



Response of vibration-isolated object to ground motions with intense vertical accelerations

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ABSTRACT

This paper reports the results of shaking table tests performed to assess the response of an object placed on a vibration isolator to intense ground motions whose peak accelerations are close to or over the gravity acceleration in both vertical and horizontal directions. The passive vertical and horizontal vibration isolator, developed by the authors, has rolling load-bearing elements and constant-force springs to provide piecewise-constant restoring forces. First, we performed shaking table tests, wherein only the horizontal vibration was isolated. An unexpected finding from the tests is that, when the vibration isolator was subjected to ground motions with intense vertical accelerations, not only vertical but also horizontal accelerations were amplified. This led to a large rocking response or overturning of the object placed on the vibration isolator. A likely reason for the amplification is rocking of the upper portion of the vibration isolator above the rolling load-bearing elements induced by intense vertical accelerations. Next, we performed shaking table tests, wherein both vertical and horizontal vibrations were isolated. In this case, the vertical as well as horizontal accelerations were significantly reduced and the rocking response of the vibration-isolated object was suppressed. These results suggest potential risks in conventional horizontal vibration isolators having rolling load-bearing elements when they are subjected to ground motions with intense vertical accelerations. The results also demonstrate the effectiveness of vertical vibration isolation to avoid such risks.

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1. Introduction

In recent years, several intense ground motions have been recorded in Japan whose vertical peak ground accelerations (PGAs) were close to or over the gravity acceleration as shown in Table 1 [1,2]. Among these earthquakes, the 2004 Niigata-ken Chuetsu earthquake attracted considerable attention from the researchers and engineers in the field of passive vibration control. In this earthquake, a historic earthenware pot, a national treasure of Japan, turned over and broke into pieces while it was placed on a horizontal vibration isolator [3]. This incident posed a serious question on the reliability of vibration isolators because the horizontal vibration isolator was designed to work against the ground motions recorded in the 1995 Hyogo-ken Nanbu earthquake, one of the most devastating earthquakes experienced in Japan. Two possible reasons were pointed out for the overturning. One was the shortage of the stroke of the vibration isolator. The other was the influence of intense vertical accelerations.

After the incident, Kamba [3] performed shaking table tests to examine the response of the objects placed on a horizontal vibration isolator to the ground motions recorded in the 2004 Niigata-ken Chuetsu and 1995 Hyogo-ken Nanbu earthquakes. It was found from the tests that the probability of the overturning of the objects to the JMA Ojiya ground motion, recorded in the 2004 Niigata-ken Chuetsu earthquake, was significantly higher than that to the JMA Kobe ground motion, recorded in the 1995 Hyogo-ken Nanbu earthquake, while the negative effect of the shortage of stroke of the horizontal vibration isolator was not observed throughout the tests. Based on these results and the PGA values of the ground motion records shown in Table 1, it was concluded that intense vertical accelerations were the likely reason for the higher probability of overturning. Nevertheless, the vibration data, for example, the accelerations and displacements, are not reported in Ref. [3] necessary for the quantitative assessment of the reasons for the higher probability of overturning.

The incident and the increase in the number of ground motion records with intense vertical accelerations have led to an increasing demand for developing passive vertical vibration isolators to protect artworks and precision instruments from intense earthquake ground motions. Some research works dealt with the

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