

EVALUATION OF DYNAMIC CHARACTERISTICS OF HIGH DAMPING RUBBER BEARING AND PROPOSAL OF HYSTERESIS MODEL CONSIDERING DEPENDENCE ON SHEAR STRAIN AND HARDENING EFFECT

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<https://hdl.handle.net/2324/7182456>

出版情報 : Kyushu University, 2023, 博士 (工学) , 課程博士
バージョン :
権利関係 :



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論 文 名 : EVALUATION OF DYNAMIC CHARACTERISTICS OF HIGH
DAMPING RUBBER BEARING AND PROPOSAL OF HYSTERESIS
MODEL CONSIDERING DEPENDENCE ON SHEAR STRAIN AND
HARDENING EFFECT

(高減衰積層ゴム支承のせん断ひずみ依存性及びハードニング現象を考慮した力学
特性評価及び履歴モデルの提案)

区 分 : 甲

論 文 内 容 の 要 旨

In regions prone to seismic activity, the imperative for seismic retrofitting and specialized structural design has become increasingly vital. This imperative arises from the inherent risks associated with earthquakes, which can cause catastrophic damage to buildings, infrastructure, and communities. Earthquakes pose a significant threat to public safety, property, and economic stability, making it essential to ensure that structures can withstand seismic forces effectively. The need for seismic retrofitting and advanced design strategies is further underscored by the aging infrastructure in many seismic-prone areas, as older buildings may not meet current seismic safety standards. As a result, the development of resilient and earthquake-resistant structures has become paramount to mitigate the potential human, economic, and societal losses stemming from seismic events. Seismic retrofitting and design practices aim to enhance the structural integrity of buildings and infrastructure, reducing the risk of collapse and ensuring the safety and well-being of occupants, thus addressing a critical need in these vulnerable regions. Japan is one of the countries in the world with frequent seismic activity and great damage, and research on earthquake-resistant design and seismic isolation design has been actively conducted. In this dissertation, the focus is on HDR (High Damping Rubber) bearings designed using high damping rubber. HDR is a type of rubber bearing used in seismic isolation systems, designed to possess high damping properties that dissipate seismic energy and prevent the transmission of earthquake forces. However, the hysteresis behavior of HDR is highly dependent on the maximum experienced strain, making it highly nonlinear. Consequently, the impact of HDR's hysteresis characteristics on the design is significant, leading to ongoing research on hysteresis models that account for HDR's nonlinearity.

The main objective of this research is to investigate the mechanical characteristics and nonlinear behavior of HDR through dynamic loading tests. To investigate hysteretic characteristics of the HDR, a dynamic loading test was conducted on a scaled-down specimen according to ISO22762-1: Elastomeric seismic protection isolators – Part 1: Test methods (2010) and the Japan Road Association: Design Specifications for Highway Bridges, Part V Seismic Design. Subsequently, based on the experimental results, the aim is to propose a hysteresis model for HDR that incorporates its nonlinearity and to provide a systematic modeling approach. Finally, the proposed hysteresis model will be validated by conducting dynamic analysis and

comparing the results with experimental data to assess their accuracy and practicality.

Chapter 1 introduced the research background, the scope, and the objectives of this dissertation. Literature reviews relating to seismic isolation and laminated rubber bearings were summarized. The organization of the dissertation was illustrated at the end.

Chapter 2 described the characteristic verification test for dependence on the shear strain of HDR conducted using scaled-down HDR specimens. These HDR specimens, one-sixth the size of full-scale HDR bearings, were manufactured by Yokohama Rubber Co. Ltd., Japan. Based on the dynamic loading tests, HDR's representative nonlinear characteristics, including its dependence on strain rate and the presence of hardening phenomenon, were elucidated. To capture HDR's historical characteristics, progressively increasing sine waves were employed as input waveforms. The test results allowed for the assessment of HDR's mechanical properties and enabled a quantitative evaluation of its nonlinearity.

Chapter 3 evaluated the mechanical characteristics of HDR based on experimental results. The equivalent stiffness, absorption energy, damping ratio, and strain energy, which crucially influence the material and dynamical characteristics of HDR, were evaluated using the data from each experimental result. A comparative analysis was conducted for each cycle and step, allowing for a quantitative assessment of the nonlinearity and dependence on shear strain of HDR through the evaluation of its mechanical characteristics.

Chapter 4 proposed an advanced hysteresis model called the trilinear double target model that takes into account the dependence on the experienced shear strain and hardening phenomenon of HDR. A proposed hysteresis model was developed that can consider and reproduce each independent dependence on shear strain in the positive and negative directions from the origin. Especially, the maximum experienced shear strain of HDR is not determined by the absolute value of the shear strain in either direction, but the maximum experienced shear strain for the shear strain in the positive and negative directions from the origin was set independently. As a result, in the proposed HDR hysteresis model, the nonlinear hysteresis characteristics due to the shear strain experienced in one direction did not affect the opposite direction. Finally, the validity of the proposed hysteresis model was assessed by reproducing the experimental results and evaluating the mechanical properties.

Chapter 5 explained dynamic loading tests conducted to examine the response of HDR under seismic shear deformation. The main purpose of these dynamic loading tests was to validate the actual behavior of HDR and assess the suitability of the proposed hysteresis model. The input waves utilized in this dynamic loading test were based on assumed design ground motions. Moreover, dynamic analyses were conducted using six design seismic motions as input for the proposed history model. The validity of the model was assessed by comparing the analysis results, considering the nonlinear history characteristics of HDR, with the actual behavior.

Chapter 6 summarized the work presented in this dissertation, and further research topics that emerged from this work were proposed.

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