# Damage Modeling of Reinforced Concrete Bridges

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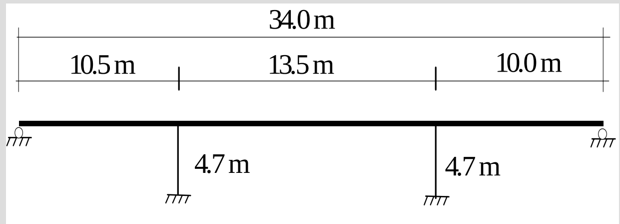
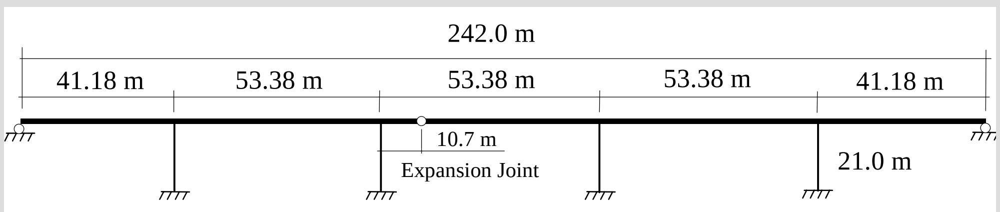
# Bridge Models

## Column Section

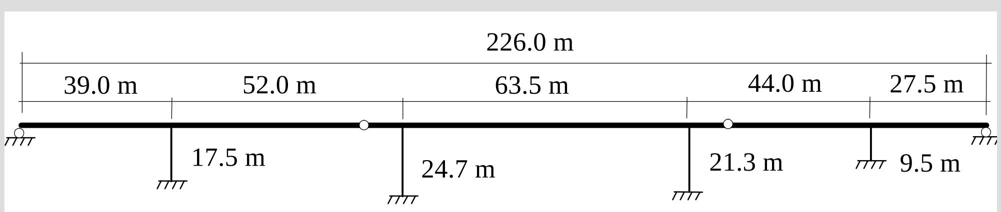
Bridge 1

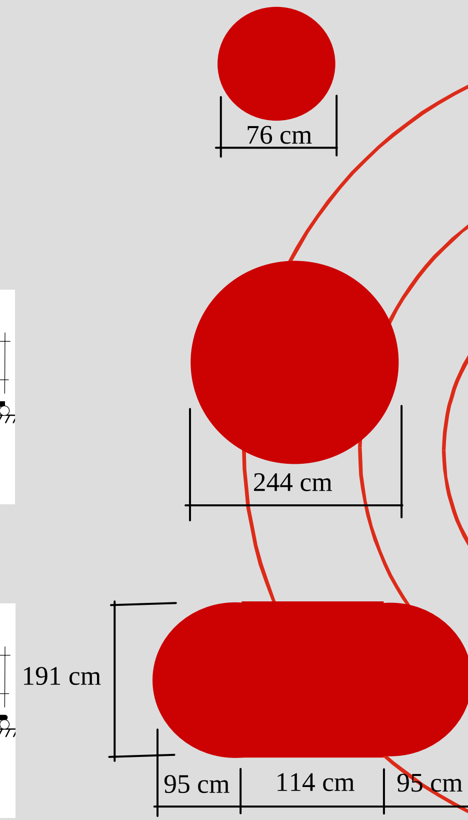



Bridge 2




Bridge 3

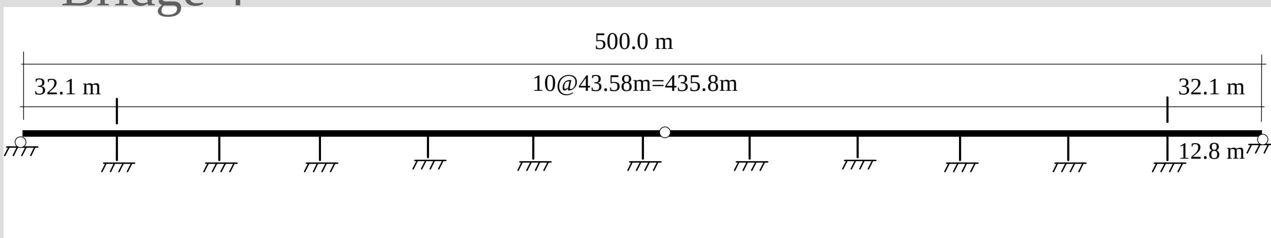


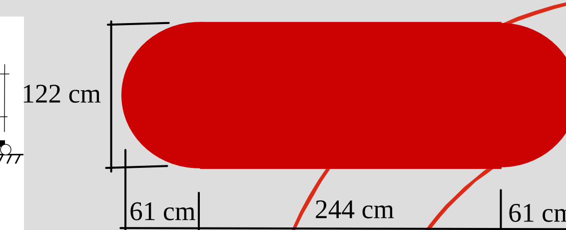



# Bridge Models (Contd..)

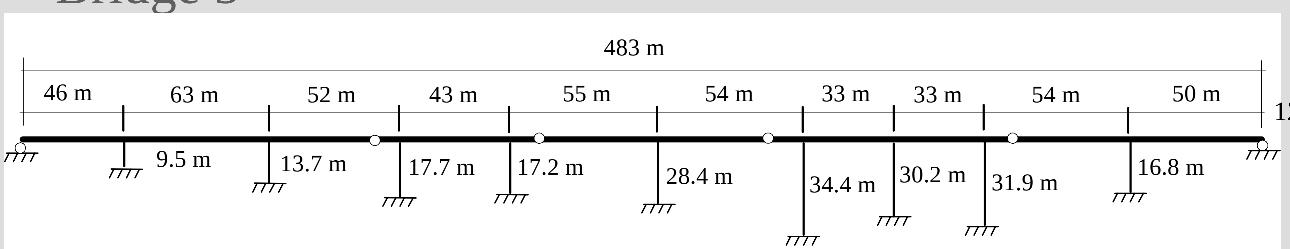
