POUNDING BETWEEN HIGH-RISE BUILDINGS FOUNDED ON DIFFERENT SOIL TYPES

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Abstract

Earthquake-induced pounding is a phenomenon that has been often experienced in previous earthquakes. The aim of this study is to investigate the effect of the soil type on high-rise buildings experiencing earthquake induced-pounding. Pounding between 7-storey and 9-storey buildings is examined under five soil types defined in the ASCE 7-10 code which are hard rock, rock, very dense soil and soft rock, stiff soil and soft clay soil. The results of this study indicate that higher displacements at all storeys, peak storey shears and pounding forces were experienced in buildings founded on the soft clay soil, then for buildings founded on the stiff soil, then for buildings founded on very dense soil and soft rock, and finally for buildings founded on the rock and hard rock. This means that considering the soil-structure-interaction and the soil type in pounding studies is apparent rather than considering fixed-base building or considering SSI in general without giving attention to the soil type used.

Keywords: structural pounding; soil type; response spectrum; earthquakes; buildings

1. Introduction

Pounding between adjacent buildings is considered as one of the major effects of earthquakes as it has a significant effect on the response of colliding structures [1-3]. The damages reported during the Mexico earthquake is considered as one of the highest damages reported due to pounding, since 40% of the buildings experienced pounding, and in 15% of the buildings with severe collapse or damage, pounding was experienced [4], where in 20-30% of them pounding was the major reason of damage [5]. Structural collisions were also observed in the Loma Prieta earthquake where in 200 out of 500 surveyed buildings pounding was found [6]. Moreover, pounding was experienced in other earthquakes, such as the Lorca earthquake (Spain, 2001) [7] and the Wenchuan earthquake (China, 2008) [8].

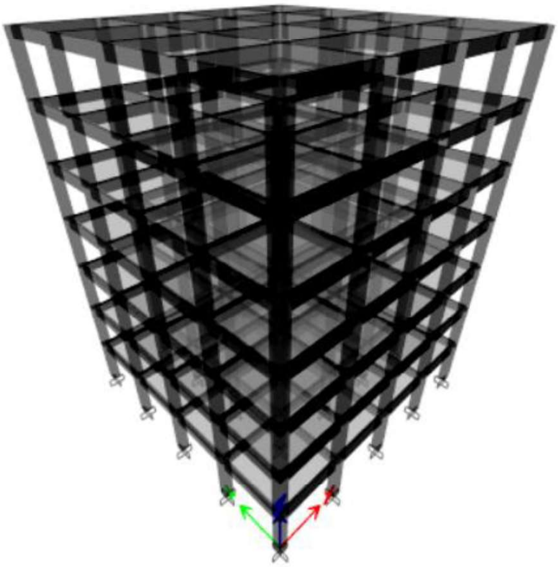
Research on earthquake-induced pounding has been conducted for more than three decades (see, for example, two state-of-the-art papers [9, 10] for details). Pounding occurs due to the out-of-phase vibrations of adjacent buildings caused by the difference of their natural periods [11, 12]. It is often classified as floor-to-floor pounding and floor-to-column pounding [13]. The first case is where the slabs of adjacent buildings collide one with another, and the second concerns the situation when the slab of one of the buildings collide with the column of the adjacent structure. The first occurs when the storey heights of the colliding buildings are equal, while the second takes place when the storey heights of the colliding buildings are different. The second case is considered as a more significant than the first one (see [5]).

Soil-structure interaction (SSI) is one of the issues that have a significant effect on the behaviour of colliding buildings. This is referred to the fact that the SSI decreases the stiffness of the building due to the flexible soil/base [14]. The flexible buildings experiences more significant damages due to pounding considering SSI [15, 16]. Pounding in buildings considering SSI was found to increase the displacements and storey shear forces in some studies [15] while other investigations indicate that it may decrease the displacements and impact forces [17]. The main reason of these contradictory results is the soil type used in these studies and the fact that these studies were focused on the consideration of the SSI without paying attention to the soil type used.

