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# POUNDING EFFECTS DURING AN EARTHQUAKE, WITH AND WITHOUT CONSIDERATION OF SOIL-STRUCTURE INTERACTION

**Daniela DOBRE , Claudiu-Sorin DRAGOMIR, Emil-Sever GEORGESCU**

The National Research and Development Institute “URBAN-INCERC” and European Center for Buildings Rehabilitation, ECBR, Bucharest, Romania

## OBVIOUS CASES OF POUNDING OF BUILDINGS IN BUCHAREST UNDER 1977 AND 1990 VRANCEA EARTHQUAKE INPUT

The effect of pounding between buildings was observed under 1977 and 1990 Vrancea earthquake input and since then the size of the seismic joint/separation gap was modified in the codes. Often, these effects have been suspected to be a reason for partial or total collapse of buildings, so the study of the pounding between buildings, in this context of Vrancea seismicity, is important.

In Bucharest, for instance, in the case of the 1977 Vrancea earthquake, a heavy pounding damage to buildings with adjacent corners. Damage occurred mostly in the frame structure including the rupture of a corner column in the story opposite the top of the next building (Fig. 1).

In the case of the 1990 Vrancea earthquake, a large damage along the expansion joint/seismic gap, Fig. 2.

Fig. 1. Heavy pounding damage to buildings with adjacent corners. (Fattal et al, 1977)

Fig. 2. Colentina district, damage down the seismic gap line, due to pounding (Pomonis et al, 1990)

## COMPARISONS OF PROVISIONS RELATED TO THE SEISMIC JOINT (SEPARATION GAP) BETWEEN TWO ADJACENT BUILDINGS

Evolution of the seismic joint/separation gap dimension is followed in all codes for the design of civil and industrial buildings in seismic regions, from 1963, 1970, 1978, 1981, 1992, 2006, 2013, with relevance to the involved effects on the response of an assembly of several adjacent buildings.

P100-2013 retains all provisions of P100-2006, but changes the computing relationship, the seismic joint width being calculated as the square root of the sum of squares of the maximum of two independent structural units under the action of seismic design loads, corresponding to the ultimate limit state, determined at the top level of the building with smaller height (P100-2013).

## MODELING OF POUNDING WITH AND WITHOUT CONSIDERATION OF SOIL-STRUCTURE INTERACTION

A parametric study was carried out in order to get the coupled effect of the supporting soil flexibility and pounding between neighboring three dimensional frame models. Pounding is simulated using a Kelvin model for contact element or nonlinear elastic gap elements, a set of springs elements have been incorporated to simulate the horizontal and rotational movements of the supporting soil, and the models have been excited using Vrancea ‘77 accelerograms.

Based on the obtained data, the following issues related to the structural response are presented:

•for structures considered at a sufficient distance from each other to avoid pounding, without considering the flexibility of soil, their fundamental periods of vibration are $T_{7lev}$ = 0.67s, with floors and walls, and $T_{5lev}$= 0.42s;

•for structures considered at a sufficient distance from each other to avoid pounding, but considering the flexibility of soil (soil-structure interaction), their fundamental periods of vibration are $T_{7lev}$ = 0.73s, with floors and walls, and $T_{5lev}$= 0.42s;

•the increase/modification of the natural periods of vibration, for these two structures separated by a separation gap of 0.02m, having different dynamic characteristics, with pounding between them, Fig. 3.

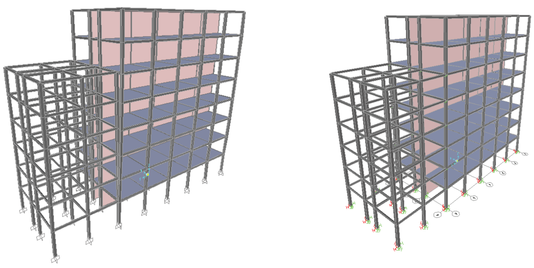


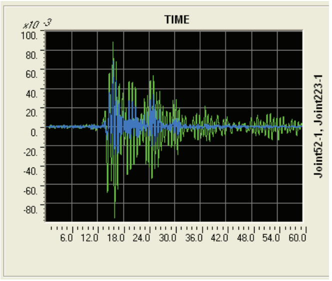
Fig. 3.Two frame buildings, one of them with floors and walls; $T_1$=0.73s (xz plane)-without SSI. $T_1$=0.80s (xz plane)-with SSI.

•variation of $T_1$ related to different separation gap, Table;

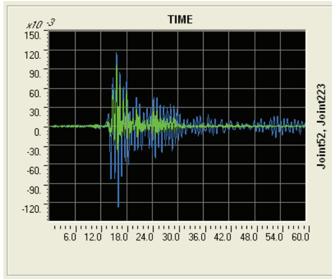
Table. Variation of $T_1$, related to different separation gap, for the assembly of two adjacent buildings, one of them with floors and walls

| $T_1$ | Separation gap | | | |
|---|---|---|---|---|
| | 0.02m | 0.04m | 0.08m | 0.10m |
| without SSI | 0.73s | 0.70s | 0.67s | 0.67s |
| with SSI | 0.80s | 0.74s | 0.73s | 0.73s |

•top floor UX displacements, impact forces, for different separation gap values, and comparisons with the results obtained for pounding buildings with fixed-base are presented, Fig. 4 (52 belongs to the structural model with 7 levels and 223 to the structural model with 5 levels);




UX displacement, max is 8.920e-02 at 1.558e+01 (gap 0.02m) - without SSI




UX displacement, max is 1.169e-01 at 1.564e+01 (gap 0.02m) - with SSI

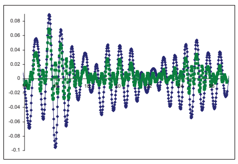


Figure 5. U1 displacements of 52-223 points (no of collisions between buildings: 25), without soil-structure interaction

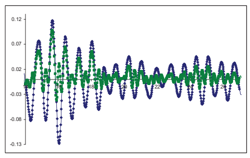


Figure 6. U1 displacements of 52-223 points (no of collisions between buildings: 50), with soil-structure interaction

## CONCLUSIONS

The effect of pounding between buildings was observed under 1977 and 1990 Vrancea earthquake input and since then the size of the seismic joint was modified (Balan et al, 1982; Berg et al, 1980; Georgescu et al, 1985, 1992, 2002; Georgescu and Radulescu, 1985).

For structures having different heights, but with aligned floors levels, the damage is typically concentrated at the top level of the shorter building and at the same level and just above pounding for the taller one. Considering the different separation gaps revealed that the stiffer structures suffer detrimentally whereas the flexible structure benefits. Also, the impact forces decrease as the separation gaps increase.

The effects of nonlinearities, the pounding effects between two adjacent buildings on the behavior of structures can cause both architectural and structural damages. Often, these effects have involved partial or total collapse of buildings, in the context of Vrancea seismicity.

For existing buildings of those generations such impact are likely to repeat during next earthquakes. Besides overall strengthening, that includes a stiffening of structure, a solution to prevent or reduce pounding effects is a target of future studies.

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