



FULL-SCALE PSEUDO-DYNAMIC TEST FOR BRIDGE RETROFITTED WITH SEISMIC ISOLATIONS

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Abstract. This paper presents the performance of a retrofitted bridge with a seismic isolation. To validate the seismic performance of retrofitted bridge experimentally, four full-scale reinforced concrete bridge piers with fixed support conditions were fabricated and tested. Several different bearing systems were installed and a static vertical load was applied to the top of the bearing to simulate the dead load of superstructure. In addition to rubber bearing (RB) and lead rubber bearing (LRB) systems, conventional pot bearing was also considered. Using a pseudo-dynamic testing method, a horizontal loading was applied to the specimen to simulate the earthquake loading. The seismic response of isolated specimens with the RB, and LRB systems were compared with that of the specimen with conventional pot bearing. The results showed that a seismic isolation system considered in this study was effective in reducing the magnitude of the forces transferred to the substructure and in shifting the period of the bridge. The LRB system can effectively reduce the peak acceleration transmitted to the structure, which is less than those with RB system under the earthquake loading. By the test results it can be concluded that the proposed seismic retrofit method was found to be valid.

Keywords: seismic retrofit, bridge, seismic isolation, RB, LRB, full-scale pseudo-dynamic test.

1. Introduction

An accurate evaluation of seismic performance of bridges in service is important for bridges designed by old standards. If the performance of a bridge does not meet the design requirements in the current standards, a seismic retrofit is required to secure the bridge safety. Retrofitting bridge bearings, piers and abutments, foundations and underlying soil, and seismic isolation bearings may be the commonly used methods in practice (Priestley *et al.* 1995).

Recently, as a seismic retrofitting method using a seismic isolation is recommended not only for the seismic design of a new structure, but also for the seismic retrofit of existing structures. This method is widely used across the world. To design seismic retrofitting work with the seismic isolation, an efficient procedure is needed that will rationally validate the seismic performance for seismic isolation (Bakir *et al.* 2007; Chehab, El Naggar 2003; Komodromos *et al.* 2007; Nagarajaiah, Narasimhan 2007; Park, Han 2004). Verifying the performance of the seismic isolation is an important procedure to make sure that the seismic

retrofitted bridge can actually satisfy and reach its target performance (ATC 1996; Peter 1996). The method using the seismic isolation bearings can improve the seismic performance without retrofit existing piers or foundations by reducing the inertia force generated in case of earthquakes. In particular, it minimises extra construction expenses because it utilises the seismic isolation bearings to replace the existing non-seismic bridge bearings.

This paper presents the performance of a seismic retrofitted bridge with the seismic isolation. To validate the seismic performance of the retrofitted bridge experimentally, four full-scale reinforced concrete bridge piers with fixed support conditions were fabricated and tested. Several different bearing systems were installed and a static vertical load was applied to the top of the bearing to simulate the dead load of superstructure. In addition to rubber bearing (RB) and lead rubber bearing (LRB) systems, conventional pot bearing was also considered.

This study experimentally verifies the retrofit effect on the seismic performance when the existing non-seismic

bearing is replaced with a bearing consisting of seismic performance retrofit capability such as RB and LRB. For the experiment, part of the real bridge was made to its full-scale model and pseudo-dynamic test method was selected for the testing this model. Pseudo-dynamic test is an appropriate method which meets the aim of this experiment because it can only produce the part of the target structure into a real model and the remaining parts exist only as an internal model. Also by inputting the earthquake load, the dynamic qualities can be identified (Buonopand, White 1999).

The seismic response of isolated specimens with the RB, and LRB systems were compared with that of the specimen with conventional pot bearing. The results showed that a seismic isolation system considered in this study was effective in reducing the magnitude of the forces transferred to the substructure and in shifting the period of the bridge. The LRB system can effectively reduce the peak acceleration transmitted to the structure, which is less than those with RB system under the earthquake loading.

2. Pseudo-dynamic test of bridge using seismic isolations

2.1. Pseudo-dynamic test and earthquake acceleration

The pseudo-dynamic test method generally shows an improved structural movement under the moderately controlled experimental conditions with an expediency and usefulness of quasi-static test to the seismic behaviour of a structure. El Centro earthquake (NS, 1940) was the seismic acceleration used for the pseudo-dynamic test of a pier. We set 15 s for earthquake application and used PGA (peak ground acceleration) of earthquake acceleration value with the increasing amounts of 1,154 g, 0,22 g, 0,34 g, and 0,7 g. With the limited number of specimens, we had to utilise a specified earthquake history data. However, in order to set up a number of meaningful levels of the earthquake load, we allowed a multiple levels of earthquake load using a controlled method of PGA. Then we placed each individual specimen to undergo the earthquake load with an increasing earthquake acceleration level for 60 s. Fig 1 shows a pseudo-dynamic test set-up and a shape of El Centro earthquake.

2.2. Selection of bridge for full-scale pseudo-dynamic testing

For the preparation of a pseudo-dynamic test in this study, a superstructure of the bridge was idealised with an internal analytical model of computer linked with the specimen. In the pier of the sub-structure only the fixed end of the pier was made into a real model. In order to eliminate a size-scaling problem encountered in the experiment, we

