Introduction to Earthquake Engineering

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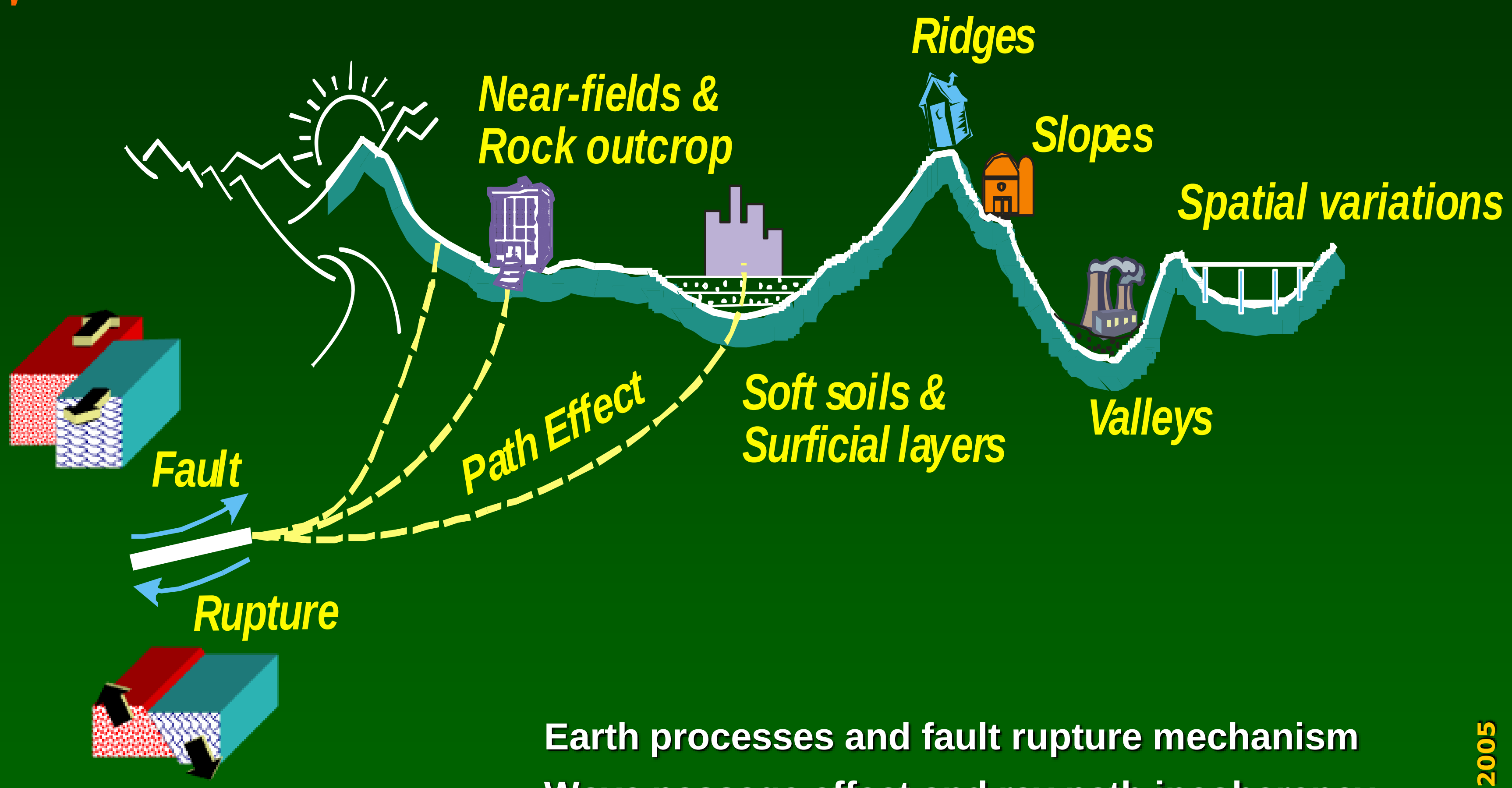
Overview

- Basic Elements
- Seismic hazard
- Earthquake effects
- Seismic risk problem
- Earthquake resistant design
- Hurdles to seismic safety
- Recent Indian initiatives

Introduction

Ground shaking as a result of complex processes



Earth processes and fault rupture mechanism

Wave passage effect and ray path incoherency

Source effects and attenuation

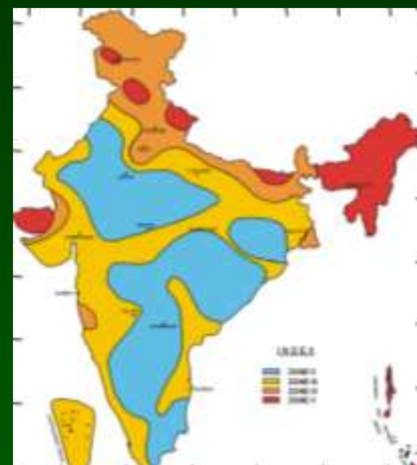
Local soil site and topography effects

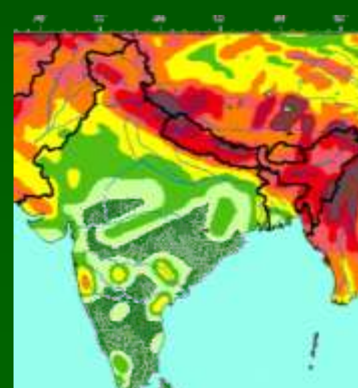
Introduction

Uncertainties loom large for earthquakes!

Earthquakes can neither be prevented nor predicted reliably as yet!

At most, probabilities of their occurrence and location are known





PGA with 10% probability of exceedance in 50 yr

FOE 2005

70% odd ± 10% of one or more M6.7 events during 2000-2030

Introduction

Preparedness as a key to disaster mitigation

Earthquake Risk

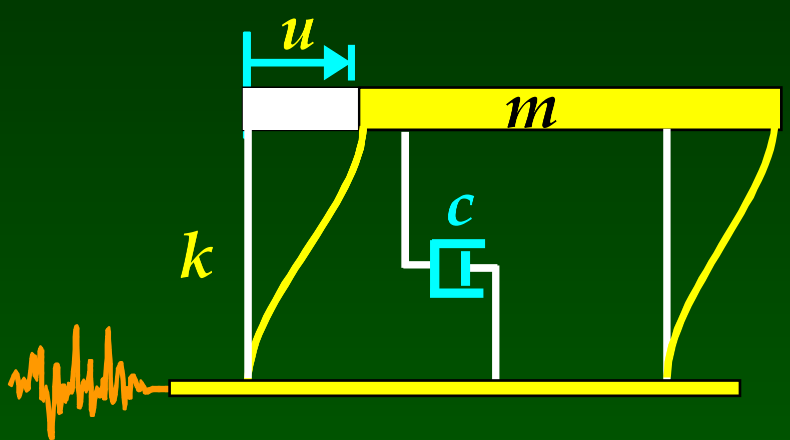
Hazard	Exposure	Vulnerability
		
Faulting, Shaking	*Built environment*	*Fragility*

Earthquake risk can be mitigated by reducing structural vulnerability

Effectiveness of Schemes

Seismic Energy Balance Equation

Single Degree of Freedom System



Equation of motion

$$m\ddot{u} + c\dot{u} + ku = -m\ddot{u}_g$$

Energy Equation

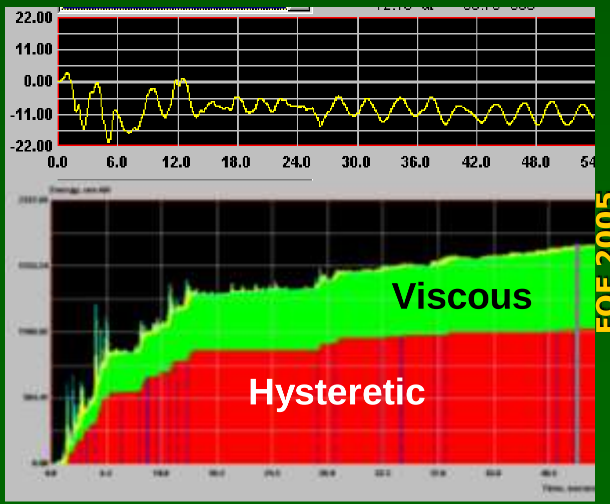
$$\frac{1}{2}m\dot{u}^2 + \int c\dot{u}^2\,dt + \int F_s\dot{u}\,dt = \int(-m\ddot{u}_g)\,\dot{u}\,dt$$

