Research Paper

EXCEL SPREADSHEET FOR DESIGN OF LEAD RUBBER BEARING USES FOR SEISMIC ISOLATION OF BRIDGES

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ABSTRACT

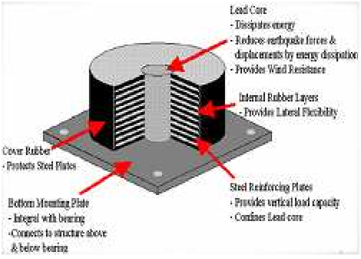
This paper presents the design methodology of Lead Rubber Bearing used for seismic isolation of bridges. Bearing is one of the important components of bridges. Instead of using traditional bearings like PTFE-POT bearing LRB is found to be effective in high seismic region and it is used in many developed countries. However it is not started in our country because of its high cost. These devices are placed in between super-structure and sub-structure. EXCEL spreadsheet is widely used in design office for various design related activities .EXCEL spreadsheet is prepared considering design criteria prescribed by AASTHO ,so optimum size can be carried by doing different trials.

KEY WORDS*:* AASHTO, Seismic behavior, Lead Rubber Bearing (LRB)

1. INTRODUCTION

Bridges are the life line structures of any country. This structures having very importance as compared to other structures. Seismic isolation is a response modification technique that reduces the effects of earthquakes on bridges and other structures. Isolation physically uncouples a bridge superstructure from the horizontal components of earthquake ground motion, leading to a substantial reduction in the forces generated by an earthquake. Improved performance is therefore possible for little or no extra cost, and older, seismically deficient bridges may not need strengthening if treated in this manner. Uncoupling is achieved by interposing mechanical devices with very low horizontal stiffness between the superstructure and substructure. These devices are called seismic isolation bearings or simply isolators. Thus, when an isolated bridge is subjected to an earthquake, the deformation occurs in the isolators rather than the substructure elements. This greatly reduces the seismic forces and displacements transmitted from the superstructure to the substructures. More than 200 bridges have been designed or retrofitted in the United States using seismic isolation in the last 20 years, and more than a thousand bridges around world now use this cost-effective technique for seismic protection. Mainly three types of devices are used for isolation are laminated rubber bearing, friction pendulum bearings, lead rubber bearings. By inserting this type of device we can lengthen the natural period of the bridge. This device accommodates the forces which are coming on the structures.

2. COMPONENTS OF LRB



3. DESIGN PROCEDURE OF LRB:

The isolation design of a bridge with lead-rubber isolators primarily involves the determination of the properties of the isolators themselves. The following properties of the isolators need to be determined to complete the design so that the bearings can be ordered from the manufacturer:

- Lead core diameter
- Isolator diameter (or plan dimensions if square or rectangular)
- Thickness and number of the rubber layers, and
- Thickness and number of steel reinforcing plates (shims).

3.1 CALCULATE MINIMUM REQUIRED DIAMETER OF LEAD CORE.

$$d_{L\,\min} = \sqrt{\frac{4n\,\psi Q}{\pi(n-1)f_{yL}}} \quad \ldots\ldots(1)$$

n = 10 for dynamic (seismic) loads
= 8 for service loads
= 5 for slowly applied loads
Ψ = load factor accounting for creep in lead
= 1.0 for dynamic (seismic) loads
= 2.0 for service loads
= 3.0 for slowly applied loads
fyL = shear yield stress of the lead (1.3 ksi, 9.0 MPa)
Qd = characteristics strength

$$=F_y\left(1-\frac{k_d}{k_u}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where k_d = post elastic stiffness
k_u = elastic loading and unloading

3.2 SET TARGET VALUES FOR EFFFECTIVE PERIOD AND DAMPING RATIO

For the bridge under consideration the following target effective period and damping values are assumed:

Te = 1.00 sec, and

β_e = 0.30 (30% damping ratio)

