame is 3, with 5 m spacing each. Meanwhile, for the 7-th story building the number of bays is 4, where the width of each bay is 5 m. The frame is assumed to be resting on soil of class C, according to Eurocode classifications. Steel bar class is S500. The thickness of the slabs is 15 cm. The concrete unit weight is taken as 25 kN/m^3. The frames are loaded under the dead loads (DL), live load (LL), wall load (WL) and earthquake loads (EQ). According to Eurocode, the loads are combined as in the following equations: DL+EQ, DL+EQ+0.33LL, 1.35DL+1.5LL, DL+1.5LL.

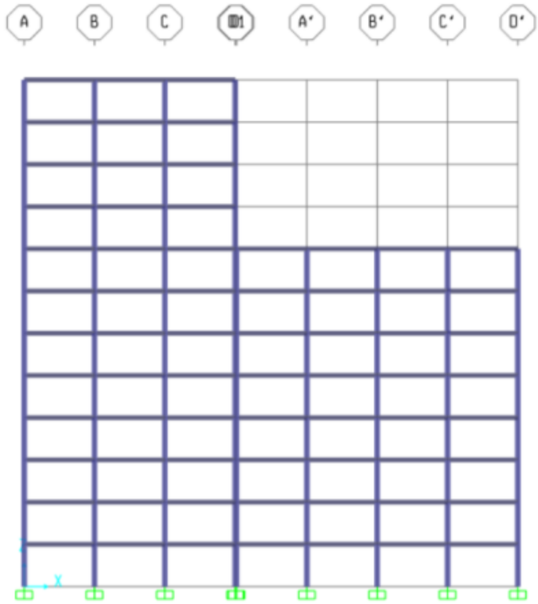

Figure 1. Elevation view of G+7 & G+11 building

ANALYSIS AND RESULTS

In this paper, all two-dimensional representative models and analysis are performed in Sap2000. Structures are loaded under DL, LL and EQ combinations, as it is indicated in Eurocode 2 [11]. Different evaluations for SG through square root of the sum of squares method (SSRSS), absolute sum method (S_{ABS}), IS1893, 2016 provision Sq*(u_i+u_j) and FEMA 356 maximum SG S_{max}, are done. The calculations for each evaluation methods for SG are tabulated in the table. N1 and N2 are the numbers of stories of the first structure and second building, respectively. From the results in the table, the SRSS method estimates the minimum values of SG, but it is not an adequate approach to follow in case out of phase vibrations occur simultaneously. So, for a safer evaluation, the S_{ABS} method is used to calculate the optimal SG. The $S_{q*(ui+uj)}$ and S_{max} give overestimated amount of SG, which is not convenient due to limitations of land usage. So, for the graphs and results, the S_{ABS} numerical values are used. The SG provision calculation according to KTP-89 is also evaluated, to check and compare the results with Eurocode and other provisions. According to KTP-89, the minimum seismic joint is calculated using Eq. (1): [12].

$$SG = u_i + u_j + 2cm \quad (1)$$

Table 1: Calculation for Separation Gap

Building Combination	C	Z	H	N1	N2	S_{ABS} (cm)	S_{SRSS} (cm)	$S_{q*(ui+uj)}$ (cm)	S_{max} (cm)
1	20	0.25	3.0	12	8	11.3907	8.967373	68.3442	96
2	25	0.25	3.0	12	8	11.2834	8.896947	67.7004	96
3	30	0.25	3.0	12	8	11.2322	8.840752	67.3932	96
4	25	0.30	3.0	12	8	13.6723	10.76199	82.0338	96
5	25	0.25	3.0	12	8	11.2834	8.896947	67.7004	96
6	25	0.20	3.0	12	8	8.987	7.072979	53.922	96
7	25	0.15	3.0	12	8	6.8367	5.3795	41.0202	96
8	25	0.25	2.8	12	8	9.2692	7.292811	55.6152	89.6
9	25	0.25	3.0	12	8	11.2834	8.896947	67.7004	96
10	25	0.25	3.5	12	8	13.3747	10.68654	80.2482	112

where C is concrete class, Z is seismic zone factor, H is story height, N1 is the number of stories for building 1 and N2 is the number of stories for building 2