$$W_E + W_D + (W_S + W_H) = I$$

Reduce energy input

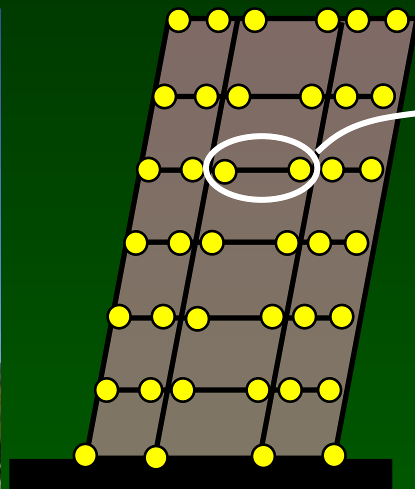
$$W_D + W_H$$

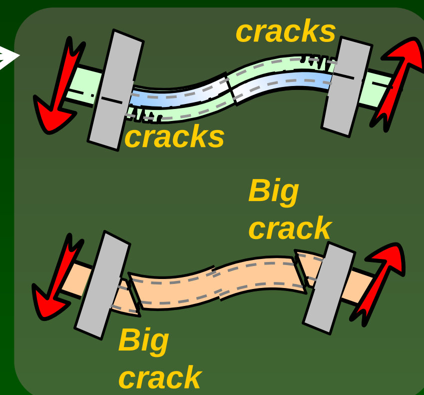
Absorb energy in structure

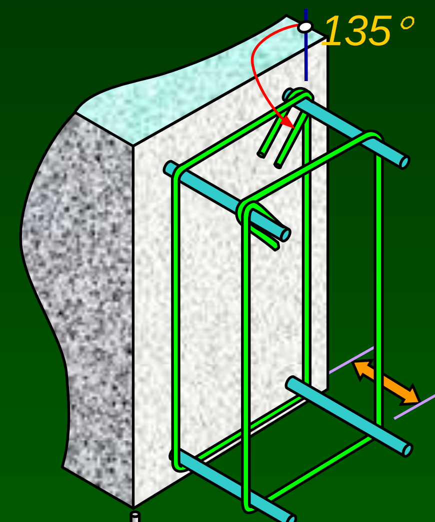


Fixed Base Structural Systems

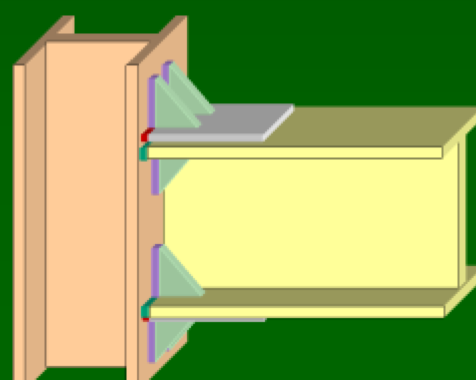
Building Earthquake Resistance

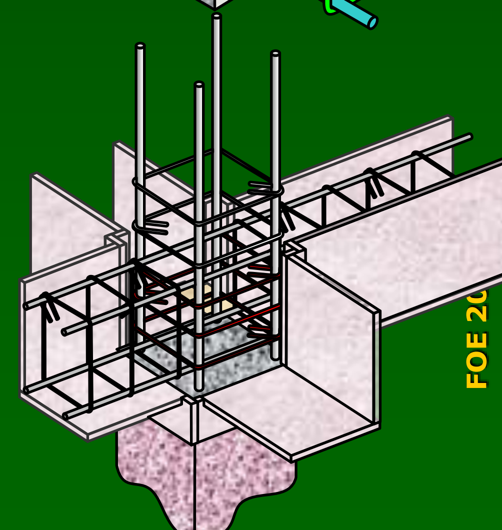






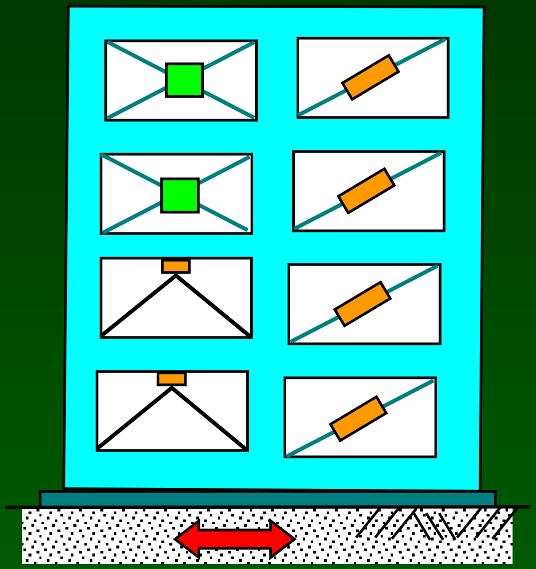
Absorb earthquake energy through inelastic deformation in structural members and prevent collapse and loss of lives

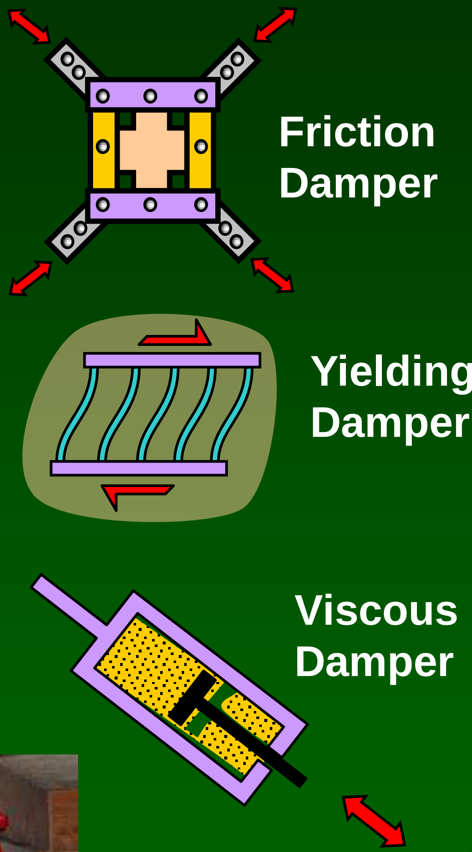




Energy Dissipation Systems
Building Earthquake Resistance

Absorb earthquake energy in EDDs to reduce damage to primary structural members





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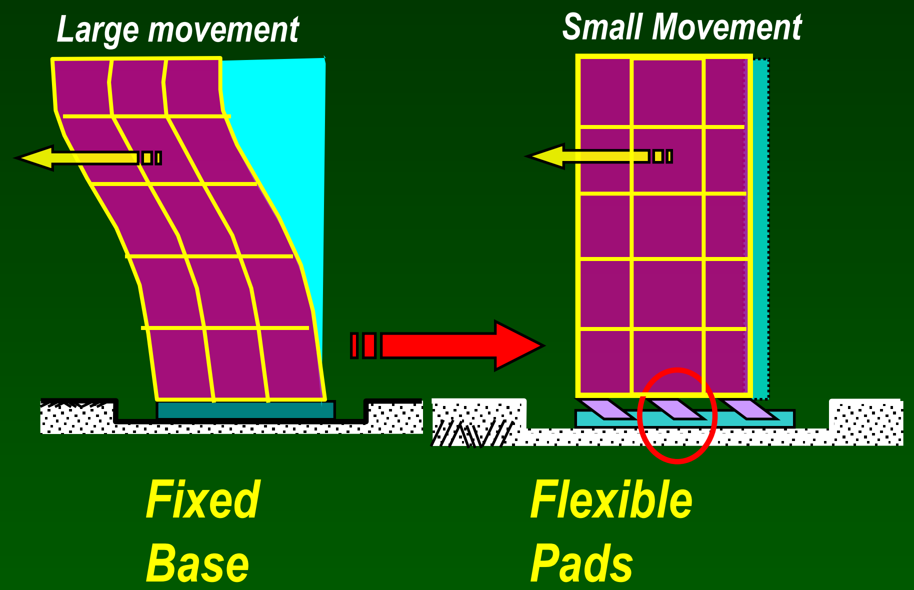
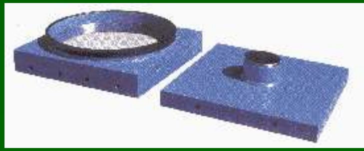
Seismic Isolation Systems

Building Earthquake Resistance

Decoupling structures from the ground shaking at base





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Seismic Isolation Systems
Building Earthquake Resistance

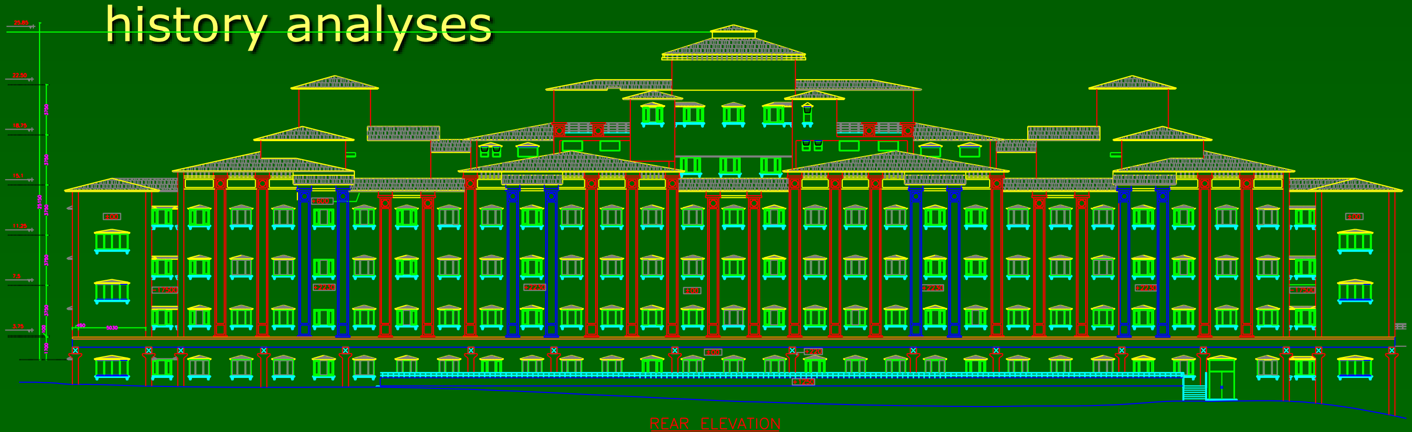
Base-Isolated Military Hospital at Shimla