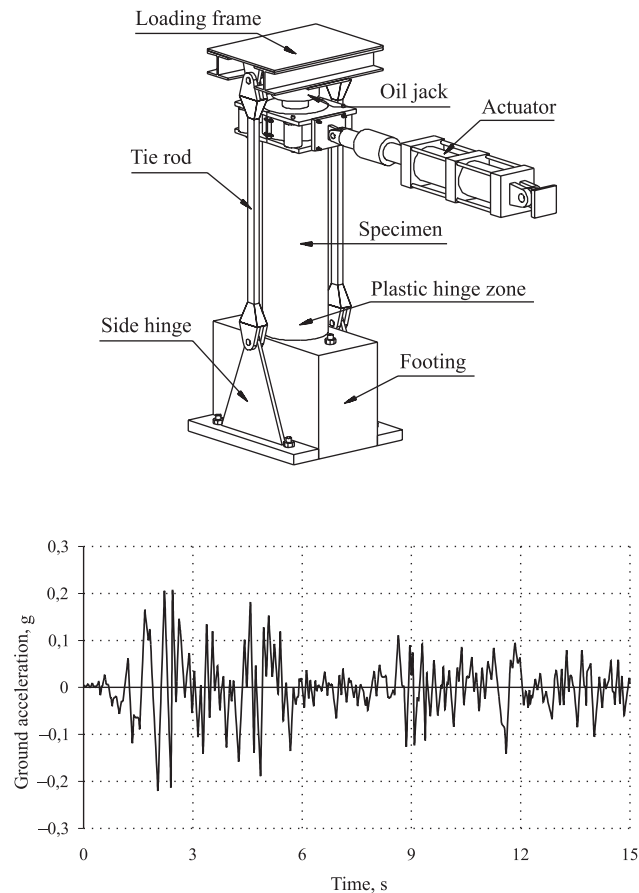


Fig 1. Pseudo-dynamic testing system and earthquake acceleration data

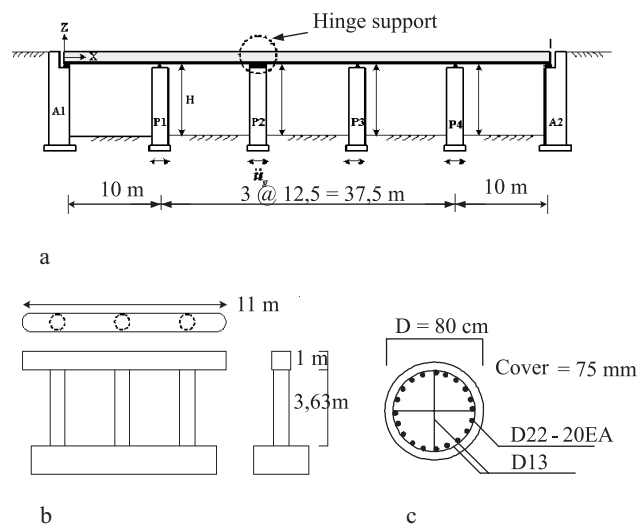


Fig 2. Geometry of example bridge: a – side view, b – cross-section of pier, c – reinforcements in pier

have focused on fabricating a real-size pier specimen for the experiment. Considering the objective and the condition of the experiment, a non-seismic designed bridge was selected as an example bridge. The geometry of an example bridge is shown in Fig 2.

Table 1. Properties of RB system

Design load, kN	W×L, mm	Thickness, mm	Height, mm	Expansion, mm	K_v , kN/m	K_h , kN/m
2 800	400×600	105	181	50	1 728,000	3 062

Table 2. Properties of LRB system

Design load, kN	Static displacement, mm	Seismic displacement, mm	Height, mm	Characteristic properties				
				d_y , cm	Q_d , kN	K_u , kN/cm	K_d , kN/cm	K_v , kN/cm
2 000	110	442	276	0,86	54,1	87,8	24,8	2 644,7

2.3. Design of seismic isolations

To design seismic isolations required to improve the seismic performance of a non-seismic designed bridge, each reaction force and expansion of the bearing need to be calculated to analyse the superstructure. From the analytical bridge object, section and material property of seismic isolation calculated with a reactive value of each bearings and displacement as the basis of load coincidence state is provided in Tables 1 and 2.

2.4. Fabrication and measurement of specimens

In this paper, a total of four different specimens were fabricated as Specimen PILOT without the bearing, Specimen POT with the existing bridge bearing, Specimen RB with the RB seismic isolation, and Specimen LRB with the LRB seismic isolation. The section view of the fixed support of the example bridge is reproduced in full-scale size. However, its foundation and coping should be flexible according to the experimental methods and locations. That is, the foundation should be designed in a way to have the stiffness higher than that of the pier so that it can be fixed completely, and the height of the foundation should be adjusted to each specimen to even the loading height, as the surfaces of seismic isolation equipments differ from one another. The section view of the coping is determined by the size and the formation of the selected seismic isolation equipment. The longitudinal reinforcements and the struts arranged in the piers of the specimen follows the actual arrangement, as indicated in the drawings of the selected bridge. The material properties of the example bridge are provided in Table 3. The production, installation process, and detail drawings of the specimens are shown in Fig 3.

The clear height of the pier is 363 cm, diameter is 80 cm and the aspect ratio exceeds 4.5. Thus we can expect a behaviour of flexural fracture and the plastic hinge is most likely to develop in the lower part of the specimen. As a result, the steel strain gauges were mounted to the lower section of the specimen. The measuring instruments and locations for the gauge installation of the specimen are shown in Fig 4.

Table 3. Materials properties of specimens

Concrete	Piers
Unit weight, kN/m ³	25
Compressive strength, MPa	27
Elastic modulus, MPa	24,648
Steel reinforcement	Yielding strength, $f_y = 400$ MPa

3. Test result and discussions

The load versus displacement history diagrams for the specimens drawn out from the experiment are shown in Figs 5–12.

In the case of specimens PILOT and POT, the measured load-displacement response represents the upper part of the whole bridge because the displacements condition of the bearing acts as a fix-end for the superior part of the bridge. However, in the case of specimens RB and LRB, a related displacement exists between the bridge and the seismic isolation, thus the load-displacement history diagram was represented by distinguishing the total displacement of the bridge, the displacement of the top pier and the displacement of the seismic isolation by a related displacement.

In case of bridges without a retrofit process (Specimens PILOT and POT), the bridge ranges from 0,154 g PGA level to a yielding point and does not satisfy the functional level. When comparing it with the retrofit bridge with RB and LRB (Specimens RB and LRB) it reached up to 0,154 g PGA and did not reach the yielding point, thus satisfying its functional level.

At the higher earthquake load level of 0,22 g PGA, the non-seismic retrofit bridges start to radically form a plastic hinge after their yield progressing from the lower part of the pier with horizontal and vertical subsurface cracks. However, the seismic retrofit bridges did not reach their yielding point of longitudinal reinforcement and only produced horizontal cracks caused by tension fracture of the cover concrete.

