Recent Developments in **Aseismic Design of Bridges** and **Indian Scenario**

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Outline

- Introduction
- Seismic Performance of Bridges in Past Earthquakes and Historical Developments
- Indian Earthquake Problem
- Current Seismic Design Practices in Japan and United States
  - Design Force Level and Design Spectrum
  - Capacity Design Concept
  - Longitudinal Linkage Elements
  - Vertical Hold Down Devices
  - Seating Widths
- Provisions in Indian Codes
- Conclusions

Introduction

- Seismic bridge code development initially based on experiences with buildings
- Modern thinking on seismic design of bridges developed after
  - The **1971 San Fernando** (California, USA) earthquake
  - The **1978 Miyaji-Ken Oki** earthquake in Japan
- Major changes in the code design philosophy for seismic design of bridges

Historical Developments (U.S.)

- CALTRANS initiated seismic design of bridges after 1933 Long Beach earthquake
- Similar design coefficients as in buildings
- 1958 AASHTO provided (2 to 6% of g):

$$V = kW; \qquad k = 0.02,\ 0.04,\ 0.06$$

- Before 1971, CALTRANS provided:

$$EQ = KCW \quad C = \frac{0.05}{\sqrt[3]{T}} \leq 0.10$$

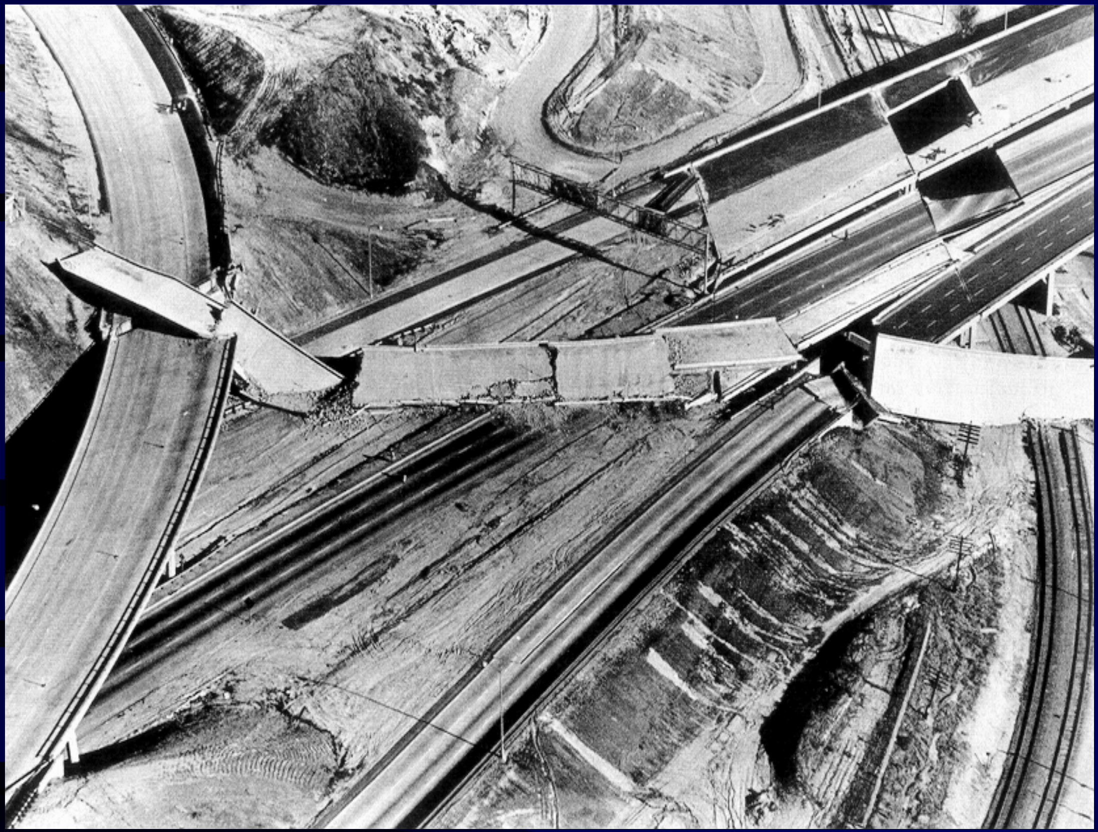
K = 1.33, 1.0, 0.67 (depending on bridge system)

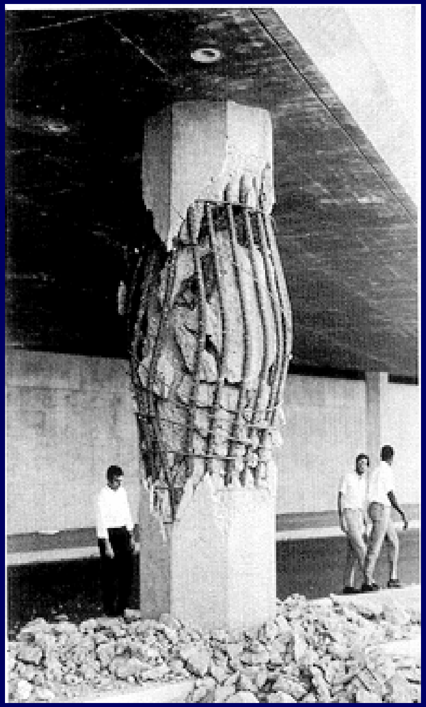
Corresponds to Peak Ground Acceleration of about 4% of gravity

Historical Developments (U.S.)