Seismic design criteria

Preliminary design & Specs for Isolation system

Technical evaluation of bearings offered by vendors

Verification of their performance using nonlinear time-history analyses



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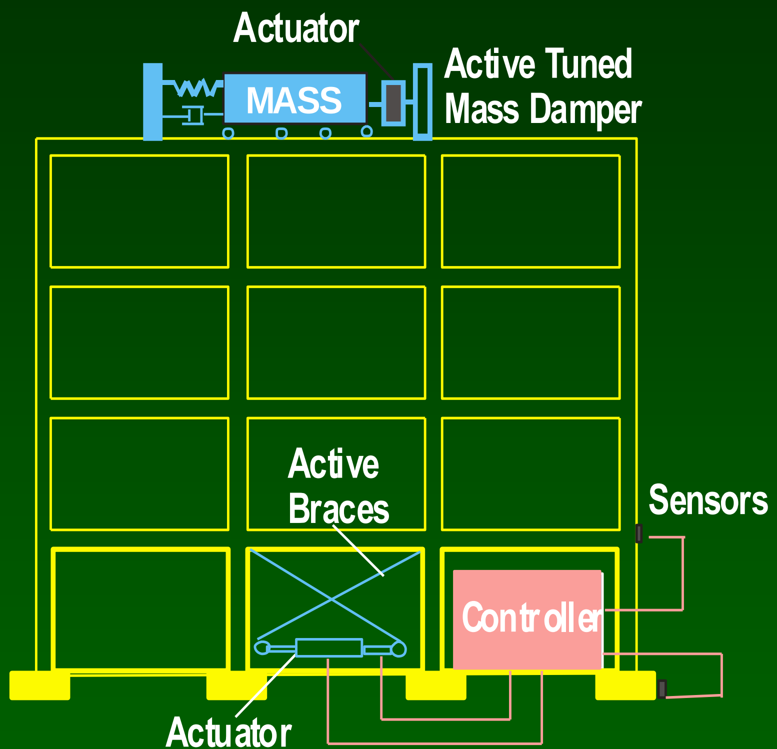
Adaptive Systems

Building Earthquake Resistance

Adjustment of strength, stiffness and dynamic properties of structure during the earthquake motion

New *smart* materials

MEMS



Active
Variable
Stiffness

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Seismic Evaluation & Upgradation

