2014 International Conference on Geological and Civil Engineering
IPCBEE vol.62 (2014) © (2014) IACSIT Press, Singapore
DOI: 10.7763/IPCBEE. 2014. V62. 11

Research on Geotechnical Seismic Isolation System

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Abstract. The seismic isolation system has been being used to improve the seismic performance of bridge structures. There are different types of seismic isolation systems for bridge structures. Typically, the isolation system is located between the top of the pier (shoe) and the bottom of the bridge girder. Occasionally, the system is positioned on the top of the foundation of the bridge. The seismic isolation system on the top of the foundation is difficult to design and to construct. Decade ago, this type of the seismic isolation system had been designed and constructed for Rion-Antrion Bridge in Greece. This paper describes the research on this type of the seismic foundation isolation system that is described as the geotechnical seismic isolation system. 2-D dynamic FEM and 1-G shaking table were used to study. The results show that the system effectively reduces the acceleration. On the other hand, the displacement increases due to sliding.

Keywords: Seismic isolation, foundation isolation, bridge foundation, seismic energy reduction.

1. Introduction

The seismic isolation system is one of the methods which are used to improve the seismic performance of bridge foundations. The system generally increases the relative displacement and decreases the acceleration between the bridge substructure and ground. During past few decades, the seismic isolation system is studied extensively using the numerical analysis. Wu (2002) studied shaking table model tests on soil-pile-superstructure interaction by using a laminar shear box [1]. Ueng et al., (2002) used two-dimensional large scale shear box on shaking table Also, 1-G shaking table tests and centrifuge tests have been used to simulate the various earthquake conditions [2]. Meymand (1998) performed shaking table model tests to study the nonlinear soil-pile-superstructure interaction in soft clay [3]. Mizuno and Iiba (1982) performed shaking table testing of seismic building-pile-soil interaction [4]. Iai (1989) evaluated the idea of similitude for shaking table tests on soil-structure-fluid model in 1g gravitational field [5]. Still, there are many limitations to perform and accurately simulate model ground tests to study the seismic isolation system of the bridge foundation.

This study investigated the effect of the seismic isolation system consist of blast-furnace slag and cement concrete which is similar in many respects to the seismic foundation isolation system employed in Rion-Antirion bridge pier.

2. 1-G Shaking Table Tests

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Model tests are essential when the prototype behavior is complex and difficult to understand. In model testing, usually the boundary conditions of a prototype problem are reproduced in a small-scale model. Model tests are used to understand the effects of different parameters and the process leading to failure of prototype at a real time (S.K Prasad et. al 2004) [6]. Iai (1988) performed large scale model tests and analyses of gravel drains [7]. Sundarraj (1996) studied the evaluation of deformation characteristics of 1-g model ground during shaking using laminar box [8]. 1-G shaking table model ground tests were performed using the laminar shear box and soft clay model ground (Kim, 2011) [9], (Kim et al., 2008, 2010, 2011) [10]-[12]. Kaolinite was used as soft clay ground in laminar shear box. Chichi earthquake and sinusoidal motions were used. Sine sweep tests were performed to determine the frequency characteristics of the model ground. Hammer blow tests were also performed before and after every test program to determine the dynamic properties of the model ground.

2.1. Test equipment

A 1-G shaking table of 5m width was used. A laminar shear box of 1.2m width, 2m length, and 1.1m height was used.

2.2. Instrumentations and model ground

13 accelerometers, 4 strain gauges, 4 LVDT sensors, and 1 wire potentiometer were installed both in the inside and outside of the laminar shear box. 10 accelerometers were placed in two columns in order to investigate the effects of boundary conditions and also the amplification of ground motion. 4 LVDT sensors were installed in the outside of the laminar shear box to compare the external and internal displacement of the model ground. The location of instrumentation is shown in Fig. 1.

The geometric scale between the prototype to the model was 50 and corresponding similitude ratio is shown in Table 1. Model ground soil properties are also shown in Table 2.

