Engineering Structures 163 (2018) 93–111

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Torsional behavior of multistory RC frame structures due to asymmetric seismic interaction

Chris G. Karayannis*, Maria C. Naoum

Civil Engineering Dept., Democritus University of Thrace, Xanthi 67100, Greece

A R T I C L E I N F O

Keywords:
Asymmetric seismic interaction of structures
Inter-story pounding
Nonlinear seismic analysis
Earthquake engineering

A B S T R A C T

Collisions between structures due to seismic oscillations have been reported many times in literature as a common case of damage. Further it is quite usual seismically induced oscillations of a structure in a city center block of buildings to be partly restrained in lateral displacements and therefore torsional behavior to be introduced in the structure. Two different types of structural interaction may be defined: (a) Diaphragm-to-diaphragm collisions (Type A). (b) The floor levels of the two structures are different. Consequently during the seismic oscillations the diaphragms of the first one impact the columns of the other (Type B or interstory pounding). In this work the cases of an 8-story reinforced concrete building that suffers pounding with an adjacent structure that has 1, 2, 3, 4, 5, 6, 7 or 8 stories are studied. Pounding occurs only in one (Case 1) or in two (Case 2) columns of the structures and since the other columns are free to move without restrictions a torsional behavior is introduced (asymmetric pounding). Moreover in Type B interaction these columns of the 8-story frame structure undergo impacts at a height equal to 2/3 of their deformable length from the diaphragms of the other structure. The influence of an initial distance between the two interacting structures on the torsion effect is investigated too. Nonlinear seismic step-by-step analyses are performed. More than two hundred pounding cases with torsional effect each one for three natural seismic excitations are studied. Results in terms of shear and ductility demands of the columns are presented and commented. Both types A and B yielded high torsional structural rotation. In interaction Type B it can be deduced from the cases under examination that the column that is endured the impact from the top floor of the other structure develops high shear demands that exceed the available capacity many times during the step-by-step seismic analysis. Moreover high ductility demands have been observed for this column. Finally it is concluded that for buildings that may undergo asymmetric pounding not taking it into account may lead under certain conditions to non-secure design or even critical situations.

1. Introduction

Based on the substantial knowledge that has been acquired so far through numerous field reports after destructive seismic excitations it has been widely accepted that pounding is always present when earthquakes occur in densely populated big city centers. Many examples about the pounding hazard can be traced in literature [1–5].

During these excitations the interaction of structures is recognized as a frequent causation of damage and moreover case studies have been reported where the pounding phenomenon has been considered as an important cause for the beginning of collapse. Particularly in the seismic excitation of Mexico City in 1985 as reported by Rosenblueth and Meli [6] and Bertero [2] the first assessment had attributed to pounding a great part of the reported damage and identified many cases that pounding initiated collapse. Even though from this point of view Mexico City can be considered as unique event in terms of reported damaged and collapsed buildings attributed to the pounding effect and it has been rather overstated concerning the damage, it is rather widely accepted that in all major earthquakes structural pounding has always been present.

Further in city centers with large blocks densely filled with buildings the land lots are mostly not equal or alike in plan geometry henceforth it's very likely adjacent buildings in a block to be partly and in a non-symmetric way in contact to each other. Consequently it is quite usual seismically induced oscillations of a structure in a block to be partly restrained in lateral displacements and therefore as Karayannis and Naoum [8,9] have shown a torsional movement to be introduced in the building during an earthquake excitation. This phenomenon can be referred to as asymmetric pounding.

Furthermore earthquake vibrations of structural parts of a building

* Corresponding author.
E-mail addresses: karayan@civil.duth.gr (C.G. Karayannis), mnaoum@civil.duth.gr (M.C. Naoum).

https://doi.org/10.1016/j.engstruct.2018.02.038
Received 17 July 2017; Received in revised form 19 December 2017; Accepted 12 February 2018

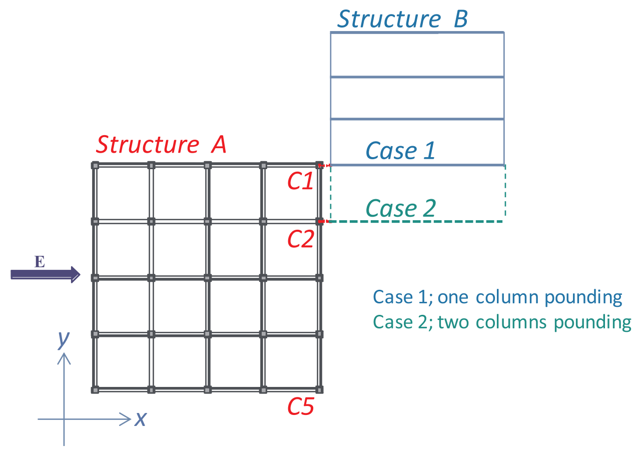

Fig. 1. Plan view. Asymmetric pounding.