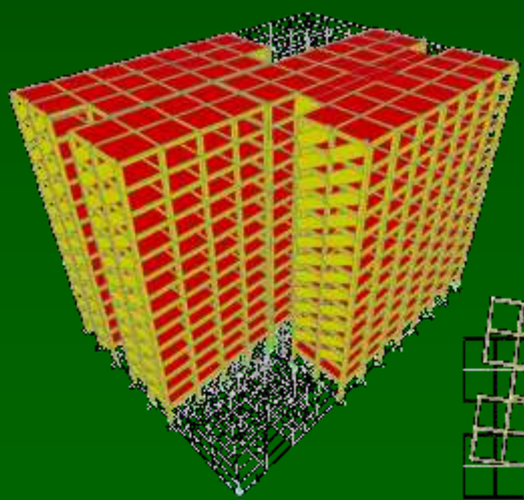
Building Earthquake Resistance

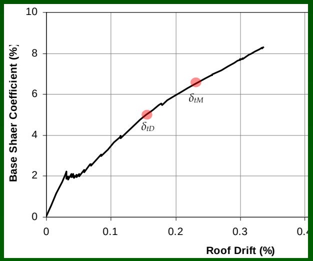
Seismic evaluation of deficient structures

Linear/Nonlinear static & dynamic analyses

Retrofitting options and their effectiveness

Pushover analyses to verify performance objectives





Delhi Police HQ Building

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Seismic Sources and Hazards

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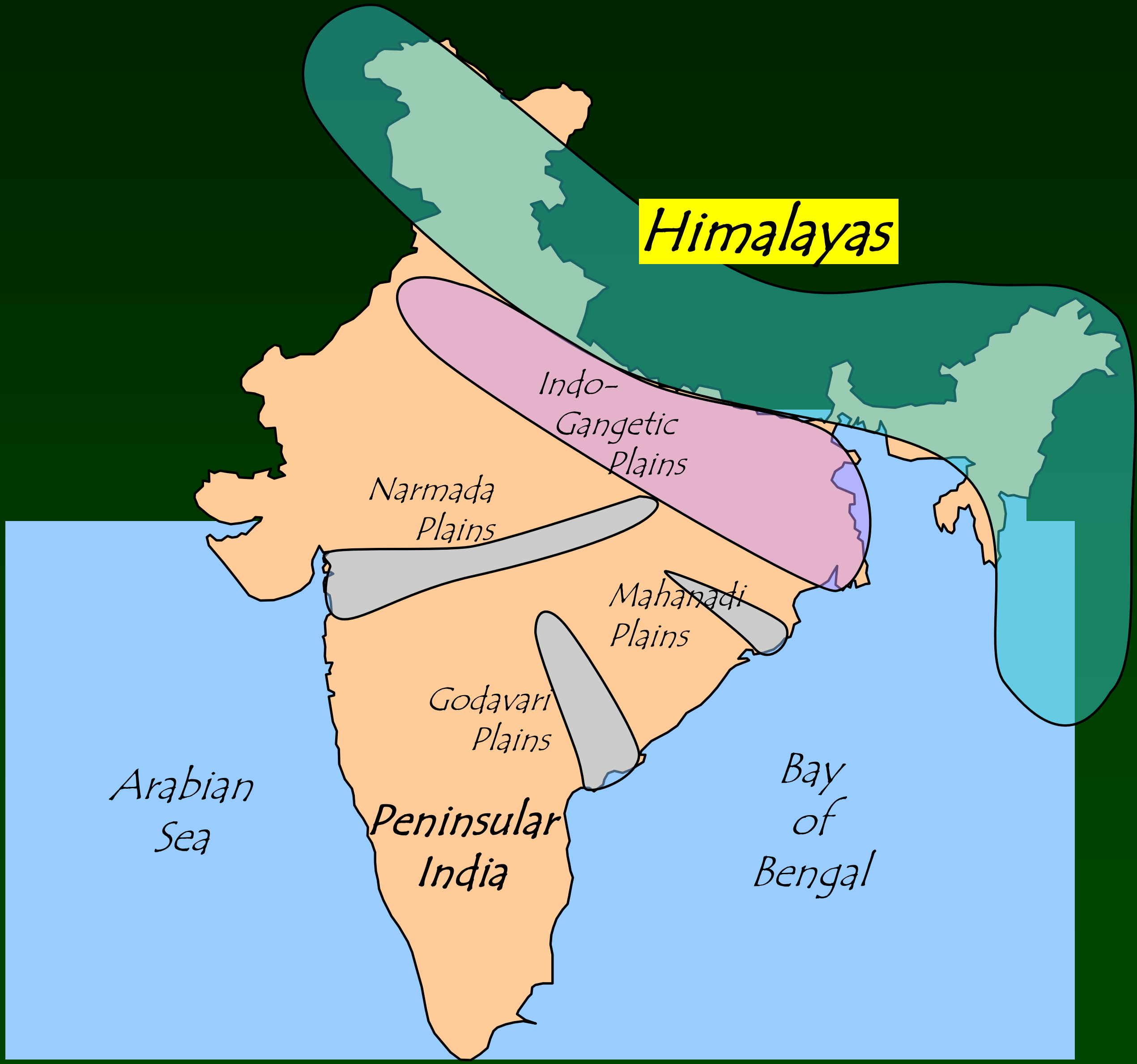
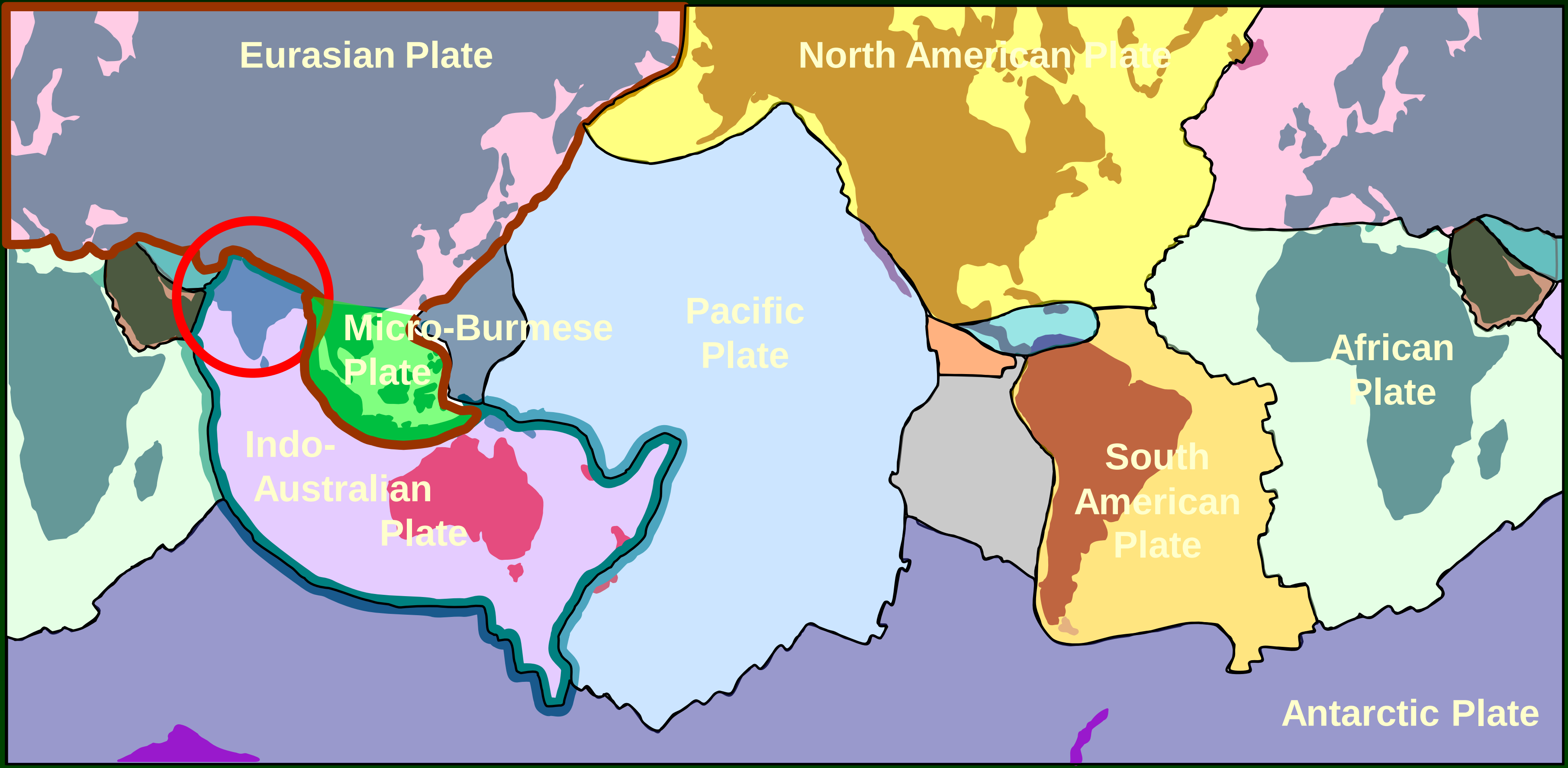
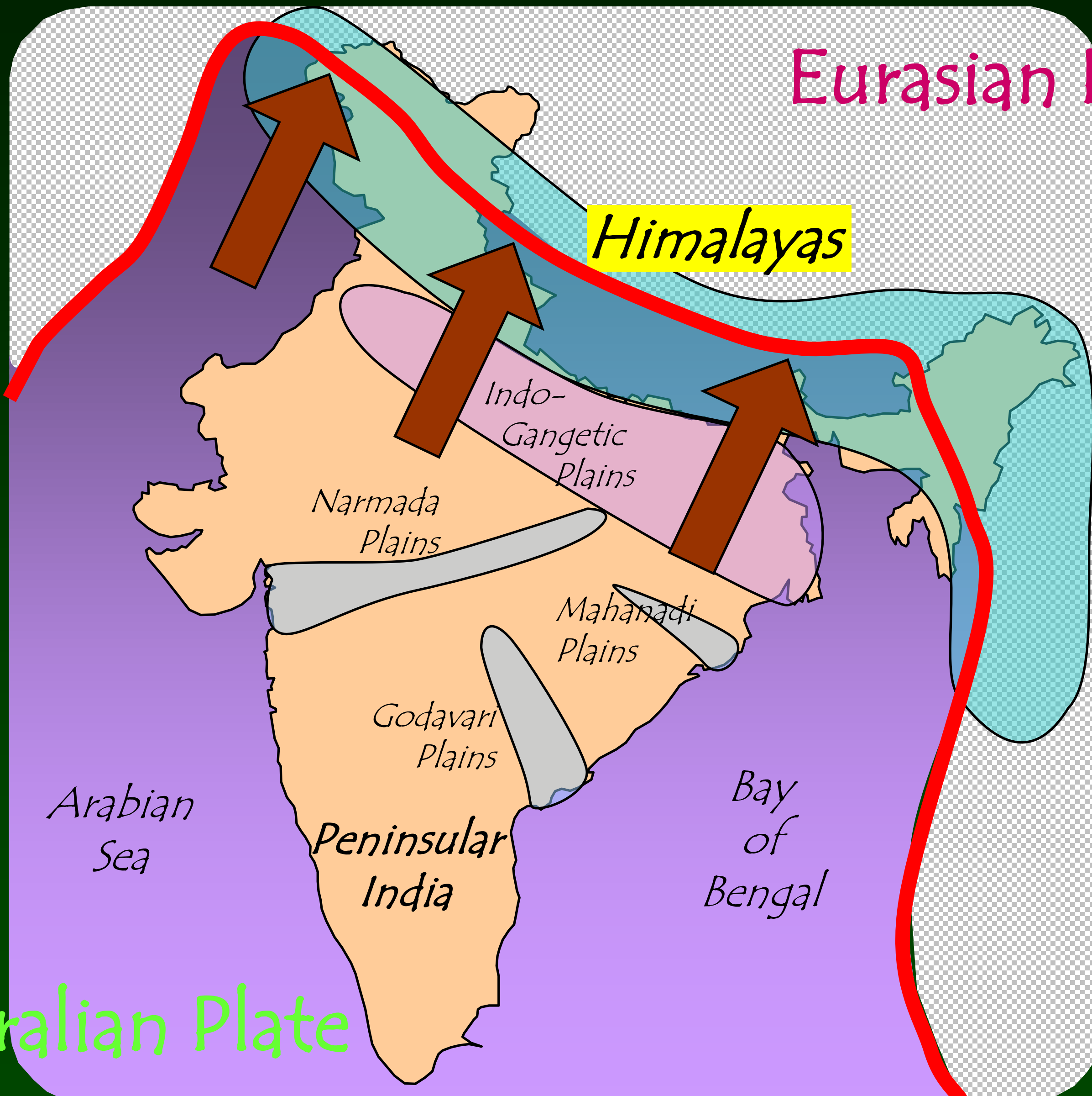
Geographical Layout

