Equivalent Damping Formulation for LRBs to be Used in Simplified Anaysis of Isolated Structures

by

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Objective

- To propose an advanced methodology for equivalent damping ratio of LRBs, in which the deterioration in strength of bearing due to lead core heating effect is taken into consideration.

Outline

Modeling of lead coreheating effect,

Properties of employed LRBs,

Description of theanalyzed superstructure,

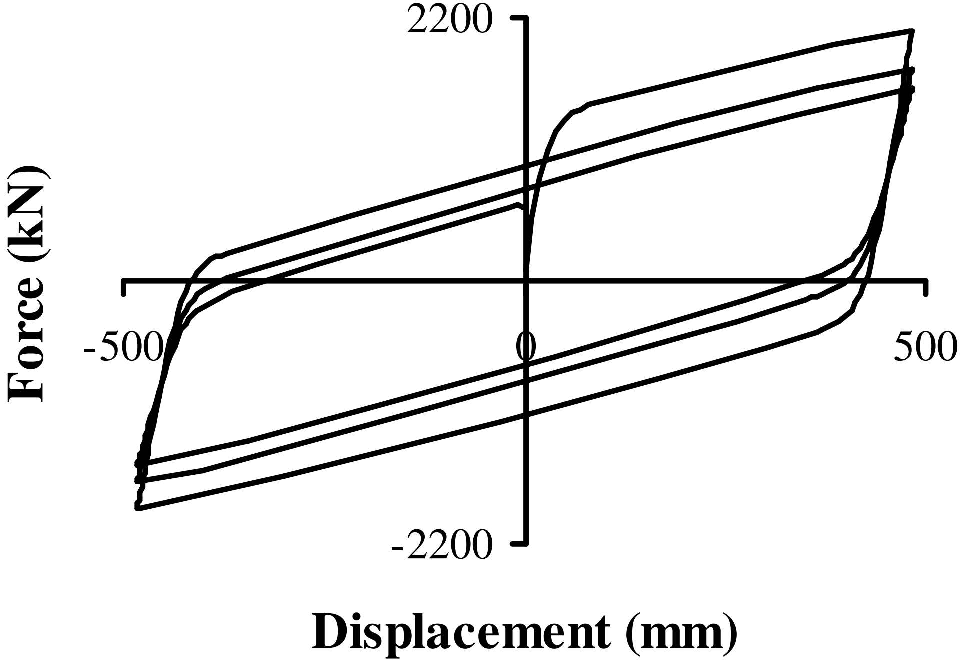
Selection and scaling of ground motions,

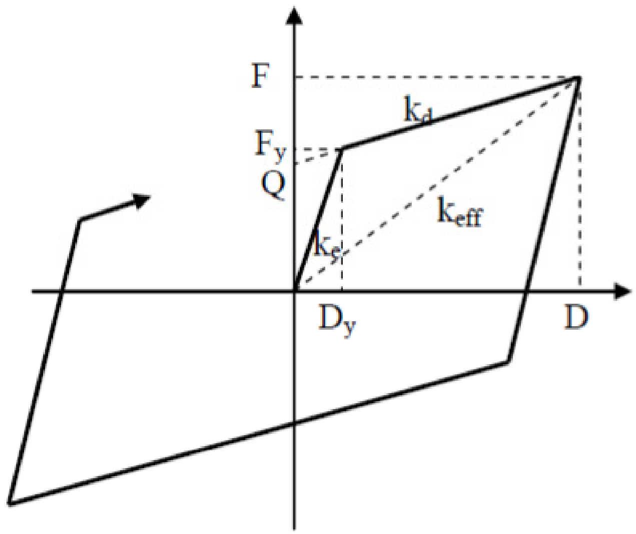
Evaluation of existing simplified methods in literature,

Relation between dissipated energies of deterioratng and non-deteriorating idealizations,