Under the 0,34 g PGA, specimen RB showed a yield of longitudinal reinforcement and further progress of

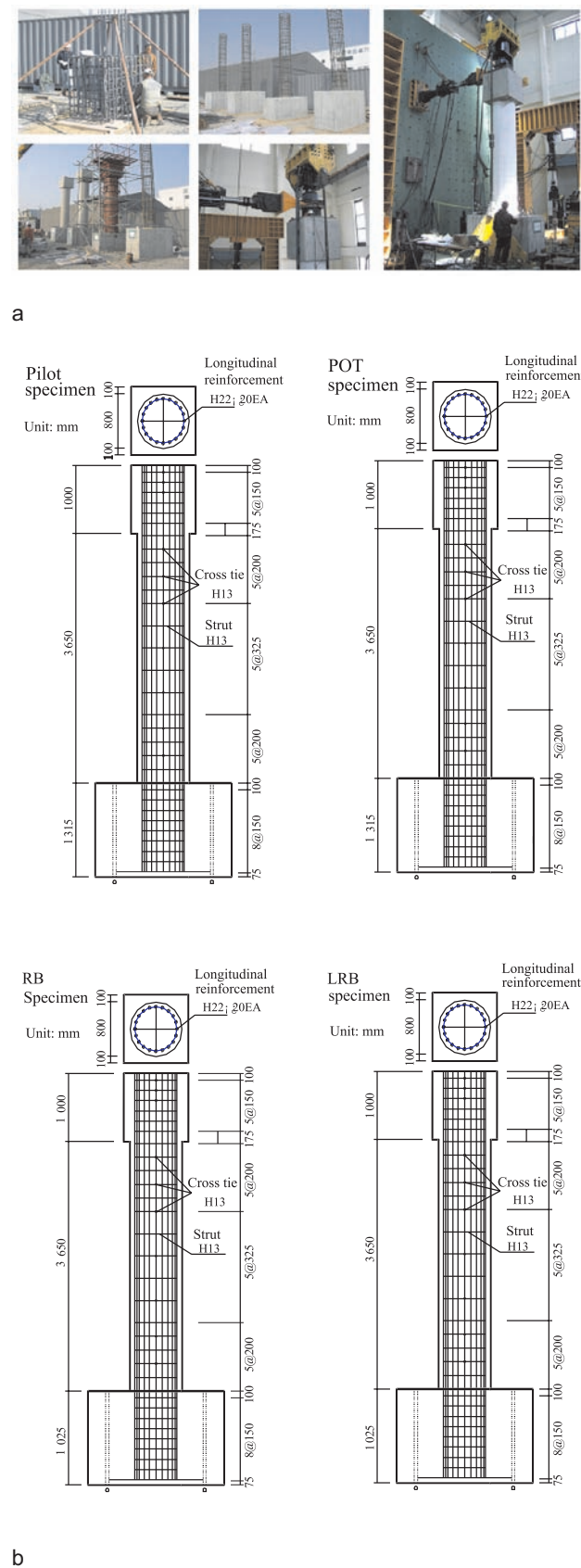


Fig 3. Schema and dimensions of specimens: a – installation of specimens, b – detail drawings of specimens PILOT, POT, RB, and LRB

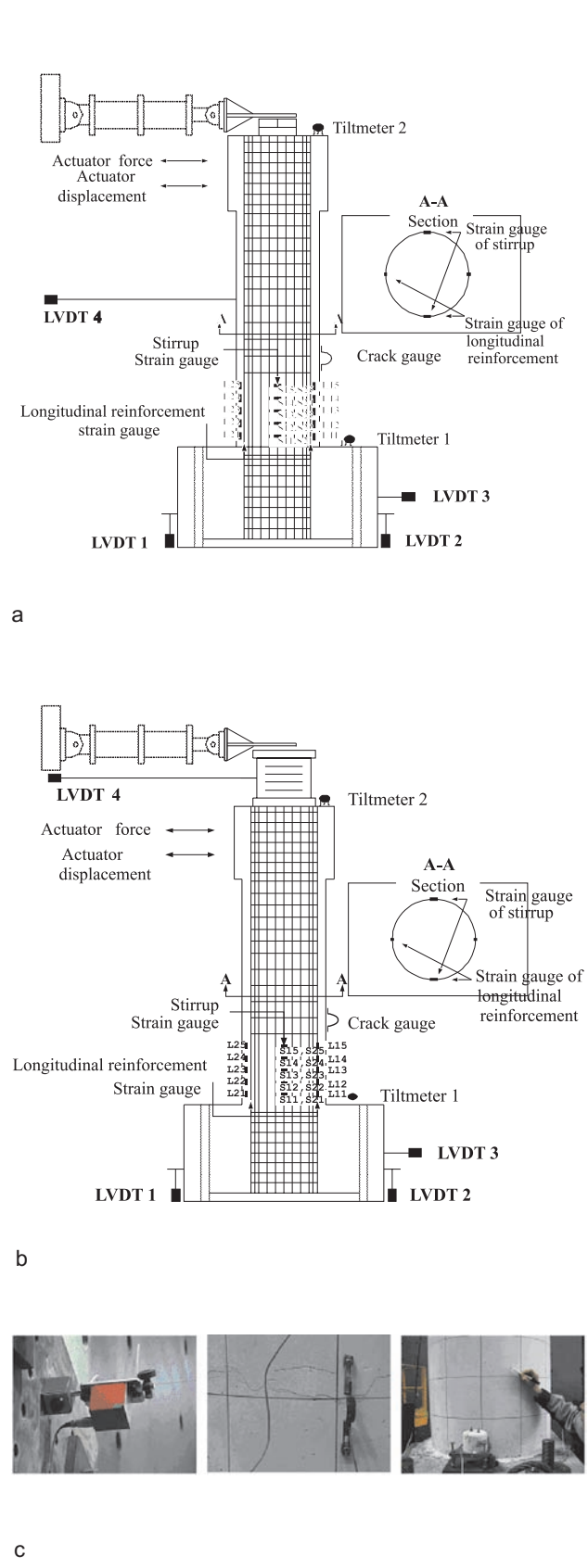


Fig 4. Measurement of the specimen: a – measuring instruments of the non-isolated specimens PILOT & POT, b – measuring instruments of the isolated Specimens RB & LRB, and c – photos of measurement

