PAPER • OPEN ACCESS

Experimental analysis of the behaviour of different types of joints in the steel structure model subjected to earthquake loading

To cite this article: T Jaroszewski *et al* 2021 *J. Phys.: Conf. Ser.* **2070** 012227

View the article online for updates and enhancements.

Experimental analysis of the behaviour of different types of joints in the steel structure model subjected to earthquake loading

T Jaroszewski[1], T Falborski [1], R Jankowski[1]

[1]Gdańsk University of Technology, ul. Narutowicza 11/12, 80-233 Gdańsk, Poland

Abstract. The present paper reports the results of the experimental study performed to investigate the behaviour of two different types of joints (destroyed and welded ones) in the model of the steel structure under seismic excitations. The structure was subjected to three earthquakes, namely Kobe, Loma Prieta and Northridge, using the shaking table investigation. The results obtained from the study indicate that there is a significant difference between the behaviour of destroyed joints and welded ones. It was concluded that the destroyed joints experience higher acceleration than the welded joints during different earthquakes.

Keywords: Destroyed joints, welded joints, steel structure, accelerations, earthquakes, shaking table tests

1. Introduction

Earthquakes, which are caused by a sudden release of stress along faults in the earth's crust, are claimed to be one of the most dangerous natural disasters. They may have a lot of destructive effects, including the collapse of roads and infrastructure as well as turning soil to liquid or causing landslides. With regard to buildings, one of the threats during earthquakes is the phenomenon of pounding, which results in collisions between adjacent buildings (see, for example, Mahmoud, Chen & Jankowski, 2008; Sołtysik, Falborski & Jankowski, 2016; 2017; Miari, Choong & Jankowski, 2019; Naderpour, Naji, Burkacki & Jankowski, 2019; Miari, Choong & Jankowski, 2020). The Kobe (1995), Loma Prieta (1989) and Northridge (1994) earthquakes are among the most destructive earthquakes over the past years. Taking into account their far-reaching consequences, strong ground motions have become a major concern for many scientists. Thus, the methods for decreasing the earthquakes' devastating effects have been sought by the researchers for many years. The most frequently used approach concerns the shaking table testing (see, for example, Falborski & Jankowski, 2013; 2017; 2018). It enables us to simulate the earthquake forces and analyze them. Due to this, the dynamics of building structures as well as joints are scrutinised, which helps to enhance their safety and reliability.

In the applicable standards for design of steel structures, joints are classified according to their stiffness and strength. Due to the rotational stiffness, joints are divided into rigid, classic pinned and semi-rigid. The behaviour of joints influences the distribution of internal forces and the deformation of the structure, the size of the critical and boundary load and the dynamic characteristics of the structure. In the case of systems with semi-rigid joints, the impact can be significant (see, for example, Reyes-Salazar & Haldar, 1999; Baniotopoulos & Wald, 2000; Ricles, Fisher, Lu L-W & Kaufmann, 2002;

Rassati, Leon & Noe, 2004; Radaj, Sonsino & Fricke, 2006; Diaz, Marti, Victoria & Querin, 2011; Trahair N. S, 2012).

The main objective of the present paper is to analyse the behaviour of two different types of joints (destroyed and welded ones) in the model of the steel structure exposed to seismic excitations. In order to achieve this aim, the shaking table investigation was performed, where three major earthquakes, namely Kobe (1995), Loma Prieta (1989) and Northridge (1994), were applied.

2. Experimental model

In order to conduct the experimental study, one single-storey steel structure, was employed (see Figure 1). The structure was composed of rectangular elements made of hollow section elements (RHS 15×15×1.5 mm). With regard to columns, they were set on a rectangular plan. The spacing in the transverse direction was 0.556 m and 0.465 m in the longitudinal direction. The height of the steel structure was 1.20 m.

Diagonal bracings, which were responsible for counteracting transverse and torsional vibrations, were employed in the planes of the sidewalls. Concrete plate (50×50×7 cm) was used to simulate the weight of the floor. The weight of the concrete slab was 47.56 kg.

Moreover, a number of sensors were applied in the experimental tests. They were located at the bottom of the steel structure (one sensor on the destroyed part and the second one on the welded one) (see Figure 2). They enabled us to measure the acceleration of the structure at the joints.

All the elements were placed on a middle-sized shaking table located at Gdańsk University of Technology, Poland. Three earthquakes, namely Kobe (1995), Loma Prieta (1989) and Northridge (1994) were simulated (see Table 1), and the seismic response of the experimental model to these ground motions was investigated. Firstly, free vibration tests were carried out, which enabled us to determine the dynamic characteristics of the experimental model (see Falborski & Jankowski, 2017). The fundamental frequency of the structure was found to be 3.31 Hz and the damping ratio was calculated as equal to 0.53%.

