DEVELOPMENT OF A SLIDING BEARING SYSTEM FOR SEISMIC ISOLATION IN VERTICAL DIRECTION

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ABSTRACT

Considering its advantages in reducing seismic effects on structures, researches on a seismic isolation system have been actively conducted to date. As a result, many seismic isolation systems and related design and construction methods have been developed. However, most research efforts have mainly focused upon isolating horizontal vibration, and less attention has been paid to mitigating vertical vibration which may also cause critical damage to a structure. In this paper, a new type of sliding bearing system utilizing friction damping and polyurethane-spring-based restoring mechanisms is presented. The new bearing system can reduce the vertical vibration more effectively than the existing system by doubling friction planes. In this paper, a theoretical model to analyze the behavior of the system and the results of laboratory tests along with numerical analyses are summarized.

Keywords: Seismic isolation, friction bearing, vertical vibration, sliding.

1. INTRODUCTION

Since the first seismic isolation system was installed to an elementary school in Macedonia in 1969, it has been applied to more than 7,000 buildings in the world to date (Stojadinovic 2011), and has proved its effectiveness during recent major earthquakes such as Northridge (1994), Kobe (1995), Fukuoka (2005), Chuetsu (2007), and Tohoku (2012). So far, the seismic isolation is known to be the most effective technique for preserving the integrity of civil engineering structures including buildings, bridges, etc.

One of the most widely adopted isolating techniques is applying isolation bearings to the foundation of a structure, and, in response, various types of isolation bearings have been developed to date (Naeim and Kelly 1999). Some of the isolation bearings in most use include elastomeric bearings using natural or synthetic rubbers, LRB (Lead Rubber Bearing), and friction bearings. However, since most research efforts on seismic isolation have focused primarily upon mitigating horizontal

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ground motion, less attention has been paid to alleviating vertical vibration and consequently only a few bearing systems for vertical action are currently available (Baek et al. 2011).

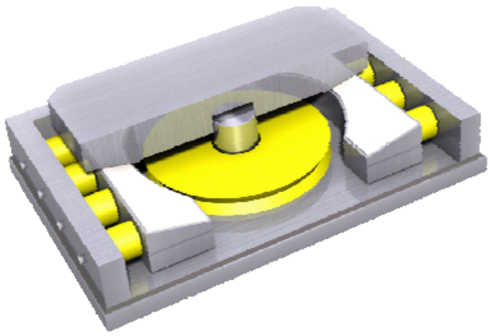
In this paper, a new type of sliding bearing system based on friction damping and polyurethane-spring-based restoring mechanism is presented. The new bearing system can reduce the vertical vibration more effectively than the existing system by doubling friction planes. In this paper, a theoretical model for analyzing the behavior of the system and the results of laboratory tests along with numerical analyses are introduced and summarized.

2. VERTICAL ISOLATION BEARING

Figure 1 shows two representative bearing systems currently available for vertical vibration (Choi et al. 2012). Figure 1(a) shows a spring-damper system in which an independent damper (e.g., a viscous damper) provides damping mechanism, and Figure 1(b) depicts a sliding friction system in which vibration is relieved via sliding friction action at the friction interfaces. Both systems have springs to provide restoring force, though the directions of spring action and the materials (e.g., steel, air, polyurethane) are different. The spring-damper type bearing has its weakness in relatively small lateral stiffness and bearing capacity. The sliding friction type bearing can overcome those shortcomings, but the authors believe that the damping performance can be enhanced by increasing friction interfaces.

The basic idea of developing a new type of vertical isolation bearing is to increase the damping performance by doubling friction interfaces as shown in Figure 2. As shown in the figure, the area of the friction surfaces are increased twice by providing additional interfaces, identical to existing bearing structure in Figure 1(b), at the bottom part of the bearing. The new bearing system has the center spring, which supports the vertical force transmitted from the top, and the lateral springs, which provides restoring capacity. The friction surfaces are made of PTFE (Poly-Tetra-Fluor-Ethylene), and the springs are Polyurethane. Note that the damping performance can be modulated by changing the slope of the interfaces and the friction coefficient of PTFE.

(a) a spring-damper type system



(b) a sliding friction type system

Figure 1: Existing vertical bearing types.