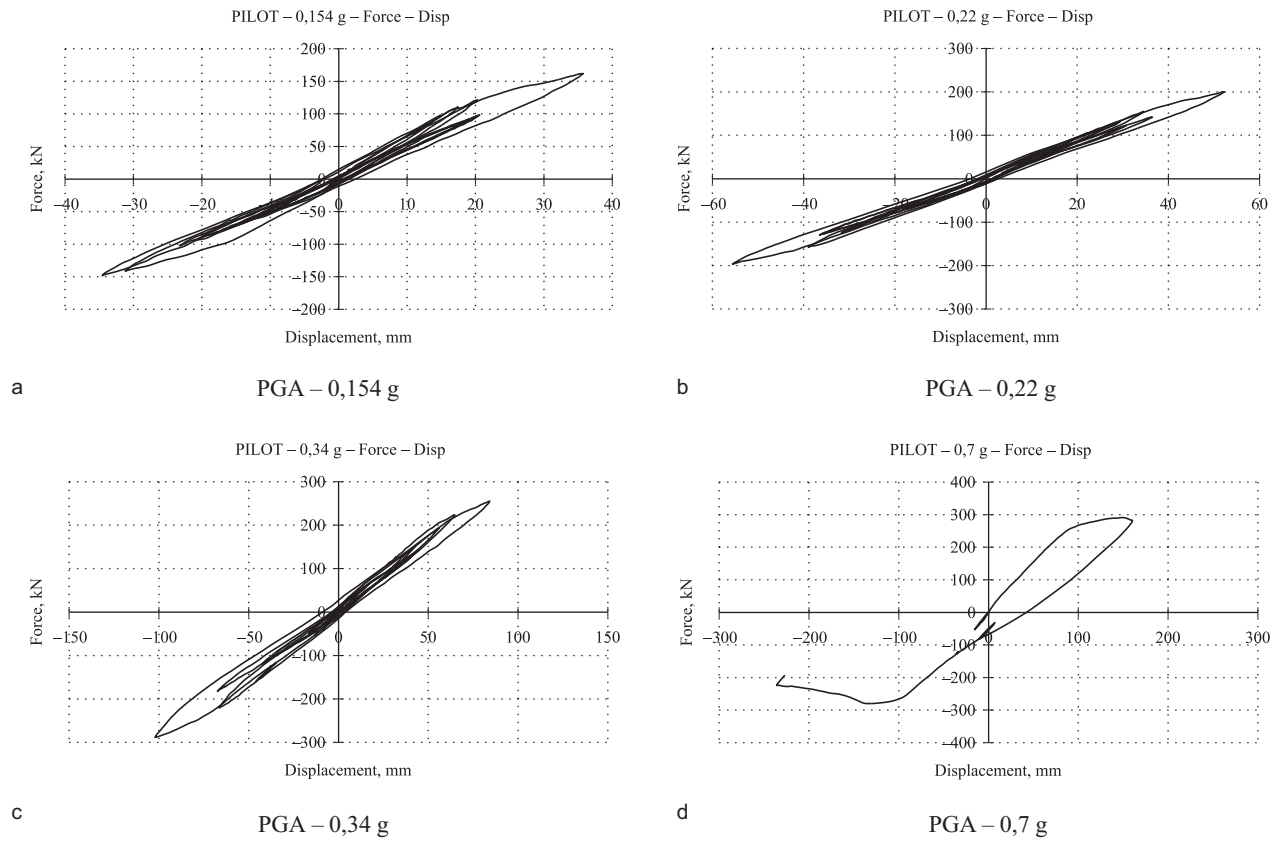


Fig 5. Load-displacement history diagrams of the specimen PILOT

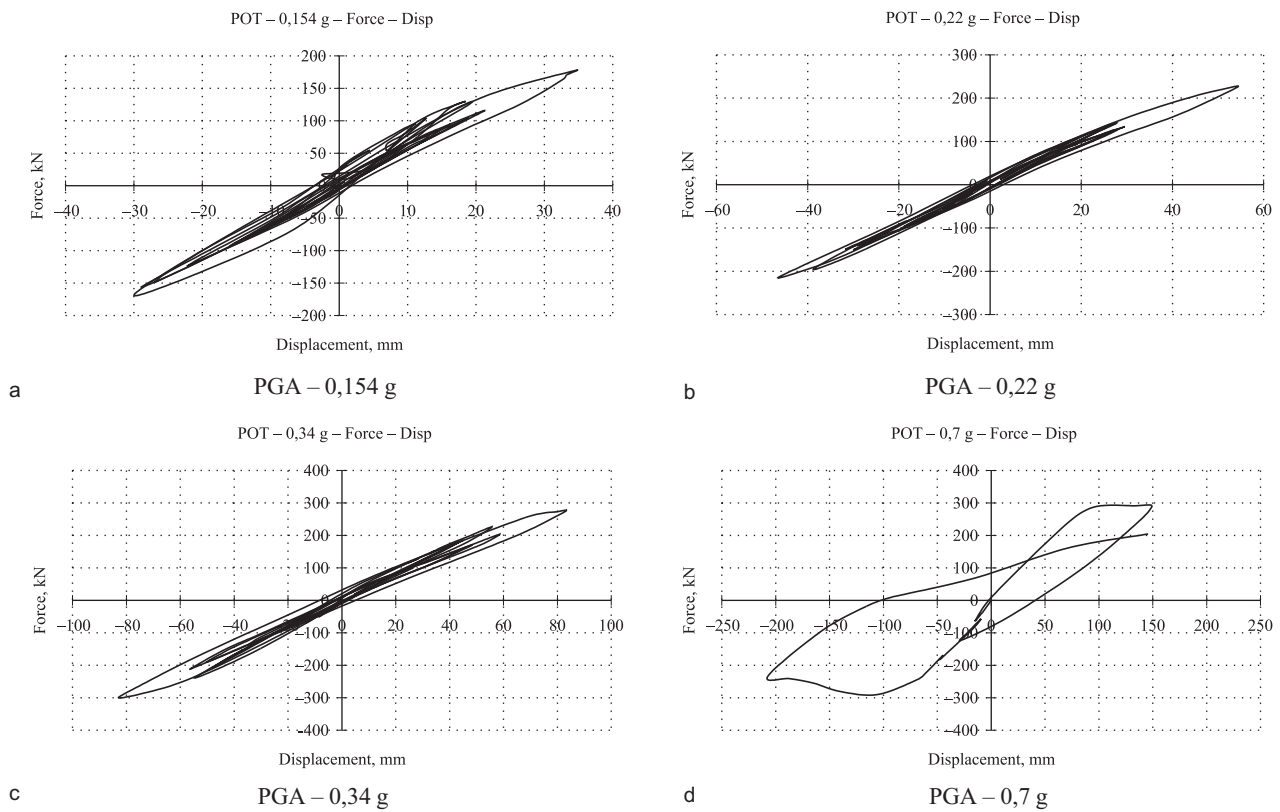