**Figure 1.** Experimental model of steel structure used in the study.
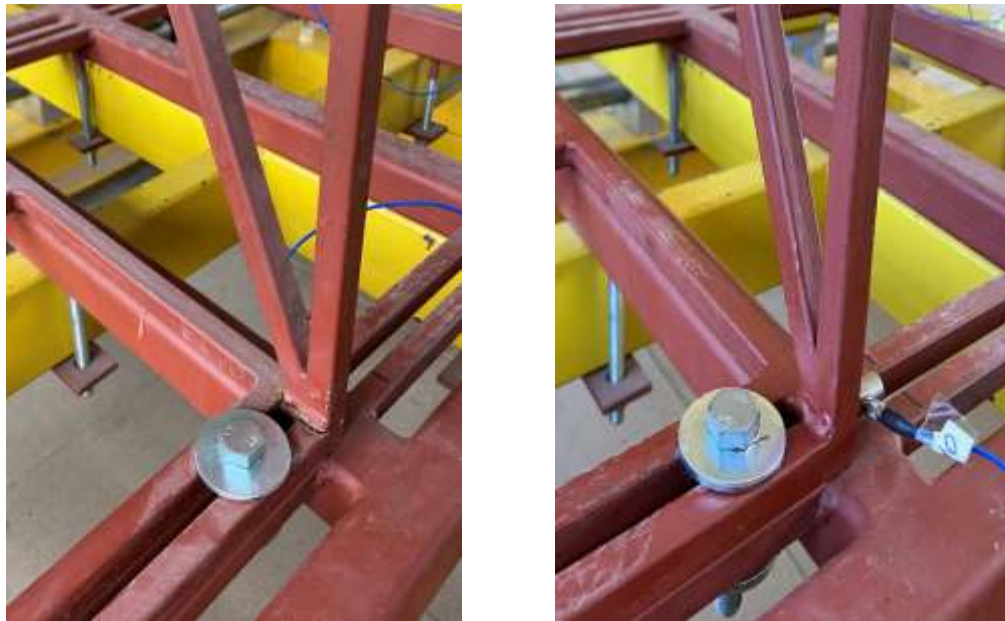
a)   Destroyed joint   b) Welded joint

Figure 2. Different types of joints.

**Table 1.** Ground motions used in this study.

Earthquake	PGA (m/s^2)	Station	Year
Kobe	2.014	JMA	1995
Loma Prieta	3.158	Corralitos	1989
Northridge	4.332	Santa Monica	1994

