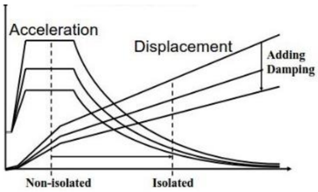
Association with response spectrum:

1. 消能元件:利用結構或裝置的良好塑性行為形成飽滿的遲滯曲線,進而消散外界輸入之能量.
2. 隔震系統:提供一個柔性並具消能能力之隔震系統,使其在地震力下,上部結構呈剛體運動,使其損壞率下降.其原理為延長結構週期,以減少地震力輸入.
3. 低矮的建築較適合用隔震來減低上部結構的需求,較高的結構因其本身周期較長故不適合.



Damping reduction factor:

1. $B_d = \dfrac{S_d}{S_{d,\xi=0.05}}$
2. Use B factor to consider the damping effect on base shear.
3. Current code allow to use B_{min} =0.75.
4. Along period increase, the effect that adding damping to reduce disp. and vel. will not very significant. Acceleration is contrary.
5. 用同樣的 B 值，在不考慮週期的情況下是不保守的

Displacement type damper:

(1)Bending type: TADAS triangle plate 設計參數: 抗彎構架側向勁度,高度寬厚比,SHR_a, SHR_d (Out of plane bending)

(2)Shear type: Low yield steel shear panel / SLEA :energy dissipate through in-plane shear deformation that cause yielding ins shear

(3)Axial type: BRB 設計參數:抗彎構架側向勁度 (4)friction type

Add stiffness, after yielding add damping. Disp. and vel. will reduce but accel. may not.

Velocity type damper:

VE:剪力變形消能.設計參數:結構頻率,環境溫度,剪應變,材料溫度

VD:阻尼動能轉換熱能. 設計參數:結構頻率,阻尼冪次,阻尼元件阻尼比

VE damper:

Feature:

1. 小變形時,比起震幅大小.環境溫度跟振動頻率對 VE 有更大的影響
2. 相同剪應變下,環境溫度的上升會減低 VE damper 的勁度.
3. 相同環境溫度下，剪應變的上升會減低 VE damper 的勁度.
4. 隨著震動的次數跟幅度增加,會提高 VE damper 的溫度而減低 VE damper 的勁度.但這影響會隨著震動的次數增加而下降.
5. Shear deformation in VE material.
6. Dissipate energy though heat.
7. Adding damping and stiffness.
8. Additional damping provide as soon as structure vibrate.

Material property:

$$K_d = nG'A/t \quad \boxed{K_v = K_d \cos^2\theta}$$

$$\eta_v = 2\pi f_1 (C_d / K_d)$$

$$\xi_r = \frac{\eta_v}{2}\left(1 - \frac{(\phi^r)^T [K_E](\phi^r)}{(\phi^r)^T [K_S](\phi^r)}\right) \rightarrow \xi_r = \frac{\eta_v}{2}\left(1 - \frac{\omega_r^2}{\omega_{sr}^2}\right)$$

Calculate equivalent damping ratio:

1. Modal strain energy method: predict ξ
2. Damping coefficient method: get C_{eq}

$$\xi_r = \frac{W_D}{4\pi W_s} = \frac{T_r \sum C_{eq,j} f_j^2 (\phi_{rj})_r^2}{4\pi \sum_i m_i \phi_{rj}^2}$$

3. Half-power method:

$$\xi = \frac{f_2 - f_1}{f_2 + f} \qquad f_1 \,\&\, f_2 \text{為} \frac{1}{\sqrt{2}} \text{倍之最大振福時之頻率}$$

VE damper design procedure:

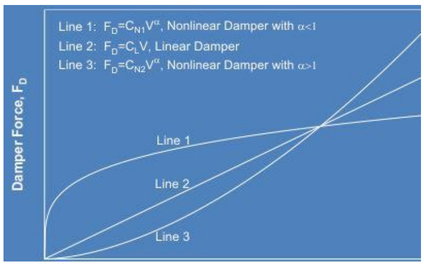
1. Seek ξ first.
2. Use modal strain energy method to get ω_{sr}
3. Trial and error

VD damper: $F_D = CV^\alpha$

Feature:

1. 和速度同向,位移反向(差 90 度)
2. 在特定頻率(f<4Hz)內沒有儲存勁度
3. Not very significant affected by temperature.
4. 速度較小時,非線性阻尼器可以提供較大之阻尼力. 但速度較大時增加的力量就有限.一般用非線性阻尼器較經濟.
5. 不具有儲存勁度,不影響結構週期,設計起來較為方便

Material property:



Linear: For each damper is same.

$$C = \frac{\xi_{eff}\, 4\pi \sum_i m_i \phi_i^2}{T \sum_j \phi_{rj}^2 f_j^2}$$

Nonlinear:

$$C = \frac{\xi_d\, 2\pi A^{1-\alpha} \omega^{2-\alpha} \sum_i m_i \phi_i^2}{\lambda \cos^{1+\alpha}\theta \sum_j \phi_{rj}^{1+\alpha}} \qquad A = \frac{h \times drift}{\phi_{max}} \qquad F_D = C(u_0\omega)^\alpha$$

VE damper design procedure:

1. Seek ϕ 、ω 、ξ_d (for nonlinear also need A)
2. Use formula to decide C value.
3. Assign in model

TMD Damper

機制: 能量由主結構傳遞至調諧質量再藉由其他 damper 進行消散

Seismic isolation:

Basic requirements:

1. 足以承受垂直向載重(勁度及強度)
2. 在大地震下,有足夠的柔度可以延長結構物側向勁度

3. 可以承受額外阻尼來降低位移需求

4. 隔震層要有一定的勁度以抵抗風力

5. 隔震層要有能力復位 (足夠的回復勁度)