Fig 6. Load-displacement history diagrams of the specimen POT

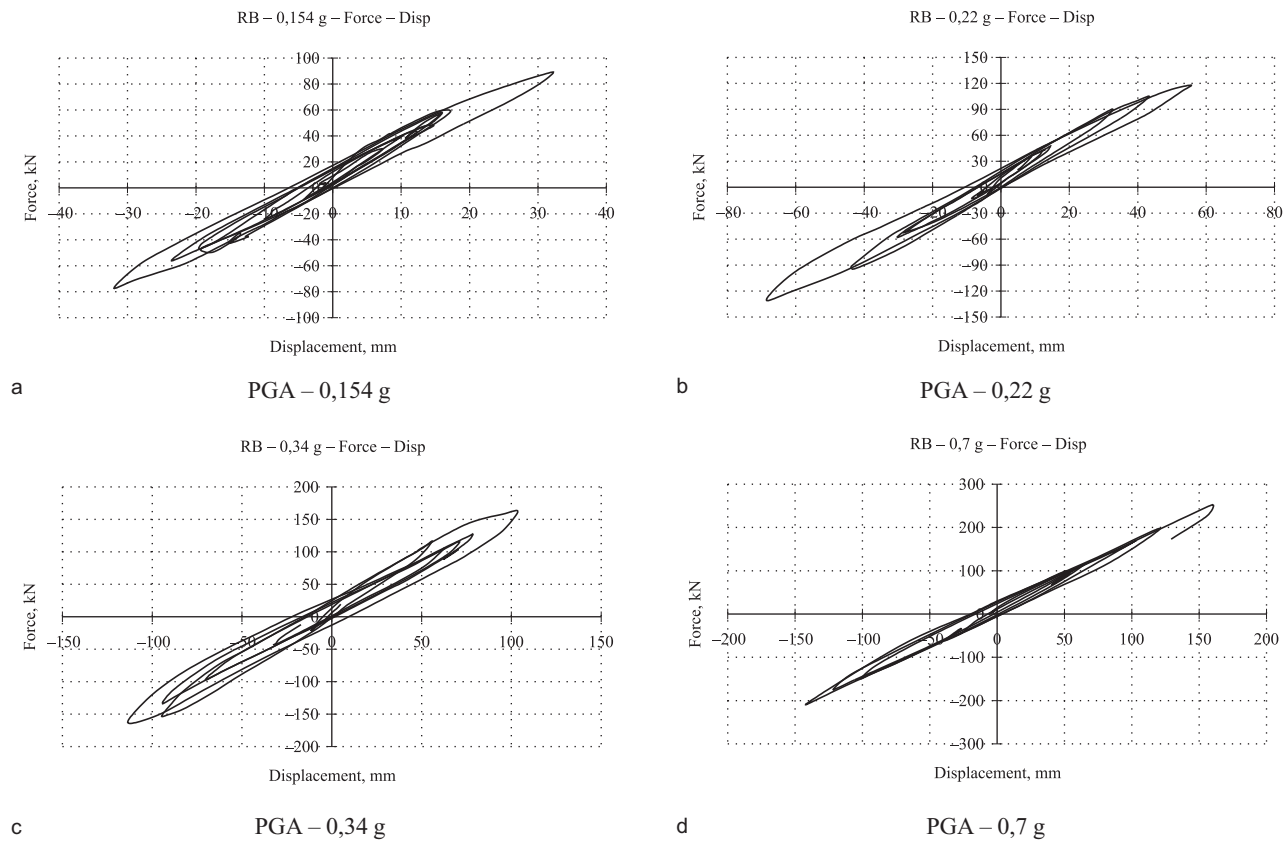


Fig 7. Load-displacement history diagrams of the specimen RB – total displacement of bridge