Proposed formulation for equivalent damping ratioand its

Deteriorating Hysteretic Behavior of LRBs due to lead core heating





Q: characteristic strengt

k_e: initial stiffness

k_d : post-yield stiffness

k_{eff}: effective stiffness

F_y: yield strength of idealized behavior

D_y: yield displacement

Modeling of Lead Core Heating Eff

$$\dot{T}_L = \frac{\sigma_{YL}(T_L)\cdot\sqrt{Z_x^2+Z_y^2}\sqrt{\dot{U}_x^2+\dot{U}_y^2}}{\rho_L\cdot c_L\cdot h_L} - \frac{k_s\cdot T_L}{r\cdot\rho_L\cdot c_L\cdot h_L}\cdot\left(\frac{1}{F}+1.274\cdot\left(\frac{t_s}{r}\right)\cdot\left(t^+\right)^{-1/3}\right)$$

$$F = \begin{cases} 2\cdot\left(\frac{t^+}{\pi}\right)^{1/2} - \frac{t^+}{\pi}\cdot\left[2-\left(\frac{t^+}{4}\right)-\left(\frac{t^+}{4}\right)^2-\frac{15}{4}\cdot\left(\frac{t^+}{4}\right)^3\right], & t^+ < 0.6 \\ \frac{8}{3\cdot\pi} - \frac{1}{2\cdot\left(\pi\cdot t^+\right)^{1/2}}\cdot\left[1-\frac{1}{3\cdot\left(4\cdot t^+\right)}+\frac{1}{6\cdot\left(4\cdot t^+\right)^2}-\frac{1}{12\cdot\left(4\cdot t^+\right)^3}\right], & t^+ \geq 0.6 \end{cases}$$

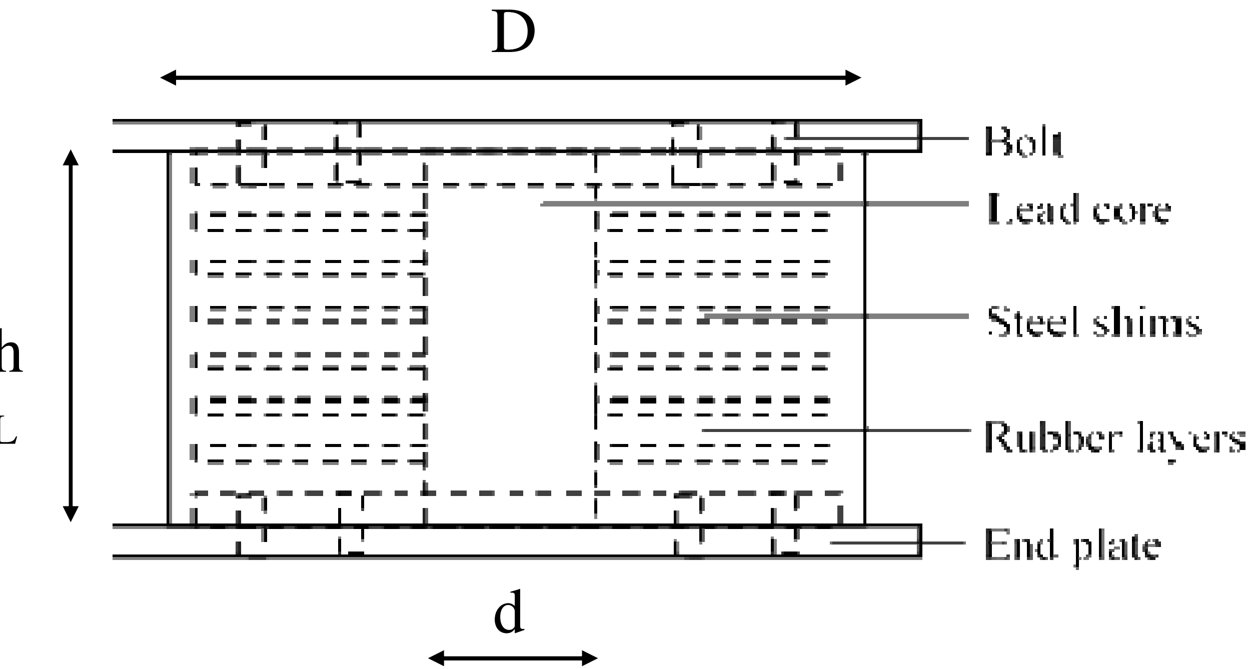
$$Q = \sigma_{lead}\left(T_L\right)\cdot A_{lea}$$

$$t^+ = \frac{\alpha_s\cdot t}{r^2}$$

$$\sigma_{YL}\left(T_L\right) = \sigma_{YL0}\cdot exp\left(-E_2\cdot T_L\right)$$

proposed by Kalpakidis and Constantinou (2009)