3. Results and discussion

The behaviour of both destroyed and welded joints for a single-storey steel structure model is presented and discussed in this section. The acceleration time histories at the joints (destroyed and welded) for the model exposed to the Kobe, Loma Prieta and Northridge earthquake are shown in Figures 3, 4, and 5, respectively. Additionally, the peak accelerations at the joints (destroyed and welded) for the model exposed to the Kobe, Loma Prieta and Northridge earthquakes are presented in Table 2. It can be clearly seen that, for the three earthquakes, the destroyed joints had higher acceleration values and higher response than the welded ones. The maximum percentage difference between the peak accelerations at the destroyed and welded joints was found to be as large as 77.96%.
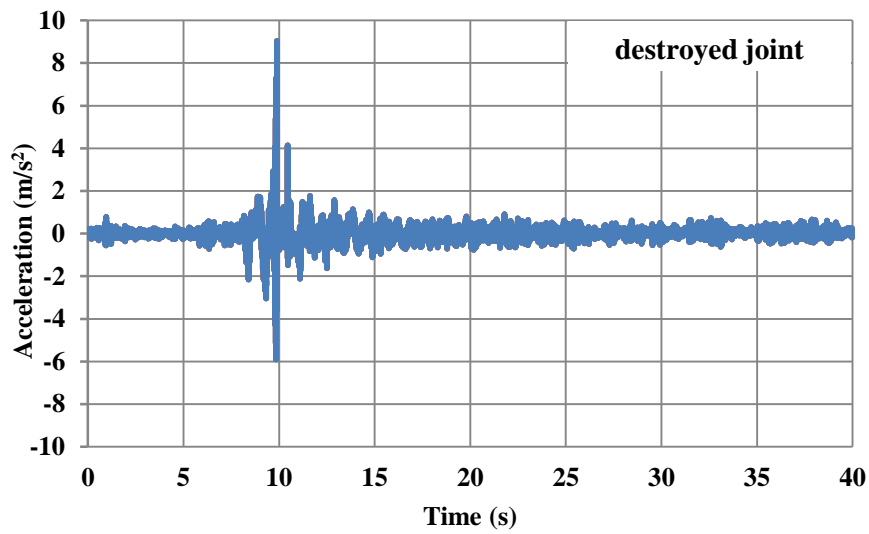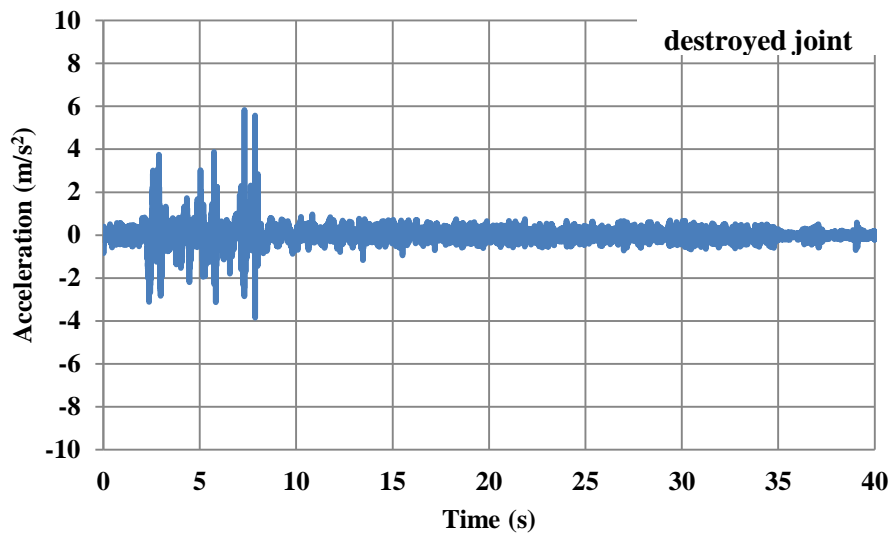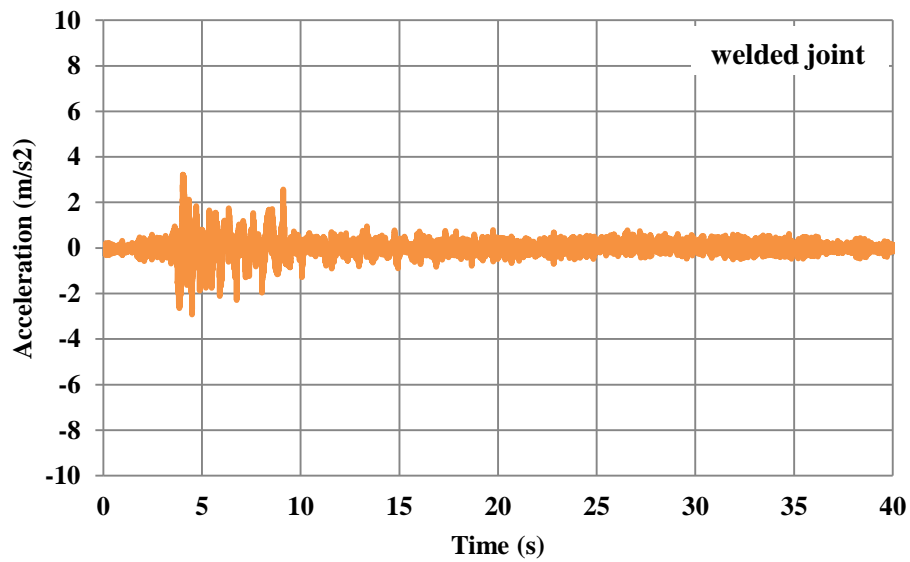
(a) Destroyed joint
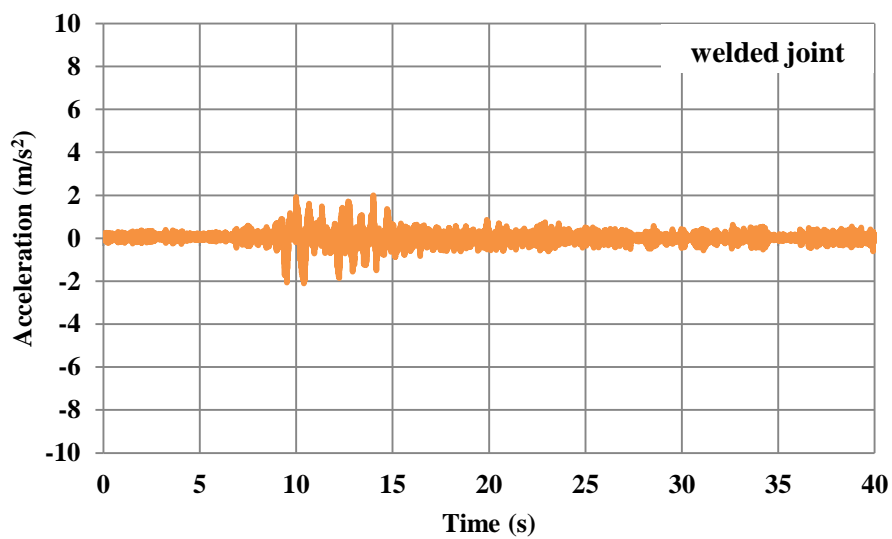
(b) Welded joint

