SEISMIC PERFORMANCE OF LRB ISOLATED BRIDGE AT COLD TEMPERATURE

The University of Tokyo, Student Member ○ Farhan Muhammad
The University of Tokyo, Regular Member Di Su

1. INTRODUCTION

Currently the most effective seismic protection strategy adopted for bridges is Lead Rubber Bearings (LRB) isolation. The goal of bridge seismic isolation is to decouple the superstructure response from the seismic excitation, hence lowering deck acceleration and force demand to the substructure. LRBs were developed in 1975, when they were initially introduced in New Zealand. As LRBs major part consists of rubber material and due to its crystalline material effect, rubber undergoes very hard stiffness in cold temperatures, which led to modifying the dynamic response of the bridge structures especially during earthquakes. By using reversed cycling loading tests, C. Mendez-Galindo et al, 2016 conducted a full-scale laboratory investigation to ascertain how lead rubber bearings behaved under cold and normal temperature conditions. They discovered that LRB exhibits significant vulnerability to low temperatures (e.g., -30°C) as effective stiffness increases at higher ranges. To utilize the LRB isolation mechanical properties in numerical simulation studies, the bilinear type of model is widely recognized and adopted because of its simplicity and authenticity. The most used bilinear model is developed by Mendez et al, 2016, which can be used for dynamic analysis of base-isolated structures. The purpose of this study is to assess the seismic performance of a base-isolated Tokyo Metropolitan Expressway bridge structure at cold temperatures by utilizing a detailed finite element model and appropriate material model.

2. METHODOLOGY

A three-dimensional finite element model of the Tokyo Metropolitan Expressway bridge is developed in Abaqus as shown in Fig. 1. The bridge is having a span length of 31.9 meters and a width of 16.5 meters. The steel frame of the bridge consists of five main girders, seven cross beams, and bracings. The steel is used as per the Japanese standard SS400. All the parts are joined together by using tie constraints. Several areas of Japan experience 0°C or less than zero temperature, which significantly affect the engineering properties of various bridge components. The lowest temperature records for Tokachi Subprefecture on Hokkaido Island, where seismic forces and low temperatures are prominent, are all under -30°C, in accordance with climate data from the Japan Meteorological Agency. Past research shows, concrete and steel are less sensitive materials to cold temperatures (Jiao et al, 2014) as compared to lead rubber bearings. Thus, in this study, the mechanical properties for normal and cold temperatures are more focused on the lead rubber bearings (LRBs). The LRBs each have plan dimensions of 550 x 550 mm, and a total height of 236 mm is idealized using a zero-length cartesian type connector element with bilinear kinematic behavior (Mendez et al, 2016) in horizontal directions for normal and cold temperatures as shown in Fig. 2. The target bridge model is equipped with a total of 120 connector elements, 12 on each side of the girder representing the lead rubber bearings (12 connectors represent one LRB) as a parallel connection. The nonlinear time history analysis is performed under dynamic implicit step by applying Kobe Takatori accelerograms in horizontal directions of the target bridge model. Finally, the seismic waves were keyed by boundary conditions at the bottom end corner points of the assumed pier cap element in longitudinal and transverse directions of the bridge.

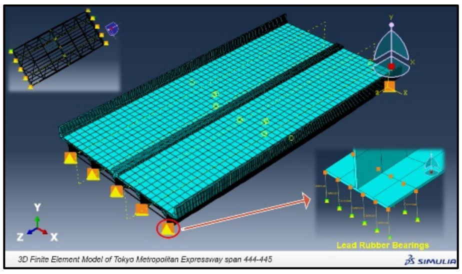

Fig. 1 TME Model in ABAQUS

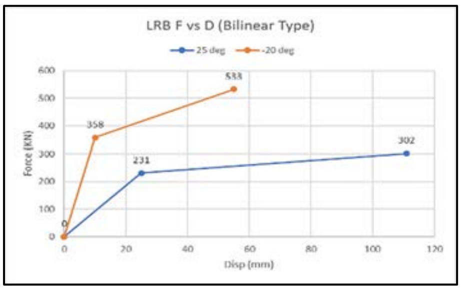

Fig. 2 LRB Bilinear Model (Mendez et al. 2014)

3. RESULTS AND DISCUSSIONS

Since the bridge's lateral directions are mainly concerned, thus seismic waves in longitudinal and transverse directions only are considered. The main responsibility of LRB is to significantly reduce the deck acceleration response by decoupling the superstructure from the substructure. Fig. 3. shows during normal temperatures the bridge deck experiences a peak acceleration of 6.23m/sec^2 which is increased significantly up to 8.94m/sec^2 during cold temperatures. This is because of the reduced horizontal flexibility and very stiff LRB during cold temperatures. One of the benefits of using an LRB isolation system is to provide a substantial amount of additional damping through hysteretic energy dissipation. Fig. 4. shows the cold temperature effects on LRB hysteretic response. During cold temperature both the LRB displacement and area of the hysteresis loop decreases (up to 75%) significantly as compared to normal temperature.