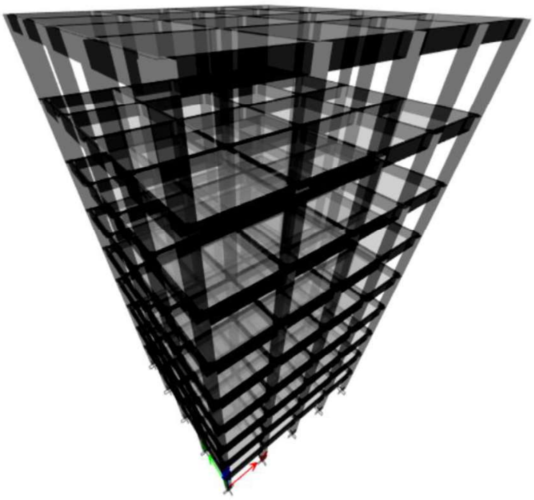
The above literature review illustrates that ignoring the soil type is a significant issue as it may lead to contradictory results concerning the earthquake-induced response of buildings experiencing pounding. Because of that, the aim of this paper is to study the effect of pounding on high-rise buildings founded on different soil types. In this study, two 3-D buildings were considered (7-storey and 9-storey structures). Then, pounding between the 7-stotey and 9-storey buildings is examined under different soil types defined in the ASCE 7-10 code [18], which are: hard rock, rock, very dense soil and soft rock, stiff soil and soft clay soil.

2. Numerical models of colliding buildings

Two 3-D buildings were used in this study. The storey height is 3 m and the bays were 4×4 m in each direction which leads to 16 m length and width. The models of both buildings were created in ETABS software [19] using the Finite Element (FE) method. The FE models of these buildings are shown in Figure 1.



(a) 7-storey building



(b) 9-storey building

Figure 1: FE models of the considered buildings

The seismic gap between buildings was considered as equal to 4 cm for all cases. The collision was modelled in ETABS software by using special gap elements (see Figure 2). These elements are two-node compression-only link elements which are activated in the case of contact and de-activated elsewhere (see [20] for details). The gap elements were placed every 4 m along the collision length at all storeys (5 elements at each storey were used).

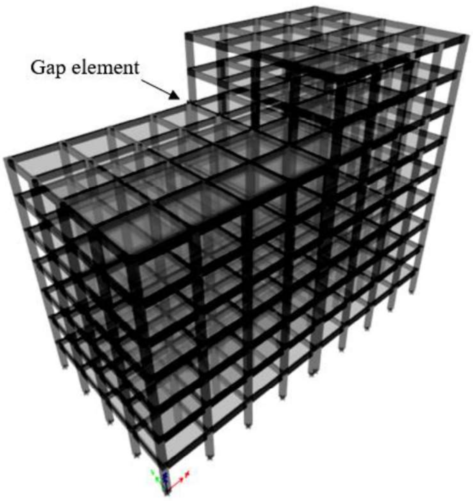


Figure 2: FE model of colliding buildings

The analysis was carried out for the Parkfield earthquake of 1966 measured in San Luis Obispo station and with the peak ground acceleration of 0.01175g (see PEER website database [21]). The structural response was obtained by applying the fast nonlinear analysis method developed by Ibrahimbegovic and Wilson [22].

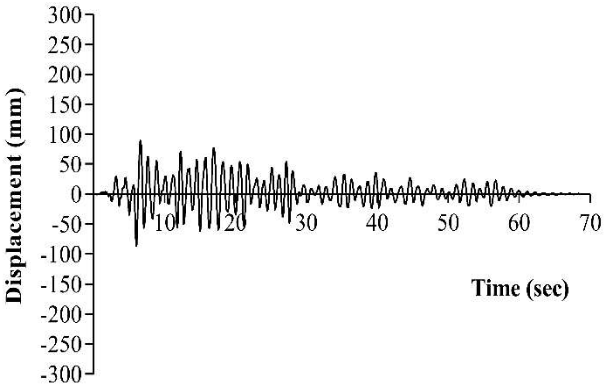
3. Soil types

In this study, the five soil types defined in the ASCE 7-10 code [18] were used which are soil types A (hard rock), B (rock), C (very dense soil and soft rock), D (stiff soil), and E (soft clay soil). The analyses were performed using ETABS software. The soil type was considered by defining the response spectrum and matching the ground motion (Parkfiled) with the target response spectrum. To define the response spectrum, three parameters need to be defined which are the values of Ss (mapped risk-targeted Maximum Considered Earthquake, MCER, spectral response acceleration parameter at short period), S1 (mapped risk-targeted MCER spectral response acceleration parameter at 1-s period) and the long-period transition period TL (s). The site parameters were selected as follows: 0.5 for S1, 1.25 for Ss and additionally 8 s for TL. After introducing these parameters, the response spectrum was defined and the Parkfield ground motion was scaled to the target response spectrum.