Properties of the employed LRB



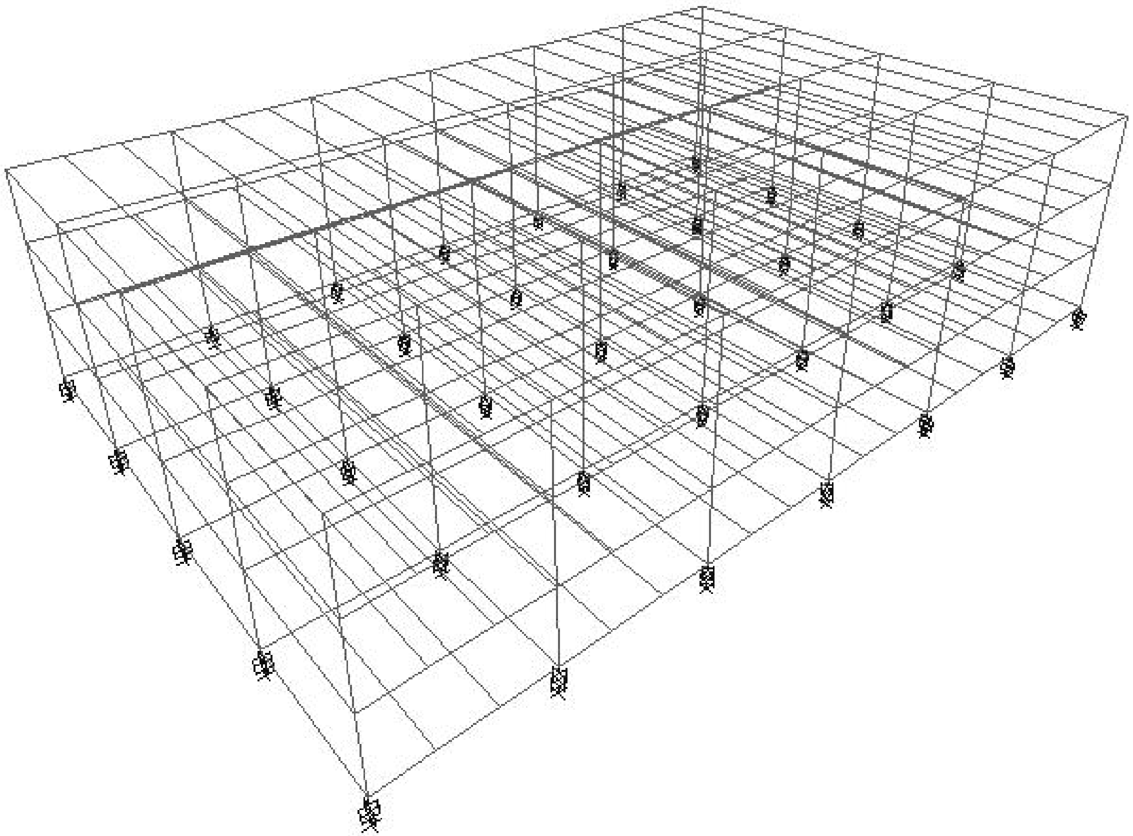
Isolation periods (bas
on post-yield stiffness)

- 2.25s , 2.50s , 2.75s , 3.00s
- Achieved by changing the rubber height h_L

Q/W ratios

- 0.075, 0.090, 0.105, 0.120
- Achieved by changing the lead core diameter d

Description of the analyzed structu



Number of story = 3

Total height = 9m

(3x 3m)

Total weight = 73000kN

Plan dimensions =

36m x 54 m

Number of isolator = 35

Selection of ground motions

40 near-field ground motion records with the following properties were taken from Gunay and Sucuoglu (2009):

- Magnitude, M_w is in between 6.2 and 7.6
- Closest distance to fault rupture, R is less than 20km
- Average shear wave velocity at the upper most 30m, V_{s30} is in between 180/s and 360m/s.