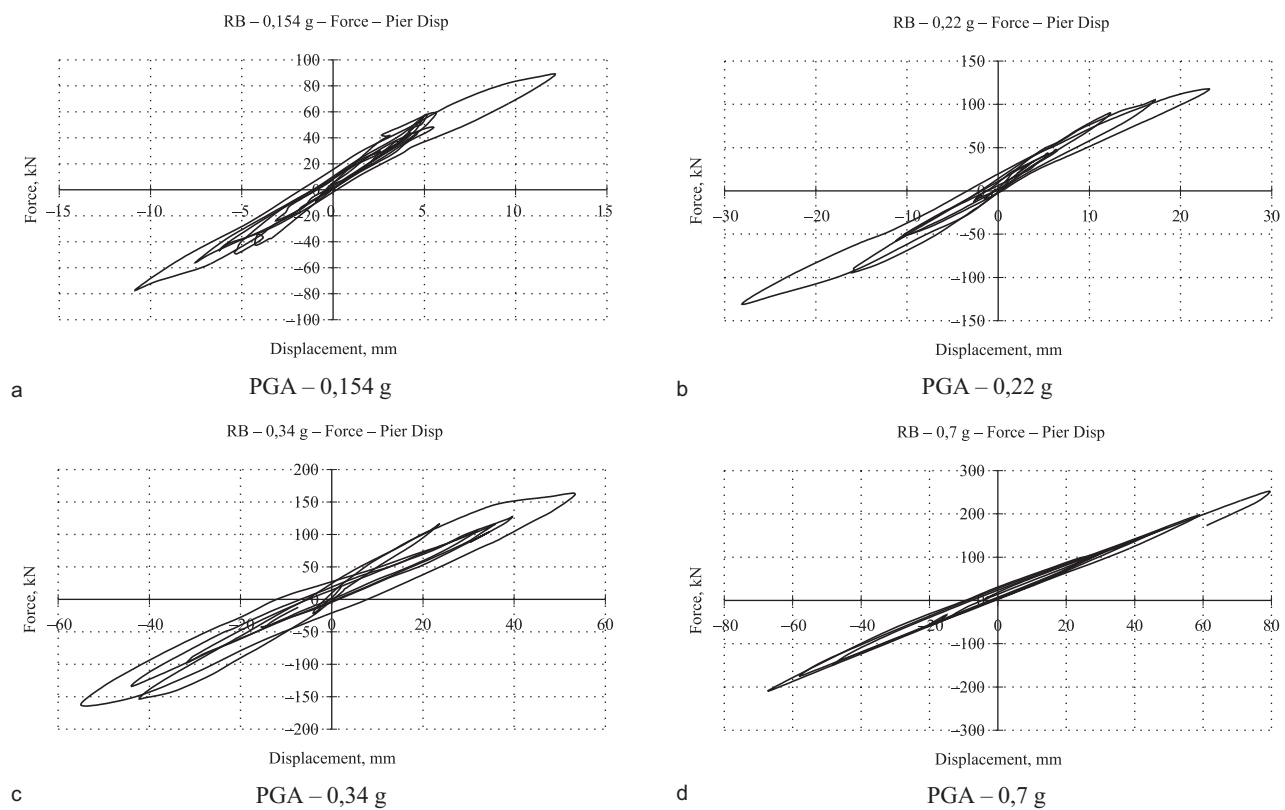


Fig 8. Load-displacement history diagrams of the specimen RB – displacement of top pier

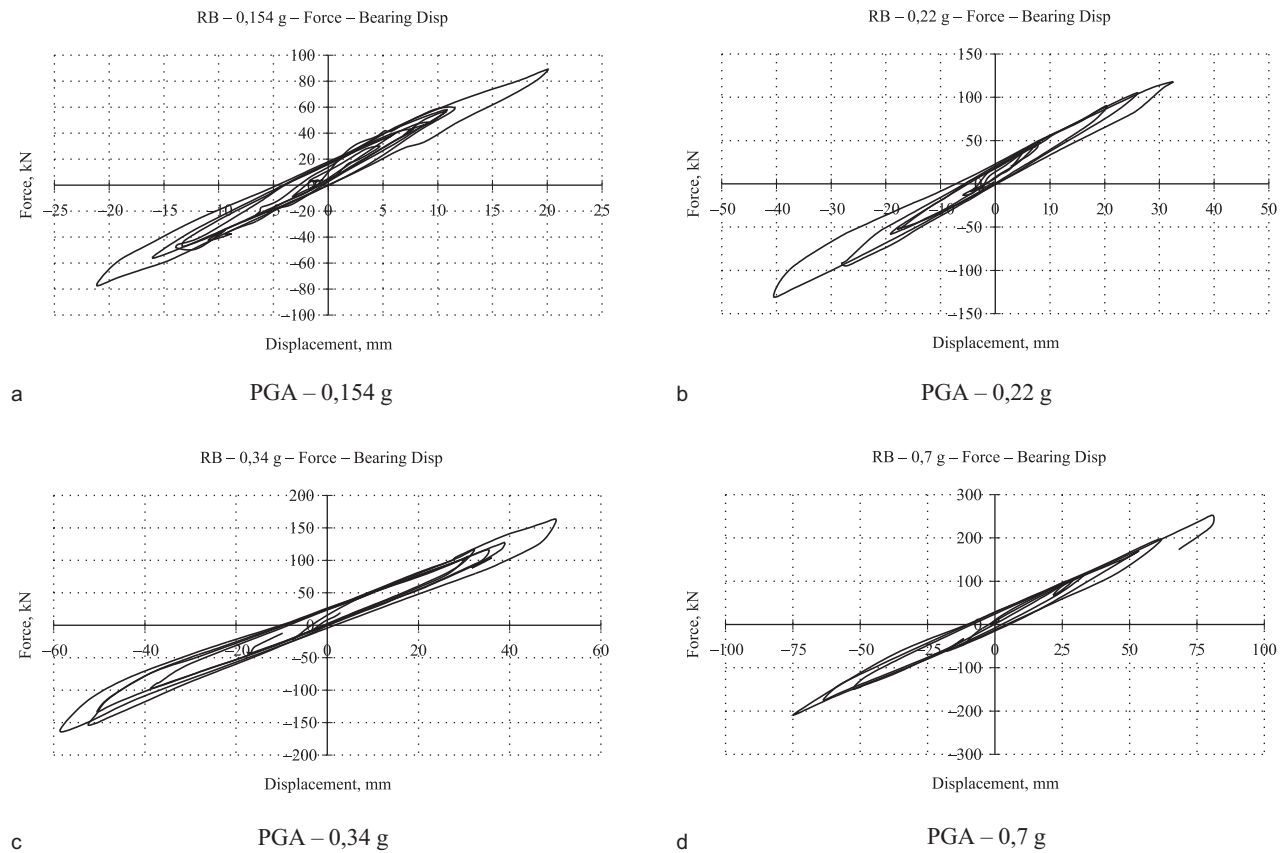


Fig 9. Load-displacement history diagrams of the specimen RB specimen – displacement of seismic isolation