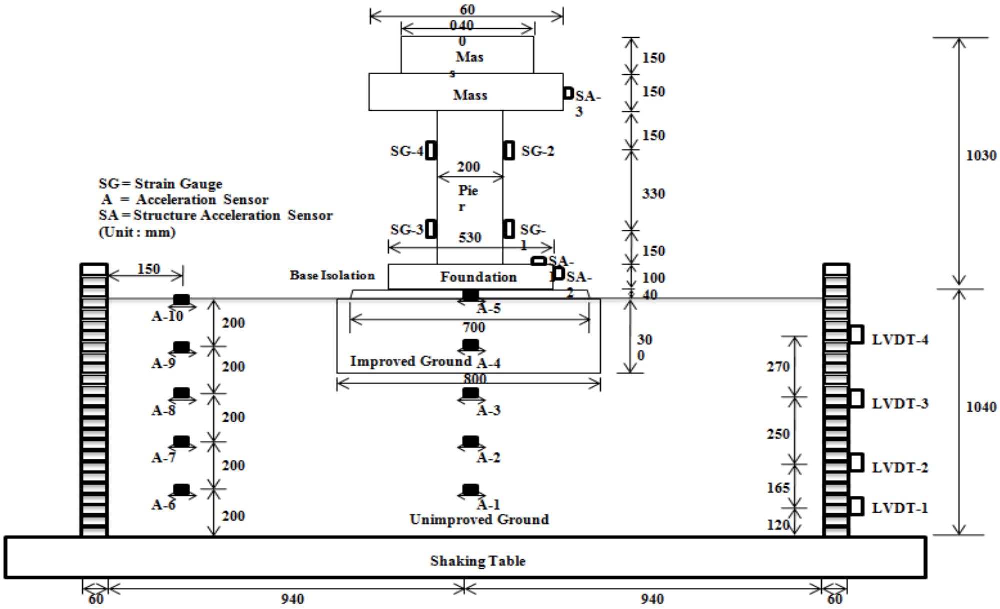


Fig. 1: Instrumentations.

Table 1: Similitude ratio for 1-G shaking table tests.

Parameter	Similitude ratio	Application
Geometry	λ	50
Acceleration	1	1
Strain	λ_e	1
Time	$(\lambda\lambda_e)^{0.5}$	7.07
Displacement	$\lambda\lambda_e$	50
Stress	$\lambda\lambda_r$	50

Table 2: Properties of model ground

Parameter	clay	improved clay	isolation layer
Shear modulus (kPa)	9,562	31,250	42,750
Shear strength, c_u (kPa)	12	35	-
Unit weight (kN/m^3)	17	20	25

2.3. Input motion

Chichi earthquake motion and sinusoidal motion were chosen as input motions (Fig. 2).