## Column Section

## Bridge 4



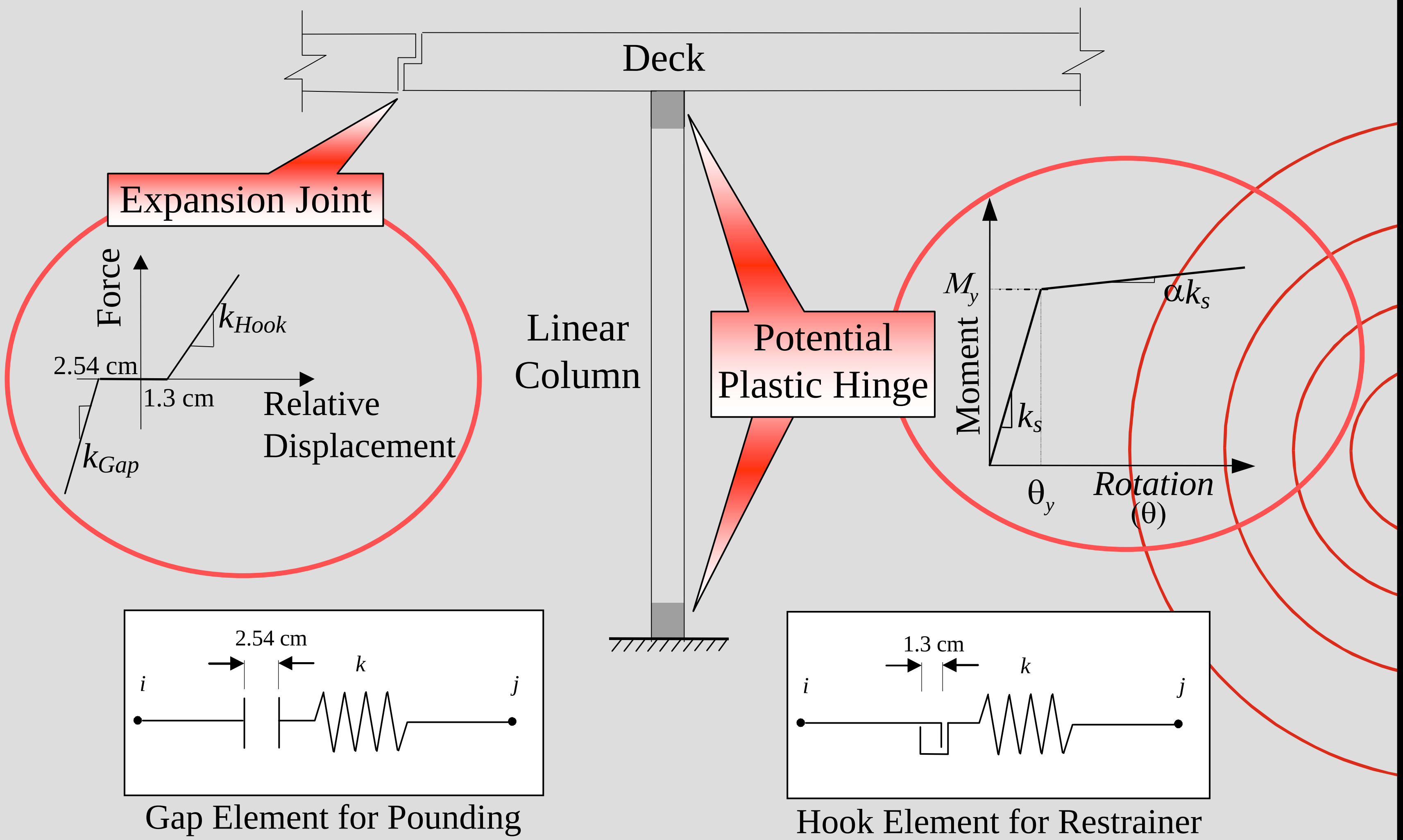

## Bridge 5



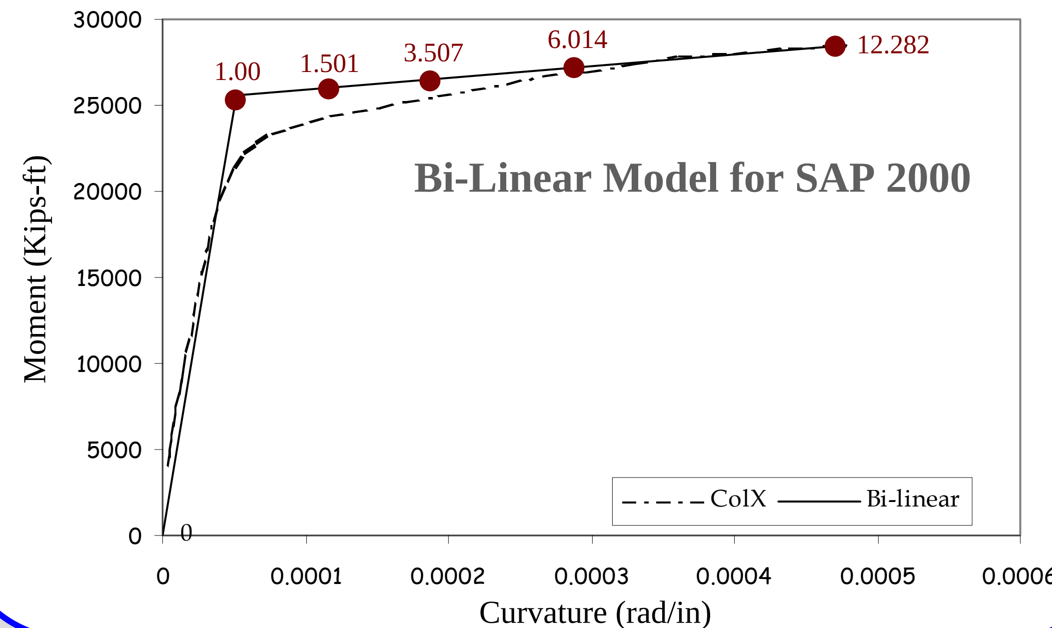

# Most Probable Bridge Failure Mechanisms

1. Formation of plastic hinge at column ends
2. Pounding between two adjacent decks at expansion joints and abutments
3. Restrainer failure at abutments and at expansion joints
4. Premature shear failure in columns
5. Liquefaction of surrounding soil

# Nonlinear Properties of the Model



# Damage States: Moment-Curvature Curve




Bridge 2

| *Damage state* | *Description* | *Drift Limits** | *Ductility Demand* |
|---|---|---|---|
| **Almost No** | **First Yield** | **0.005** | **1.00** |
| **Slight** | **Cracking, Spalling** | **0.007** | **1.501** |
| **Moderate** | **Loss of Anchorage** | **0.015** | **3.507** |
| **Extensive** | **Incipient Column Collapse** | **0.025** | **6.014** |
| **Collapse** | **Complete Column Collapse** | **0.05** | **12.282** |

* By Dutta and Mander (1998)