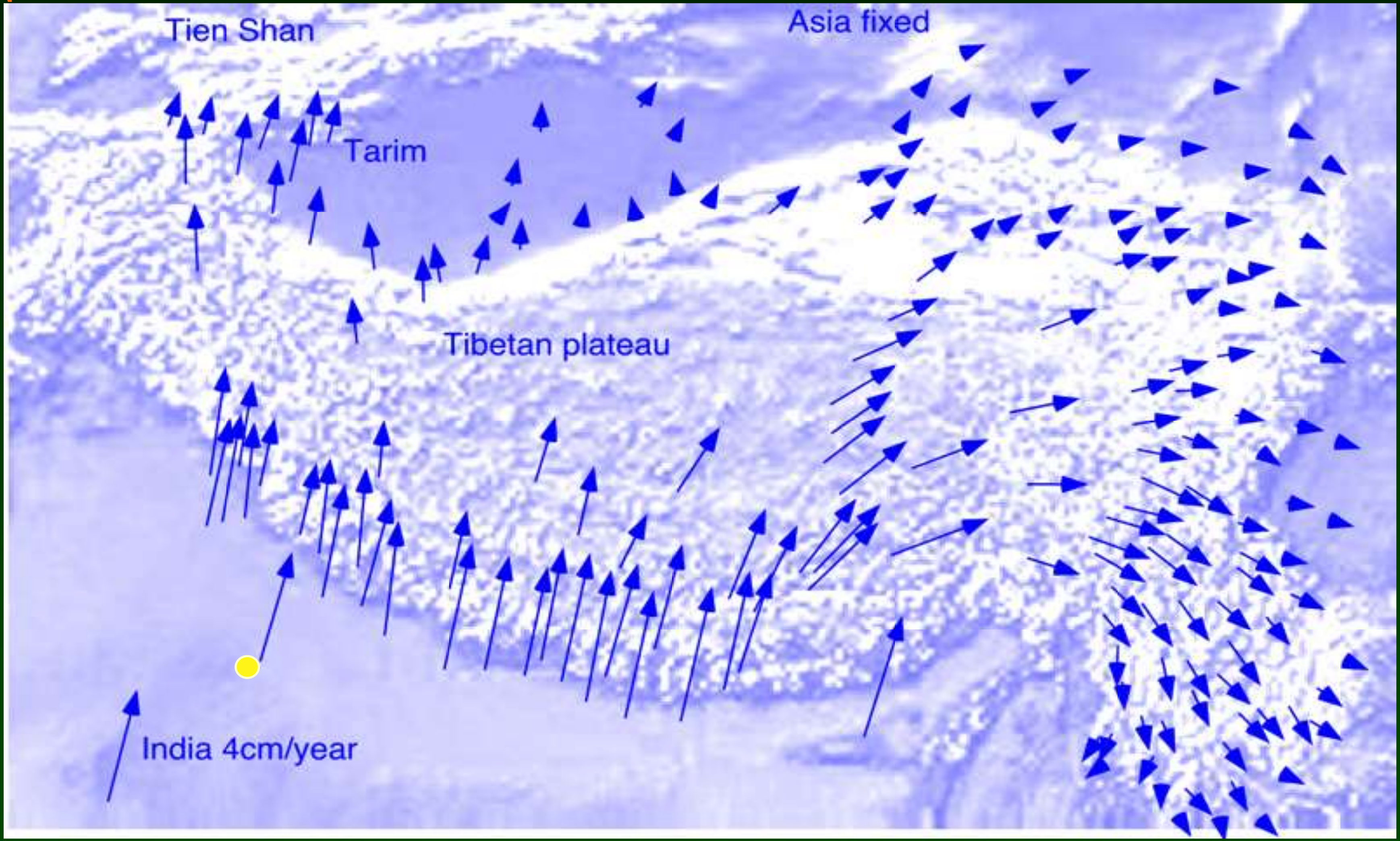


Tectonic plate boundaries

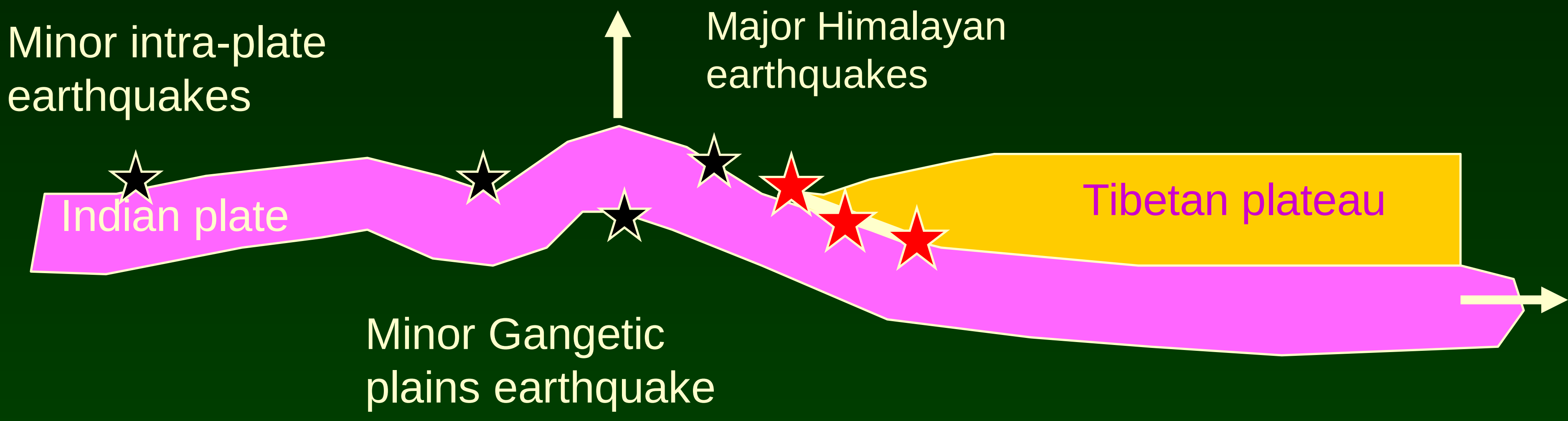


Tectonic plate boundaries



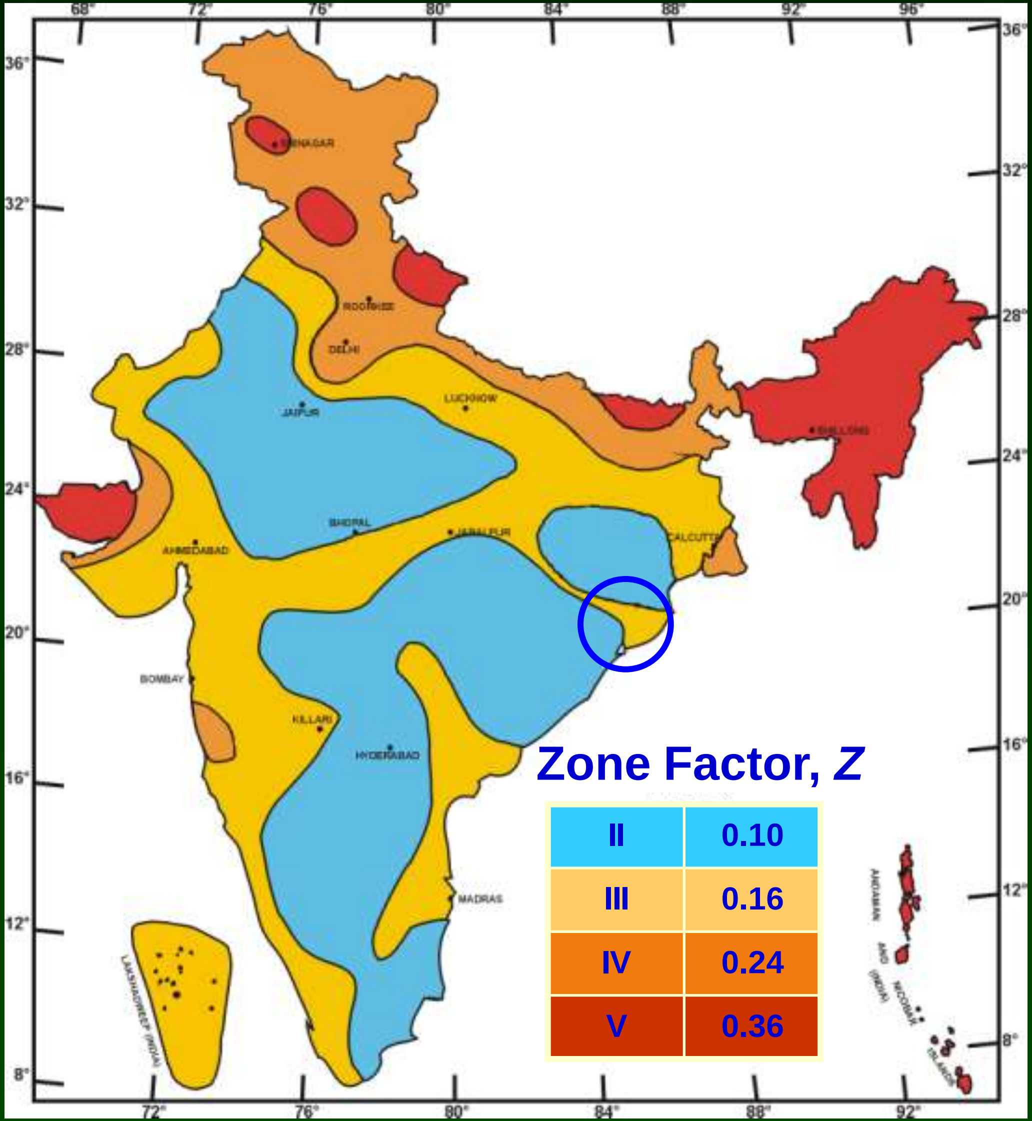


10 years of GPS


Minor intra-plate earthquakes
Major Himalayan earthquakes
Tibetan plateau
Indian plate
Minor Gangetic plains earthquake