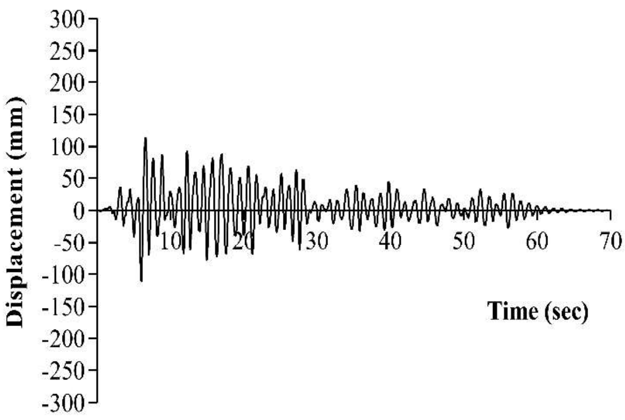
4. Pounding between buildings founded on different soil types

In this section, pounding between the 7-storey and 9-storey buildings is studied under different soil types. Five soil types were considered in the analysis, which are soil type A (hard rock), soil type B (rock), soil type C (very dense soil and soft rock), soil type D (stiff soil) and soil type E (soft clay soil). The site parameters are: 0.5 for S1, 1.25 for Ss and additionally 8 s for TL.

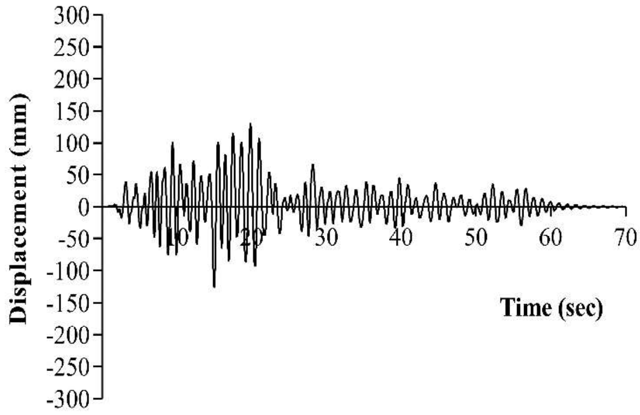
Figure 3 shows the displacement time histories of the 9-storey building at the 7th storey (level of collision) founded on different soil types. The results presented in the figure indicate that higher displacements were experienced in the 9-storey buildings when founded on soil type E, then D, then C, then B and finally A. The peak displacements of the 9-storey building at the 7th storey founded on different soil conditions are: 90.5 mm for soil type A, 114.989 mm for soil type B, 130.234 mm for soil type C, 172.402 mm for soil type D and 279.539 mm for soil type E. It can be clearly seen that also the peak displacement at the level of collision is experienced in buildings founded on soil type E, then D, then C, then B and finally A. This is not only experienced at the level of collision, but also at all storeys (see Figure 4 which shows the peak storey displacements of the 9-storey building). Therefore, it can be concluded that larger displacements were experienced at all storeys of the colliding buildings founded on soil type E, then D, then C, then B and finally A. This means that higher seismic gaps are required for buildings founded on soil type E, then D, then C, then B and finally A.