Design Coefficients

- **1971 San Fernando earthquake (M6.4)**
  - massive damages to bridge systems
- **Till 1971**, very little bridge damage from any California earthquake





State Foothill Freeway Interchange
1971 San Fernando Earthquake

EERL 1971

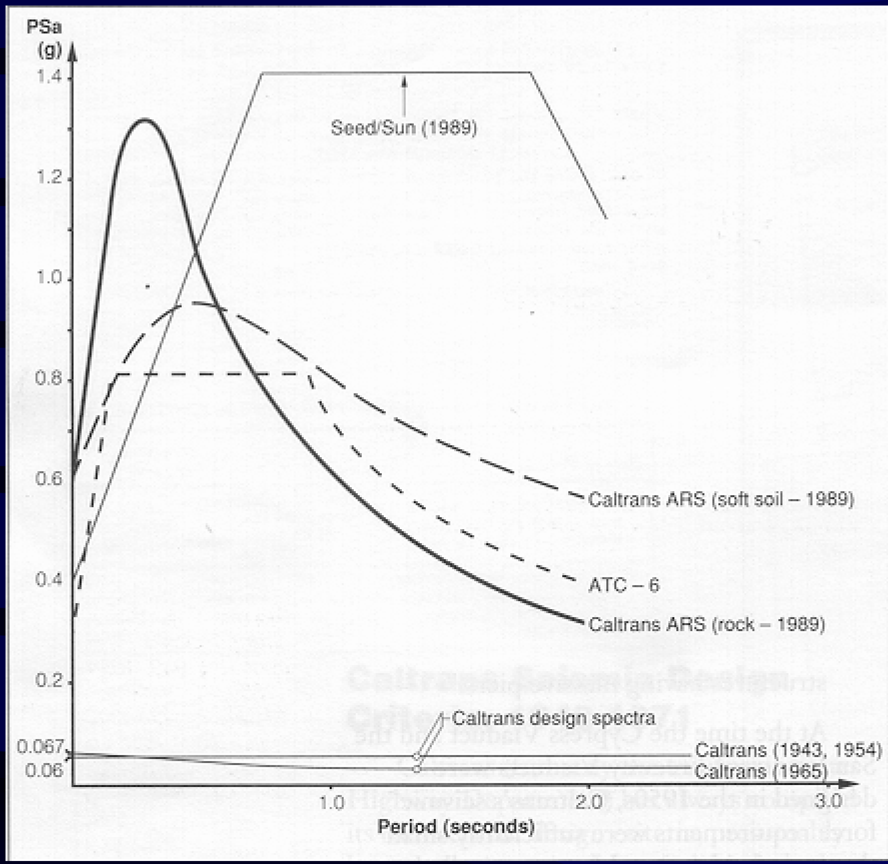
- 1971 San Fernando earthquake led to an ad-hoc increase of 200-250%:

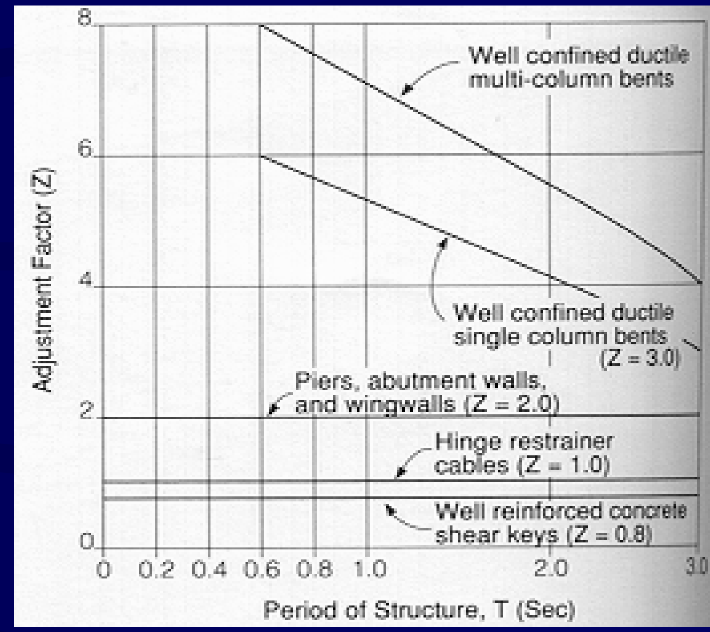
$$EQ = \begin{cases} 2.0KCD & \text{for frames on spread footings} \\ 2.5KCD & \text{for frames on pile footings} \end{cases}$$