Scaling of ground motions

$$\varepsilon = \sum_{i=1}^{n} b_i \left(a \cdot y_i - y_{Ti}\right)^2$$

$$a = \frac{\sum_{i=1}^{n} b_i \cdot y_i \cdot y_{Ti}}{\sum_{i=1}^{n} b_i \cdot y_i^2}$$

where ε is the error term

b_i is the weighting factor

a is the scaling factor

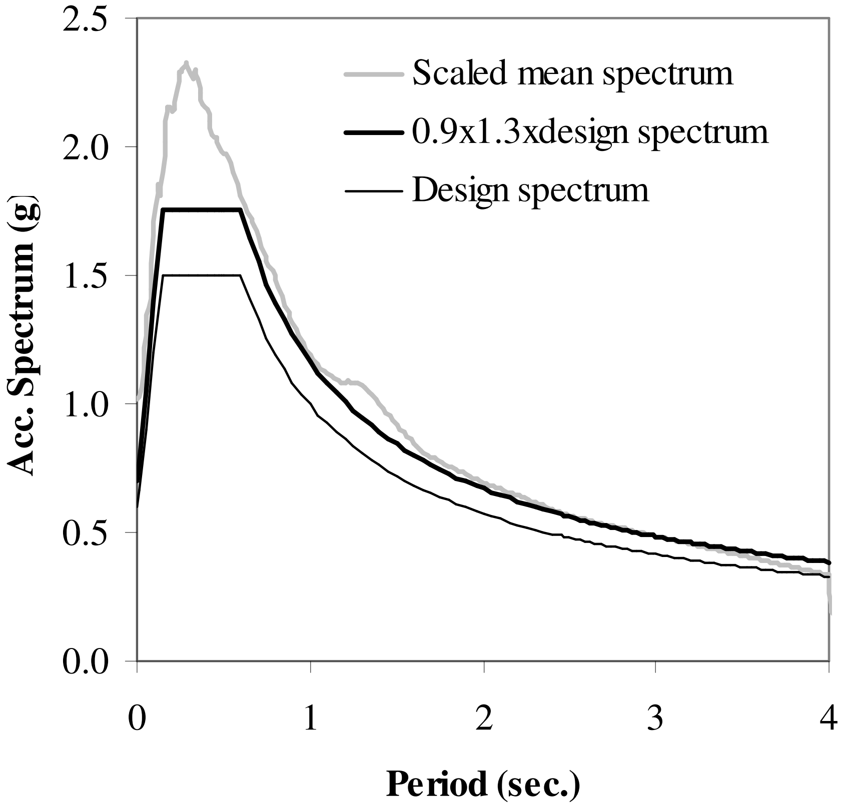
y_i is the spectral ordinate at period T_i

y_{Ti} is the target spectral ordinate period T_i

n is the number of target spectr

values considered.

Scaling of ground motions



The minimum, maximum, and average values of the scale factors used in this study are, 0.8, 4.3, and 2.6, respectively.

Existing Simplified Models in Literature

- Hwang and Sheng (1993)

$$k_{eff} = \left[1 + \ln\left[1 + 0.13(\mu - 1)^{1.137}\right]\right]^{-2} \cdot k_e$$

$$\xi_{eq} = 0.0587(\mu - 1)^{0.371}$$

- Hwang et al. (1995)

$$k_{eff} = \frac{1 + \alpha(\mu - 1)}{\mu}\left[1 - 0.737\frac{\mu - 1}{\mu^2}\right]^{-2} \cdot k_e$$

$$\xi_{eq} = \frac{2(1 - \alpha)\left(1 - \frac{1}{\mu}\right)}{\pi[1 + \alpha(\mu - 1)]} \cdot \frac{\mu^{0.58}}{6 - 10\alpha}$$