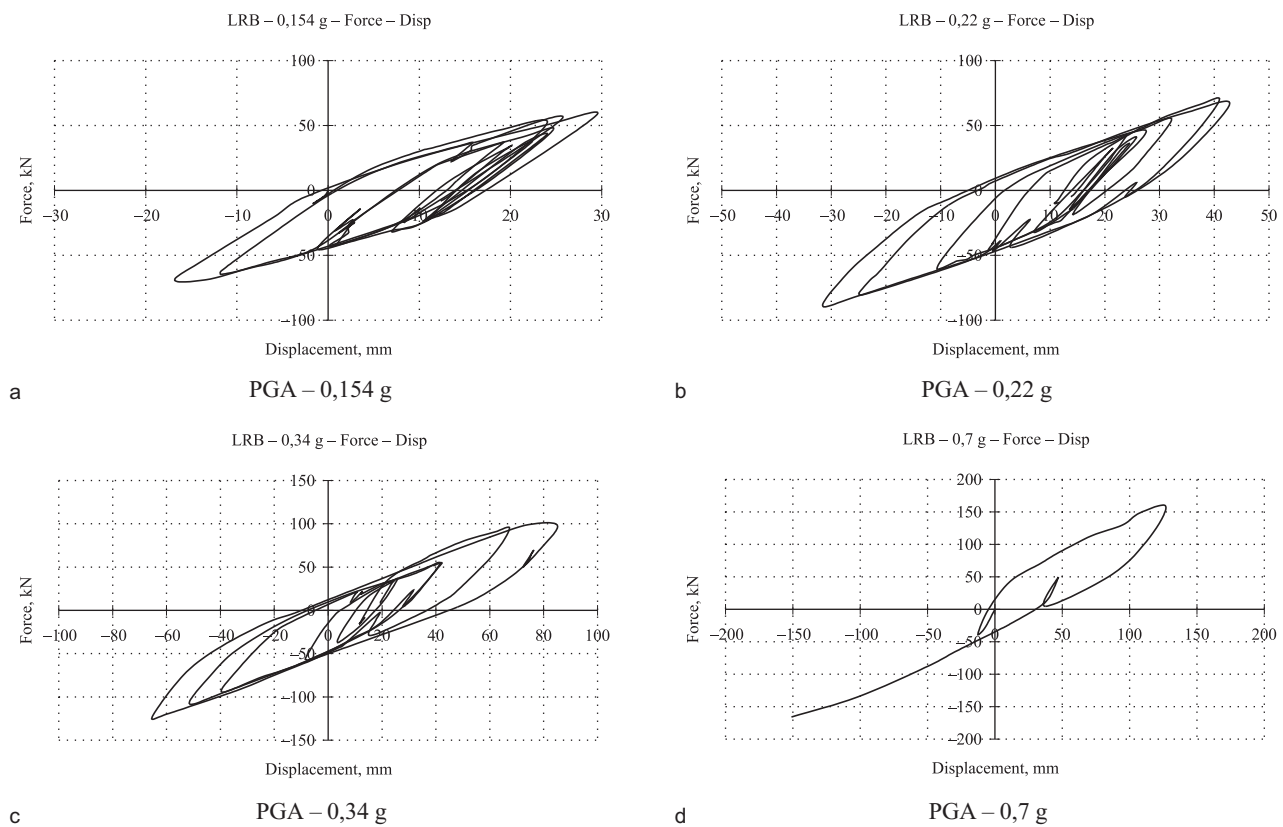


Fig 10. Load-displacement history diagrams of the specimen LRB – total displacement of bridge

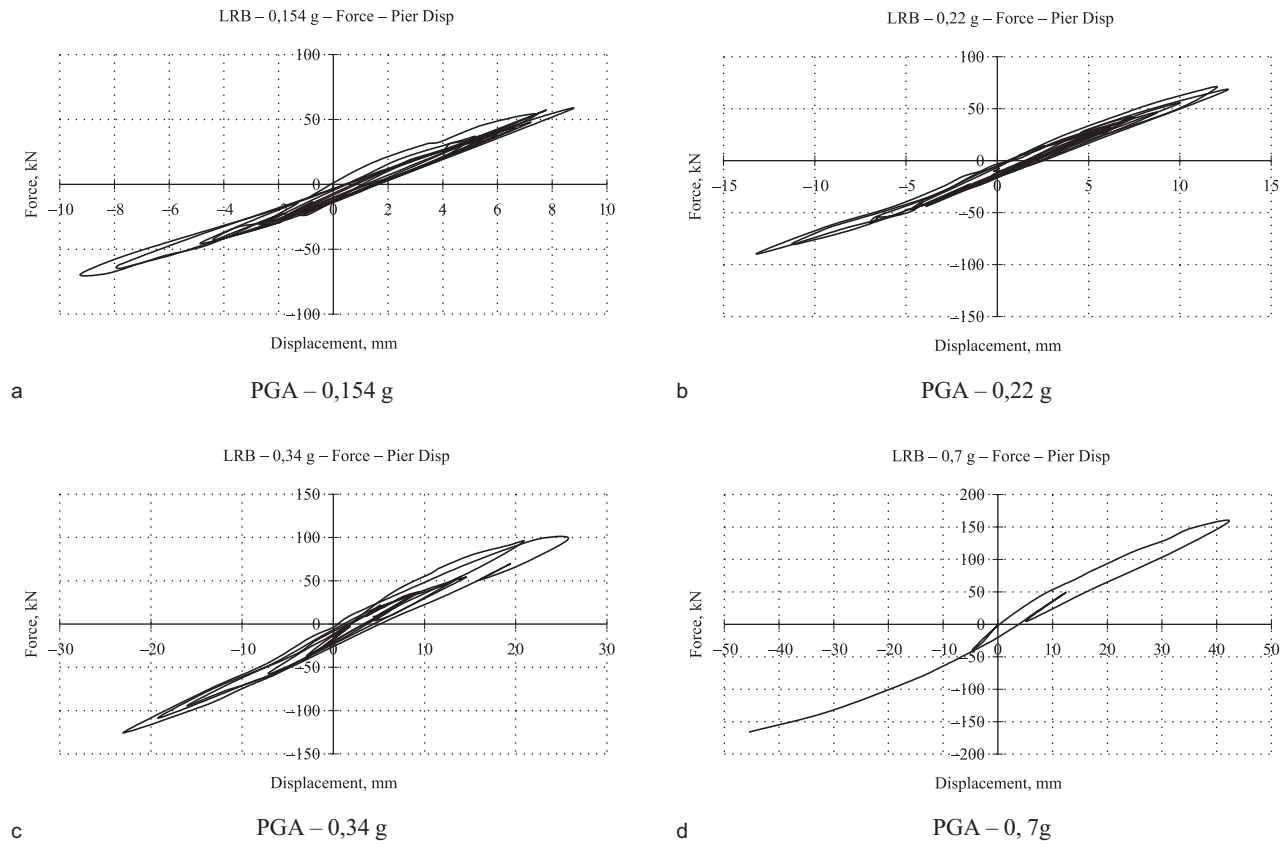


Fig 11. Load-displacement history diagrams of the specimen LRB – displacement of top pier