Table 2: Calculation for Separation Gap according to KTP-89

Building Combination	C	Z	H	N1	N2	KTP-89 (cm)
1	20	0.25	3.0	12	8	13.3907
2	25	0.25	3.0	12	8	13.2834
3	30	0.25	3.0	12	8	13.2322
4	25	0.30	3.0	12	8	15.6723
5	25	0.25	3.0	12	8	13.2834
6	25	0.20	3.0	12	8	10.987
7	25	0.15	3.0	12	8	8.8367
8	25	0.25	2.8	12	8	11.2692
9	25	0.25	3.0	12	8	13.2834
10	25	0.25	3.5	12	8	15.3747

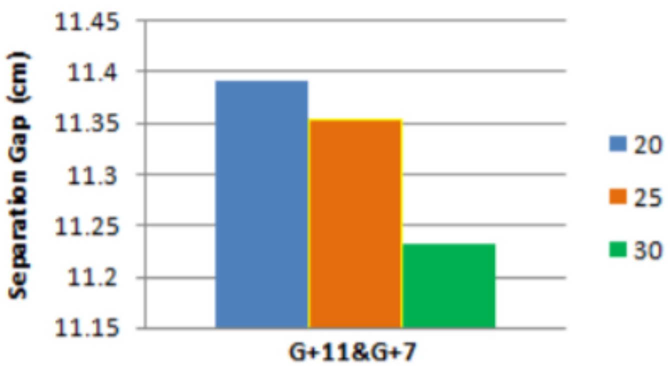

Figure 2. Variation of Separation Gap with Grade of Concrete

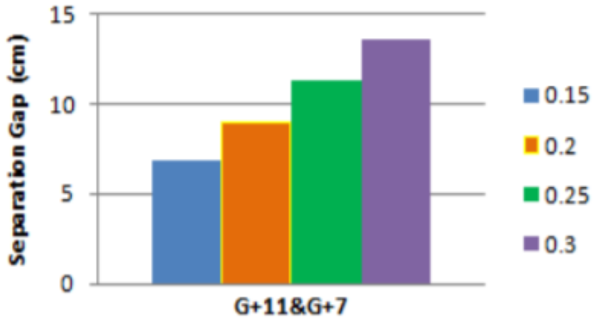

Figure 3. Variation of Separation Gap with Seismic Zone Factor

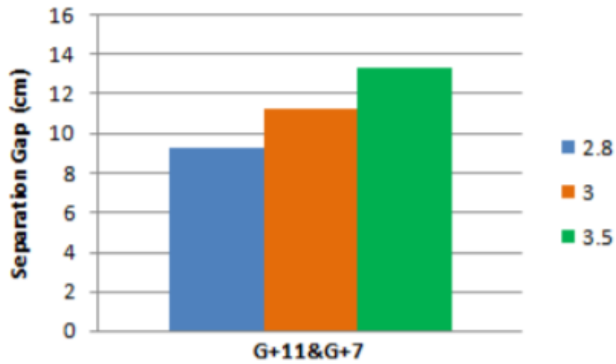

Figure 4. Variation of Separation Gap with Story Height

By comparing all the results coming from the cases, the most critical case is considered the one with the highest seismic zone factor. Due to the large impact, both buildings suffer greater damages during the earthquake. So, in order to prevent serious damages, the provision of sufficient SG is very crucial while designing adjacent structures. By analyzing the first case, it can be noticed that by increasing the concrete class (C), the SG between adjacent structures decreases. The percentage of decrease for SG is calculated to decrease with the increase of the concrete class.

Meanwhile, in the case number two it is observed that with the increase of the zone factor, the SG gets larger. For the increase of zone factor from 0.15 to 0.20, the percentage increase is 31.5%, for the increase from 0.20 to 0.25, the percentage increase is 25.5 % and for the increase from 0.25 to 0.30, the percentage increase is 21.2%. For the case number three, where the variable is the change of story level, it is observed that with the increase of story height, the lateral displacements of the structures increase. With the increase of story height from 2.8m to 3.0m, the SG increases by 21.7% and with the increase of story height from 3.0m to 3.5m, the SG increases by 18.5%.

