A Shaking Table Test of Scaled Model for an Emergency Diesel Generator System for Evaluation of Seismic Force Decrease by Using a Spring-Viscous Damper System

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ABSTRACT :

The effectiveness of a coil spring-viscous damper system for a seismic isolation of an Emergency Diesel Generator (EDG) in Nuclear Power Plants (NPP) was evaluated through a shaking table test and a numerical analysis. The EDG system consists of an engine, a generator and a concrete foundation. Net weights of the engine unit, the generator unit, and the concrete mass are 912 kN, 392 kN, and 2,474 kN, respectively, and the total weight is 3,779 kN. It is impossible to perform a real scale shaking table test for an EDG system. Therefore, a scaled EDG model was constructed using steel and concrete blocks. Total weight of the test model was 39 kN and the steel blocks were placed to have an equivalent mass center for the prototype. For the seismic isolation of the EDG test model, a spring-damper unit that consists of a combination of 2 coil springs and one viscous damper was adapted. The stiffnesses and the damping coefficients of the spring-damper unit for the vertical and horizontal directions were determined by a mechanical characteristic test. The test model was supported by 4 spring-damper units. A shaking table test for an EDG model was conducted for an evaluation of the seismic isolation performance of a coil spring-viscous damper system. An artificial time-history corresponding to the scenario earthquake for a Korean nuclear site and US NRC design spectrum were used as an input motion, and three peak acceleration levels were applied. The effectiveness of the coil spring-viscous damper system was evaluated by the ratio of the maximum acceleration responses measured at the model to the table acceleration. A numerical model for the test model was constructed and also a numerical analysis was performed by using the same seismic input motion. The EDG model tests and numerical analysis showed that the spring-viscous damper system could reduce the seismic force transmitted to the EDG by up to 50 percent.

KEYWORDS: coil spring-viscous damper system, seismic isolation, Emergency Diesel Generator (EDG), shaking table test

1. INTRODUCTION

An Emergency Diesel Generator (EDG) is the primary power source to supply AC power to the Class 1E power systems and equipment when the main turbine generator and offsite power source are not available in nuclear power stations. The EDG reduces the probability of a station blackout (SBO) due to a failure of AC power and finally it reduces the core damage frequency. For the purpose of improving the integrity of an EDG set, a spring-damper system has been adopted as a vibration and seismic isolation system because it is able to reduce the mechanical vibration level on the floor during an operation of the engine as well as the seismic force transmitted to an EDG body from the ground during an earthquake[Malushte and Whittaker, 2005, Tajirian, 1998].

In spite of the many potential advantages of a base isolation, however, the applications of a base isolation to nuclear facilities has been very limited because of a lack of sufficient data for the long-term operation of isolation devices. Since 1984, six large pressurized water reactor units have been isolated in France and South Africa [Malushte and Whittaker, 2005, Tajirian, 1998]. At the Cruas plant in France, where the site safe shutdown earthquake (SSE) acceleration is 0.2g, four units are constructed on base isolation devices. Each of the four units is supported by 1,800 neoprene pads. At the Koeberg nuclear power station in South Africa, where the site SSE acceleration is 0.3g, two units are isolated. A total of 2,000 neoprene pads with friction plates are used.

The most important advantage of base isolation applications in nuclear power plants is that the safety and reliability of the plants can be remarkably improved through a standardization of the structures and equipment regardless of the seismic conditions of the sites. The standardization of structures and equipment will reduce the capital cost and design/construction schedule for future plants. Also, a base isolation can facilitate in a decoupling of the design and development for equipment, piping, and components due to the use of the generic in-structure response spectra associated with a standardized plant. Moreover, a base isolation will improve the plant safety margin against a design basis earthquake as well as a beyond design basis seismic event due to its superior seismic performance. Base isolation of individual components is especially beneficial in a situation where existing components and their supports have to be requalified for higher seismic loads. By using a base isolation, it may be possible to avoid an expensive retrofitting of a supporting facility and foundation.