Ductility Capacity $= \theta / \theta_y$

# Time History Analysis of a Sample Bridge

**Bridge**

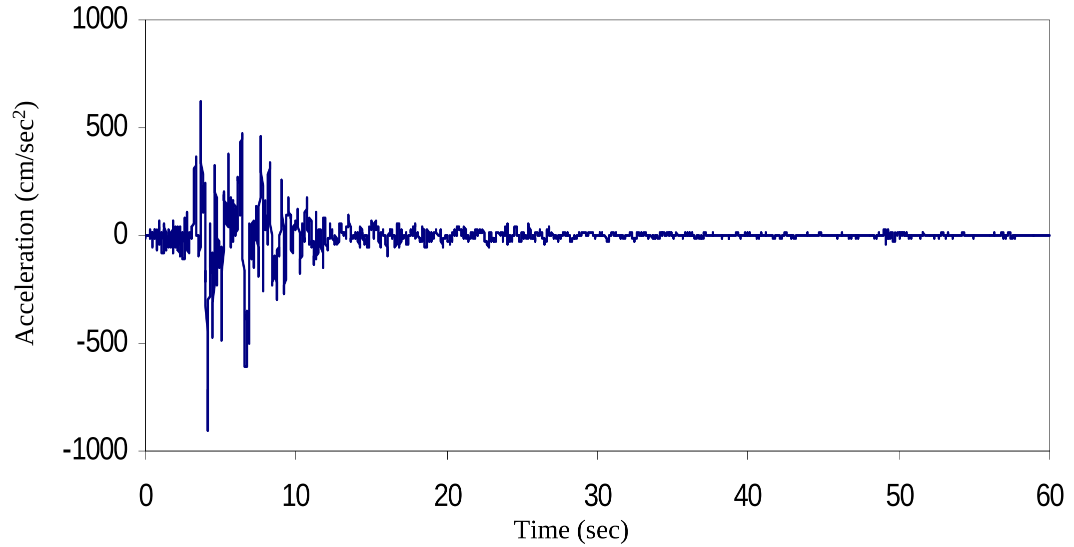
**Bridge 2**

**Ground Motion**

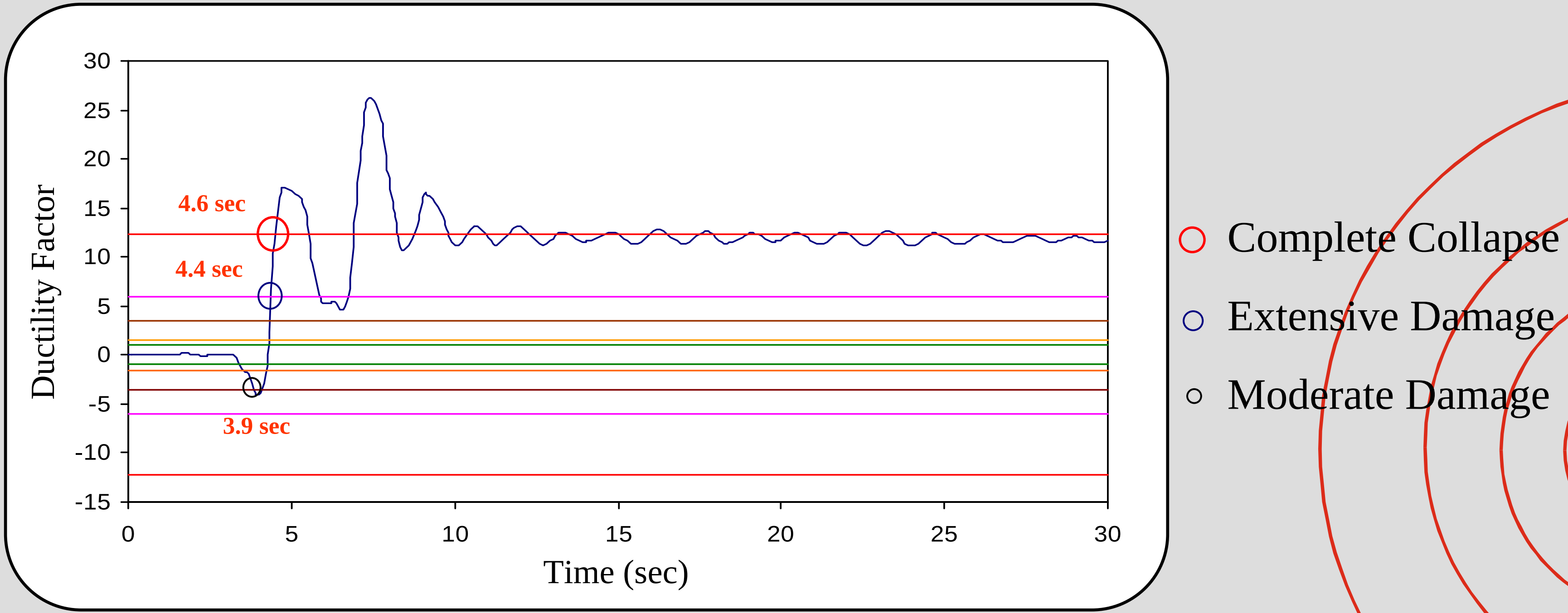
**1994 Northridge Earthquake (LA 27)**

✓Probability of Exceedence of 2% in 50 Years

✓PGA : 908.70 $cm/sec^2$

