Shaking table experimental study on the base isolation system made of polymer bearings

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SUMMARY:
Base isolation is one of the most popular and effective means of protecting structures against earthquake forces. Base isolators like lead rubber bearings, high damping rubber bearings or friction pendulum systems are extensively used in practice. The present paper reports the results obtained from the experimental study aimed to determine the effectiveness of the Elastomeric Polymer Bearings (EPB) in suppressing structural vibrations during dynamic excitations. The responses of the analyzed single-storey structure model both fixed and supported by the EPB during different earthquake excitations was studied. The reduction in lateral response due to seismic event was measured by comparing the peak accelerations of two identical single-storey steel model structures – with and without base isolation system. The use of the EPB showed a significant improvement in dynamic properties by reducing the structural vibrations.

Keywords: Elastomeric Polymer Bearings, base isolation, earthquake excitations, shaking table

1. INTRODUCTION

Base isolation is one of the most popular and effective means of protecting structures against earthquake forces. The system, which has been mostly adopted in recent years, works by decoupling the building or structure from the horizontal components of the earthquake ground motion by interposing a layer with low horizontal stiffness between the structure and the foundation. The philosophy behind the installation of base isolation is to lengthen the period of vibration of the protected structure, so as to reduce the base shear induced by the earthquake, while providing additional damping or reducing the relative displacement across the isolators themselves (see Chopra, 1995). This is why most seismic design codes suggest the use of base isolation systems that have the dual function of period elongation (period shift effect) and energy dissipation (increasing damping effect). Moreover, it is required for the isolators to be stiff enough under the wind loads or minor earthquakes, so as not to create frequent vibration, which may be inconvenient for the occupants. The ideas behind the concept of base isolation are quite simple and many mechanisms to produce this result have been recently proposed (see Mavronicola *et al.*, 2011, Skinner, 1975). Generally, the base isolators can be grouped under laminated bearings and friction bearings. Among the laminated bearings, lead rubber bearings (see Robinson, 1982) and high damping rubber bearings (see Jankowski, 1998, 2003) are extensively used in practice (see Kelly, 1993). Of a friction type, friction pendulum systems and elastic sliding bearings are very popular (see Komodromos, 2010). However, the past few decades have witnessed a giant leap in material engineering, which resulted in an increasing number of new isolators and modifications of the existing ones. The present paper reports the results obtained from the experimental study aimed to determine the effectiveness of the Elastomeric Polymer Bearings (EPB) in suppressing structural vibrations during dynamic excitations.

2. ELASTOMERIC POLYMER BEARINGS

The prototype of the EPB presented in this paper is made of a cylindrical-shaped elastomeric polymer composite with a central hole where a pin-ended steel core is inserted (Figures 1-2). The steel core sustain vertical forces while the elastomeric polymer composite is subjected only to shearing. The diameter of the polymeric cylinder is 28.0 mm and it is equal to its height. The diameter of the hole is 14.0 mm and the total height of the EPB is 58.0 mm. The material used to make the EPB is a specially prepared flexible two-component grout based on the polyurethane resin. The basic mechanical properties of the elastomeric polymer composite has been already determined in experimental studies and the obtained results have been presented in previous publications (see Jankowski and Kwiecień, 2008, Falborski *et al.*, 2012). The polymeric composite exhibits highly non-linear and time-dependent behaviour, which is typical for viscoelastic materials. The observed hysteresis loops during the cycling testing indicate relatively high damping and energy-dissipation properties of the analyzed polymeric composite.