- **1973:** New Criteria by CALTRANS
  - These adopted by AASHTO in 1975 for US
  - Revised in 1978
- **1977:** Major study initiated by ATC

Historical Developments (U.S.)
Design Coefficients

- **1981:** ATC-6 came out with **modern seismic design criteria** (adopted by AASHTO in 1983)
- Continuous revisions since then
- After **1971 earthquake**, CALTRANS began **phase I seismic retrofit programme** (cable restrainers to prevent falling of superstructures)
  - about **1,265** bridges retrofitted in this phase





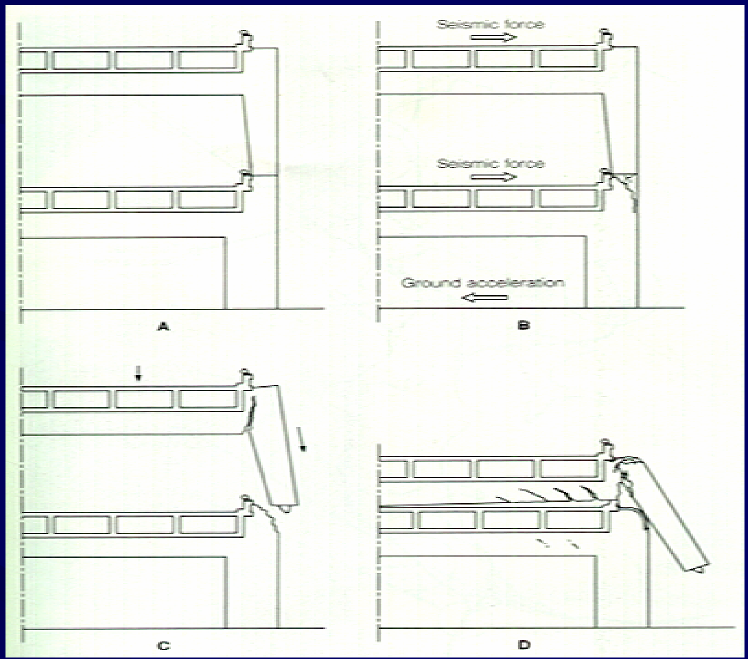
Frame type	Caltrans Z[1]	ATC-6 R[1]	ATC-3 R[2]
Single colum	6	3	2.5
Multiple column	8	5	7

Notes: 1. Bridge structure, maximum value
2. Building structure

CALTRANS ARS Elastic Spectra (1989) and Design Spectra (1965, 1954, 1943) for multi-pier bents

Department of General Services,1990

- **1989 Loma Prieta** (M6.7), California, **earthquake**
  - Massive damages; mostly to pre-1971 bridges
  - 43 persons died and 121 injured due to bridge collapses (till 1989 only 2 persons were killed in California due to earthquake damage to bridges)
  - Repair and replacement costs: US$2 billions (Rs 9,000 crores)