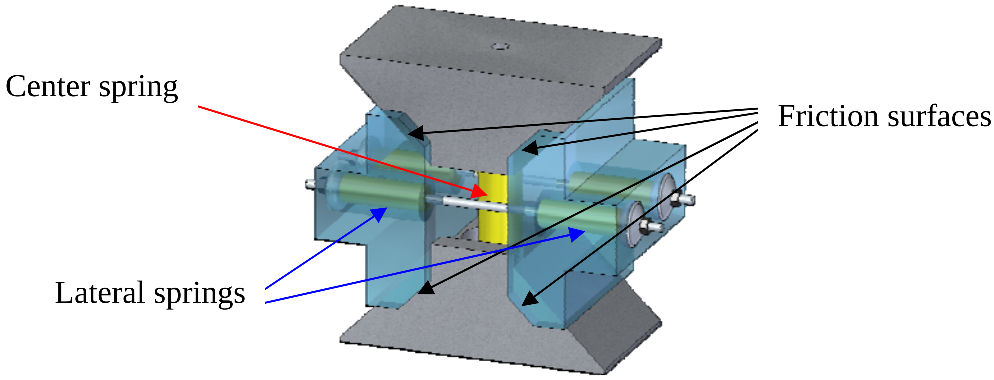


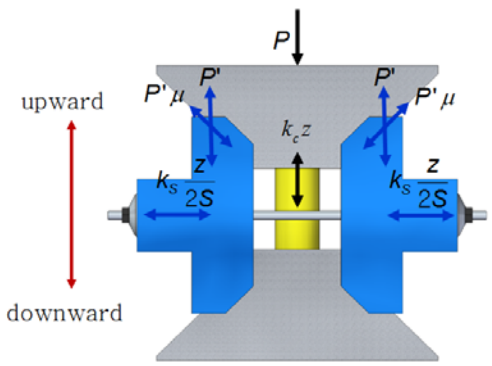
Figure 2: New vertical bearing.

3. ANALYSIS MODEL OF ISOLATION BEARING

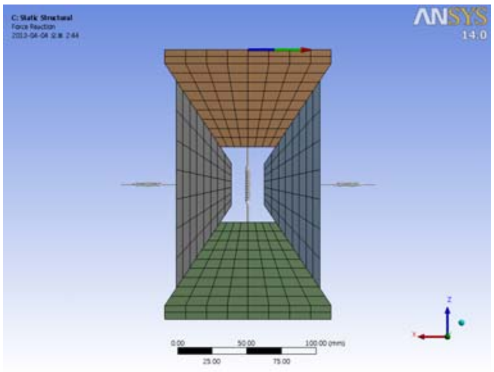
The behavior of the developed bearing system is analyzed theoretically and numerically. The theoretical model is derived from the force equilibrium relationship as shown in Figure 3(a). From the figure, the vertical force P can be obtained as follows:

$$P = \left[k_c + \frac{k_s(1 \pm \mu S)}{2S(S \mp \mu)} \right] z \tag{1}$$

where k_c and k_s represent the stiffness of the center spring and the lateral springs, respectively; S is the slope of the interfaces; μ is the friction coefficient; and z is the vertical displacement of the isolation system. In the equation, the positive and negative signs mean upward and downward movements, respectively.



(a) theoretical model



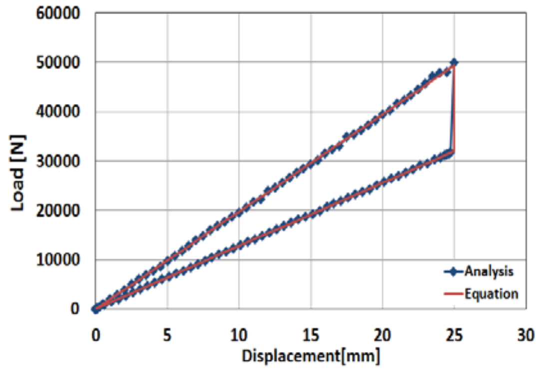
(b) numerical model

Figure 3: Theoretical and numerical models for the new vertical bearing.