- Jara and Casas (2006)

$$\xi_{eq} = 0.05 + 0.05\ln(\mu)$$

- Jara et al. (2012)

$$\xi_{eq} = 0.05 + \eta\ln(\mu)$$

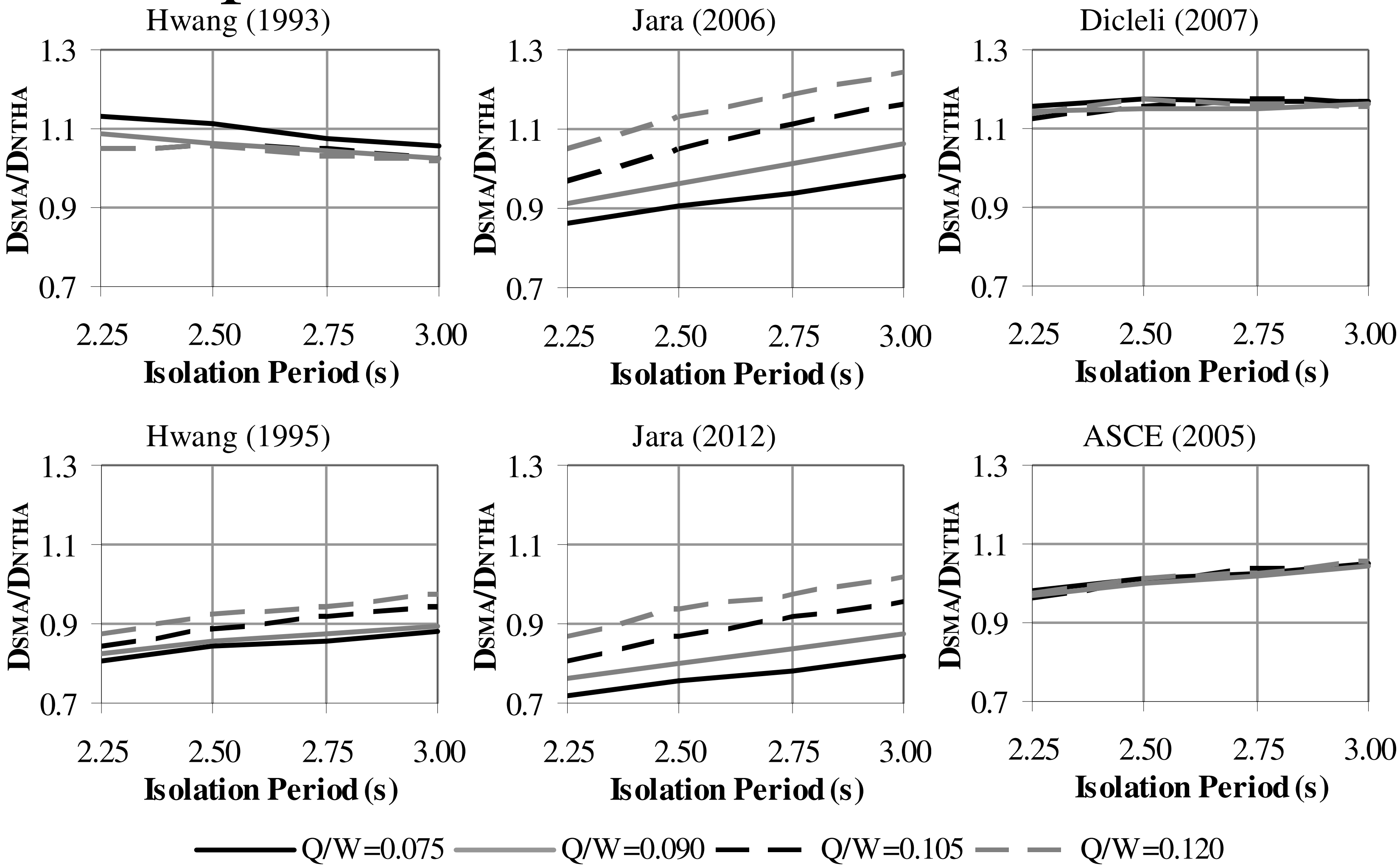
- Dicleli and Buddaram (2007)

$$\xi_{eq} = \frac{4Q(U - U_y)}{2\pi k_{eff} U^2}\sqrt{0.41\left(\frac{T_{eff}}{T_e} - 1\right)}$$

- ASCE (2005)

$$\xi_{eq} = \frac{4Q(U - U_y)}{2\pi k_{eff} U^2} \quad where \quad k_{eff} = \frac{F}{U} = \frac{Q}{U} + k_d$$

Evaluation of Existing Simplified Models



$$\xi_{eq} = \frac{4Q(U - U_y)}{2\pi k_{eff} U^2} \sqrt{0.41\left(\frac{T_{eff}}{T_e}\right.}$$

