IMPROVEMENT OF SEISMIC CONTROL OF CABLE - STAYED BRIDGE USING SIMULTANEOUS ANALYSIS OF COST AND LOSS

Vahid AKHOONDZADE NOGHABI
M.Sc. Student, University of Tehran, Tehran, Iran
akhoondzade@ut.ac.ir

Khosrow BARGI
Professor, University of Tehran, Tehran, Iran
kbargi@ut.ac.ir

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In cable-stayed bridges, passive seismic control is usually performed by using bearing devices in the place where deck and pylons connect to each other. However, owners usually refuse to use more expensive bearing devices despite their superior seismic behavior. In Mashhad cable-stayed bridge as a case study, Pot Bearing device has been used which is not very effective in seismic behavior. On the other hand Elastomeric Bearings or Lead Rubber Bearings are more effective in absorbing earthquake's energy due to higher damping. So the use of Pot Bearing was probably because of the lower costs compared to Lead Rubber Bearing. Also different connection types between deck and pylons affect the seismic demand and dimension of the other bridge components (Li et al., 2009). So we should thoroughly compare the use of different bearing devices in Mashhad cable-stayed bridge using simultaneous analysis of the construction costs and losses due to earthquake. The mentioned different bearing devices include Pot Bearing, Elastomeric Bearing and Lead Rubber Bearing.

If economically justified, this paper tries to improve the passive seismic control system of the Mashhad cable - stayed bridge from its current Pot Bearing to another type. The economic justification is done using seismic risk assessment process and simultaneous analysis of costs and losses (Tesfamariam and Goda, 2013). To achieve this goal, it is necessary to design and control the bridge for seismic behavior with three different bearing devices using Calvi et al. (2010) approach. For nonlinear dynamic analysis of the bridge, based on the suggestions of Pacific Earthquake Engineering Research Center report (Aviram et al., 2008), the nonlinear model of the bridge is made by SAP2000. Also for more detailed study on the effectiveness of bearing devices upon seismic behavior of bridge, recommendations provided by Agrawal et al. (2012) have been applied in the field of Elastomeric Bearing and Lead Rubber Bearing modeling.

Then, the seismic risk assessment process is performed for each of three aforementioned cases. The final results of seismic risk assessment process are achieved as "Total Loss Ratio" based upon Equation 1 (Tesfamariam and Goda, 2013).

$$Total\ Loss\ Ratio(IM = im) = \sum_{i=1}^{4} [P(DS_i | im) - P(DS_{i+1} | im)] \times LR_i \qquad (1)$$

Where P is the probability function, DS_i is the *ith* damage state, *im* is the intensity measure of the earthquake and LR_i is the loss ratio in *ith* damage state.

The Total loss ratio resulted from equation 1 versus its annual frequency are represented in Figure 1.

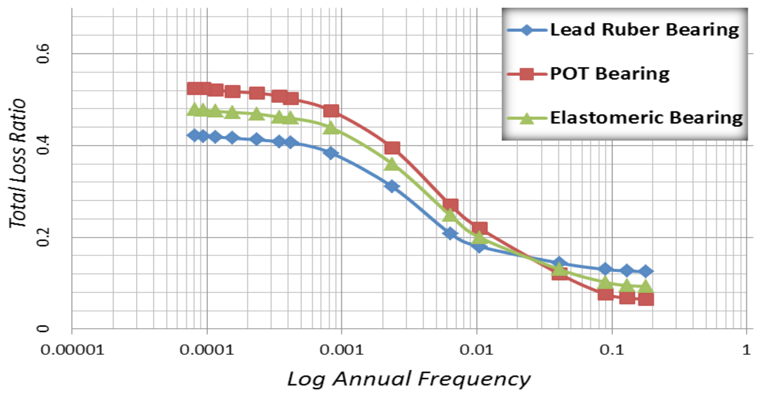

Figure 1. Total loss ratio curves of the bridge system with different bearing devices

In the next step, the proposed Cost-Loss-Benefit (CLB) method will compare the three cases by defining Benefit Ratio (BR) as a profitability measure based on the Equation 2.

$$BR_s = (\frac{C_{s=1}}{C_s})^2 \times (\frac{EAL_{s=1}}{EAL_s}) \qquad (2)$$

Where *EAL* is the Expected Annual Loss (the area under each curve in Figure 1), *C* is the construction costs, index '*s*' represents the type of the bearing device, and index '*s=1*' represents the Mashhad cable - stayed bridge with Pot Bearing device.

One of the advantages of this method is that CLB method uses the relative cost and loss amounts that are independent of absolute cost of materials and construction. Table 1 shows the costs, losses, and BR values as a profitability of each three schemes of the Mashhad cable - stayed bridge

Table 1. The CLB data and results

Bearing Device	Material Volume Coefficient of				Bridge System $(\frac{C_{s=1}}{C_s})$	$(\frac{EAL_{s=1}}{EAL_s})$	BR_s
	Cables	Pylon	Bearing	etc.			
POT Bearing	1	1	1	1	1	1	1
Elastomeric Bearing	0.97	0.9	1.3	1.13	0.95	1.07	0.97
Lead Rubber Bearing	0.97	0.8	1.45	1.1	0.94	1.22	1.08

The final results indicate that both of the alternative cases increase the costs and decrease the losses compared to the existing Pot Bearings. However, simultaneously considering the costs and losses, the BR coefficient reveals the profitability of the use of Lead Rubber Bearings in Mashhad cable-stayed bridge. Expressing in more detail, the use of LRB instead of Pot Bearing caused an 18 percent reduction of loss due to earthquake, while it only increased the construction cost by 6 percent.

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