Figure 3. Acceleration time history at the joint of the steel structure model under the Kobe earthquake.
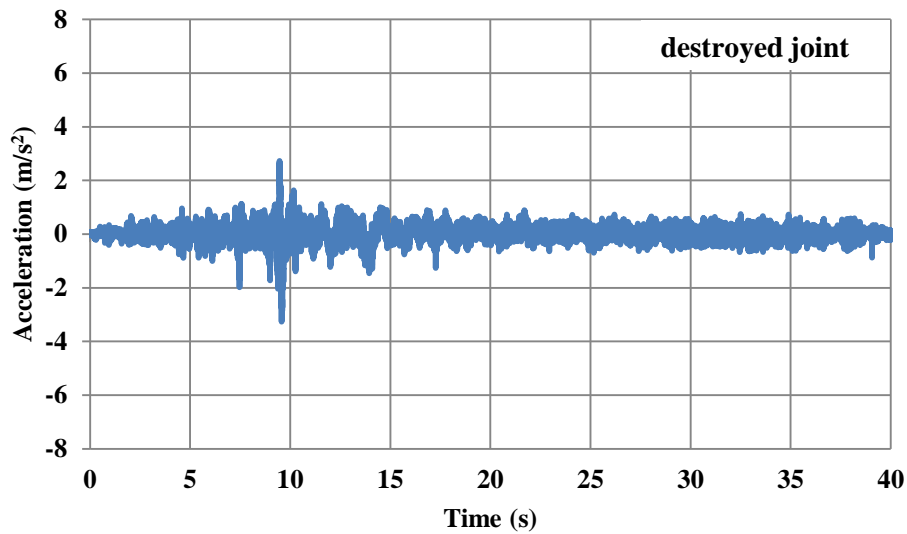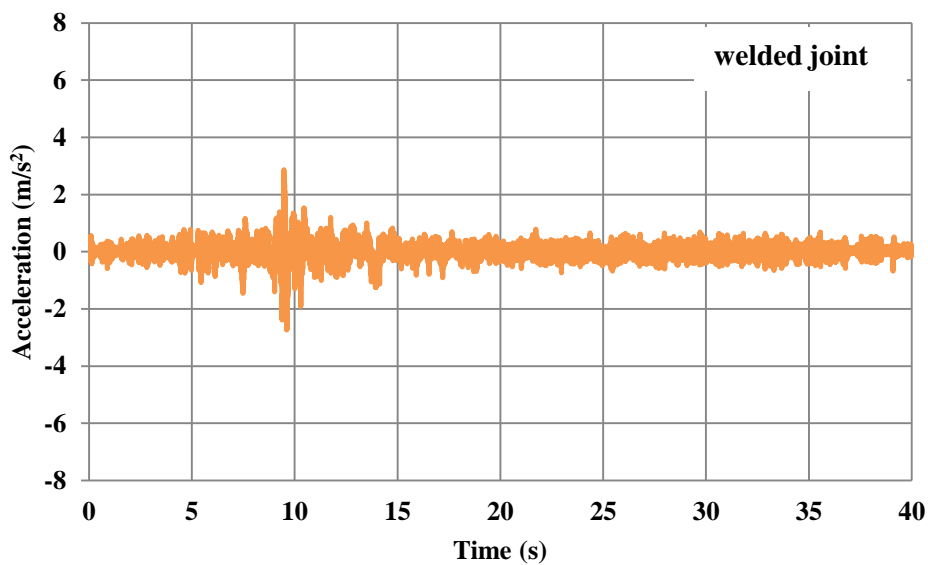
(a) Destroyed joint

(b) Welded joint

Figure 4. Acceleration time history at the joint of the steel structure model under the Loma Prieta earthquake.

(a) Destroyed joint

(b) Welded joint

Figure 5. Acceleration time history at the joint of the steel structure model under the Northridge earthquake.