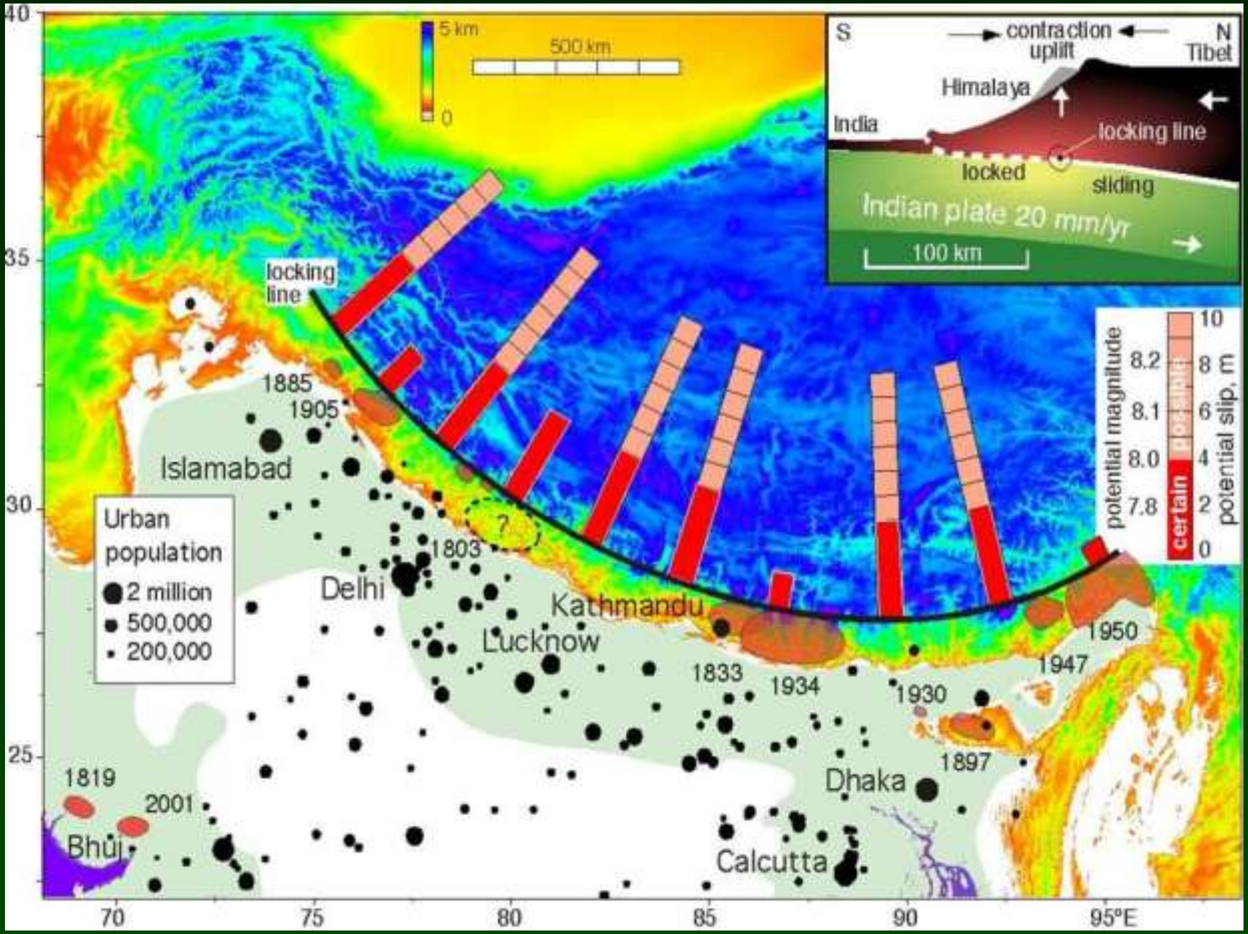
Seismic Hazard

- **Seismic zones largely based on shaking experienced in past earthquakes**



II	0.10
III	0.16
IV	0.24
V	0.36

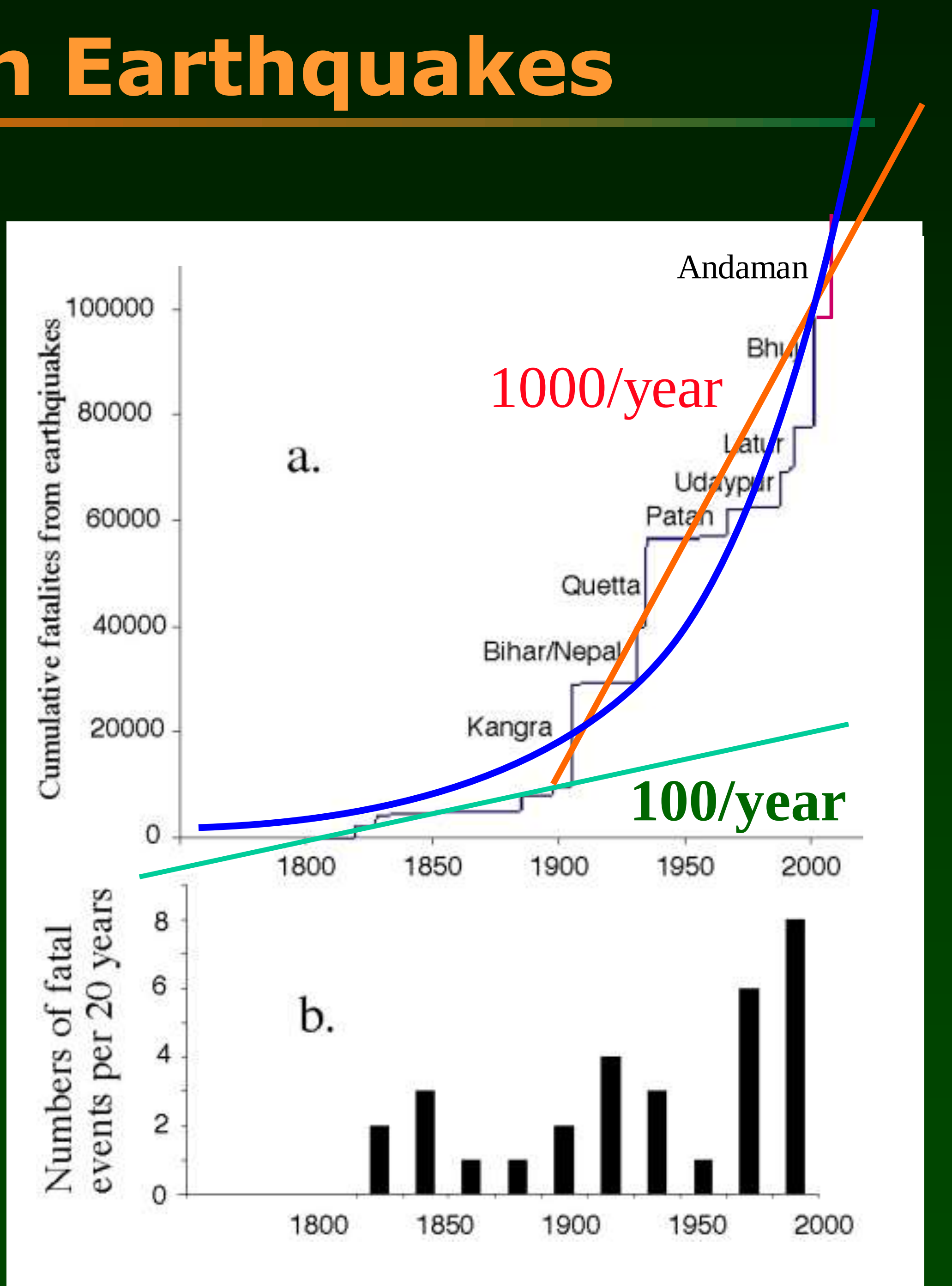
Future Seismic Hazard



Several M>8 earthquakes are probable either as repeat events of historical ruptures or 'gap filling' earthquakes in the intervening regions' (Bilham & Ambraseys, 2005)

Fatalities in Earthquakes

- **Fatalities have significantly increased in the last century**
- **Greater population at risk**



[Bilham, 2005]

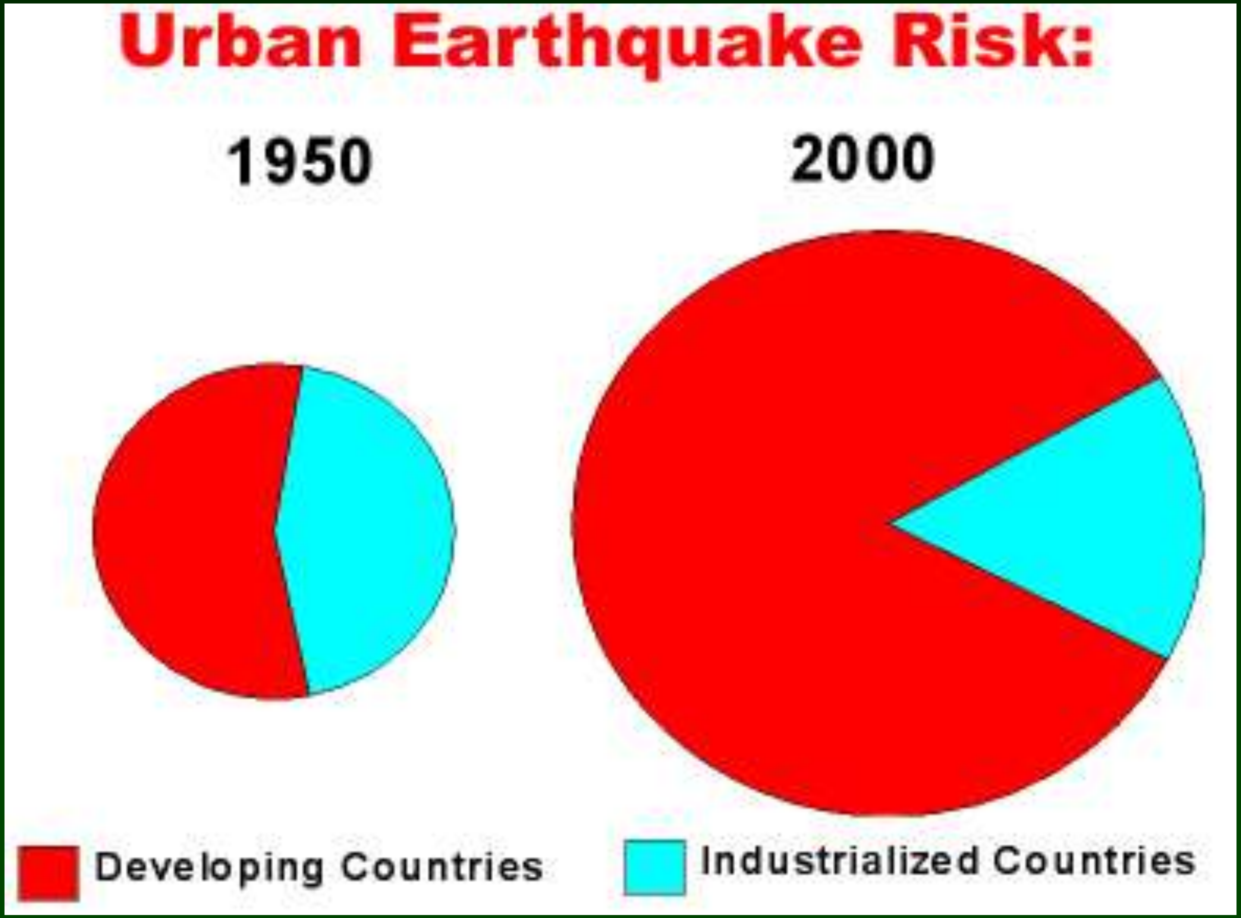
Global Scenario

- **Industrialized Nations**
  - ✓ *Early 1900's :: High human fatalities & high economic loss*
  - ✓ *Early 2000's :: High economic loss*
    - ***Role of Engineers***

- **India**
  - ✓ *Early 1900's :: High human fatalities & high economic loss*
  - ✓ *Early 2000's :: High human fatalities & high economic loss*