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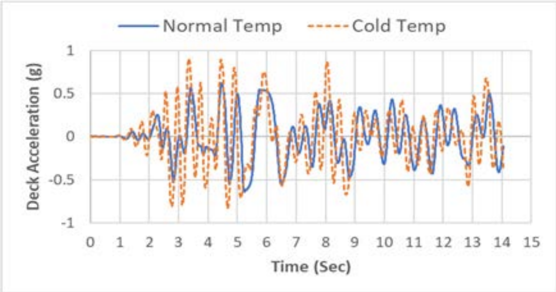
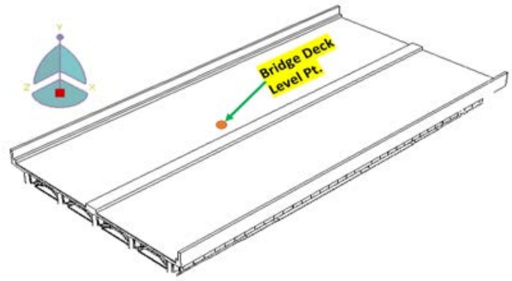
Contact address: Faculty of Engineering Bldg. #1 /, Hongo Campus, The Univ. of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656 JAPAN TEL: +81-3-5841-6084

This reduction in the hysteresis loop indicates decreased energy dissipation capacity of LRB. Moreover, due to increased stiffness under low temperatures, the force demand on LRB is also increased to 28%. Furthermore, there is no significant difference in response at external and internal girder LRBs because of symmetric condition of bridge. In addition to the LRB individual response, the response on other steel components of the bridge model is also studied. Fig. 5. shows during cold temperatures, the tendency of yielding of steel bracings has increased. At cold temp, the member is taking 308 MPa which is greater than yield pt. (250 MPa).

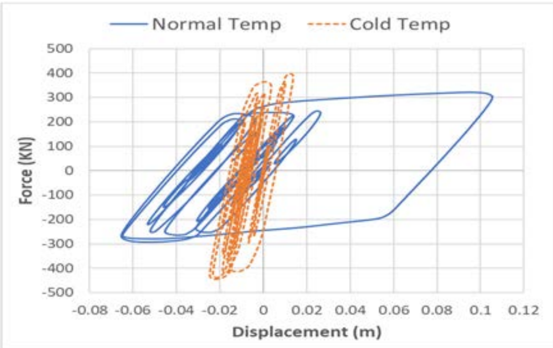


(a)



(b)

Fig. 3 Bridge deck acceleration response (a) Transverse direction response (b) Response location



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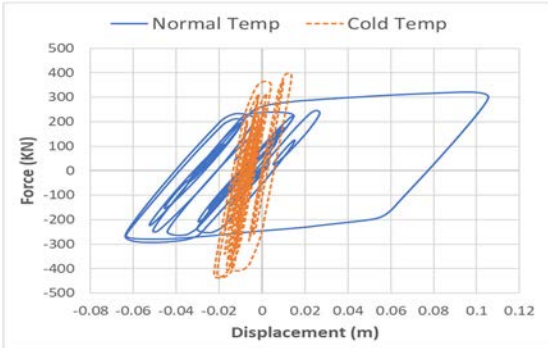

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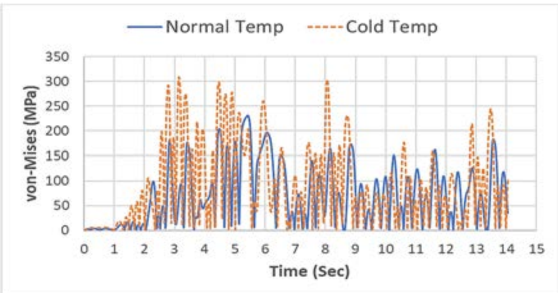
Fig. 4 LRB Force-Displacement (a) Transverse dir-external girder LRB (b) Transverse dir-internal girder LRB



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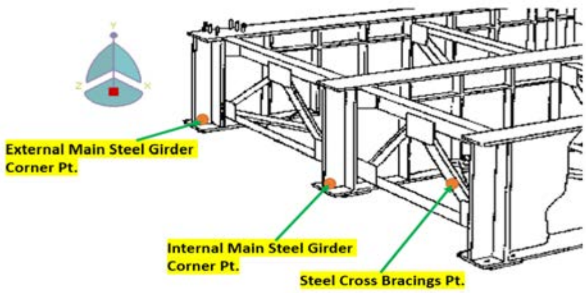

(b)

Fig. 5 von-Mises (a) At steel cross bracings (b) Response location

4. CONCLUSIONS

From the comparison of results, it is concluded that bridge structures experiencing seismic excitations at cold temperatures may have the totally different response as compared to normal temperatures. During cold temperatures, the LRB stiffness becomes very high just equivalent to a rigid support, thus showing high vulnerability. Finally, this type of very large variation should be considered carefully while designing the bridge structural members in a cold region, especially during the design of bridge columns/piers. As most of the bridge columns face abrupt shear failure under seismic events.

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