Cypress Viaduct
1989 Loma Prieta Earthquake

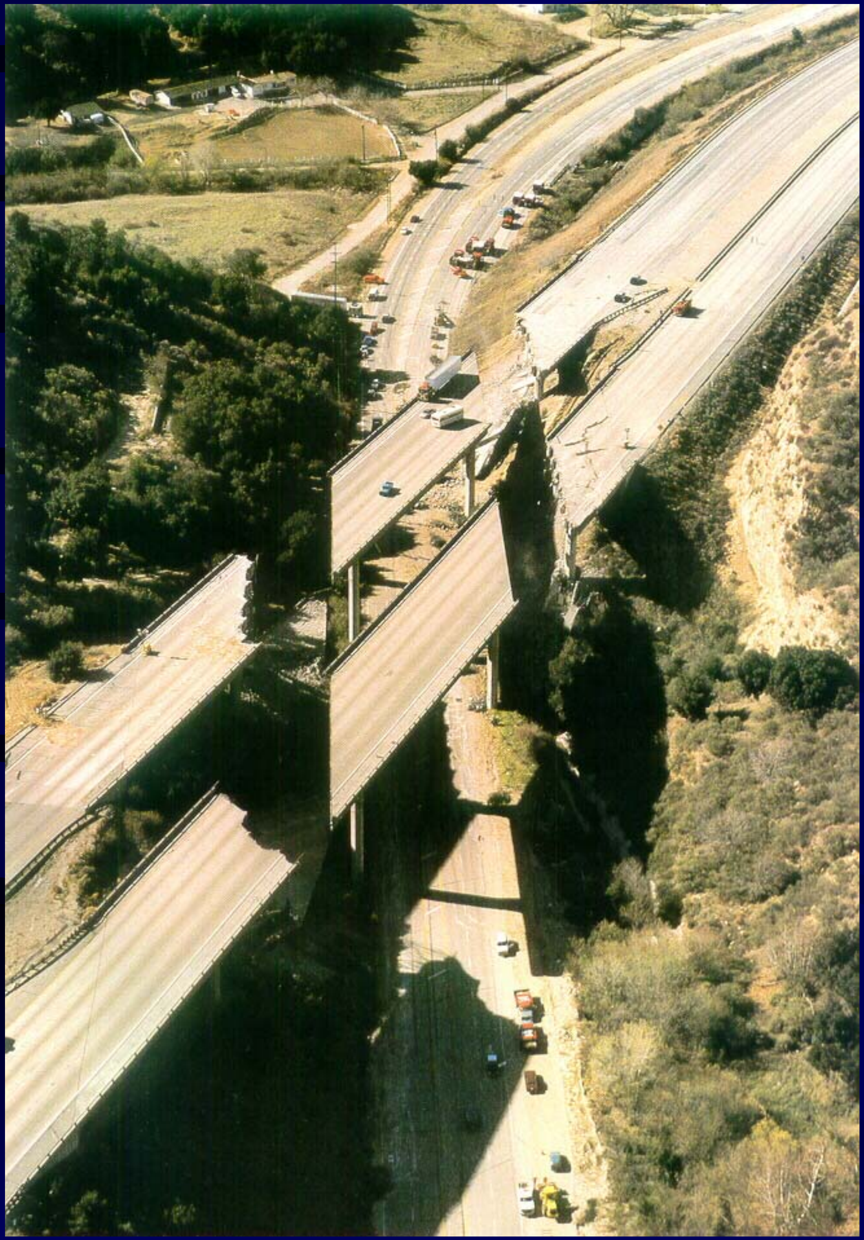
Department of General Services,1990

Cypress Viaduct
1989 Loma Prieta Earthquake

EERI Slides

Historical Developments (U.S.)
Design Coefficients

- Led to **major policy changes** and design practices **in many seismic countries**
- **Law for seismic retrofit program** for all public bridges
- Phase II of retrofit program for **confinement of columns**
- **1% of CALTRANS construction budget on research** (US$5 millions: Rs 22 crores per year)
- ¼% sales tax for seismic retrofit
- Revisions to seismic performance expectations; **two level design concept** (ATC-32 report)