Figure 1. Prototype of the Elastomeric Polymer Bearing

3. STRUCTURE MODEL

For the purpose of the experimental study a single-storey structure model was firstly prepared (Figure 3). The model was made of rectangular hollow section steel elements (RHS 15×15×1.5 mm). The steel columns were arranged in a rectangular pattern with a spacing of 0.465 m along the longitudinal direction and 0.541 m along the transverse one. Additional bracings in the longitudinal direction were used to prevent transverse and torsional vibrations. Moreover, two concrete paving slabs (50×50×7.0 cm) were mounted at the top as well as at the bottom of the steel model to simulate the weight of the floor and foundation slabs. The structure weights 91.98 kg and its overall height is 1.20 m. The presented single-storey model was mounted on a middle-sized shaking table platform located at Gdansk University of Technology (Poland). The shaking table was used as the base acceleration system to simulate the lateral forces and displacements caused by an earthquake. The shaking table platform is 2.0 m by 2.0 m and the one-dimensional lateral motion is powered by the linear actuator PARKER ETB125 with the stroke of 0.5 m and the maximum acceleration of 10 m/s^2.

Figure 2. A close up view of the Elastomeric Polymer Bearings base

Figure 3. Non-isolated single-storey steel structure model mounted on the shaking table

4. FREE VIBRATION AND SINE SWEEP TESTING

The first sequence in the experiment testing was to determine the response of the structure model under free vibration. A drift was applied to the top of the model with and without base isolation system to allow comparison of the responses during lateral loading. The force was released and the structure allowed to oscillate until the natural damping of the structures brought the system to stop. The accelerometers recorded acceleration and the laser displacement sensor measured displacement at the top of the structure until it stopped oscillating (Figure 4). The natural frequency of the single-storey model without the EPB was determined to be 3.31Hz. The second sequence of the experiment was the forced vibration of the structure. The shaking table was loaded by harmonic excitation with an increasing frequency for a period of 40 seconds (sine sweep test). The frequency range was set to 0.1÷15.0 Hz. The responses at the top of the structure with and without the EPB were also recorded. The peak accelerations experienced by the structure model with and without base isolation system are summarized in Table 1. The free vibration test showed a significant increase in structural damping. On the other hand the responses of the model under forced vibration showed a significant decrease in acceleration at the top of the structure. The peak accelerations experienced by the structure with and without base isolation system were 3.25 m/s^2 and 7.74 m/s^2, respectively. This means over 58% decrease in acceleration due to the base isolation system.

Figure 4. Base isolated single-storey model with two accelerometers and a laser displacement sensor

Table 1. Results of the free vibration and sine sweep testing

	Free vibration testing		Swept sine testing	
	With Base Isolation	Without Base Isolation	With Base Isolation	Without Base Isolation
Peak acceleration [m/s^2]	-	-	3.25	7.74
Damping ratio [%]	29.97	0.59	-	-

5. SHAKING TABLE TESTING

In the second stage of the investigation the behaviour of the analyzed single-storey structure model both fixed and supported by the EPB during different earthquake excitations was studied. Two accelerometers were mounted on the top and the bottom plate. The examples of the results in the form of the acceleration time histories registered at the top of both structures during the 1940 El Centro earthquake (NS component, PGA=3.07 m/s^2), the scaled 1971 San Fernando earthquake (Pacoima Dam station, N74°E component, PGA=5.69 m/s^2) and the scaled 1989 Loma Prieta earthquake (Corralitos station, NS component, PGA=3.16m/s^2) are shown in Figures 5-10. The peak accelerations experienced by both structures were measured and summarized in Table 2. The results showed a significant decrease in accelerations at the top of the structure equipped with the EPB. The peak accelerations measured at the top of the structures were reduced by over 40% for all ground motions considered.

Table 2. Results of the shaking table testing for different earthquake excitations

Earthquake excitation	Peak acceleration at the top of the structure [m/s^2]		Reduction [%]
	With Base Isolation	Without Base Isolation	
El Centro (1940)	6.51	11.39	42.8
San Fernando (1971)	9.17	15.59	41.2
Loma Prieta (1989)	7.70	13.82	44.3