Earthquake Risk Reduction

- **Role of Earthquake Engineering Practice**

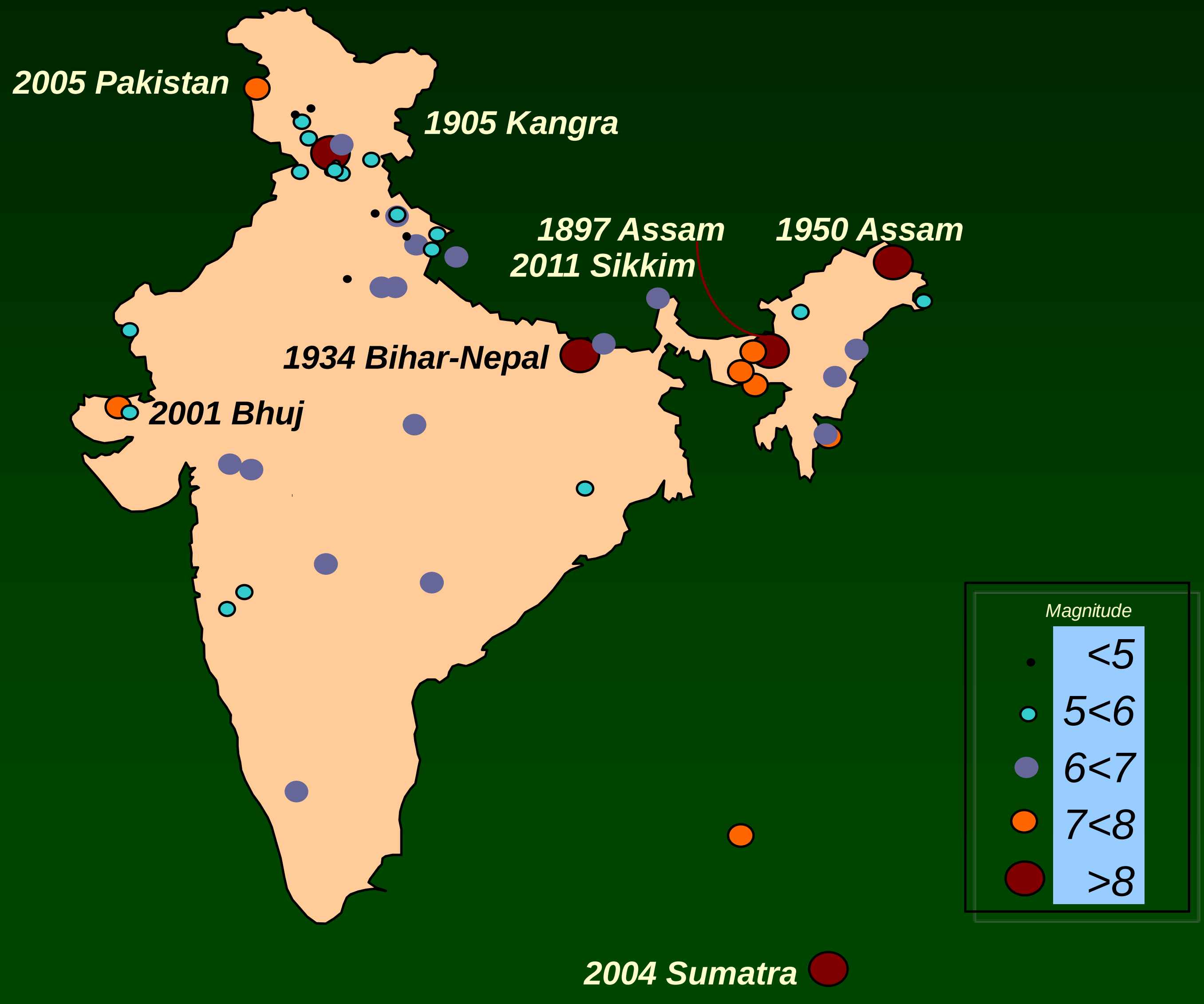


Some Great Indian Earthquakes

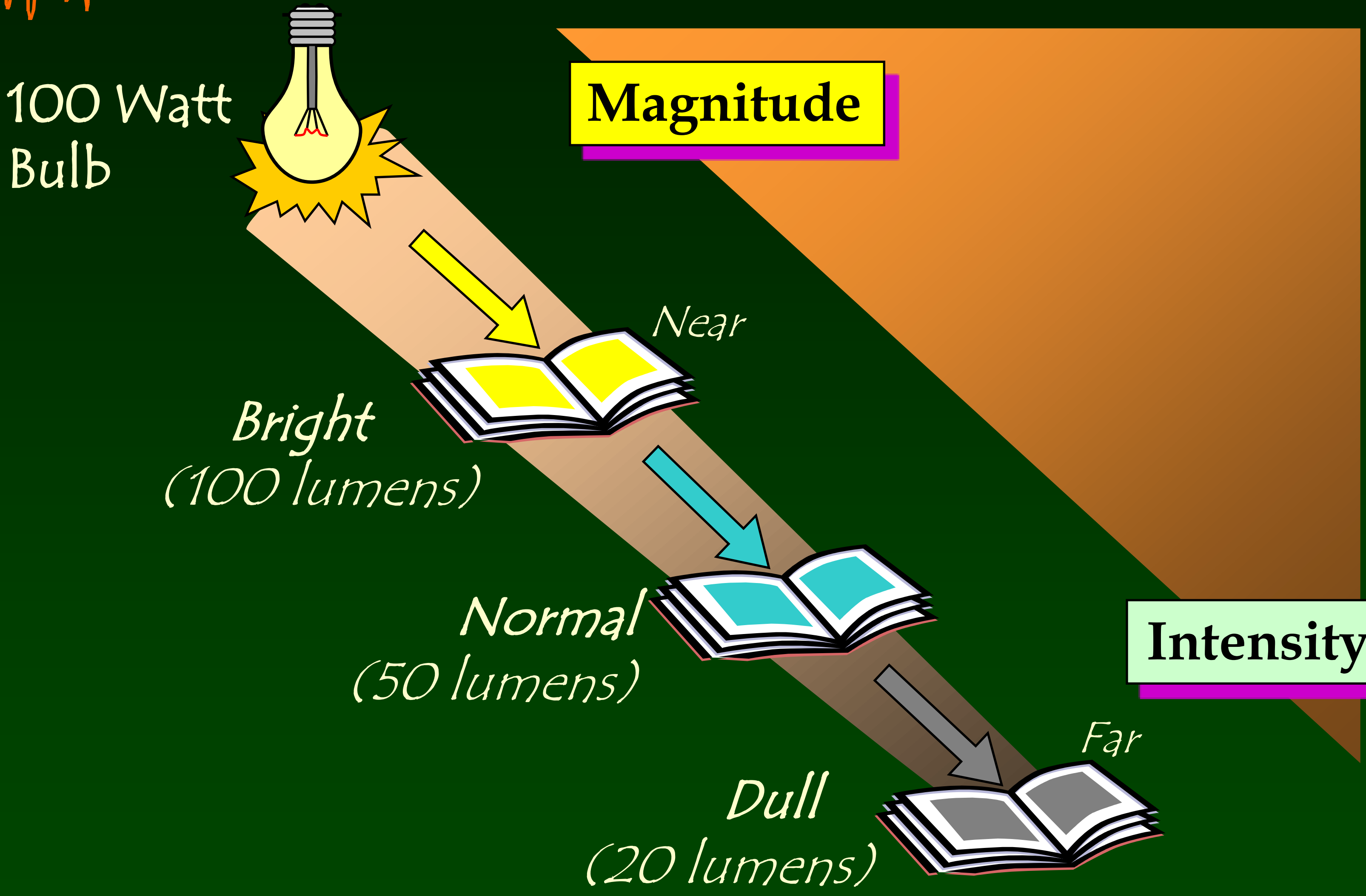
Some Great Indian Earthquakes

- **Earthquakes of Magnitude >8**
  - ✓ *1819 Cutch Earthquake (M8.3)*
  - ✓ *1897 Assam Earthquake (M8.7)*
  - ✓ *1905 Kangra Earthquake (M8.6)*
  - ✓ *1934 Bihar-Nepal Earthquake (M8.4)*
  - ✓ *1950 Assam Earthquake (M8.7)*
  - ✓ *2004 Sumatra Earthquake (M9.3)*
- **Observations**
  - ✓ *India prone to Great Earthquakes*
    - ***Four M>8 events in 53 years***
  - ✓ *2001 Bhuj (M7.7), 2004 Sumatra (M9.3) and 2005 Kashmir (M7.7) to be seen in this light*

Indian Earthquakes …



Magnitude *versus* Intensity



Magnitude *versus* Intensity…

Magnitude

Richter Scale

…
6.0
7.0
8.0

Intensity

MSK Scale

V
VI
VII
VIII
IX
X
XI
XII

Structural Damage

Seismic Performance of Structures

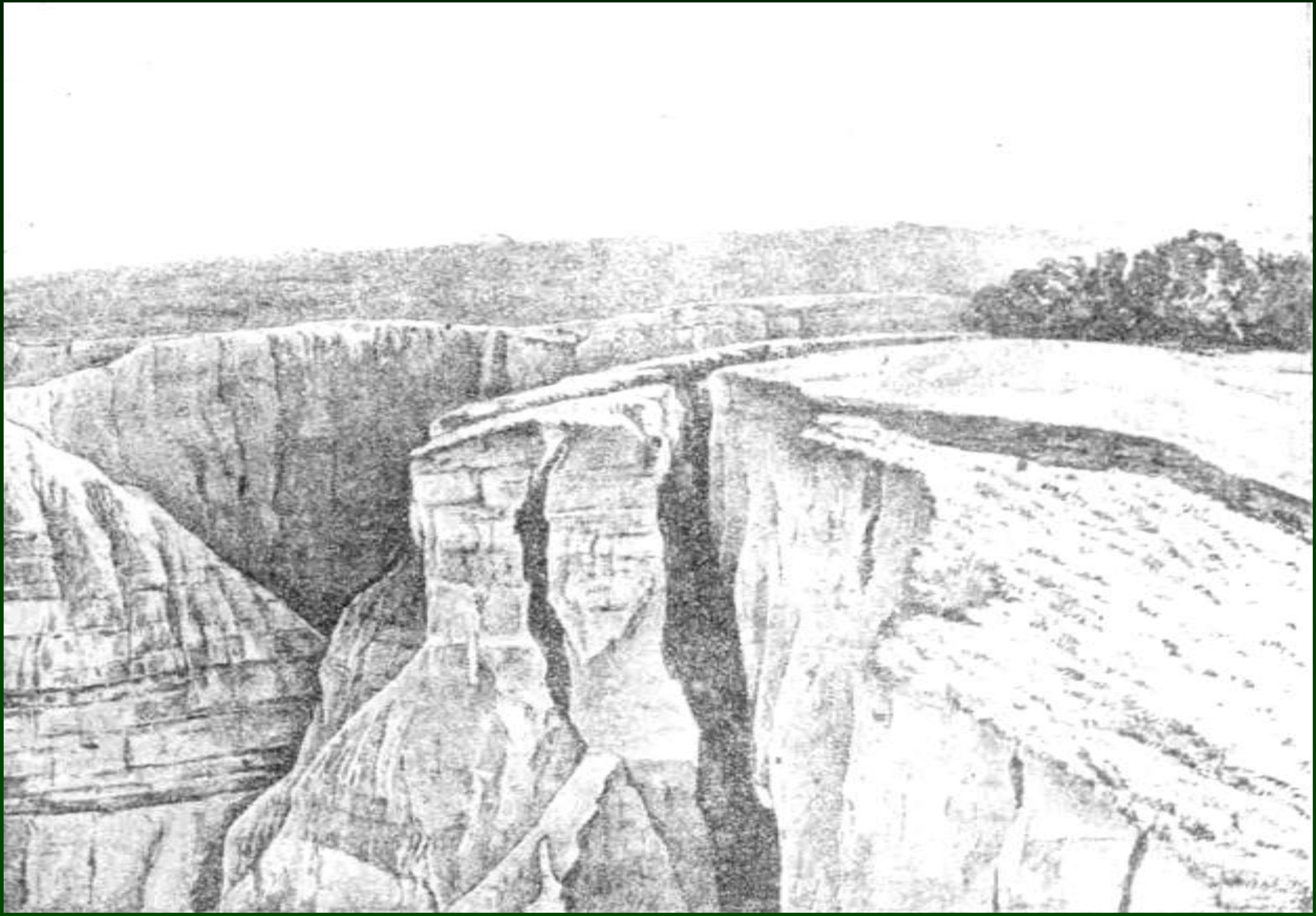
"In a way, earthquake engineering is a cartoon of other branches of engineering. Earthquake effects on structures systematically bring out the mistakes made in design and construction – even the most minute mistakes"

Emilio Rosenblueth and Nathan Newmark (1971)

1897 Assam Earthquake

- **Amongst greatest earthquakes of world**
  - ✓ *Magnitude 8.7*
  - ✓ *Mean radius of perception : 900 miles*
  - ✓ *Mean radius of area of serious damage: 300 miles*
  - ✓ *Longest dimension of meizoseismal area: 160 miles*
- **Chendarang fault**
  - ✓ *12 miles long, throws up to 35ft*
  - ✓ *Surface distortion*
- **Upthrow of objects**
- **Liquefaction in alluvial plain of Brahmputra**
- **Effects in meizoseismal area provided model for Modified Mercalli Intensity XII**