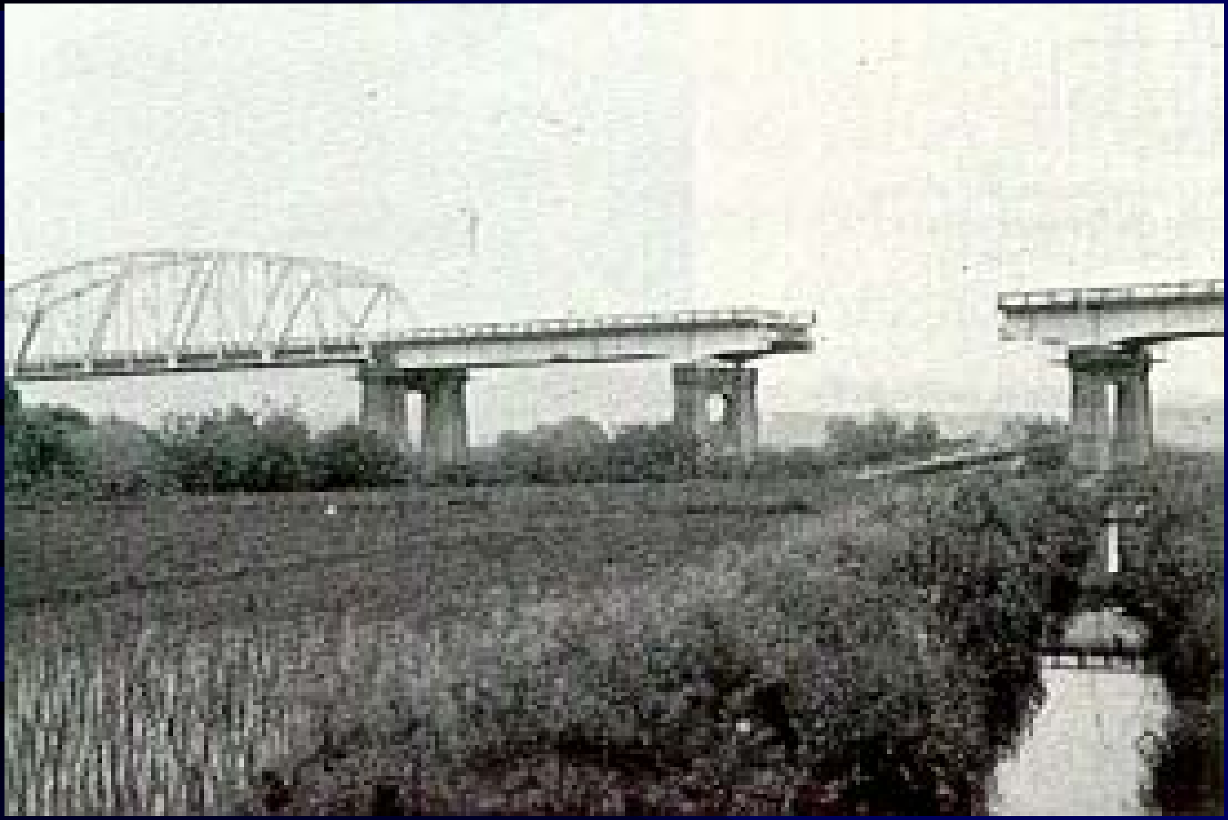


Golden State Freeway
1994 Northridge Earthquake

Los Angles Times1994

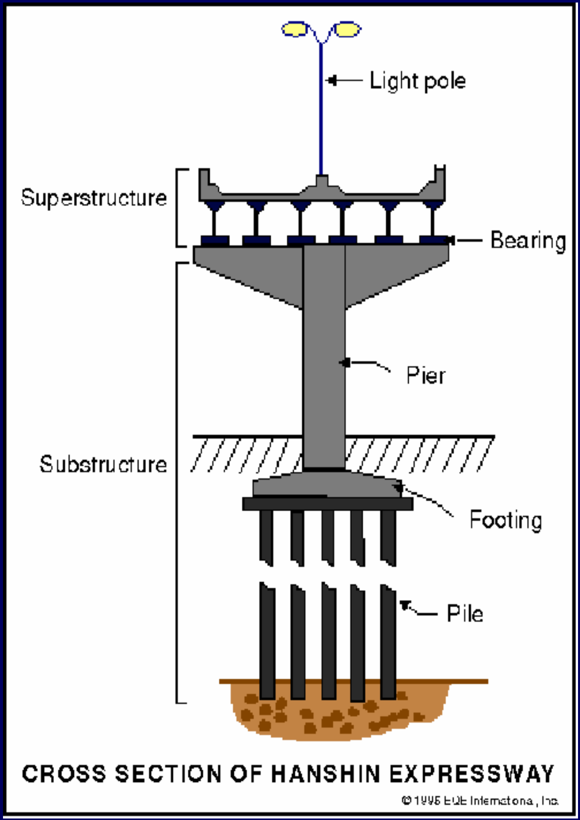
Historical Developments (Japan)

- **1971**: Seismic Design Guidelines for Highway Bridges
- **1980**: Specifications for Highway Bridges, Part V: Seismic Design
- **1990**: Revision of Specifications for Highway Bridges, Part V: Seismic Design
- **1995 Kobe** Earthquake (M6.9): **Worst ever damage to bridges**



Kin-noh Bridge
1978 Miyagi-ken-oki Earthquake

JSCE 1995



Hanshin Expressway
1995 Kobe Earthquake

JSCE 1995

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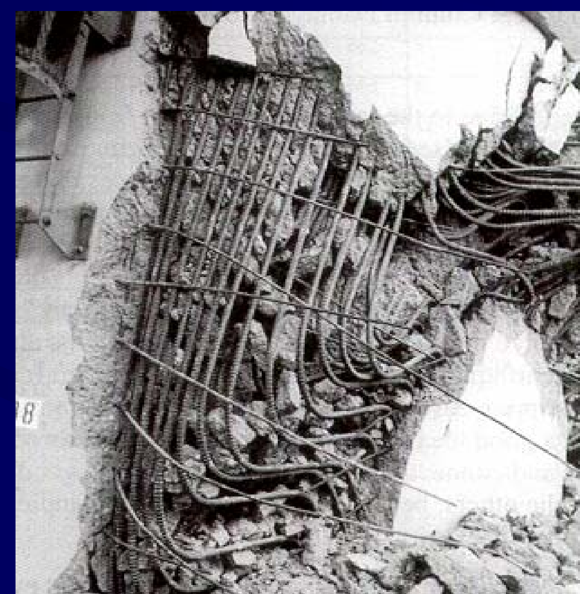


Hanshin Expressway
1995 Kobe Earthquake

ASCE 1995

Historical Developments (Japan)

- About US$6.5 billions (**Rs 28,000 crores**) **repair costs of bridges alone**
- **1998**: **Major revision** of Specifications for Highway Bridges, Part V: Seismic Design

Earthquake Problem in India

- **More than 50%** land in high seismic zones
- **Potential for great earthquakes** (M>8.0) (four such earthquakes during 1897-1950)
- **Many major cities in high seismic zones**
  - Guwahati, Darbhanga, Srinagar: zone V
  - Delhi, Chandigarh, Dehradun, Patna: zone IV
  - Bombay, Calcutta, Ahmadabad, …: zone III
  - Madras: zone II (*being changed to zone III*)