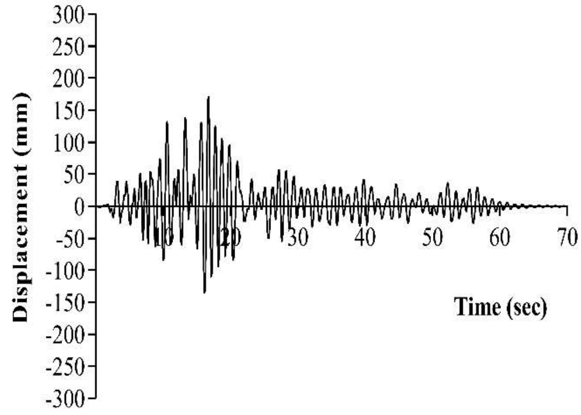
(a) Soil type A



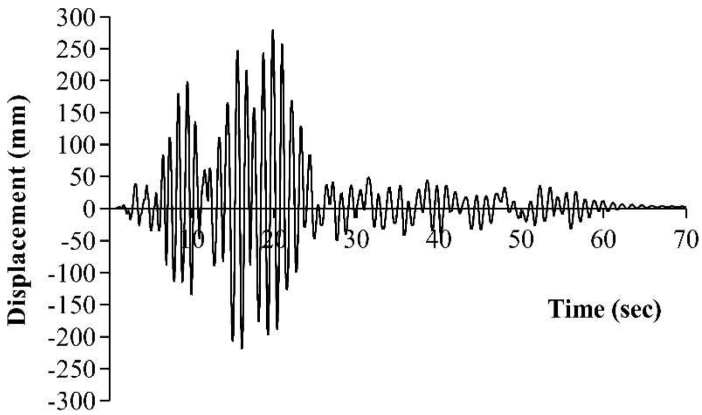
(b) Soil type B



(c) Soil type C



(d) Soil type D



(e) Soil type E

Figure 3: Displacement time histories of the 7th storey of the 9-storey building founded on different soil types

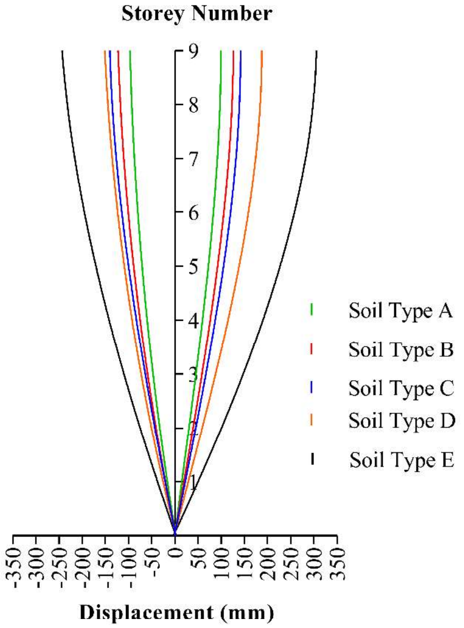


Figure 4: Peak storey displacements of the 9-storey building founded on different soil types

Figure 5 shows the peak storey shear of the 9-storey building under different soil conditions. The results presented in this figure illustrates that higher storey shears were experienced in the 9-storey building when founded on soil type E, then D, then C, then B and finally A. Furthermore, Figure 6 shows the pounding force time histories. It can be seen that larger pounding forces were experienced when the buildings founded on soil type E, then D, then C, then B and finally A. The peak pounding force of the 7-9 pounding case under different soil conditions is: 18858.3 kN for soil type A, 24017.2 kN for soil type B, 25166.7 kN for soil type C, 43151.5 kN for soil type D and 86132.4 kN for soil type E. It can be clearly seen that also the peak pounding force is larger when the buildings were founded on soil type E, then D, then C, then B and finally A. This indicates that pounding in is more destructive when buildings founded on soil type E, then D, then C, then B and finally A. These conclusions clearly confirm the necessity of the consideration of the soil in the future studies focused on earthquake-induced structural pounding, rather than considering only fixed-base buildings. Indeed, in the studies that consider the soil and the SSI, special attention should be given to the soil type used and not only considering SSI in general.

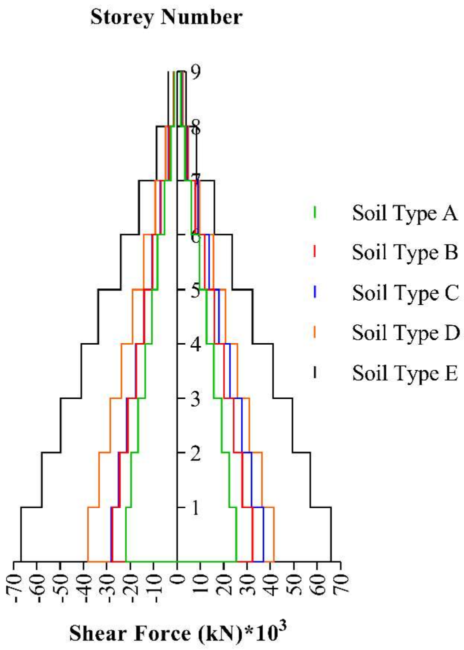
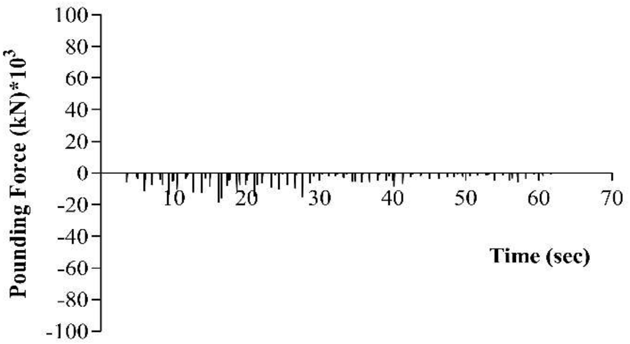
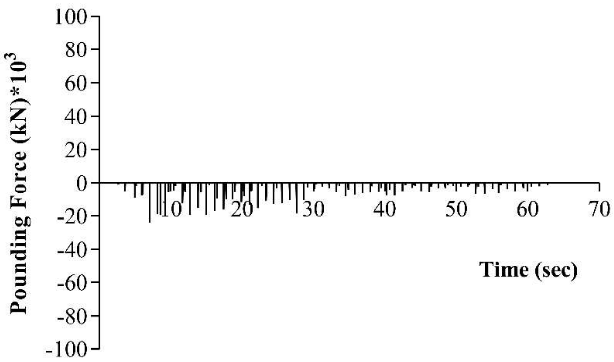