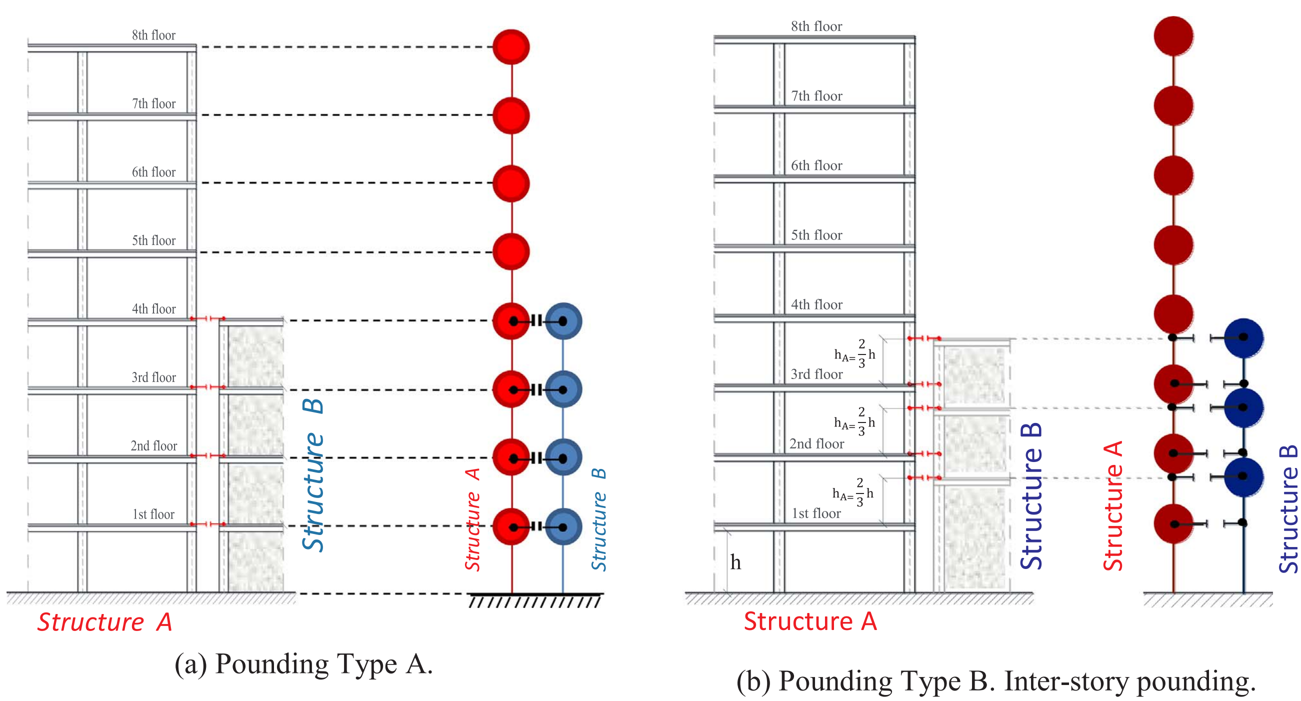

Fig. 2. Actual condition and model idealization of the pounding problem.

system consisting of two or three structural parts can also induce torsional vibrations in the other building components or the main building of the building system as it has been observed and analytically proven by Jankowski [4] and by Jankowski and Mahmoud [5] in their study for the Olive View Hospital.

The typical provision of modern codes against structural interaction is the competent separation in order to avoid pounding between structures [10]. However inherent factors make these code provisions not always effective or applicable. The main concept behind the philosophy of contemporary seismic codes is that inelastic response can occur during major seismic excitations and further large deformations may be observed. Therefore separation provisions may lead sometimes to inadequate and inconsistent building separations. Besides the high cost of land in city centers and the small size of the lots make the building separation provisions not always easily applicable.

Karayannis and Fotopoulou [7] have studied the pounding between structures that were designed to Eurocodes 2 and 8. The aim of this work was to present for the first time results about the influence of factors for the interaction of structures on the column ductility demands. Useful factors have been introduced for this purpose. Further

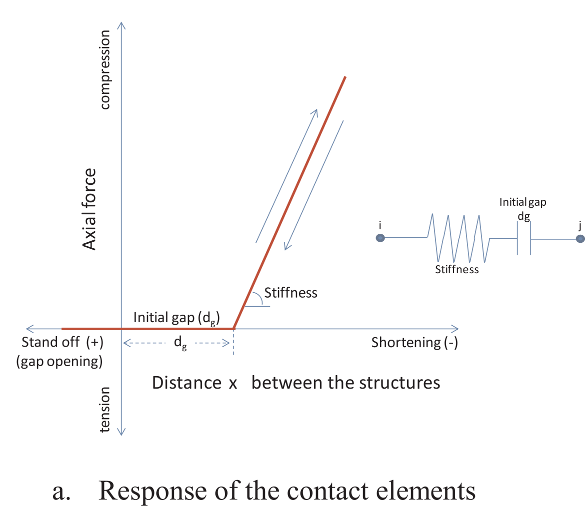

Fig. 3. Contact element. Response of contact elements (a) and influence of stiffness (b) and damping (c) of the contact elements on the results of pounding analysis.