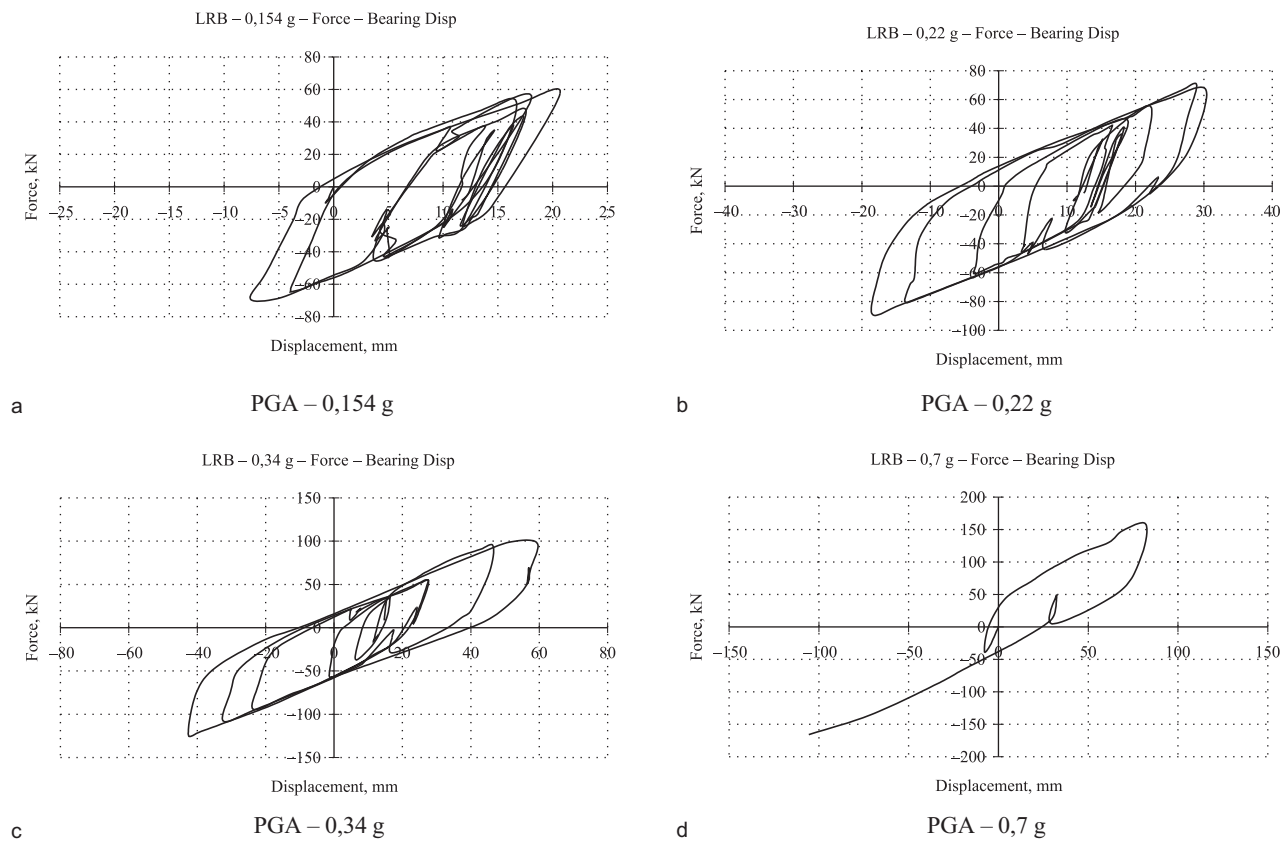


Fig 12. Force-displacement history diagrams of the RB specimen – displacement of seismic isolation

horizontal cracks, whereas the non-seismic retrofit bridges increased the crack width and reached the compression crushing point. Specimen LRB has maintained a functional level of performance equal to non-yielding state.

In the level of 0.7 g PGA, horizontal resistance capacity of the non-seismic bridge was totally lost due to the flexural fracture. Specimen RB has shown a higher seismic performance than the non-seismic retrofit bridge by incorporating the vertical cracks of pier and reaching its initial stage where concrete cover starts a compressive fracture. Specimen LRB showed a yield of longitudinal reinforcement. However, the seismic retrofitted bridge using LRB has shown a higher seismic performance because the state of failure mode was lower level than of other specimens.

4. Conclusions

This paper experimentally verifies that there is a significant seismic performance improvement as a seismic isolation by carrying out and comparing the pseudo-dynamic test with seismic performance of bridge, when the seismic retrofit was carried out for an existing non-seismic bridge using the seismic isolation. As the experimental studies result, it was verified that this full-scale pseudo-dynamic test method is an effective means to evaluate the seismic performance of the retrofitted bridge using the seismic isolation. Testing the non-seismic bridge does not satisfy the functional standards under a weak seismic level but it experimentally verifies that if the seismic performance is retrofitted with the seismic isolation, it fully satisfies the functional performing standards. If the bridge is properly retrofitted with the seismic isolation, the bridge can sustain the earthquake loading.

References

- ATC (Applied Technology Council). 1996. *Seismic evaluation and retrofit of concrete buildings*, ATC-40 Report, California Seismic Safety Commission, 218–226.
- Bakir, P. G.; De Roeck, G.; Degrande, G.; Wong, K. K. F. 2007. Seismic risk assessment for the mega-city of Istanbul: Ductility, strength and maximum interstory drift demands, *Soil Dynamics and Earthquake Engineering* 27(12): 1101–1117.
- Buonopand, S. G.; White, R. N. 1999. Pseudo-dynamic testing of a masonry infilled reinforced concrete frame, *ASCE Journal of Structural Engineering* 125(6): 578–589.
- Chehab, A. G.; El Naggar, M. H. 2003. Design of efficient base isolation for hammers and press, *Soil Dynamics and Earthquake Engineering* 23(2): 127–141.
- Komodromos, P.; Polycarpou, P. C.; Papaloizou L.; Phocas, M. C. 2007. Response of seismically isolated buildings considering poundings, *Earthquake Engineering & Structural Dynamics* 36(12): 1605–1622.
- Nagarajaiah, S.; Narasimhan, S. 2007. Seismic control of smart base isolated buildings with a new semiactive variable damper, *Earthquake Engineering & Structural Dynamics* 36(6): 729–749.
- Park, S. K.; Han, K. B. 2004. Effect of seismic isolation bearing with sliding mechanism on the response of bridge, *Materials and Structures* 37(270): 412–421.
- Peter, F. 1996. Capacity spectrum method based on inelastic demand spectra, *Earthquake Engineering & Structural Dynamic* 28(9): 979–993.
- Priestley, M. J. N.; Seible, F.; Calvi, G. M. 1995. *Seismic design and retrofit of bridges*, John Wiley and Sons, Inc, 653.

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