3.3 CALCULATE LEAD CORE DIAMETER AND RUBBER STIFFNESS

Calculate the design displacement

Dd = 250ASiTe/B

where

A is the acceleration coefficient
Si is the site coefficient for seismic isolation
B is the damping coefficient corresponding to βe

Calculate the required effective stiffness of the bearings

$$k_e = \frac{W_s}{n_b g}\left(\frac{2\pi}{T_e}\right)^2 \quad \ldots\ldots(3)$$

where

Ws is the weight of the bridge superstructure

Calculate the initial required characteristic strength (seismic resistance), Qi, of the lead core.

$$Q_i = \frac{1}{2}\pi\beta_e k_e D_d \quad \ldots\ldots.(4)$$

Calculate diameter and check against minimum values required to resist service loads by eq(1)

3.4 CALCULATE ISOLATOR DIAMETER AND RUBBER THICKNESS

Calculate the bonded plan area, Ab, of the bearing (mm2) per AASHTO 1998, article 14.7.5.3.2-1

$$A_b = \frac{P}{f_c} \quad \text{............(5)}$$

Where p = total axial load

f_c= allowable compressive stress=11.0MPa

Calculate the total thickness, Tr, of the rubber

Total rubber thickness is given by

$$T_r = \frac{GA_b}{k_r} \quad \text{.............(6)}$$

3.5 CALCULATE THICKNESS OF RUBBER LAYERS

Calculate Ar at design displacement

$$A_r = \frac{d_b^2}{4}(\delta - \sin\delta) \quad \text{.......(7)}$$

Where

$$\delta = 2\cos^{-1}\left(\frac{D_d}{d_b}\right) \quad \text{..........(8)}$$

Dd= dia of lead core

db= dia of the isolator

Calculate the required shape factor S, to satisfy limits on compression strainγ_c

$$S = \frac{3P \pm \sqrt{9P^2 - 32(\gamma_c A_r G)^2 k'}}{8\gamma_c A_r G k'} \quad \text{if S < 15}$$

$$S = \frac{\gamma_c A_r K}{12P} \pm \sqrt{\left(\frac{\gamma_c A_r K}{12P}\right)^2 - \frac{K}{8Gk'}} \quad \text{if S > 15}$$

Also, from AASHTO 1998, equation 14.6.5.3.2.1

$$S \geq \frac{P}{1.66GA_b} \quad \text{...........(9)}$$

Where

$\gamma_c = 2.0$

K = 2000 MPa (bulk modulus)

K' = 0.73 (material constant)

G = 0.62 Mpa (shear modulus)

Calculate the thickness of rubber layers

The maximum layer thickness is given by:

$$t_i = \frac{d^2 - d_L^2}{4dS} \quad \text{..........(10)}$$

Where

d = dia of isolator

d_l= dia of lead core

S = shape factor

3.6 CHECK ISOLATOR STABILITY

Calculate the critical buckling load, Pcr, of the bearing in the undeformed state using equation.

$$P_{cr} = \sqrt{\frac{\pi^2 E_c IGA}{3T_r^2}} \quad \text{............(11)}$$

Calculate the factor of safety against buckling instability

FS= P_{cr}/P

Where

P is the total load due to dead and live load

Check if FS > 3 (12.3 AASTHO1990) if not reverse the dimensions

Calculate the critical buckling load, P'cr, of the circular bearing in the deformed state

Since A=0.3g > 0.19g, the critical load must be calculated at a displacement equal to 1.5 Dd in eq(8)