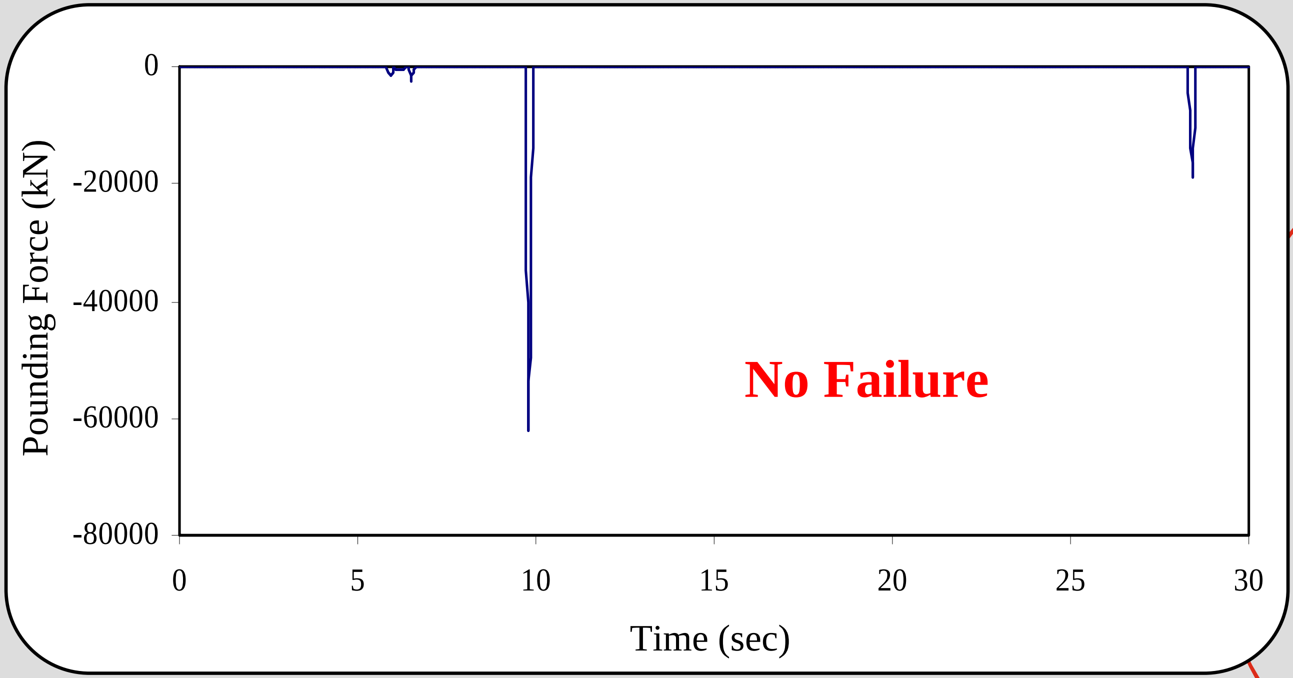


# Formation of Plastic Hinge at Column Ends



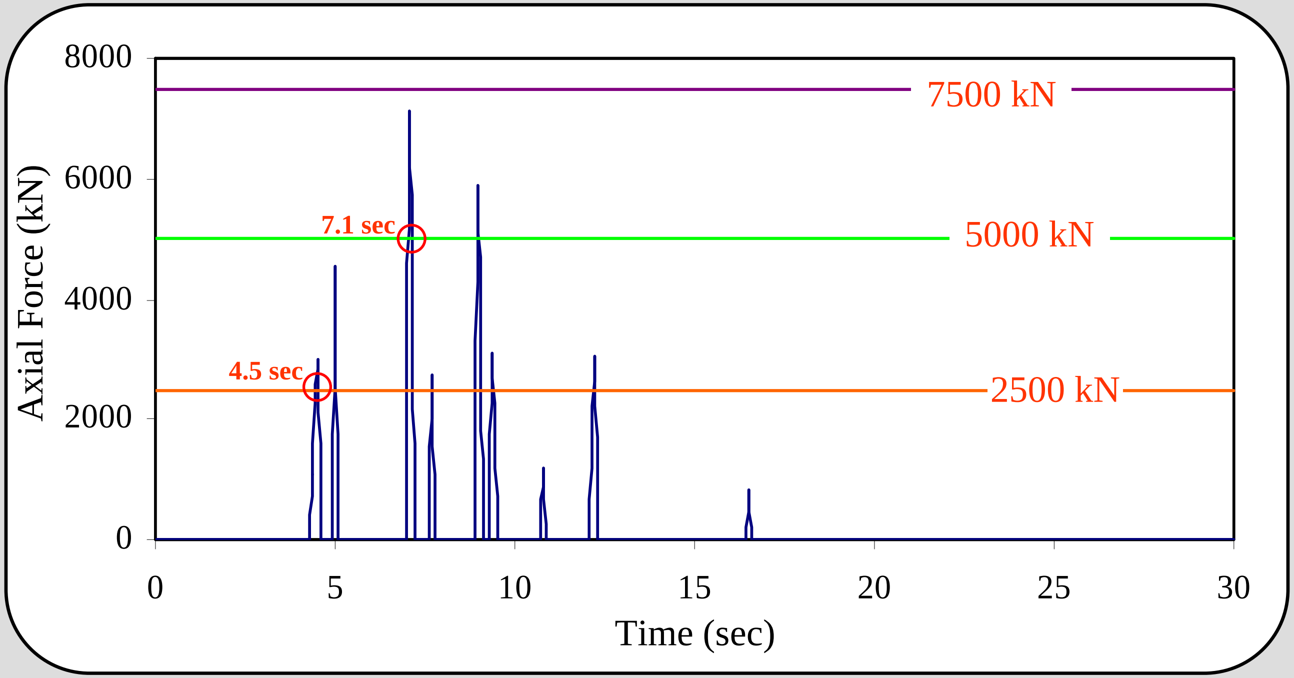

**Plastic Hinge forms at Column End**

# Pounding Between Two Adjacent Decks




**Pounding Force**
**(Capacity 2,43,690 kN)**

# Restrainer Failure at Expansion Joints

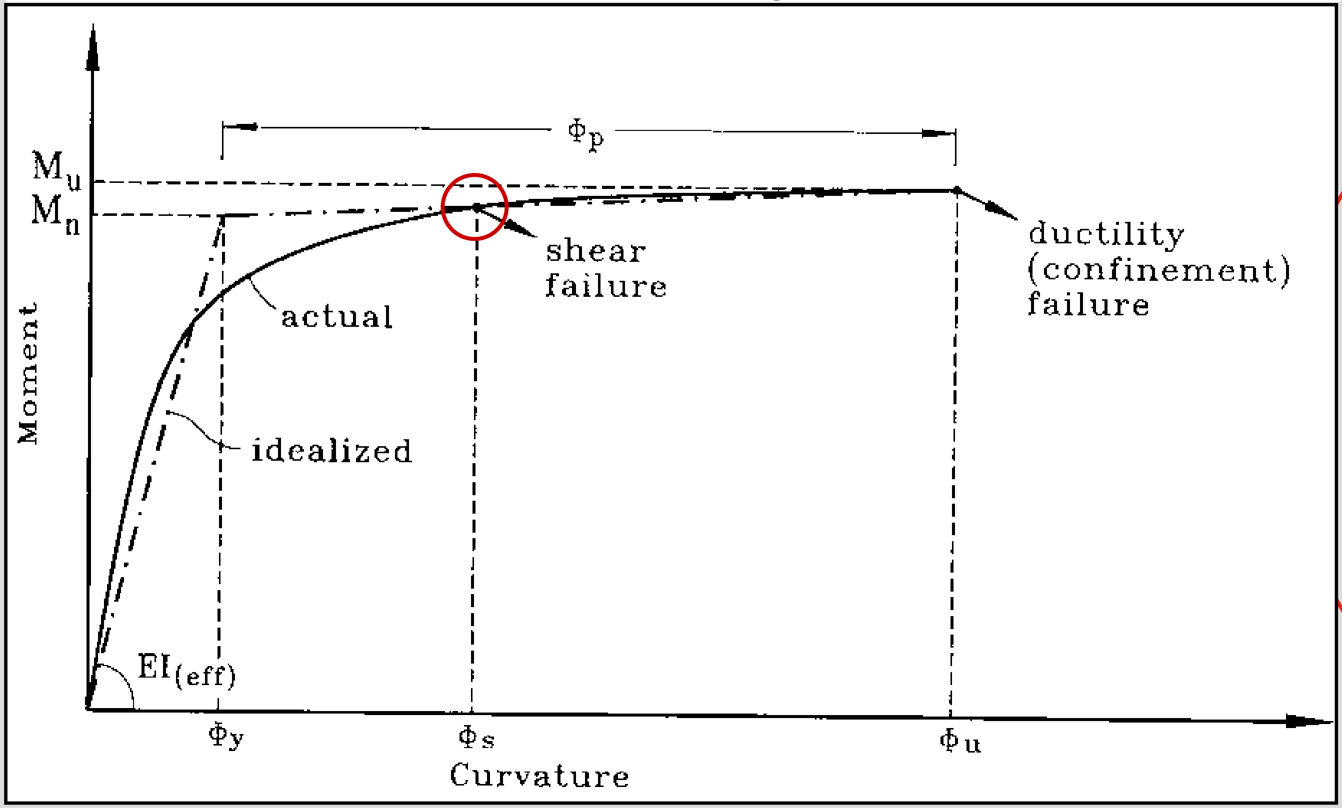