Recent studies have shown that the use of base isolation devices instead of anchor bolts for an Emergency Diesel Generator (EDG) can remarkably increase the seismic resistance of an EDG and finally reduce the core damage frequency in a nuclear power plant [Choun and Choi, 2005, Choun et al., 2004]. For a base isolation of rotating equipment such as an EDG, especially, a coil spring-viscous damper system is suitable because a mechanical vibration in a vertical direction is generated during an operation and it is reduced by a coil spring with a low vertical stiffness. Thus, a coil spring-viscous damper system has been adapted to vibrating machines to reduce their mechanical vibration during an operation as well as the seismic force during an earthquake[Huffmann, 1985]. This study demonstrates the effectiveness of a coil spring-viscous damper system for a seismic isolation of EDG sets through a shaking table test.

2. OVERVIEW OF THE SHAKING TABLE TEST

The seismic effectiveness of a coil spring-viscous damper system was demonstrated by seismic tests with a scaled model of a base-isolated EDG on a shaking table. As a prototype, an EDG set with a HANJUNG-SEMT Pielstick Engine 16PC2-5V 400 was chosen, which is identical to the EDG installed at Yonggwang Nuclear Unit 5 and Ulchin Nuclear Unit 3 of Korea, and the scaled model was designed to represent the seismic behavior of a prototype of an EDG set. Concrete and steel blocks were used to build an EDG model, and a coil spring-viscous damper system was used as a base isolation system. The dynamic characteristics of the coil spring-viscous damper system were obtained by cyclic tests and the seismic responses of the base-isolated EDG model were obtained by shaking table tests.

2.1. Test Model

The prototype of an EDG set consists of an engine unit, a generator unit, and a concrete mass. Net weights of the engine unit, the generator unit, and the concrete mass are 912 kN, 392 kN, and 2,474 kN, respectively, and the total weight is 3,779 kN. A 6-DOF seismic simulator with a table dimension of 2.5 m x 2.5 m was used for the model test. Test model was designed by considering the size of the shaking table of the simulator as shown in Figure 1, which consists of a concrete block of 2,300 mm x 800 mm x 450 mm, four steel blocks of 600 mm x 600 mm x 140 mm, and two steel plates of 1,500 mm x 300 mm x 30 mm. Total weight of the test model is 39 kN and the steel blocks were placed to have an equivalent mass center of the prototype.

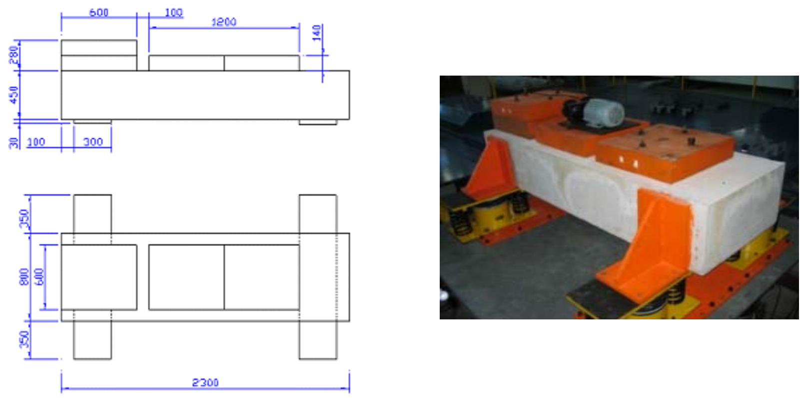


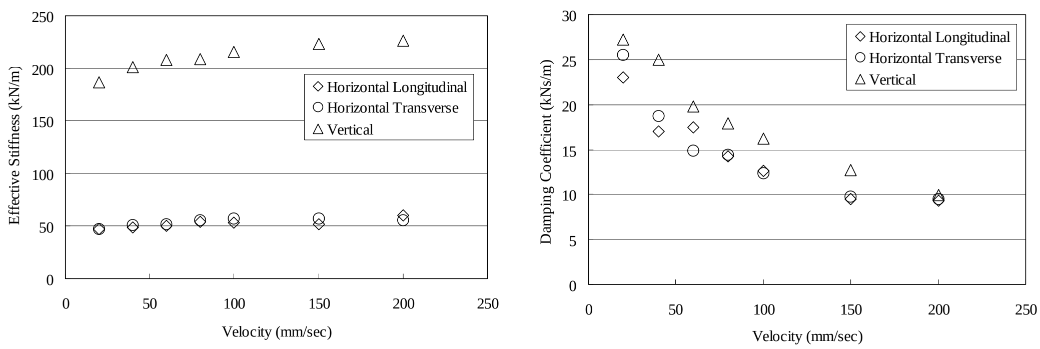
Figure 1 EDG test model for the table tests