6. 可以提供第二防禦措施、防火保護、檢測與更換

7. $H/B \le 4$(flexural 效應造成隔震層被拉拔破壞，高樓層不適合隔震)

Feature:

1. The effect of substructure is really important in particular when substructure possesses a smaller stiffness and a larger mass.
2. The design of substructure and superstructure with higher vibration frequencies exhibits a better seismic performance.
3. The participation of the modal responses of the higher modes should be taken into account for the design of substructure.
4. The responses at isolation layer and superstructure are significantly enlarged within the certain frequency ratio bandwidth due to the modal coupling effect.
5. Nonlinear response history analyses are needed for mid-story

Isolation designs. Type:

NRB:

The bearing consists of two thick plates on the top and bottom to connect the bearing and the structure. Rubber layers with low shear modulus provide lateral flexibility. Shim steel plates are used between the rubber layers to prevent from lateral bulge and increase vertical stiffness and load capacity. In general, the lateral surface of bearing is covered by a thin layer of rubber to protect from UV light and Oxidation.

Advantage: easy and economical to make.

Disadvantage: low damping, need to provide extra damping.

LRB: (invented by Bill Robinson in New Zealand in 1970)

Similar to the NRB except the addition of lead plugs at the center core. The shim plates & rubber layers confine the lead plug to develop stable shear hysteresis behavior under lateral deformation that provide additional damping.

HDRB: (invented in England in 1982)

HDRB added materials such as fine carbon powder, oil, resin and other additives to increase damping of rubber. HRB provides high damping and stiffness at large shear strain. Even under low strain conditions, HRB also provide significant and lateral stiffness and may filter out vibration noises resulted from traffic.

FPS:

Combines sliding and re-centering mechanism, composes of a articulated slider on a stainless steel ball surface. The contact between the slider and ball surface is coated with low friction, low wear & auto lubricates composite material.

Roller-Type Bearing

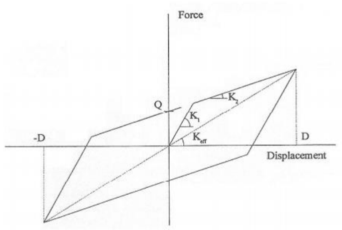
Formula:

Rubber bearing: $K_H = \dfrac{GA}{t_r}$ $\gamma = \dfrac{D}{t_r}$ $K_v = \dfrac{E_c A}{t_r}$

$S =$ load area/free area $E_c = 4GS^2$ (unfilled hole)

t_r: Total rubber thickness.

LRB Model:



Modeled as a bi-lnear element with three parameters：K_1、K_2、Q.

K_1 is elastic stiffness, normally difficult to measure, usually use K_2 times a empirical value.

Q is the characteristic strength.

Left figures show:
$K_{eff}\,D = K_2\,D + Q$

Effective Stiffness $K_{eff}=K_2 + Q/D$， where$D \geqq D_y$， D_y: yield displacement.

Effective Frequency $\omega = \sqrt{\dfrac{K_{eff}g}{W}} = \sqrt{\omega_o^2 + \gamma\dfrac{g}{D}}$ ， $\gamma = Q/W$， $\omega_o^2 = \dfrac{K_2 g}{W}$。

Effective Period $T = 2\pi/\omega = 2\pi/\sqrt{\omega_o^2 + \gamma\dfrac{g_o}{D}}$

Equivalent Damping Ratio，for$D \ge D_y$ ，

$$\beta_{eff} = \frac{area\ \ of\ \ hysteresis\ \ loop}{2\pi K_{eff} D^2} = \frac{4Q(D-D_y)}{2\pi(K_2 D+Q)D}$$ ，where，$D_y = \dfrac{F_y}{K_1}$ ，

$F_y = Q + K_2 D_y$: yield strength of LRB. $D_y = \dfrac{Q}{K_1 - K_2}$

In general，$K_1 \fallingdotseq 10\times K_2$，therefore, $D_y=Q/9K_2$, and

$$\beta_{eff} = \frac{4Q(D-Q/9K_2)}{2\pi(K_2 D+Q)D}$$

Isolation design procedure: Disp. based design

Iteration general procedure(D_D 、D_M 、T_{eD} 、T_{eM})

1. Determine design disp. $D_D = (g/4\pi^2) S_{aD} T_{eD}^2 / B$
2. Determine design force ($V_S = K_{eD} D_D / \alpha_y$ 、$V_b = 1.25 V_s$)

   Try bearing properties (use vender's information)
3. Design the structure
4. Analysis and check drift, bearing pressure, bearing deformation.

LRB detail:

分析得 $\boxed{D_{TD} = D_D(1 + y\dfrac{12e}{b^2 + d^2})}$ $K_{eff} = \dfrac{4\pi^2 W}{T_e^2 g}$ 、$Q_d = \dfrac{\pi \xi_b K_{eff} D_D}{2}$ 、

$K_d = \dfrac{K_{eff} D_D - Q_d}{D_D}$ 、$K_u = K_d / 0.1$、

$F_y = Q_d / (1 - 0.1)$ 、$D_y = F_y / K_u$ 、ξ_{eq} $D_{TM} < 1.5 D_{TD}$

	Isolation	Superstructure	Non-structural
DBE	發揮功能無損壞	保持彈性	無損壞，正常運轉
MCE	發揮功能保持穩定	允許降伏韌性設計	無嚴重損壞可運轉

制震系統在 MCE 下，消能系統須發揮功能保持穩定而原結構可容許降伏但不得高於規定 R 值，非結構部分則無嚴重毀損且可運轉