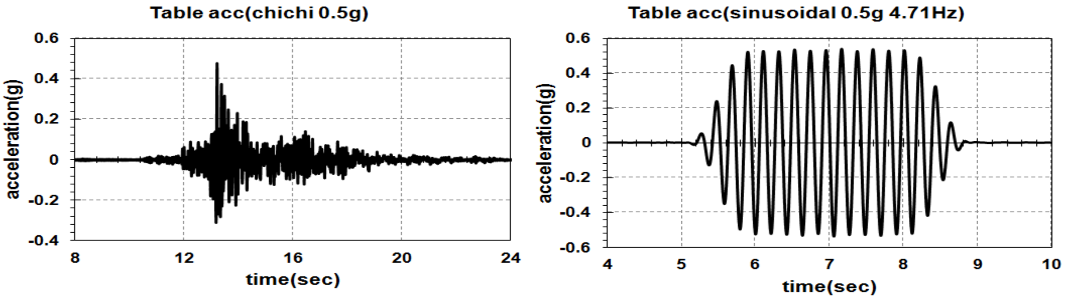


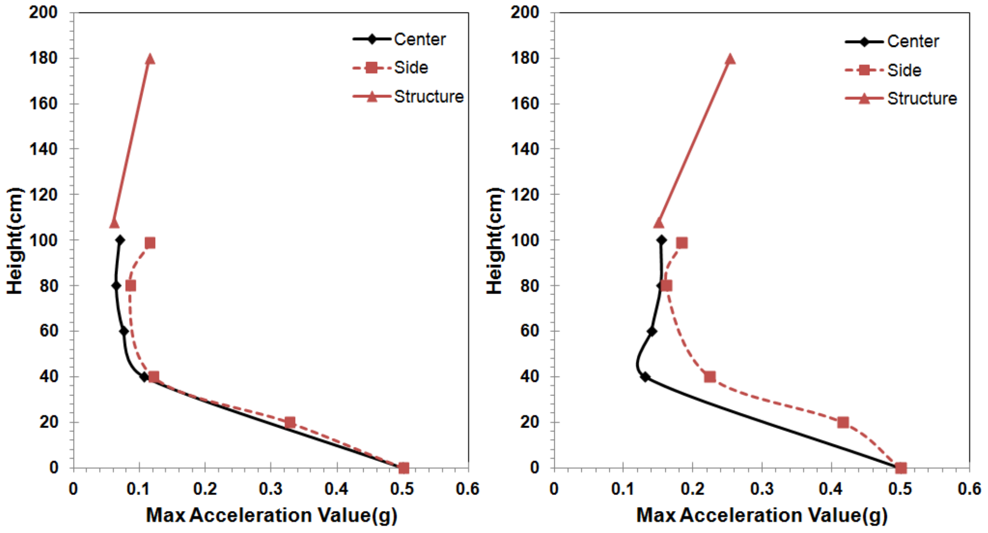
Fig. 2: Scaled input motions.

3. Test Results and Discussion

The tests results were analyzed in terms of response spectra and time histories. Baseline correction is made, if necessary.

3.1. Ground response

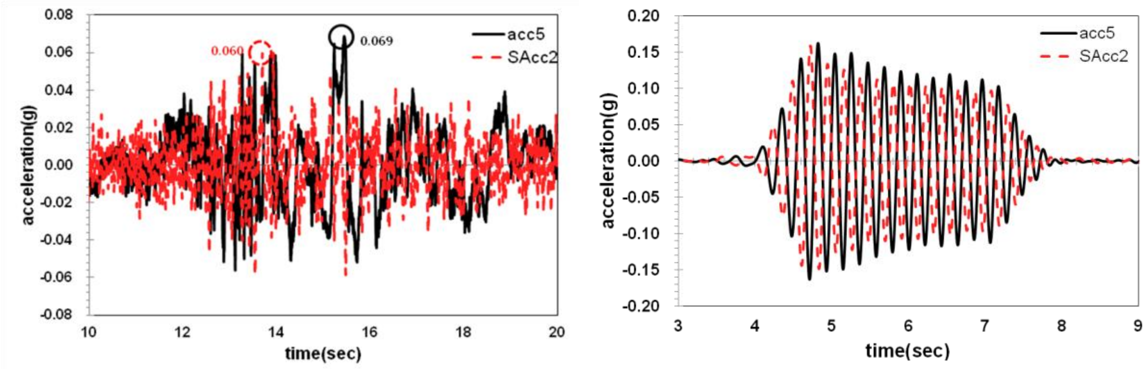
Fig. 3 shows the seismic response for 0.5g Chichi input motion and 0.5g sine wave input motion. For Chichi earthquake input motion, the value of maximum acceleration of the seismic isolation system (acc 5) is 30% less than that of the free field case (acc 10). In case of sinusoidal motion the value of maximum acceleration of the seismic isolation system (acc 5) is 20% less than that of free field case (acc 10). Fig. 4 also shows the structural acceleration and the acceleration of the seismic isolation system. Both cases of Chichi earthquake input motion and the sinusoidal input motion, ground motion does not attenuate significantly through the isolation system because sliding does not occur due to small ground acceleration level at the bottom of the system and also due to the relatively large interfacial friction between the system and the structure. The results lead to the important findings that this type of isolation system may not be effective in soft and medium ground, and may be only effective in hard ground of large impedance difference.