2.2. Coil Spring-Viscose Damper System

A spring-damper unit that consists of a combination of two coil springs and one viscous damper, as shown in Fig. 2, was adopted for the seismic isolation of the EDG test model. At the design stage of the spring-damper unit, the stiffnesses and the damping coefficients of the spring-damper unit for the vertical and horizontal directions were determined by the seismic responses of the EDG test model for the input motion. The design properties of the spring-damper unit are shown in Fig. 2 and and the dynamic properties determined using the hysteretic force-displacement relationships for the spring-damper unit are shown in Figs. 3. The EDG test model was supported by 4 spring-damper units.

Item		Properties
Load Capacity		15 kN
Height		410 mm
Stiffness	Vertical	0.144 kN/mm
	Horizontal	0.04 kN/mm
Damping Coefficient	Vertical	3.5 kNs/m
	Horizontal	4.0 kNs/m

Figure 2 Spring-damper unit for the EDG test model

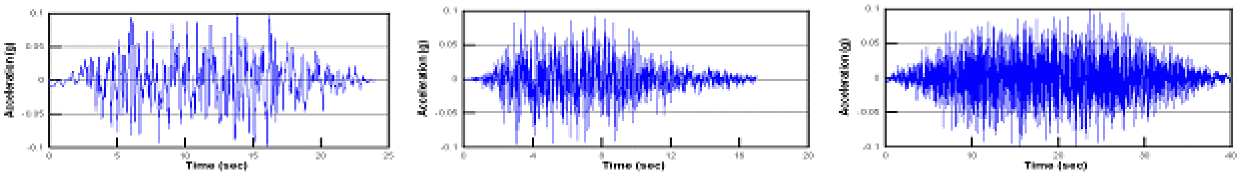


(a) Effective Stiffness (b) Damping Coefficient

Figure 3 Mechanical Characteristics of the Spring-damper unit for the EDG test model

2.3. Input Seismic Motion

Seismic tests were carried out for one and three directional excitations with three peak acceleration levels of 0.1g, 0.2g, and 0.3g. Artificial time-histories corresponding to the NRC Reg. Guide 1.60 spectrum [1973], scenario earthquake for a Korean nuclear site [Choi et al., 2003] and for a uniform hazard spectrum for a Korean nuclear site[Choi et al., 2004] were used as table input motions. Identical input motions and peak acceleration levels were used in the horizontal and vertical directions. Figures 4 and 5 show the artificial time histories and response spectrums of the input motions, respectively.



(a) NRC (b) Scenario (c) UHS

Figure 4 Time history of the Seismic Input Motion

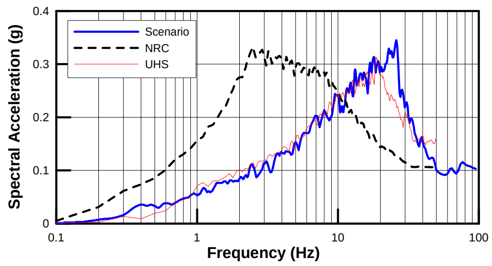


Figure 5 Response Spectrum of the Seismic Input Motion

2.4. Measurement and Test Procedure

The acceleration and displacement responses were measured by using two accelerometers (A1 & A2) and eight LVDTs (D1-D8) as shown in Figure 6.