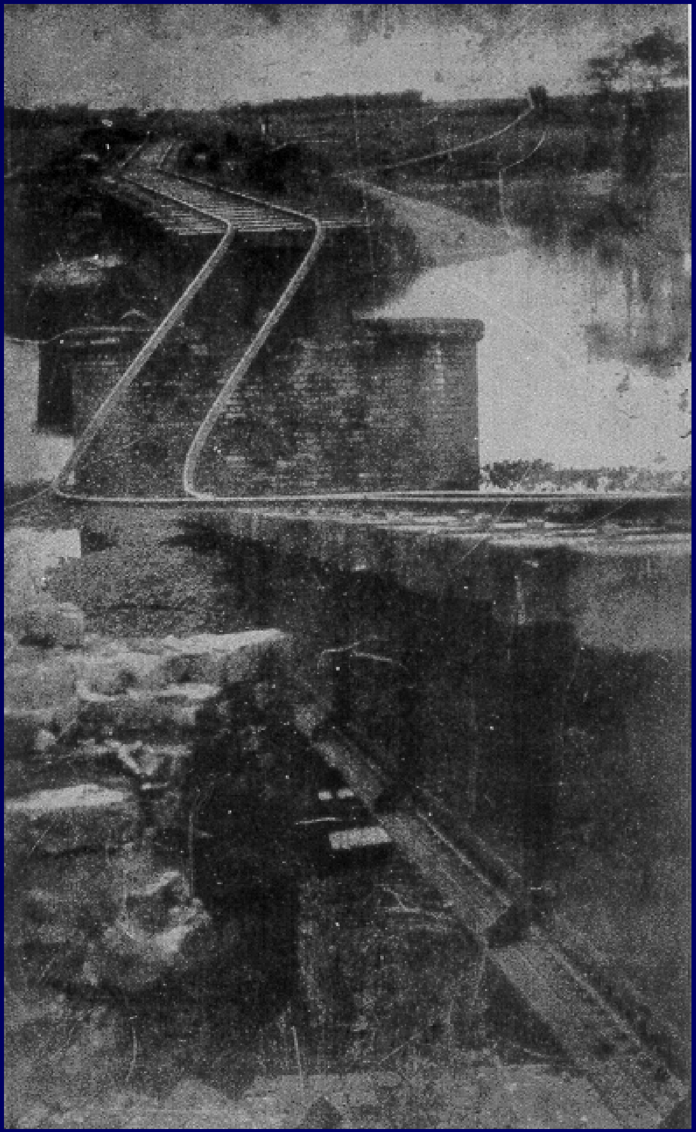
Earthquake Problem in India

- **Major infrastructure development** phase in the country
- **Number of metro projects** being planned/ constructed
- **Indian seismic code provisions** for bridges **not revised** for about thirty years and are **highly inadequate**

Performance of Indian Bridges in Past Earthquakes

- In **1897** Assam earthquake (M8.7)
- In **1934** Bihar-Nepal earthquake (M8.4)

  … Not a bridge remains undamaged from minor cracks in arches, wing walls and abutments, displaced piers and girders, to complete destruction (GSI, 1939)



Performance of Indian Bridges in Past Earthquakes

- Only moderate earthquakes in recent years
  - Magnitude ~6.5
  - Maximum intensity of shaking (VIII-IX on MMI)
  - In areas with relatively low level of development (1988 North Bihar, 1991 Uttarkashi, 1993 Killari, 1997 Jabalpur, 1999 Chamoli)

Performance of Indian Bridges in Past Earthquakes

- Performance in moderate earthquakes not very satisfactory
  - Burma-India (1988) earthquake (M6.8): **distress** to the Tejpur bridge across Brahamputra
  - Uttarkashi earthquake of 1991 (M6.6): **collapse** of the Gawana bridge
  - Killari earthquake of 1993 (M6.4): **damage to bearings** of a bridge
  - Jabalpur earthquake of 1997 (M6.0): **damage to bearings** of a railway bridge

Gawana Bridge
1991 Uttarkashi Earthquake

Performance of Indian Bridges in Past Earthquakes

- Potential for M>8.0 earthquakes with shaking intensity of upto X- XII!

Current Seismic Design Practices

- Two levels of design
- Realistic values of peak horizontal ground acceleration (upto about 70% - 80% of gravity)
- Realistic shape of design spectrum
- Super-structure is usually not a problem
- **Connections** are **most critical**

Current Seismic Design Practices

- **Damage preferred in piers**; piers detailed for ductility; consideration of ductility and overstrength for design of pier sections
- **Capacity design concept** for connections and foundations