○ Complete Collapse

**Axial Force in Restrainer**

# Shear Failure Mode

**Premature shear failure may lead to collapse by preventing rotational ductility capacities at the ends of columns from fully utilized**




Ref. '*Seismic Design and Retrofit of Bridges*' by Priestley et al., 1996, John Wiley & Sons, Inc.

# Shear Strength of Column

$$V_n = V_c + V_s + V_p$$

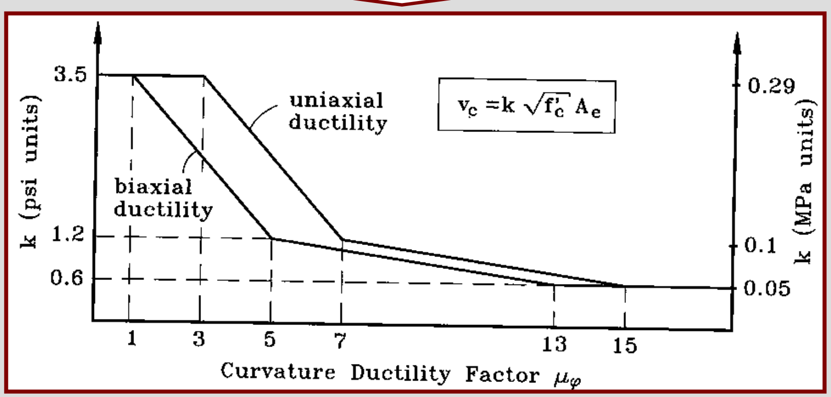
where, $V_c$ = Nominal shear strength of concrete

$V_s$ = Shear resistance of transverse reinforcements

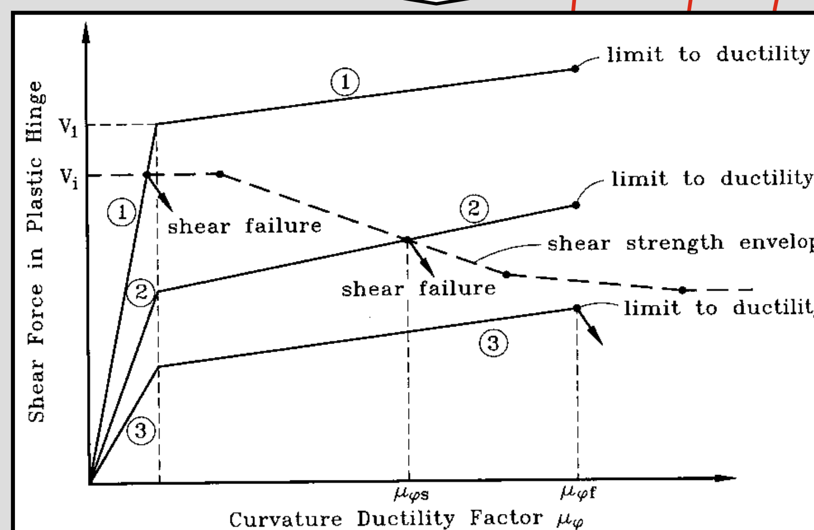
$V_p$ = Shear strength from diagonal compression strut