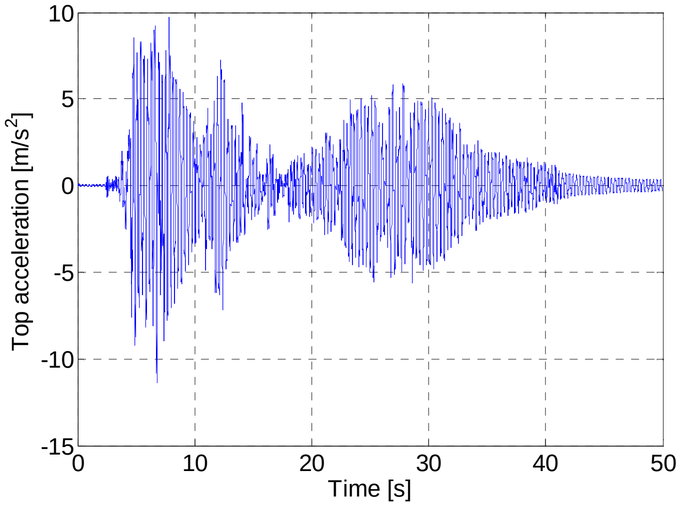

Figure 5. Response of the non-isolated structure during the El Centro earthquake

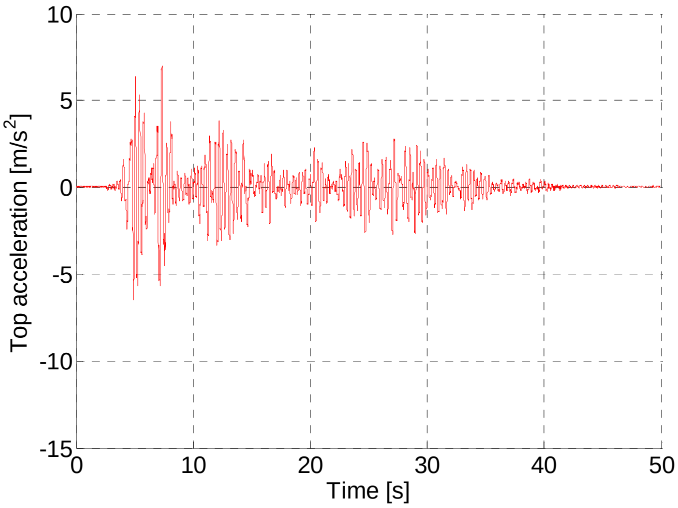

Figure 6. Response of the base isolated structure during the El Centro earthquake

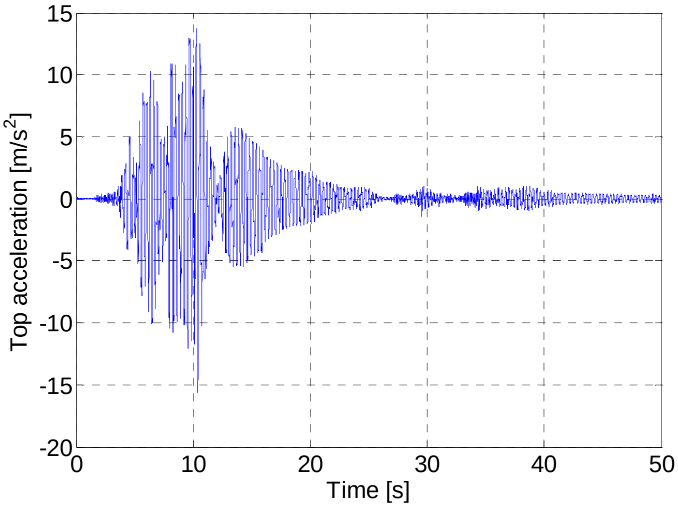

Figure 7. Response of the non-isolated structure during the scaled San Fernando earthquake