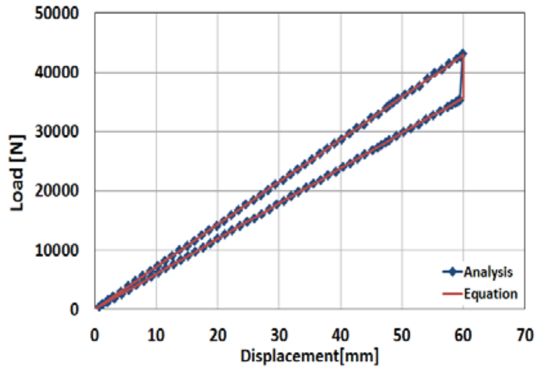
The numerical model is constructed using ANSYS as shown in Figure 3(b). To identify the effect of changes in lateral stiffness, slope, and friction coefficient, parametric study is performed. The parameters utilized in the study are described in Table 1. Note that the spring stiffness of the center spring is set to 350kN/m. Figure 4 shows the force-displacement relationship obtained from both theoretical and numerical analyses. The figure shows that theoretical and numerical analysis results are almost identical.

Table 1: Parameters used in the analytical study

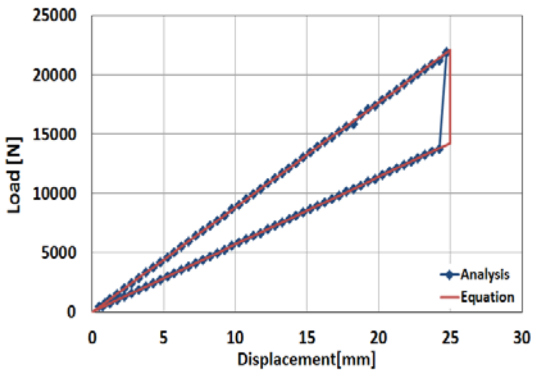
Case	*Lateral spring* (kN/m)	*Slope*	*Friction coefficient*
1	600	0.5	0.11
2	600	1.0	0.10
3	1,600	1.5	0.20
4	1,600	2.0	0.10



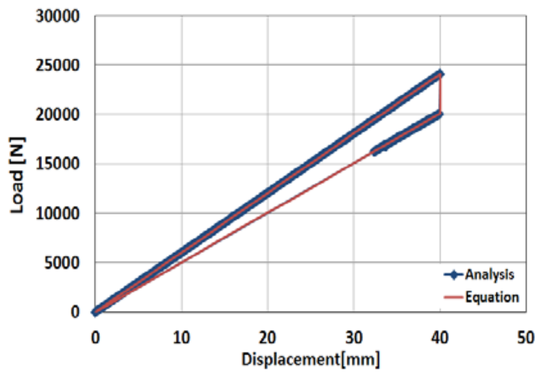
(a) Type 1



(b) Type 2



(c) Type 3



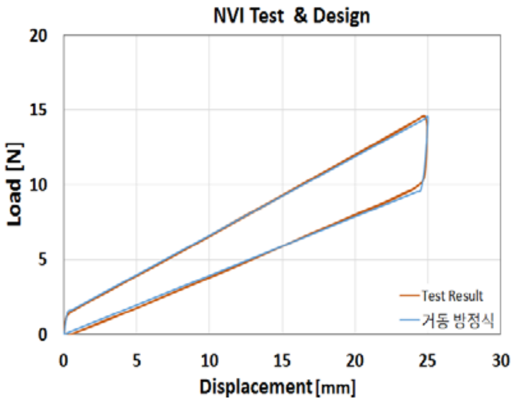
(d) Type 4

Figure 4: Force-displacement relationship obtained from analytical study

4. LABORATORY TEST

The prototype test is conducted in the laboratory to identify the real behavior of the bearing system and to compare to the analysis results (Lee et al. 2013). The prototype system is shown in Figure 5(a). Note that, in the prototype test, the specimen is built using Belleville springs, which have more constant stiffness property, instead of usual Polyurethane springs for more clear identification of behavioral characteristics. Figure 5(b) shows the comparison between the experimental and analytical results. The figure shows that the two results are almost identical.

(a) Test layout



(b) Test result

Figure 5: Prototype test layout and result

5. CONCLUSIONS

In this paper, a new type of sliding bearing system for isolating vertical vibration, which can significantly increase the damping performance by doubling the friction interfaces, is introduced. To verify the performance and predictability of the bearing system, analytical and numerical analyses are conducted and the results, i.e., force-displacement relationships, are compared to the laboratory test result. From the comparison, it is observed that the theoretical, numerical, and experimental results are almost identical. Consequently, the behavior of the developed vertical isolation bearing system can be analyzed with sufficient predictability.

6. ACKNOWLEDGMENTS

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