Table 2. Peak acceleration at the joints of the steel structure model under the Kobe, Loma Prieta and Northridge earthquakes.

Seismic excitation	Peak acceleration at the joint of the steel structure model (m/s^2)		Percentage difference
	Destroyed joint	Welded joint	
Kobe	9.03	1.99	77.96%
Loma Prieta	5.83	3.67	37.05%
Northridge	3.26	2.87	11.96%

4. Conclusions

This paper investigated the behaviour of destroyed and welded joints in the model of the steel structure under different earthquakes. A single-storey steel structure model was used in the study. In order to analyze the behaviour of joints, three earthquakes (Kobe, Loma Prieta and Northridge) were applied using the shaking table. The results of the experimental study indicate that the destroyed joints experience higher acceleration than the welded joints during different earthquakes. The maximum percentage difference between the peak accelerations at the destroyed and welded joints was found to be 77.96%.

References

[1]   Baniotopoulos C.C and Wald F. (ed.) 2000: *The paramount role of joints into the reliable response of structures: from the classic pinned and rigid joints to the notion of semi-rigidity.* NATO Science Series. (Dordrecht: Kluwer Academic Publishers)

[2]   Diaz C, Marti P, Victoria M and Querin O.M 2011 *Review on the modelling of joint behaviour in steel frames* Journal of Constructional Steel Research 67 pp 741-758.

[3]   Falborski T and Jankowski R 2013 *Polymeric bearings – a new base isolation system to reduce structural damage during earthquakes*. Key Engineering Materials 569-570 pp 143-150.

[4]   Falborski T and Jankowski R 2017 *Experimental study on effectiveness of a prototype seismic isolation system made of polymeric bearings.* Applied Sciences 7 (8) p 808.

[5]   Falborski T and Jankowski R 2018. *Advanced hysteretic model of a prototype seismic isolation system made of polymeric bearings.* Applied Sciences 8 (3) p 400.

[6]   Mahmoud S, Chen X and Jankowski R 2008 *Structural pounding models with Hertz spring and nonlinear damper*. Journal of Applied Sciences 8(10) pp 1850-1858.

[7]   Miari M, Choong K.K and Jankowski R 2019 *Seismic pounding between adjacent buildings: Identification of parameters, soil interaction issues and mitigation measures.* Soil Dynamics and Earthquake Engineering 121 pp 135-150.

[8]   Miari M, Choong K.K and Jankowski R 2021 *Seismic pounding between bridge segments: a state-of-the-art review.* Archives of Computational Methods in Engineering 28(2) pp 495-504.

[9]   Naderpour H, Naji N, Burkacki D and Jankowski R 2019 *Seismic response of high-rise buildings*

equipped with base isolation and non-traditional tuned mass dampers. Applied Sciences 9(6) p 1201.

[10] Radaj D, Sonsino C.M and Fricke W 2006 Fatigue assessment of welded joints by local approaches. (Cambridge: Woodehead Publishing Limited)

[11] Rassati G.A, Leon R.T and Noe S 2004 *Component modeling of partially restrained composite joints under cyclic and dynamic loading.* Journal of Structural Engineering 130, 2 pp 343-351.

[12] Reyes-Salazar A and Haldar A 1999 *Nonlinear seismic response of steel structures with semi-rigid and composite connections.* Journal of Constructional Steel Research 51 pp 37-59.

[13] Ricles J.M and Fisher J.W and Lu L-W and Kaufmann E.J 2002 *Development of improved welded moment connections for earthquake-resistant design.* Journal of Constructional Steel Research 58 pp 565-604.

[14] *Semi-rigid behaviour of civil engineering structural connections* 1992 COST C1 (Strasbourg: Proc. of the first State of the Art Workshop)

[15] *Semi-rigid behaviour of civil engineering structural connections* 1994 COST C1 (Prague: Proc. of the second State of the Art Workshop)

[16] *Semi-rigid behaviour of civil engineering structural connections* 1998 COST C1. (Strasbourg: Proc. of the third State of the Art Workshop)

[17] Sołtysik B, Falborski T and Jankowski R 2016 *Investigation on damage-involved structural response of colliding steel structures during ground motions*. Key Engineering Materials 713 pp 26-29.

[18] Sołtysik B, Falborski T and Jankowski R 2017 *Preventing of earthquake-induced pounding between steel structures by using polymer elements – experimental study.* Procedia Engineering 199 pp 278-283.

[19] Trahair N.S 2012 *Trends in the analysis and design of steel framed structures.* Research Report R926. (Sydney: School of Civil Engineering)