CONCLUSIONS

Since the urbanization rate is increasing day by day, the available land is very limited, and this results in higher costs of land and closely built structures. In order to avoid the seismic pounding, which is a serious issue during an earthquake, a solution for such problem is the provision of a safe separation gap between adjacent structures. For that reason, the focus of the work has been to evaluate the minimum separation gap which provides enough security and safety during seismic vibrations of adjacent structures.

- It has been noticed that in most of the studies and code provisions, SG is evaluated based on the overall elevation of buildings, meanwhile this study gives an emphasis in the influence of other parameters such as concrete class, seismic zone factor and story height. By analyzing these parameters in the buildings, it is concluded that with their variation, the SG changes as well.

- All results presented in this study are derived from linear static analysis performed on regular two-dimensional RC framed structures.
- It can be noticed that by increasing the concrete class (C), the SG between adjacent structures decreases. The percentage of decrease for SG is calculated to decrease with the increase of the concrete class (0.94% and 0.45%). Even though providing a higher concrete class will reduce the spacing of separation gap, for construction companies this approach might increase the total cost of the project, which is not convenient, especially for Albanian practices. Beside this, considering the amount of percentage change, the difference of the SG is not very significant.
- For the change of zone factor from 0.15 to 0.20, the percentage increase is 31.5%, for the increase from 0.20 to 0.25, the percentage 35 increase is 25.5 % and for the increase from 0.25 to 0.30, the percentage increase is 21.2%. With the increase of story height from 2.8m to 3.0m, the SG increases by 21.7% and with the increase of story height from 3.0m to 3.5m, the SG increases by 18.5%.
- Based on the limited number of the analyses and the constraints considered in this study, the required SG calculated by using IS1893, 2016 provision Sq*(u_i+u_j) and FEMA 356 maximum SG S_{max} values are remarkably higher than the values calculated in this study, which is not convenient for land usage and cost.
- The closest building combination for the current existing set of buildings is the combination 2. Since the existent buildings are designed and constructed based on Eurocodes, the SG of the adjacent buildings is calculated using SRSS method. For building combination 2, according to SRSS method, the SG is 8.896947cm. The current separation joint between the structures is 10 cm. This means that the model results are in consonance with the real provided gap.
- The KTP-89 provision from Albanian Seismic Design Code requires a minimum separation gap that is larger than Eurocode minimum separation gap required. From the safety perspective we can say that the Albanian practice provides a safer seismic joint, but from the economic perspective we would say that it is more costly to implement it due to high price of land usage.

RECOMMENDATIONS FOR FUTURE RESEARCH

This study was focused only on reinforced concrete, mid-rise buildings designed by Eurocodes, meanwhile in Albania most of the buildings are constructed using old Albanian code practice or without any code. For an accurate estimation of SG between adjacent buildings in Albanian practice, further studies should include in investigation different types of structure. 36 Buildings are assumed as symmetrical in plan and structural irregularities are not included. Further investigations can be done taking into consideration asymmetrical structures with irregularities and non-linear analysis can be performed for more realistic results.

NOMENCLATURE

ABS	Absolute Sum Method
C	Concrete Class
DL	Dead Load in kN/m^2
EQ	Earthquake Loading

ESFM	Equivalent Static Force Method
FEMA	Federal Emergency Management Agency
H	Storey height in meters
LL	Live Load in kN/m^2
N1	Number of Floors of Structure 1
N2	Number of Floors of Structure 2
q	Response Reduction Factor
RC	Reinforced Concrete
S_{ABS}	Separation Gap as per ABS method in cm
SG	Separation Gap in cm
S_{max}	Separation Gap as per code FEMA 356 maximum SG provisions in cm
$S_{q*(ui+uj)}$	Separation Gap as per IS1893-2016 provision in cm
SRSS	Square Root of Sum of Squares Method
u_i	Maximum Displacement of Structure 1 at pounding location in cm
u_j	Maximum Displacement of Structure 2 at pounding location in cm
WL	Wall Load
Z	Seismic Zone Factor

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