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学　位　論　文　内　容　の　要　旨

博士の専攻分野の名称　　博士（工学）　　氏名　干 治平

学　位　論　文　題　名

Seismic Performance of Base-isolated Bridges under Low Temperature in Snow Cold Region
(積雪寒冷地における低温時免震橋梁の地震応答性状に関する研究)

Base isolation system is one of the most effective technologies for protecting structures from damages in earthquakes. It has been extensively used worldwide in recent years, considering the increasing threat of great earthquakes. The basic strategy of base isolation system is that a structure can be uncoupled from the damaging effects of the ground movement in a strong earthquake, by taking advantage of the flexibility of base isolation devices, which provides flexibility through its ability to deform and move but return to its original position, i.e., restoring ability.

Base isolation devices, which are mainly made of material rubber, have temperature dependence behavior due to its material characteristics as an elastomer type of polymer. The thermal effect, when applied to polymers, induce a transition from a elastomeric, rubbery phase to a brittle, glassy solid amorphous phase on cooling. Consequently, the stiffness of polymer trends to increase with the decreasing temperature. With the increment of stiffness of rubber material, the flexibility of base isolation devices is deteriorated and therefore its seismic protection capability will be weakened.

For engineering purposes, cold regions are defined as any region where cold temperatures, unique terrain, and snowfall significantly affect engineering structures for one month or more each year. About one quarter of the earth's land mass may be termed severely cold. Since the area of cold regions unavoidably overlap with seismic zone, i.e. Hokkaido Island of Japan, it is necessary to take account of the low temperature effect on base isolation system in seismic response analysis.

This study conducts a three-dimensional non-linear numerical analysis to evaluate the seismic performance of curved grillage girder viaducts equipping base isolation system when it is applied in severe cold environment. For this purpose, a finite element modeling is adopted to examine the seismic response of bridge system in detail under the action of near-fault earthquake ground motions. Various base isolation systems which represent various temperature conditions are systematically compared and discussed. Temperature effect and temperature variation is taken into account particularly. And for the practicability and preciseness, a dynamic bearing property definition method is introduced to carry out the temperature and performance variation process of base isolation system during earthquake.

The temperature effect on lead rubber bearing (LRB) base isolation system is the main focus of this study, since it has been widely applied. Anylytical cases of high-damping bearing (HDR) bearings are also added as comparison. For practice and accuracy, the parameters of commercial products are adopted, which have been proved to be proper design under room temperature in previous studies. Nonlinear dynamic analysis is performed to obtain structural responses of the viaducts under the input earthquake waves which are obtained from 1995 Kobe earthquake which supposed an inflection point

in seismic design of highway bridges in Japan, and 2003 Tokachi-oki earthquake which has a much longer duration to raise the temperature of bearings higher.

The main object of this study is to confirm the necessity of considering low temperature effect of base isolation system in seismic response analysis. In order to achieve this, a series of numerical results are carried out. Base-isolation bearings with energy dissipation capacity, demonstrate to be very effective in suppressing excessive force responses acting on bridge piers when subjected to strong earthquakes. Based on the dynamic analysis results, it is found that these types of bearing systems may prevent structural damage during a seismic event, because their demand-reduction features provide a significant reduction in the seismic forces that the bridge structure must resist. Moreover, due to an appropriate selection of the design parameters of these bearing systems, moderate deformations of isolator devices are observed. This result is significant in that it indicates that LRB base-isolation systems are capable of controlling peak deck displacement response. Whereas cold region factors conspicuously weaken this base isolation function, which is the main conclusion of this study. In this study, by adopting dynamic bearing property definition method and examining the numerical results, the necessity of considering low temperature effect, not only in a short-duration earthquake, but also in a long-duration earthquake, has been clearly indicated.

On the other hand, high damping rubber (HDR) bearing system, which are expected to be an improvement of LRB system, still keep relatively large area of hysteresis loops under low temperature. This is because the yield force of HDR is much lower than LRB with a lead plug inside. Then HDR could take more advantage of stiffness after yield stage, achieving an overall low stiffness.

Temperature dependence performance of base-isolation systems of highway viaducts offers many possibilities for further research. In the present study, additional investigation has been conducted to study the response of variable performance of base isolation system, which is time and temperature dependence. In particular, application of heat conduction technology to different types of base isolation systems, acquiring the accurate temperature value in specified time and finally putting a dynamic properties definition of base isolation systems into use in the seismic analysis.

A further area for research concerns more detailed evaluation of HDR bearing system in cold region, which has better performance than LRB system in this study. As mentioned above, seismic protection capacity should be balanced with deformation, which may be the main problem of application of HDR bearing system.

It is also suggested to develop more temperature independence isolator devices. Since additional constant temperature equipment for base isolation systems is obviously inefficient, temperature independence materials and structures could be a better idea. And this is actually being studied by several manufacturers.