$V_c \propto k$

$k$ in terms of the curvature ductility factor, $\mu_\phi$

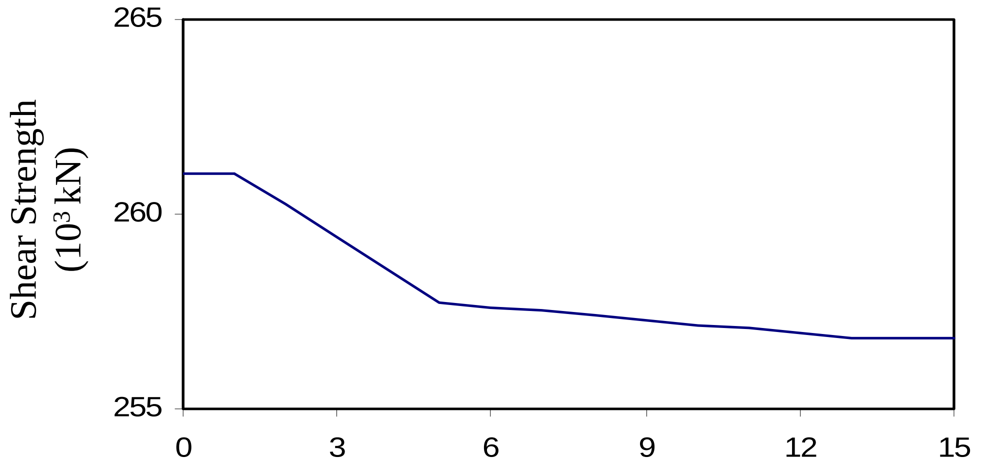



Total shear strength in terms of the curvature ductility, $\mu_\phi$

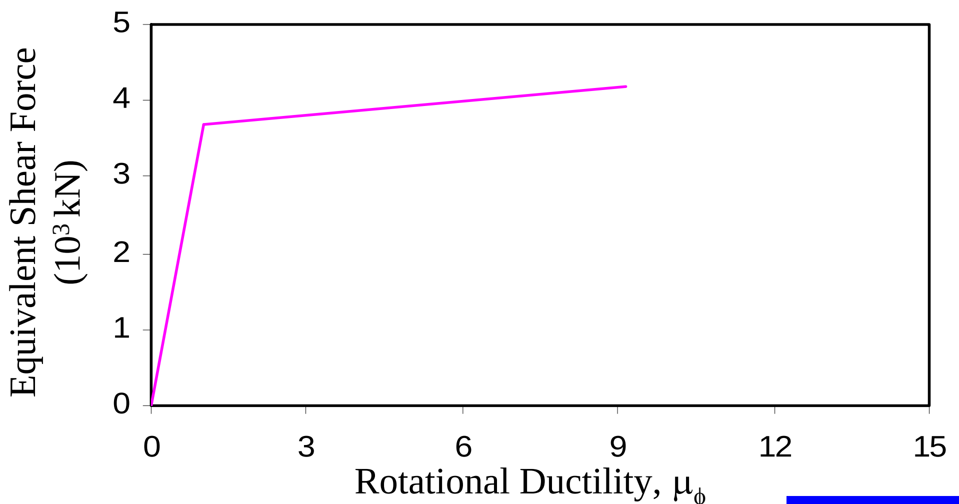



*(Priestley et al., 1996)*

# Shear Force in Columns of Bridge 2




**Shear Strength Envelope: Shear Strength in Column at Plastic Hinge Locations**




**Equivalent Shear Force-Curvature Relation from Moment-Curvature Relation**

**No Premature Shear Failure**

# Modifications

1. Introduction of Gap element at the abutment locations in longitudinal direction
2. Non-uniform pounding (i.e. not face-to-face impact)