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PHYSICAL-BASED MULTIPLE-FACTOR MODEL OF A LEAD-CORE RUBBER BEARING FOR SEISMIC ISOLATION

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Seismic isolation is a commonly used technique to mitigate the damage induced in structures and structural elements during an earthquake. In the first place, this is one of the measures that can contribute to minimizing the casualties – a crucial factor making the research deserving of interest. Furthermore, adequate seismic isolation of critical civil engineering structures, such as nuclear power plants, is a prerequisite to avoid environmental pollution that can occur as a consequence of a strong ground motion. Overall, the implementation of techniques for seismic isolation fosters the development of a sustainable and resilient built environment.

Seismic isolation can be identified with base isolation designed to decouple the structure from the ground. Commonly used devices for base isolation are Lead-Core Rubber Bearings (LRB) and Friction-Pendulum bearings. For existing structures and buildings, retrofitting by adding seismic isolation might be technically difficult for implementation. The so-called hysteretic dampers provide an alternative option. They can be added to structural elements in order to dissipate energy transmitted to the structure during a strong ground shaking.

The article focuses on the modelling of the behaviour of LRBs. To the knowledge of the author, the first described applications are in New Zealand, specifically the Scamperdown Bridge [1] and the base isolation of the William Clayton Building [2]. An LRB generally consists of alternating layers of rubber and steel, the former providing the desired horizontal deformability along with the restoring capabilities and the latter – the required resistance to vertical loads transferred from the superstructure. If the isolator is provided with a lead core, the response of the isolator is characterized by well-pronounced hysteresis loops during seismic events. Compared, for example, with a high-damping rubber bearing (an equivalent unit for seismic protection not containing the lead core but only the alternating steel and rubber layers), the energy dissipation capacity of the LRB is larger. Figure 1 presents the general scheme of an LRB consisting of rubber layers (1), steel shims (2), a lead core (3), and tick steel plates (4).

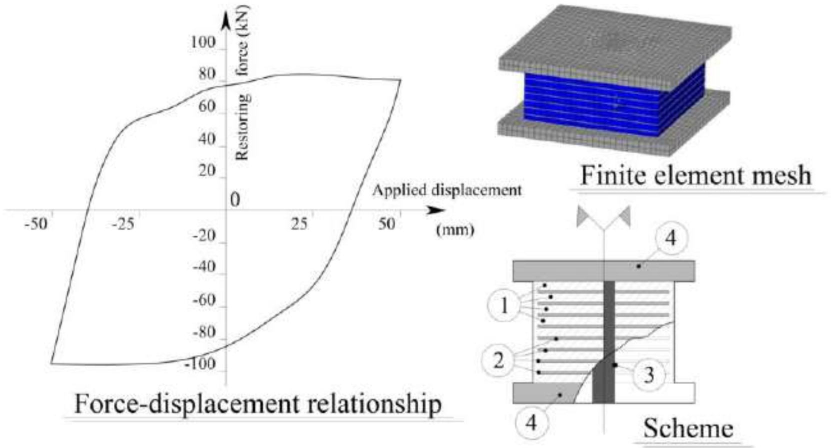

Figure 1 – Scheme of the LRB, the generated finite element mesh, and the force-displacement relationship obtained by FE analysis

The first models for LRBs referenced in the literature are the smooth bilinear model proposed by Robinson [3] and the Ramberg-Osgood model. Both these models define a skeleton curve and hysteresis variable separately. The skeleton curve provides the relation between the varying boundary conditions of the bearing device and the generated shear force. The analytical (or closed-form solutions) have been improved since then to take into account various phenomena such as effects due to the temperature increase [4, 5], strength degradation [6, 7], strain hardening at large shear deformations [8], etc.

