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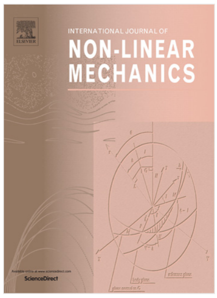

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Numerical investigation on scaling a pure friction isolation system for civil structures in shaking table model tests

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Abstract: Many Coulomb friction-based devices have been used for seismic isolation of modern civil structures. Aiming at a practical problem that if the friction action could be scaled in a shaking table model test, a base isolation system using Coulomb friction was numerically scaled in different ways by considering the gravity distortion, friction distribution and other influence factors. The seismic responses back calculated from the scaled models were compared with those of the full-scale model to evaluate the accuracy of scale theory for such a Coulomb friction action. The above numerical results show that the scale theory is still applicable for the uniform and non-uniform friction distribution patterns with nonlinear characteristics. The gravity distortion and uneven friction distribution are the most important factors, causing the errors of scale theory for the Coulomb friction system. However, the unallowable errors, caused by the un-scaled gravity acceleration on common shaking tables, can be avoided by reasonably changing the friction coefficients at the scaled friction interface. And other unallowable errors, caused by the uneven friction distribution, can be prevented if the specific positions with different friction coefficients for the full-scale model are proportionally moved with the scaled contact surface.

Keywords: civil structures; Coulomb friction; scaled model; numerical analysis; seismic isolation

1. Introduction

A friction-based isolation method has been investigated to reduce the seismic damage of civil structures in recent years. The pure friction device was summarized by Nanda [1] to be the simplest and best isolation system to resist strong earthquakes. For example, a type of similar isolation system was developed by Kurita [2] to reduce the structural acceleration responses by about 50-90%. However, the above reduced range is so large due to the complex characteristics of both friction actions and ground motions. Similarly, a roll-n-cage (RNC) isolator was invented by Ismail and Casas [3-5] to protect cable-stayed bridges and other structures against near-fault (NF) earthquakes. Those studies proposed that the friction-based device had strongly non-linear behaviors, and was intended to achieve a balance in controlling isolator displacement demands and structural accelerations. And hence Chung, Kao, et al. [6] even considered that the friction is one of the most complex non-linear phenomena in civil engineering, and studied a theoretical method determining the best friction coefficient in a seismic isolation structure.

The friction action is so complex that many researchers have found that the numerical results don’t well match with the experimental ones under earthquakes. Aiming at double rolling isolation systems (RISs), a mathematical model was built by Harvey and Gavin [7]. And this model was used to predict the peak responses of RISs of a seismic experiment with errors. More attentions were paid for the initial conditions, ground motions, simplification and accuracy of the proposed mathematical model [8, 9]. It was considered that those seismic responses were strongly sensitive to the initial conditions, and could not be calculated by a uni-axial model [10]. And there were chaotic behaviors including impacts in the isolation system [11]. However, those errors between the results of the numerical and experimental models were not analyzed in detail. Similar unconcerned errors were also exhibited when Wang, Hwang, et al. [12] studied a type of sloped multi-roller isolation device to protect equipment and facilities, and when Ortiz, Magluta and Roitman [13] investigated similar rolling bearings to improve the building structural responses in terms of modal parameters, frequency response functions (FRFs) and seismic acceleration responses. In addition, an experiment of concrete ball-in-cone isolator with rubber and polyurethane balls was carried out to