Check isolator condition in deformed state

Since A = 0.3g > 0.19g,

check if P'cr > 1.2PD + PSL, at 1.5Dd

3.7 CHECK STRAIN LIMITS IN RUBBER

Calculate the maximum shear strain due to the effect of vertical loads

$$\gamma_c = \frac{3SP}{2A_r G(1+2k'S^2)} \quad \text{........(12)}$$

Calculate the shear strain due to non seismic lateral displacement

The thermal expansion at Pier due to a thermal variation of 33oC is first calculated as

$$\Delta_s = \alpha \, \Delta T \, L \quad \text{........(13)}$$

The shear strain due to non-seismic lateral displacement is then calculated

$$\gamma_{s,s} = \frac{\Delta_s}{T_r} \quad \text{...............(14)}$$

Calculate the shear strain due to seismic lateral design displacement

$$\gamma_{s,eq} = \frac{D_d}{T_r} \quad \text{...............(15)}$$

Calculate the shear strain due to design rotation

$$\gamma_r = \frac{d_b^2 \theta}{2t_i T_r} \quad \text{................(16)}$$

Check strain limits per equations

1. $\gamma_c \leq 2.5$.................(17)
2. $\gamma_c + \gamma_{s,s} + \gamma_r \leq 5.0$........(18)
3. $\gamma_c + \gamma_{s,eq} + 0.5\gamma_r \leq 5.5$..(19)

3.8 CALCULATE REMAINING PROPERTIES

Characteristic strength (seismic resistance):

$$Q_L = \frac{n-1}{n\psi} f_{yL} \frac{\pi d_{L\min}^2}{4} \quad \text{......(20)}$$

Post-elastic stiffness

$$k_d = \frac{f.GA_b}{T_r} \quad \text{.............(21)}$$

4. INPUT

The following material properties are assumed:

Effective yield stress of lead, fyL = 11.4 MPa

Factor to account for effect of lead on post elastic stiffness of bearing, f = 1.1

Shear modulus of rubber, Gr = 0.62 MPa

Bulk modulus of rubber, K = 2000 MPa

Material constant for rubber, k' = 0.73

Maximum loads and rotations:

At Pier 1 (most critical pier)

PD: Dead load = 300 Kn

PL: Live load = 217 kN

P: Total load = 517 kN

Rotation = 0.00233

At Abutment (most critical abutment)

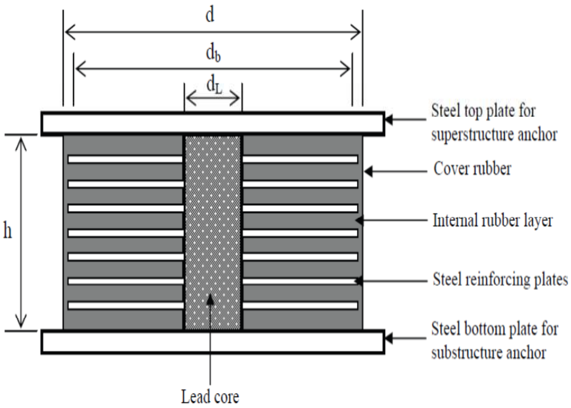
PD: Dead load = 66 kN

PL: Live load = 157 kN

PL: Live load = 223 kN

Rotation = 0.00274

5. RESULT



Summary of properties of pier isolators:

Overall diameter, d(mm)	350
Bonded diameter, db(mm)	340
Total height, h(mm)	175
Total rubber thickness, Tr(mm)	150
Thickness of rubber layers, ti(mm)	6
Number of rubber layers, Nr(nos)	24
Thickness of top and bottom rubber layer ,tc(mm)	3
Thickness of steel plates (shims), hs(mm)	1
Number of steel plates (shims), Ns(nos)	25
Characteristic strength Q(kN)	39.64
Post-elastic stiffness, kd(kN/mm)	0.395

Summary of properties of abutment isolators:

Overall diameter, d(mm)	250
Bonded diameter, db(mm)	240
Total height, h(mm)	112
Total rubber thickness, Tr(mm)	96
Thickness of rubber layers, ti(mm)	6
Number of rubber layers, Nr(nos)	15
Thickness of top and bottom rubber layer ,tc(mm)	3
Thickness of steel plates (shims), hs(mm)	1
Number of steel plates (shims), Ns(nos)	16
Characteristic strength Q(kN)	20.22
Post-elastic stiffness, kd(kN/mm)	0.308

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