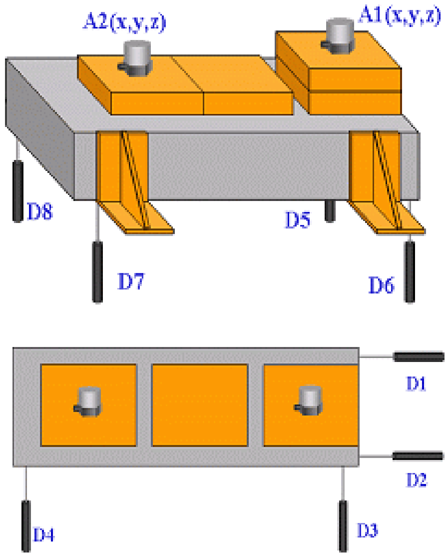


Figure 6 Accelerometer and LVDTs Arrangement

3. RESULTS OF THE SHAKING TABLE TEST

3.1. Acceleration Response

Figures 7 to 9 show the acceleration responses obtained from accelerometer A1 for the peak acceleration levels of 0.2g during the one directional excitation and the spectral accelerations for the peak acceleration level of 0.2g, respectively. Figures 7 to 9 show that the acceleration responses on the EDG model are reduced significantly by the spring-damper system. There is little difference between the acceleration responses in the one horizontal excitation and those in the one directional excitation. Figures 7 to 9 also show that identical spectral accelerations are obtained from the accelerometers. The spectral accelerations decrease significantly. The differences between the acceleration responses in the one horizontal excitation and the three directional excitations are very small.

The seismic effectiveness of the coil spring-viscous damper system was evaluated by the ratio of the maximum acceleration response for the model to the table acceleration as arranged in Figure 10. The average response ratios for the one horizontal excitation and the horizontal and vertical directions for three excitations are 0.283, 0.305, and 0.558, respectively. This indicates that the spring-damper system reduces the seismic force transmitted to the EDG model from the table by up to around 70 percent in the horizontal direction. But in the case of the NRC design spectrum, only about 25 percent of the seismic forces are decreased.

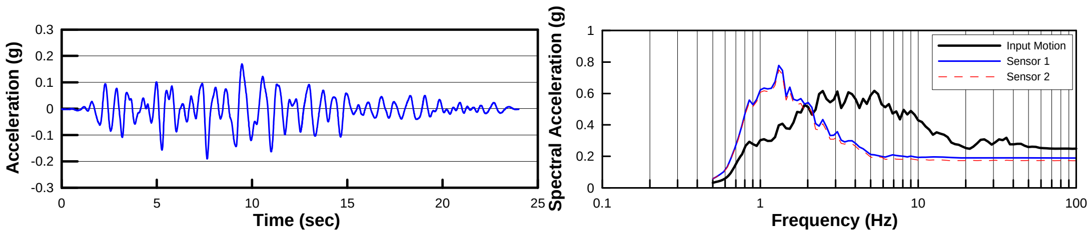


Figure 7 Seismic Response according to the NRC Earthquake (0.2g, 1D)

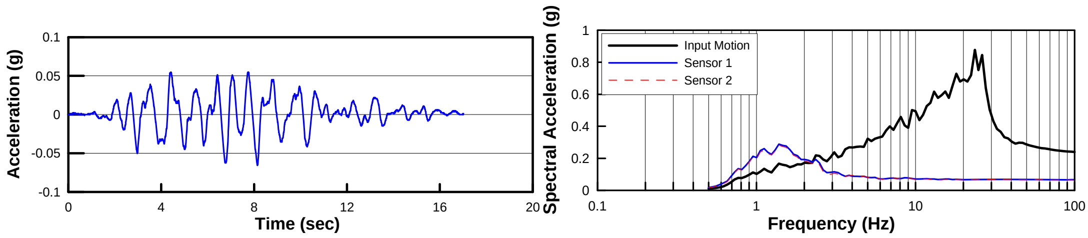


Figure 8 Seismic Response according to the Scenario Earthquake (0.2g, 1D)

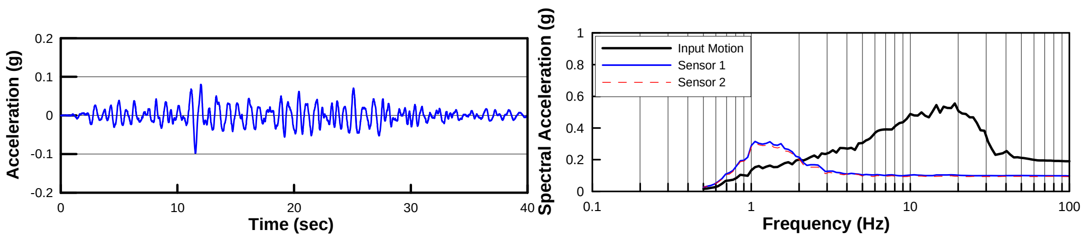


Figure 9 Seismic Response according to the UHS Earthquake (0.2g, 1D)