Another investigation method is the Finite Element (FE) analysis. A typical FE mesh and a numerically obtained force-displacement relationship are depicted in Figure 1. Transient dynamic analysis has been employed for the numerical simulations based on the defined boundary conditions, initial conditions, and material models. For the lead core, the steel shims, and the top and bottom steel plates, a rate-independent plasticity model has been employed with the assumption for isotropic hardening after yielding [9]. The hyperelastic response of the rubber has been modelled using the Mooney-Rivlin model. Thus far, the developed finite element model doesn’t account for the rise in the temperature occurring during the dynamic response of the LRB. Integration of procedures designed for the evaluation of degradation in different components of the isolators (rubber and, possibly, lead core) into the numerical analyses is also forthcoming. In a more general context, such studies will allow for the verification of some hypotheses on the materials’ behaviour (considered as constituencies of an LRB), such as no damage is accumulated in the lead core (i); the dynamic response of the lead within the plastic domain is rate-independent (ii).

The results obtained by finite element analysis are used within ongoing research to calibrate an analytical model or to provide input data for a data-driven model, e.g., a multilayer perceptron. The analytical model and the multilayer perceptron are being developed within the perspective for a subsequent implementation into a model of a seismically protected structure. The multilayer perceptron comprises one input layer, several hidden layers, and one output layer. The backpropagation algorithm is employed for the training. Implementation of data-driven models will potentially allow for a better investigation of the “design space” (i.e., the space containing the crucial model parameters) and, thus, a better calibration of the model parameters. Overall, the adequate model definition yields an accurate prediction of the response of the devices for seismic isolation and the whole seismically isolated structure (buildings or bridges), respectively.

References

1 **Park, R.** Seismic Design of Bridges. Structures Committee Summary 3, Road Research Unit / R. Park, R.W.G Blakeley // National Roads Board. – New Zealand, 1978.

2 **Megget, L. M.** Analysis and design of a base-isolated reinforced concrete frame building / L. M. Megget // Bulletin of the New Zealand Society for Earthquake Engineering. – 1978. – No 11 (4). P. 245–254.

3 **Robinson, W. H.** Lead rubber hysteretic bearings suitable for protecting structures during earthquakes / W. H. Robinson // Earthquake engineering & structural dynamics. – 1982. – No 10 (4). P. 593–604.

4 **Kalpakidis, I. V.** Effects of heating on the behavior of lead-rubber bearings. I: Theory / I. V. Kalpakidis, M. C. Constantinou // Journal of Structural Engineering. – 2009. – No 135 (12). – P. 1440–1449.

5 **Kalpakidis, I. V.** Effects of heating on the behavior of lead-rubber bearings. II: Verification of theory / I. V. Kalpakidis, M. C. Constantinou // Journal of Structural Engineering. – 2009. – No 135 (12). P. 1450–1461.

6 **Kumar, M.** An advanced numerical model of elastomeric seismic isolation bearings / M. Kumar, A. S. Whittaker, M. C. Constantinou // Earthquake engineering & structural dynamics. – 2014. – No 43 (13). – P. 1955–1974.

7 A new nonlinear model to describe the degradation law of the mechanical properties of lead rubber bearings under high speed horizontal loading / Y. Liu [et all.] // Structural Control and Health Monitoring. –2021. – No 28 (12). – P. 2836.

8 **Eem, S.** Large strain nonlinear model of lead rubber bearings for beyond design basis earthquakes / S. Eem, D. Hahm // Nuclear Engineering and Technology. – 2019. – No 51 (2). – P. 600–606.

9 **Lemaitre, J.** Mechanics of solid materials / J. Lemaitre, J. L. Chaboche. – Cambridge : Cambridge university press, 1990.

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СОВЕРШЕНСТВОВАНИЕ КОНСТРУКТИВНЫХ СХЕМ БОЛЬШЕПРОЛЕТНЫХ ПОКРЫТИЙ. АЛЬТЕРНАТИВНЫЙ ВАРИАНТ ПОКРЫТИЯ

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С ростом городов появляется необходимость возводить сооружения большой площади с приданием роли архитектурного акцента в градостроительной среде. Как сделать необычный фасад и восхищаться формой здания с высоты птичьего полета, не используя большого количества громоздких несущих конструкций? С решением этих инженерных задач справляются далеко не все конструктивные схемы.

Для выполнения перекрытия больших пролетов и придания сооружению архитектурно-эстетических образов необходимо затратить большое количество материалов. Выбор материалов для таких