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Contents

Chapter 1
Introduction

It has been observed during earthquakes that adjacent building, or bridge segments, might come into contact if the separation distance between them is not sufficient so as to accommodate their relative movements. This phenomenon, known as the earthquake-induced structural pounding, may lead to local damage at the contact locations during moderate seismic excitations or may result in significant damage or even total collapse of colliding structures in the case of severe ground motions.

The report after the Kaliningrad earthquake (21.09.2004), for example, shows that interaction between adjacent parts of the apartment building led to spalling of plaster at the contact locations, as can be seen in Fig. 1.1 (Zembaty et al. 2005). Local damage at the interaction points was also observed in a number of buildings after the Darfield earthquake of September 2, 2010 (Cole et al. 2011). Vasiliadis and Elenas (2002) reported considerable damage at the locations of impacts due to pounding between two different parts of a school building during the Athens earthquake (7.09.1999). The SSK Hospital in Izmit suffered major damage during the Kocaeli earthquake (17.08.1999) due to interactions between different parts of the structure (Gillies et al. 2001). Extensive pounding damage was also observed in low-rise unreinforced masonry buildings after the Christchurch earthquake of 2011 (Cole et al. 2012). It was observed after the Mexico City earthquake (19.09.1985) that about 40 % of the damaged structures experienced some level of pounding and, in the case of 15 % of them, pounding was identified as one of the reasons of structural collapse (Rosenblueth and Meli 1986). During the San Fernando earthquake (09.02.1971), structural interactions between the main building of the Olive View Hospital and one of its independently standing stairway towers resulted in substantial damage and permanent tilting of the weaker stairway tower (Bertero and Collins 1973). Over 200 pounding occurrences, involving more than 500 buildings, were observed at locations within the distance of 90 km from the epicentre after the Loma Prieta earthquake (17.10.1989). Structural pounding during that earthquake was identified as the reason for collapses of some of buildings (see, for example, Fig. 1.2) (Kasai and Maison 1997).

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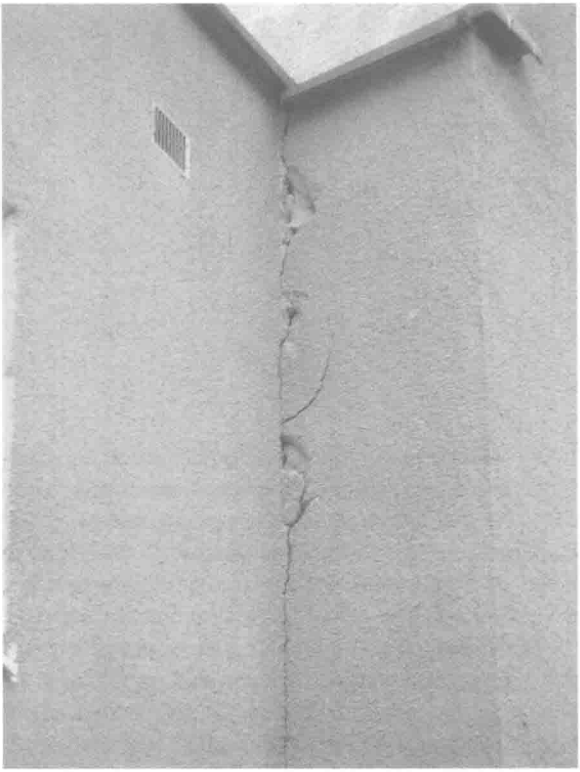

Fig. 1.1 Local damage at the contact locations (Kaliningrad earthquake, 2004)

The negative effects of earthquake-induced structural interactions were also observed in the case of bridge structures. Priestley et al. (1996) reported that impacts between the lower roadway and columns supporting the upper-level deck of the Southern viaduct section of the China Basin during the Loma Prieta earthquake of 1989 resulted in significant structural damage. After the Northridge earthquake of January 17, 1994, substantial pounding damage was observed at expansion hinges and abutments of standing portions of bridges at the Interstate 5 and State Road 14 interchange (EERI 1995). The report after the Kobe earthquake (17.01.1995) identifies pounding, due to fracture of bearing supports, as a reason leading to considerable local damage at the contact points (see Fig. 1.3) and a contribution to falling down of superstructure segments, as can be seen in Fig. 1.4 (Otsuka et al. 1996). Severe damage due to pounding between adjacent segments of the New Surajbadi Highway Bridge was also observed during the January 26, 2001 Gujarat (India) earthquake (Singh et al. 2002).