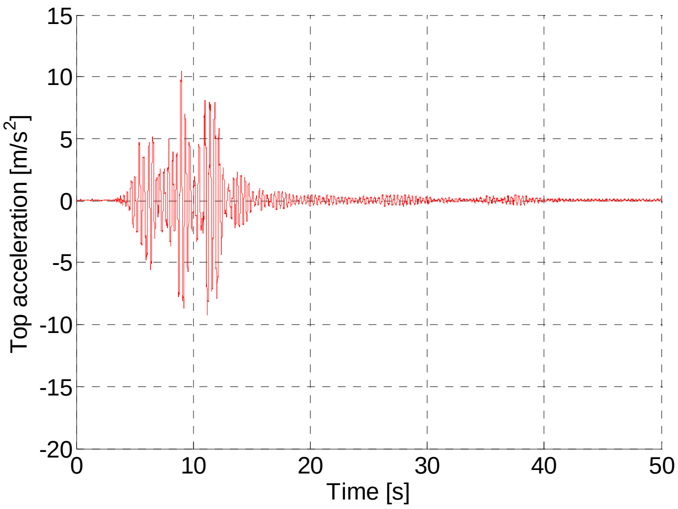

Figure 8. Response of the base isolated structure during the scaled San Fernando earthquake

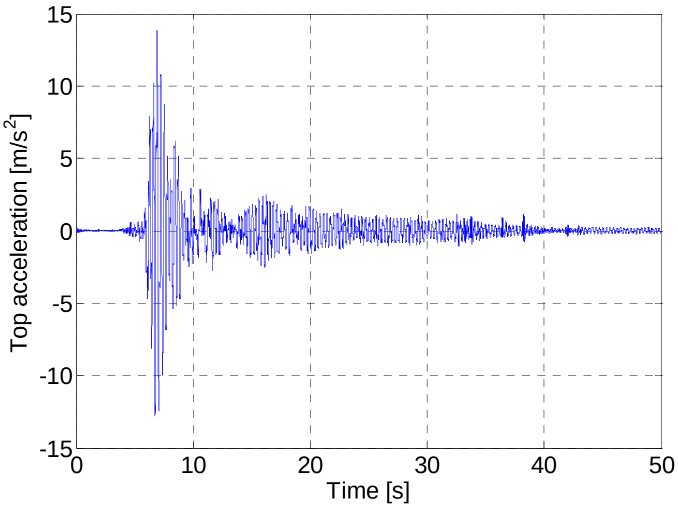

Figure 9. Response of the non-isolated structure during the scaled Loma Prieta earthquake

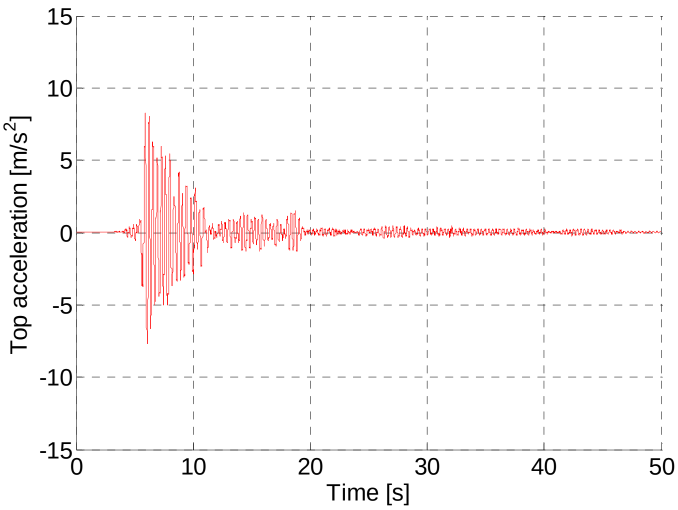

Figure 10. Response of the base isolated structure during the scaled Loma Prieta earthquake

6. CONCLUSIONS

The objective of the study presented in this paper was to verify the efficiency of the Elastomeric Polymer Bearings in suppressing structural vibrations during dynamic excitations. The reduction in lateral response due to seismic event was measured by comparing the peak accelerations of two identical model structures – with and without base isolation system. After extensive testing on a shaking table, the structure with the EPB showed a significant decrease in lateral acceleration. The peak lateral acceleration was reduced by over 40% during dynamic tests and over 58% during the sine sweep test. The free vibration test showed a considerable increase in structural damping. The use of the EPB showed a substantial improvement in dynamic properties by reducing the structural vibrations. Nevertheless, further experimental study is required to fully verify the efficiency of this new base isolation system.

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