(a) 0.5g Chichi

(b) Sine wave 0.5g 4. 71Hz

Fig. 3: Acceleration of Ground

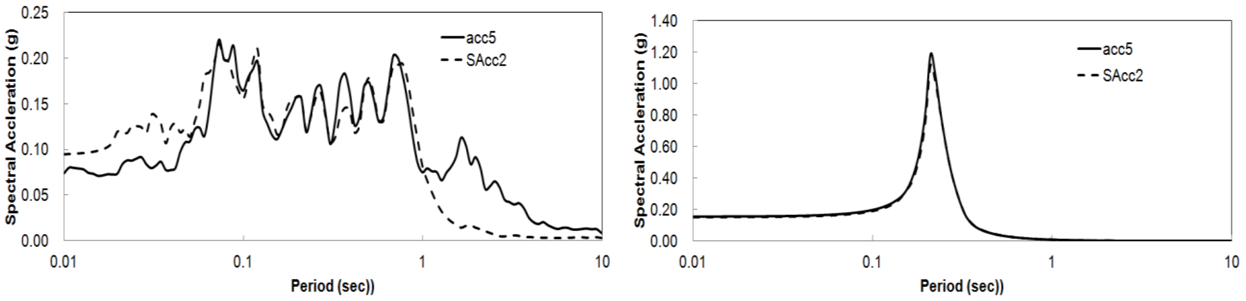


(a) 0.5g Chichi (b) 0.5g sine wave 4.71Hz

Fig. 4: Acceleration changes through the seismic isolation system

3.2. Acceleration response spectrum

Fig. 5 shows the change in acceleration response through the seismic foundation isolation system. Chichi response decreases between 1~10 seconds and increases 0.01~0.08 seconds after passing through the system. In case of sine wave, the value decreases in its frequency range.



(a) 0.5g Chichi (b) 0.5g sine wave 4.71Hz

Fig. 5: Acceleration Response Spectrum through the seismic isolation system

4. 2-D Dynamic FEM Analysis

In order to develop a numerical model for the seismic foundation isolation system, 2-D dynamic FEM analyses were performed. Fig. 6 shows the geometry and boundary conditions of the model. The ground boundary is extended far away from the structure to minimize boundary effects. Interfacial elements are employed to allow sliding between the system and the structure above.

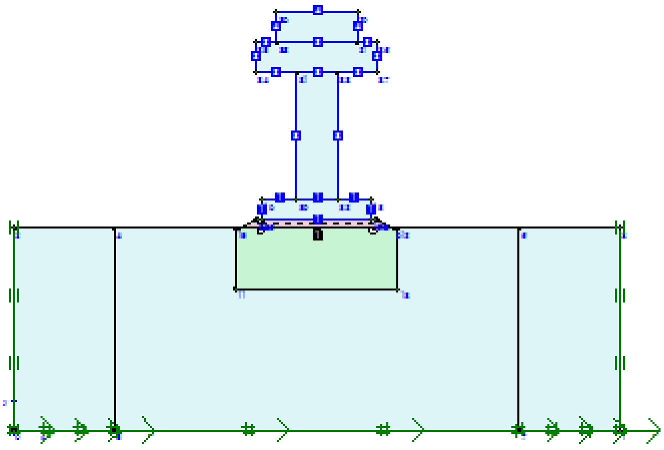


Fig. 6: Numerical Model for the Seismic Foundation Isolation System

5. Summary

The seismic response of the foundation isolation system was investigated by performing 2-D dynamic FEM analyses and 1-G shaking table tests. Seismic isolation system consist of blast-furnace slag and cement concrete which was similar in many respects to the seismic foundation isolation system employed in Rion-Antrion bridge pier. The findings are summarized as follows.

The seismic isolation system gets acceleration 20 to 30% smaller than the acceleration of free field because soil-isolation layer-structure interaction affects the stiffness of the ground.

However, ground motion does not attenuate significantly through the isolation system because sliding does not occur due to small ground acceleration level at the bottom of the system and also due to the relatively large interfacial friction between the system and the structure.

The results lead to the important findings that this type of isolation system may not be effective in soft and medium ground, and may be only effective in hard ground of large impedance difference.

Further experimental and numerical studies are going on hard ground condition and high acceleration levels. Those studies will be discussed in the conference.

6. Acknowledgements

This research was financially supported by the Ministry of Education, Science Technology (MEST) and National Research Foundation of Korea(NRF) through the Human Resource Training Project for Regional Innovation.

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