Two Level Design

- ATC-32

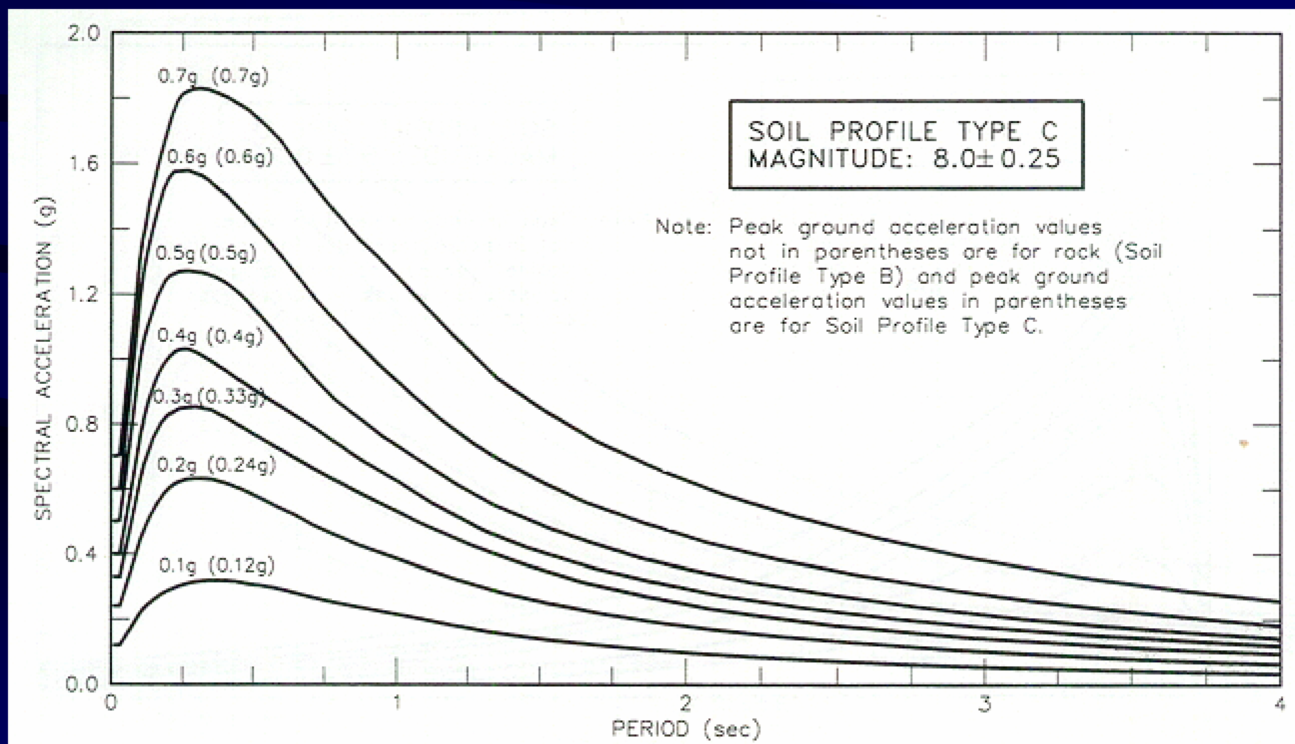
Motion	Earthquake	Ordinary Bridges	Important Bridges
Functional Evaluation Earthquake	Moderate 60% probability in bridge life	Service Level- Immediate *Repairable* Damage	Service Level- Immediate *Minimal* Damage
Safety Evaluation Earthquake	Max. Credible Earthquake 1000-2000 year return period	Service Level- Limited *Significant* Damage	Service Level- Immediate *Repairable* Damage

Design Force Level and Design Spectrum

- Max. value of peak ground acceleration
  - **0.8g** in AASHTO code
  - **0.7g** in CALTRANS code
  - **0.8g** in New Zealand code
  - **0.8g** in Japanese code

Design Force Level and Design Spectrum

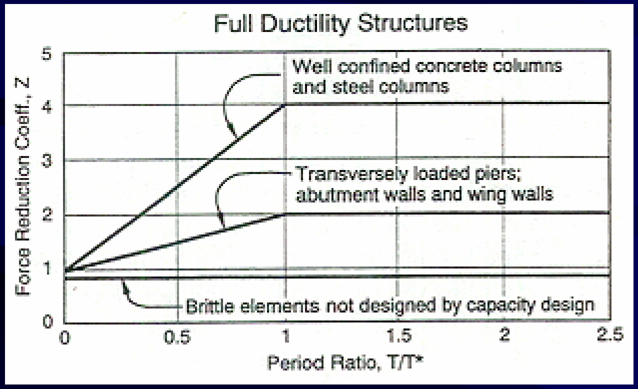
- Realistic shape of response spectrum to **obtain maximum elastic seismic forces** on the entire bridge

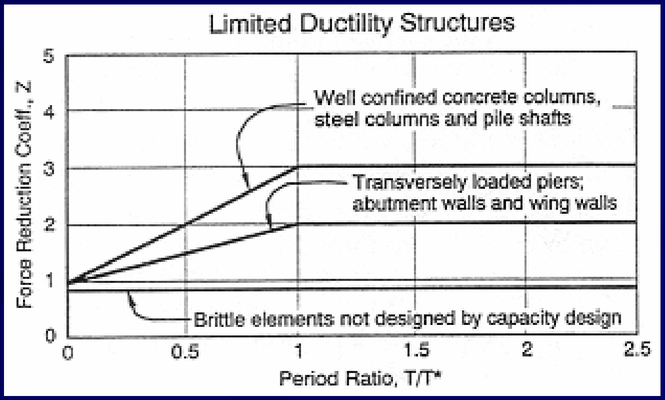


Response Modification Factor

(Accounts for ductility and overstrength)

