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Preventing of earthquake-induced pounding between steel structures by using polymer elements – experimental study

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Abstract

Pounding between two, or more, adjacent buildings during earthquakes has been identified as one of the reasons for substantial damage or even total collapse of colliding structures, so it has been the subject of numerous studies in the recent years. A major reason leading to interactions between adjacent, insufficiently separated structures results from the differences in their dynamic properties. A number of different methods have been considered to mitigate earthquake-induced structural pounding. One of the techniques is linking structures which allow the forces to be transmitted between buildings and thus eliminate interactions. The aim of the present paper is to show the results of the experimental study focused on the application of polymer elements placed between the colliding members so as to mitigate earthquake-induced pounding between adjacent steel structures in series. In the study, three steel model towers with different dynamic parameters and various in-between distances were considered. The unidirectional shaking table was used in the experimental study. Models of steel towers were prepared and mounted to the platform of the shaking table. Additional mass was added at the top of each tower so as to obtain different dynamic characteristics of the structures. The results of the study indicate that earthquake-induced pounding may have a significant influence of the structural response. Moreover, the application of polymer elements between the structures can be an effective pounding mitigation technique. It allows us to prevent damaging collisions between adjacent structures during earthquakes. It also improves the structural behaviour leading to the reduction in vibrations under different seismic excitations.

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Keywords: Structural pounding; earthquakes; steel structures; polymer elements

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1. Introduction

Observations after past earthquakes have demonstrated that buildings may experience major damage if they are not appropriately designed for dynamic loads observed during earthquakes. On the other hand, due to high cost of land in the urban areas, there is a kind of pressure on designers to construct structures with very small in-between separation gap. This situation may result in structural interactions between adjacent buildings during seismic excitations (known as earthquake-induced structural pounding). Pounding of closely separated structures increases damage to structural elements and it may even cause collapse of structures. Rosenblueth and Meli [1] referred that the earthquake that struck the Mexico City in 1985 caused significant damage of structures and that more than 40% of these damages occurred as the result of pounding. Also, after the Kocaeli earthquake (17.08.1999), interactions between too closely situated apartment buildings were recognized as a main reason of substantial damage of elements in the places of collisions. Vasiliadis and Elenas confirmed that a number of buildings suffered due to pounding during the earthquake in Athens in 1999 [2]. Similar observations confirmed that pounding was also the main reason of permanent titling of a stairway tower, which resulted from collisions with the main building of the Olive View Hospital during the San Fernando earthquake in 1971 [3]. The building damages due to earthquake-induced structural pounding during other seismic excitations were also reported by Anagnostopoulos [4].

The main recognized reason leading to interactions between insufficiently separated structures is usually the difference in dynamic parameters of each structure [5-7]. The difference in mass or stiffness leads to the out-of-phase vibrations, and finally to collisions. Another reason, more important in the case of large buildings and bridge structures, is related to the spatial seismic effects due to propagation of seismic wave [8]. The phenomenon of earthquake-induced structural pounding has been intensively studied for nearly three decades (see, for example, [9-13]). However, most of the analyses have concerned collisions between reinforced concrete buildings and the studies on pounding between steel structures are very limited (see [14-16]).

A number of different methods have been considered to mitigate earthquake-induced structural pounding. The most natural one is to assume large enough in-between gap size so as to prevent collisions. Another technique is linking structures which allow the forces to be transmitted between buildings and thus eliminate interactions [17]. Stiff links as well as some viscoelastic elements have been tested for such purposes. The aim of the present paper is to show the results of the experimental study focused on the application of polymer elements placed between the colliding members so as to mitigate earthquake-induced pounding between adjacent steel structures in series.

2. Experimental setup

2.1. Experimental model

The experimental study presented in this paper is focused on structural pounding between three models of steel structures standing in a raw and subjected to different seismic excitations. The shaking table located in the Laboratory of Department of Metal Structures and Construction Management of Gdańsk University of Technology (Poland), was used in the experimental study. This unidirectional device is equipped with the platform with dimensions of 200x200 cm which allows us to test models of the maximum weight of 1000 kg. The linear actuator, which may induce movement with maximum acceleration of 10 m/s^2 and a maximum strength of 44.5 kN, is connected to the platform.

In order to simulate the behaviour of small (up to few-storey in height) buildings under earthquake excitations, the tower models with different dynamic characteristics were prepared (Fig.1). Each steel tower was constructed out of four vertical columns with cross section 15x15x1.5 mm and height of 1000 mm. Vertical elements with the same cross section were connected with the horizontal ones at the base and at the top. To make the structures more rigid and to prevent torsional and transverse vibrations, additional skew bracings were used. Additional concrete plates with dimension 500x500x70 mm and weight of 42.2 kg were used to build towers with different dynamic parameters, making the structures to act as single degree-of-freedom systems. The configuration with two concrete plates mounted at the top of the external towers and only one plate on the middle tower has been analyzed in this paper. Additionally, the influence of different earthquake excitations as well as different thickness of polymer elements mounted between models (see Fig.1) has been tested and the results have been presented in this paper.