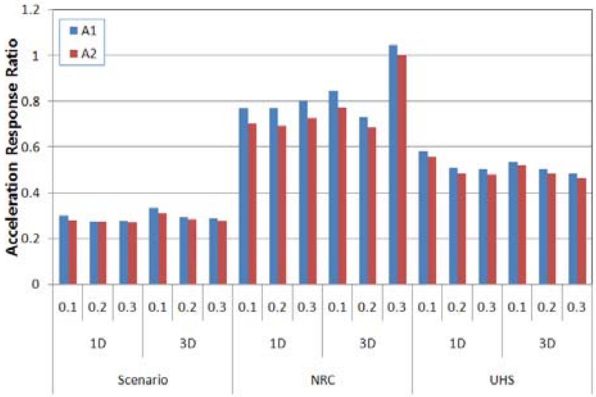
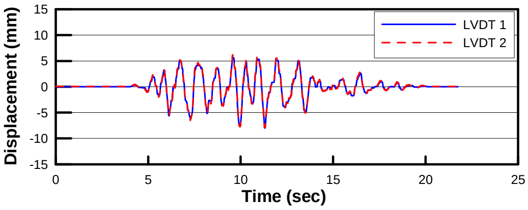


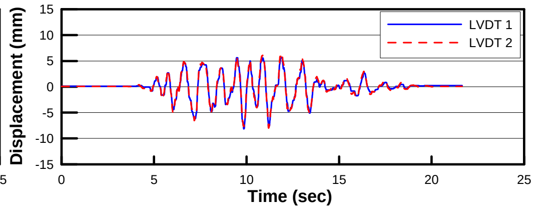
Figure 10 Comparison of the Acceleration Response Ratios for the Isolated EDG Model

3.2. Displacement Response

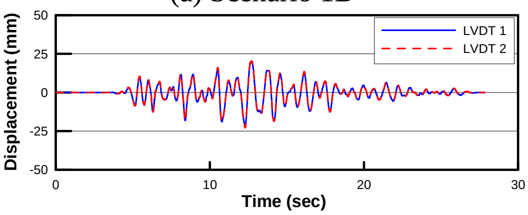
Figure 11 shows the displacement response time histories obtained from LVDT 1 and 2 for the peak acceleration level of 0.2g during the one and three directional excitations. And also the maximum displacement responses of all shaking table test cases are summarized a figure 12. As shown in Figures 11 and 12, the maximum displacements increase linearly according to the increase of the seismic input motions. The displacement time histories weren’t really affected by the one and three dimensional excitations. But in case of the NRC Reg. Guide 1.60 design spectrum, the maximum displacement increases in line with the three dimensional excitations.



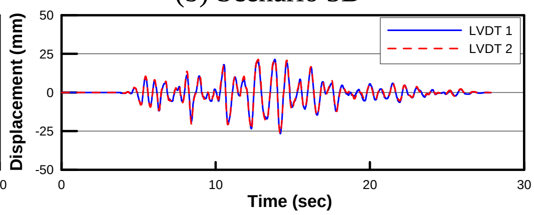
(a) Scenario 1D



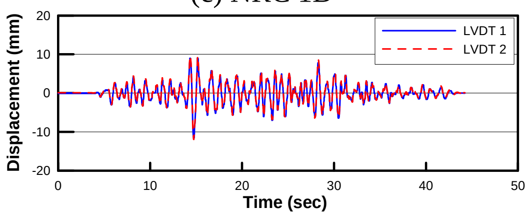
(b) Scenario 3D



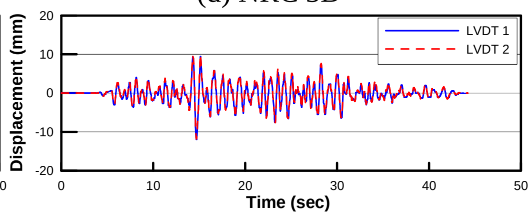
(c) NRC 1D



(d) NRC 3D



(e) UHS 1D



(f) UHS 3D

Figure 11 Maximum Displacement Response according to the Seismic Input Motion (PGA=0.2g)