Relation Between Dissipated Energies

$$\left(\frac{Total\ dissipated\ energy\ under\ all\ excitation\ cycles\ obtained\ from\ deteriorating\ idealization}{Total\ dissipated\ energy\ under\ all\ excitation\ cycles\ obtained\ from\ non-deteriorating\ idealization}\right)_{a}$$

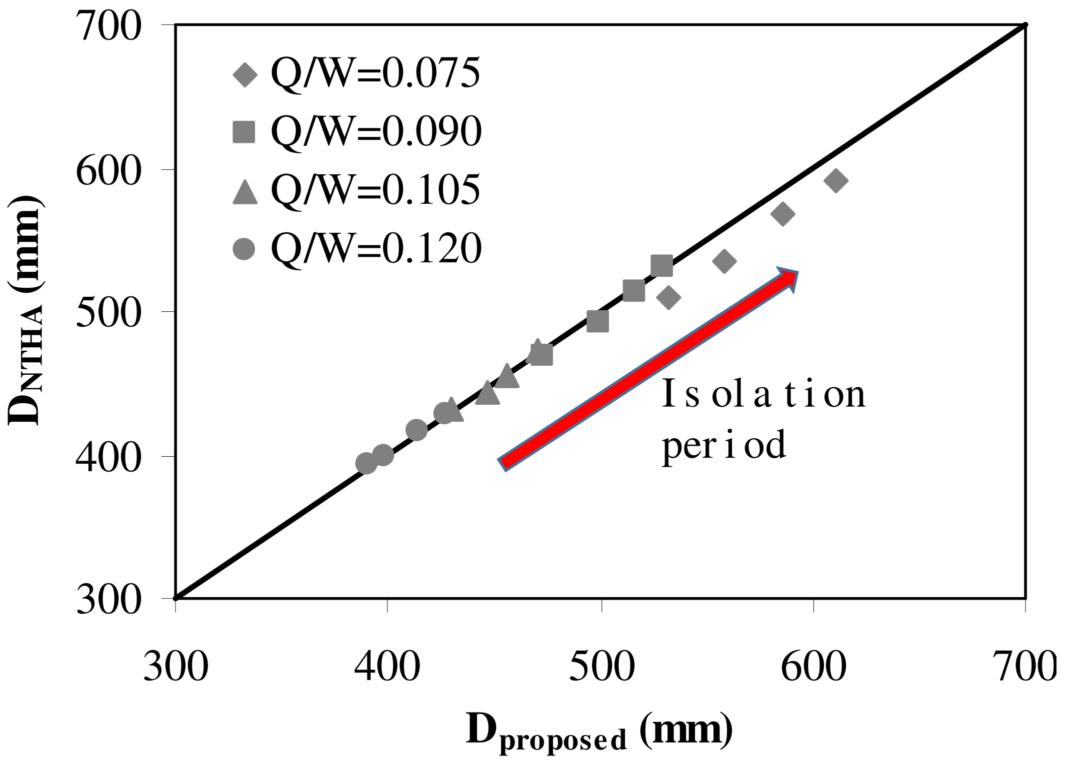
Q/W ratio	**Isolation Period, T_d (sec)**			
	2.25	**2.50**	**2.75**	**3.00**
0.075	1.02	1.03	1.03	1.04
0.090	1.03	1.03	1.03	1.04
0.105	1.02	1.03	1.02	1.03
0.120	1.02	1.02	1.03	1.03

→ $E_r = 1.03$

Proposed Formulation

$$\xi_{eq} = \frac{4Q(U - U_y)}{2\pi k_{eff} U^2} \sqrt{0.41\left(\frac{T_{eff}}{T_e} - 1\right)}$$

$$\xi_{eq} = E_r \cdot \frac{4Q(D - D_y)}{2\pi k_{eff} D^2} \sqrt{\varphi \cdot \left(\frac{T_{eff}}{T_e} - 1\right)}$$



where $\varphi = 0.7$

Conclusions

- A new formulation is introduced to calculate equivalent damping ratio of LRBs subjected to cyclic motion.
- Accuracy of the proposed formulation in estimating the maximum isolator displacement is high and independent of the isolator characteristics.