In the case of buildings, the major factor recognised as the reason of structural pounding is the difference in natural periods of vibrations (see Anagnostopoulos 1988; Anagnostopoulos and Spiliopoulos 1992; Maison and Kasai 1990, 1992; Tena-Colunga et al. 1996; Karayannis and Favvata 2005a, b; Jankowski 2005, 2007, 2008; Komodromos 2008; Mahmoud and Jankowski 2009, 2011; Polycarpou and

Fig. 1.2 Collapse of a building (Loma Prieta earthquake, 1989) (reprinted from Kasai and Maison 1997 with permission from Elsevier)

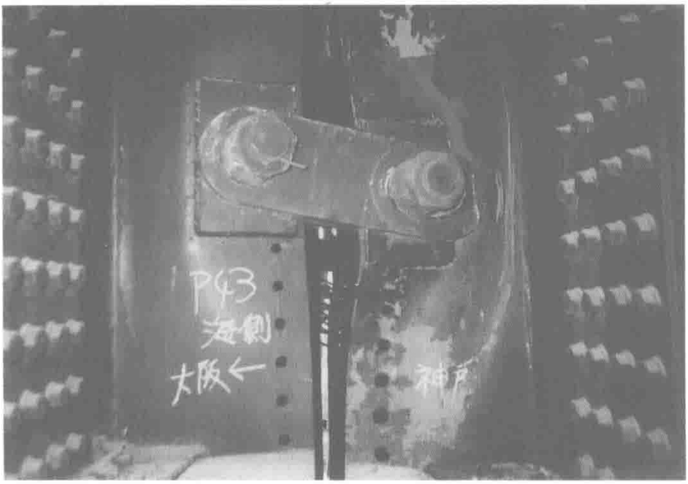

Fig. 1.3 Local damage at the ends of superstructure segments (Kobe earthquake 1995)

Fig. 1.4 Pounding as one of the reasons for falling down of superstructure segments (Kobe earthquake, 1995)

Komodromos 2010; Mahmoud et al. 2012, 2013; Falborski and Jankowski 2013; Sołtysik and Jankowski 2013; Polycarpou et al. 2014). The difference in mass or stiffness makes the adjacent buildings to vibrate out-of-phase during the earthquake and increases the probability of structural interactions (see Fig. 1.5). In contrast to buildings, pounding in bridges is usually caused by the spatial seismic effects related to the propagation of the seismic wave (see, for example, Jankowski et al. 1998, 2000; Kim et al. 2000; Zanardo et al. 2002; Chouw and Hao 2005). These effects, which may include time lag and lack of coherence of seismic wave as well as spatially varying local soil conditions (see Der Kiureghian 1996), lead to different earthquake excitations acting at different structural supports (see Fig. 1.6) resulting in the out-of-phase vibrations of adjacent superstructure segments (Jeng and Kasai 1996; Hao and Liu 1998). Spatial seismic effects may also be responsible for earthquake-induced pounding between buildings with spatially extended foundations (Jankowski 2009, 2012) or buildings in a row (Athanassiadou et al. 1994; Hao and Zhang 1999).

Earthquake-induced structural pounding is a complex phenomenon, often involving plastic deformations, local cracking or crushing at the points of contact, fracturing due to impact, friction, etc. Impact induces forces which are applied and removed during a very short time, what initiates stress waves travelling away from the impact location. The process of energy transfer during collision is much complicated making the analysis of this type of problem to be highly difficult.

In spite of its complexity, the phenomenon of structural pounding during earthquakes has recently been intensively studied applying various structural