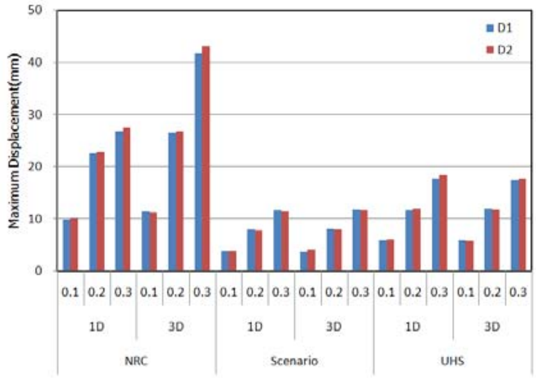


Figure 12 The Maximum Displacement Response according the Input Seismic Motion

4. NUMERICAL ANALYSIS

Figure 13 shows a numerical model for a seismic response analysis for the scaled EDG model. This model was constructed as solid elements for the body of the EDG model and shell elements for the steel plate. Coil spring and viscose damper system was modeled as a linear property by considering the velocity range of seismic input motion. Therefore a nonlinearity of the viscose damper wasn't considered in this analysis. In the case of the NRC design spectrum, the acceleration and displacement responses are shown in Figure 14. As shown in this figure, the results are matched well with the experiment and numerical analysis results. As a result, it can be said that a simple numerical analysis can predict behavior of a coil spring and viscose damper system. But if the PGA level us much higher, a nonlinear behavior of the viscose damper could govern the total behavior of an isolated EDG system.

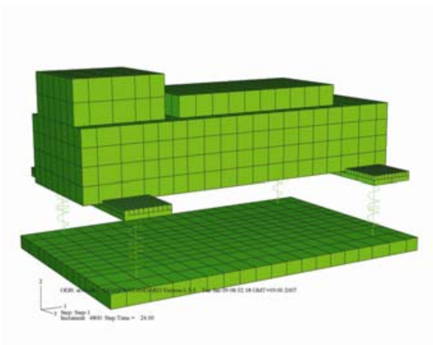
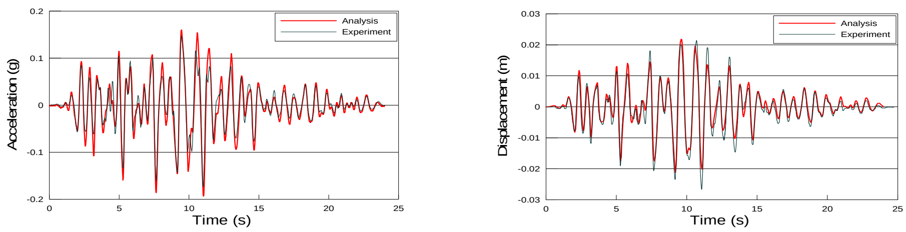


Figure 13 A Numerical Model for the Scaled EDG Model



(a) Acceleration Response (A1) (b) Displacement Response (D1)

Figure 14 Comparison of Experimental and Numerical Analysis Results

5. CONCLUSIONS

The effectiveness of a coil spring-viscous damper system as a vibration and seismic isolation system for an EDG was evaluated in this study. The seismic effectiveness of a coil spring-viscous damper system was evaluated by seismic tests with a scaled model of a base-isolated EDG on a shaking table. The scaled model was designed to represent the seismic behavior of a prototype of an EDG set. The seismic responses of the base-isolated EDG model obtained by the shaking table teats showed that the spring-viscous damper system could reduce the seismic force transmitted to the EDG by up to 70 percent.

It was demonstrated that a spring-viscous damper is an effective seismic isolation system for an EDG in nuclear power plants through an evaluation of its seismic isolation effectiveness. A coil spring-viscous damper system is suitable for vibrating machines to reduce both the transmission of their mechanical vibrations to a floor during an operation and the transmission of a seismic force to them during an earthquake.

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