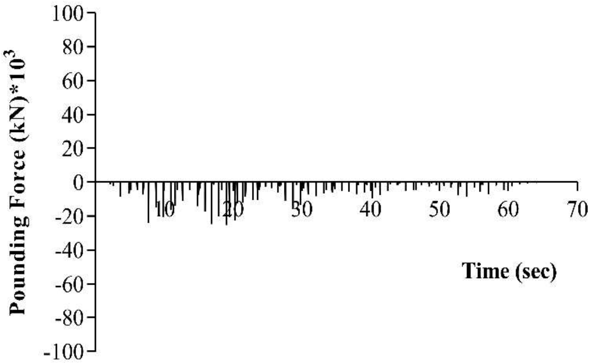
Figure 5: Storey shears of the 9-storey building founded on different soil types



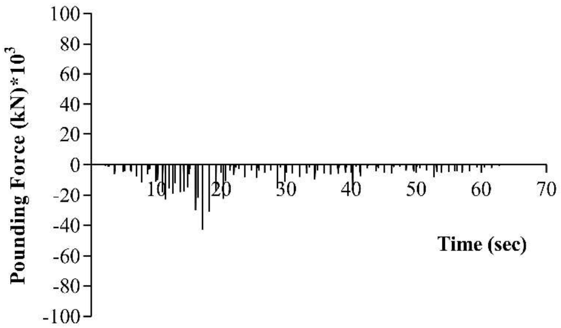
(a) soil type A



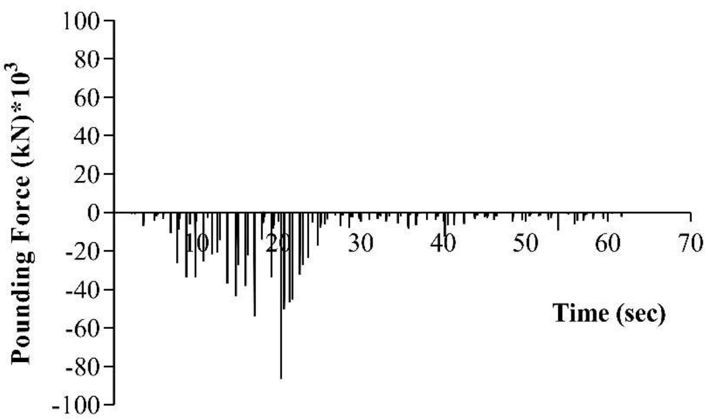
(b) soil type B



(c) soil type C



(d) soil type D



(e) soil type E

Figure 6: Pounding force time histories of the 7-9 pounding scenario founded under different soil types

5. Conclusions

In this study, pounding between high-rise buildings founded on different soil types was investigated. To achieve that, pounding between 7-storey and 9-storey buildings is examined under five soil types defined in the ASCE 7-10 code which are soil type A (hard rock), soil type B (rock), soil type C (very dense soil and soft rock), soil type D (stiff soil) and soil type E (soft clay soil).

The results of this study indicate that higher displacements at all storeys, peak storey shears and pounding forces were experienced in buildings founded on soil type E, then D, then C, then B and finally A. This conclusion means that considering the SSI and the soil type in pounding studies is apparent rather than considering fixed-base building or considering SSI in general without giving attention to the soil type used.

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7. Copyrights

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