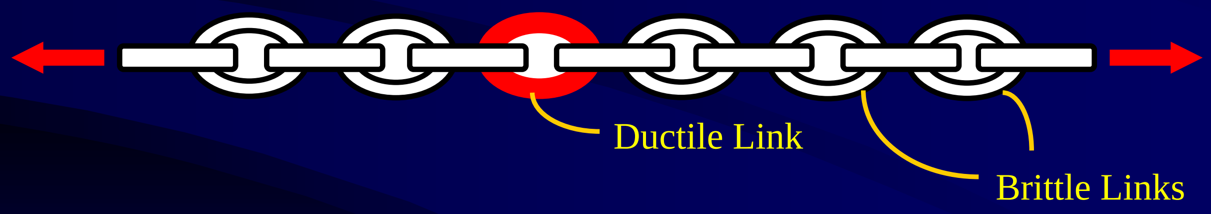
- ATC-32





Capacity Design Concept

- **Ensures that ductile elements** in the structure will **yield prior to failure of brittle elements**
- Example of a chain



Capacity Design Concept

- **Piers** designed for flexure and **detailed for ductility**
- **Shear design of piers by capacity design** (ensures flexural failure occurs before shear failure)

Capacity Design Concept

- **Using capacity design concept**, force that can be transmitted to **foundation** and to the **connections** is computed
  - Foundations and connections designed for lower of
    - Max. elastic force divided by *R*
    - Force computed by capacity design concept
  - Usually the latter will govern the design in severe seismic zone

Longitudinal Linkage Elements

- To prevent undesirable movements of adjacent superstructure units at supports, **horizontal linkage elements** to be provided
- These may be ties, cables, dampers or other mechanical means
- Linkage elements **to connect two adjacent superstructure units** (or each span may be connected to the column or pier)

Longitudinal Linkage Forces

- Designed for **acceleration coefficient** times the weight of the lighter of the two adjoining spans or parts of the structure

Hold Down Devices

- To take care of **uplift forces** under seismic forces acting transverse to the longitudinal girders
- Required at all supports or hinges if vertical seismic force due to longitudinal horizontal seismic load opposes and exceeds 50% of the dead load reaction

Hold Down Devices

- Minimum design force for the hold-down device is the **greater of**
  - 10% of the dead load reaction that would be exerted if the span were simply supported, and
  - 1.2 times the net uplift force (i.e., vertical upward seismic force minus the dead load reaction), if any.

Seating Widths

- Numerous loss-of-span type of failures in past earthquakes
- At expansion end of the girders, at least a minimum support length to be provided.

Seating Widths

- **AASHTO** provides:
  - $W_b = 203 + 1.67L + 6.66H$

    (for low seismic performance category)
  - $W_b = 305 + 2.50L + 10.00H$

    (for high seismic performance category)

    L = Span length for simply supported bridges (in m)

    H = Pier height (in m)

    W_b= Min. seat width (in mm)
- Japanese Code more conservative:
  - $W_b = 700 + 5L$

Indian Code Provisions

- IS:1893-1984 and IRC:6-1966 [1985 reprint]
- Essentially the same for design seismic force [IS:1893 more elaborate on hydrodynamic pressures on submerged parts]
- Practically not revised for thirty years
- IRC provisions in 4 pages, IS provisions in 6 pages; CALTRANS and Japanese provisions in **200+pages**

Indian Code Provisions

- Seismic design force F is given by

$$F = \begin{cases} \beta I \alpha_0 W_m & \text{in horizontal direction} \\ 0.5\beta I \alpha_0 W_m & \text{in vertical direction} \end{cases}$$

β = soil-foundation system factor (1.0 - 1.5)

I = importance factor (1.0 or 1.5)

W_m = seismic weight

α_0 = basic horizontal seismic coefficient which reflects seismic zone (0.01 - 0.08)

Indian Code Provisions

- **Important**: The above does not include
  - Sa /g (or C) to account for structural flexibility
  - Performance factor (K)

  [both included in IS:1893 for buildings]
- Design force in zone V is **only 8%-12%** of gravity!

  (Peak ground acceleration **3%-5% of gravity**!)

Proposed Design Criterion for a Major Bridge on Brahmputra

- **Limit state design** as per new RC code of Indian Railways
- **Capacity design concept**
- Peak ground acceleration
  - 0.10g for **Functional Evaluation Earthquake**
  - 0.60g for **Safety Evaluation Earthquake**

Conclusions

- Significant developments in last thirty years
- **Indian practices have not kept pace**; seismic provisions for bridges are highly inadequate
- Major infrastructure development taking place
- **Serious earthquake problem in a large part of the country**

Conclusions

- Revisions of Indian codes are **too infrequent**
- **Need for paradigm shift in code development**
- ACCE(I) and such other professional agencies need to play a proactive role in evolution of codes and in development of professional practices.