1897 Assam Earthquake…

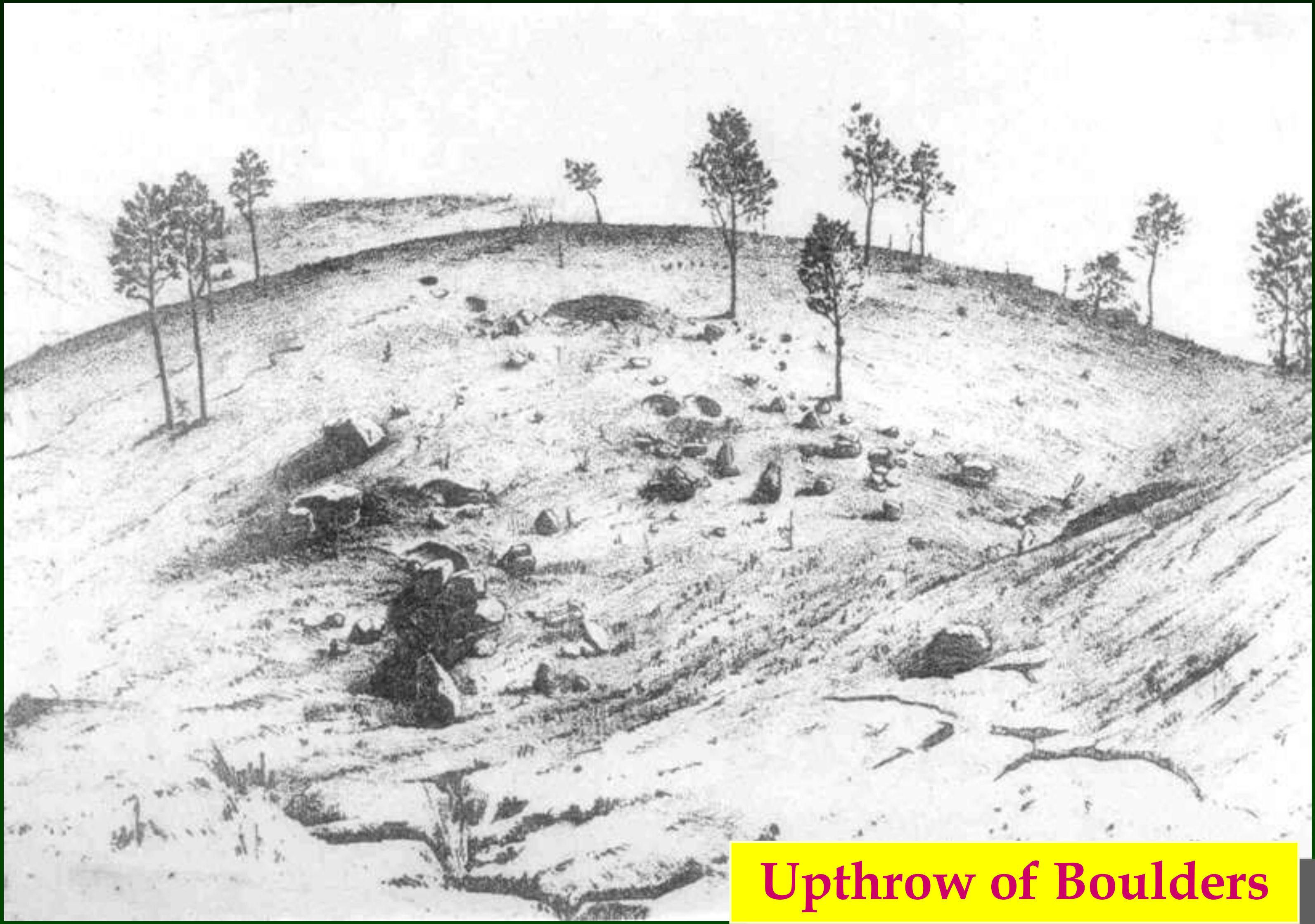


GSI Memoirs, Oldham

1897 Assam Earthquake…

GSI Memoirs, Oldham

1897 Assam Earthquake…



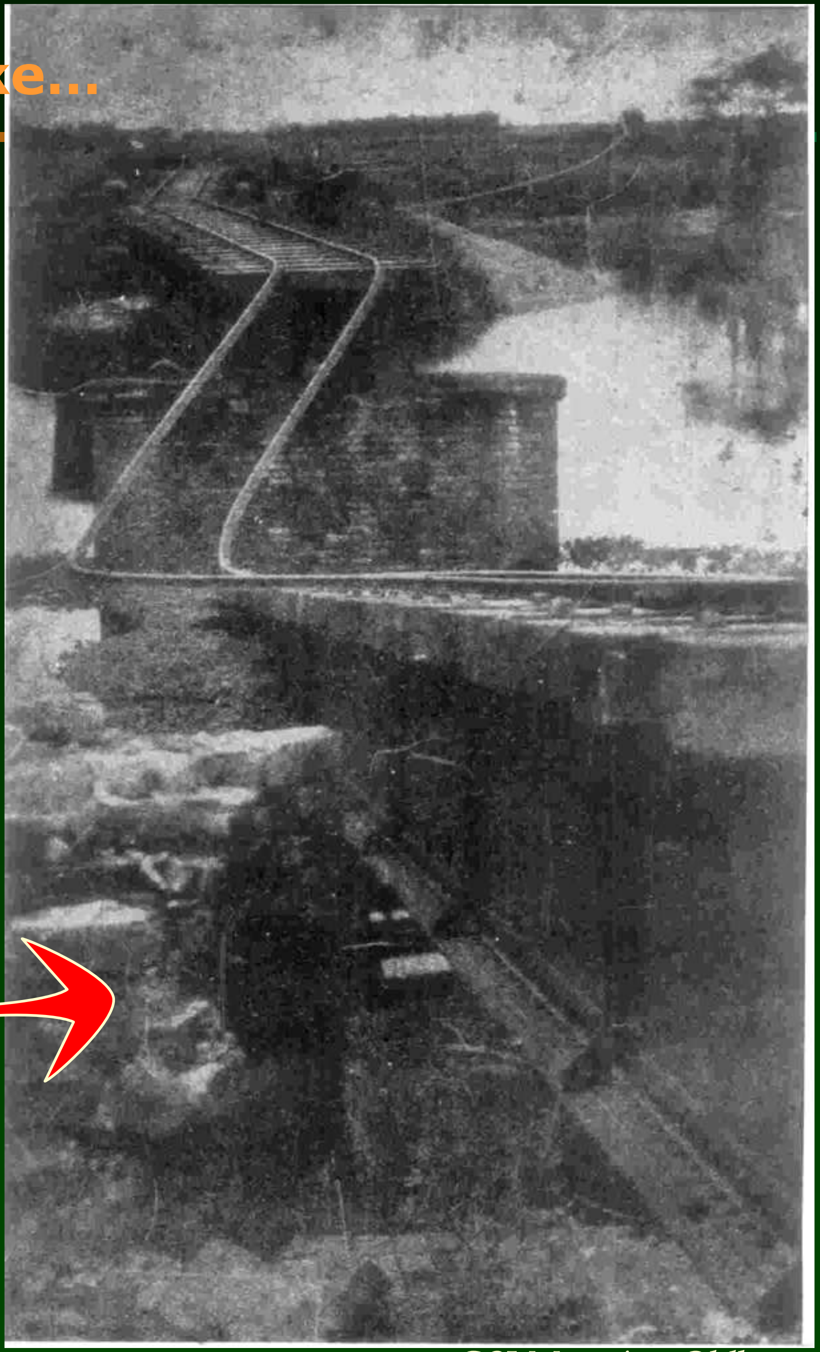
GSI Memoirs, Oldham

1897 Assam Earthquake...

Bent Rails at Rangapara, Tezpur-Balipara Tramway

GSI Memoirs, Oldham

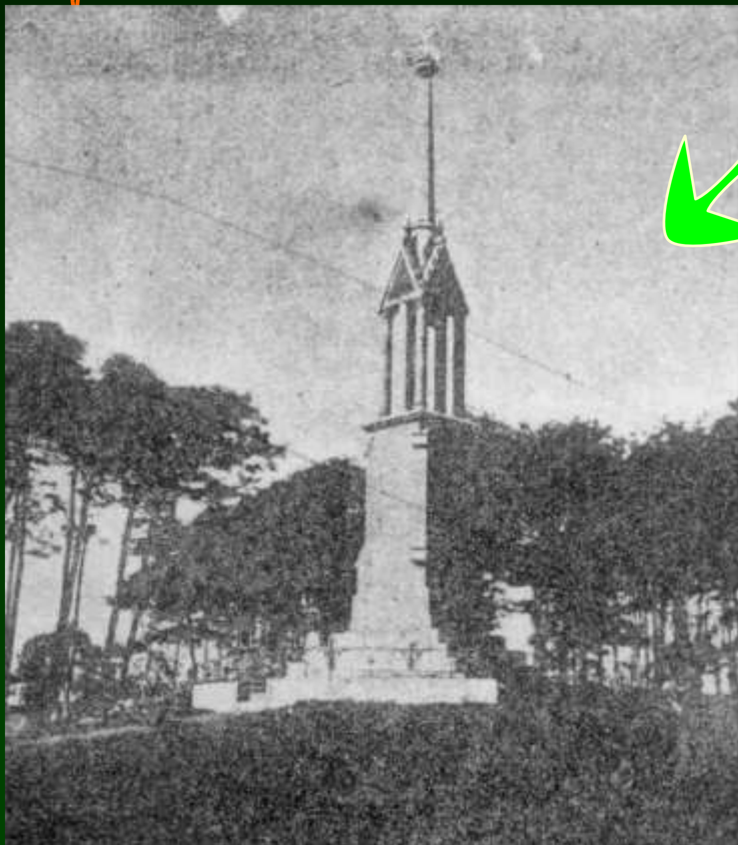
1897 Assam Earthquake...

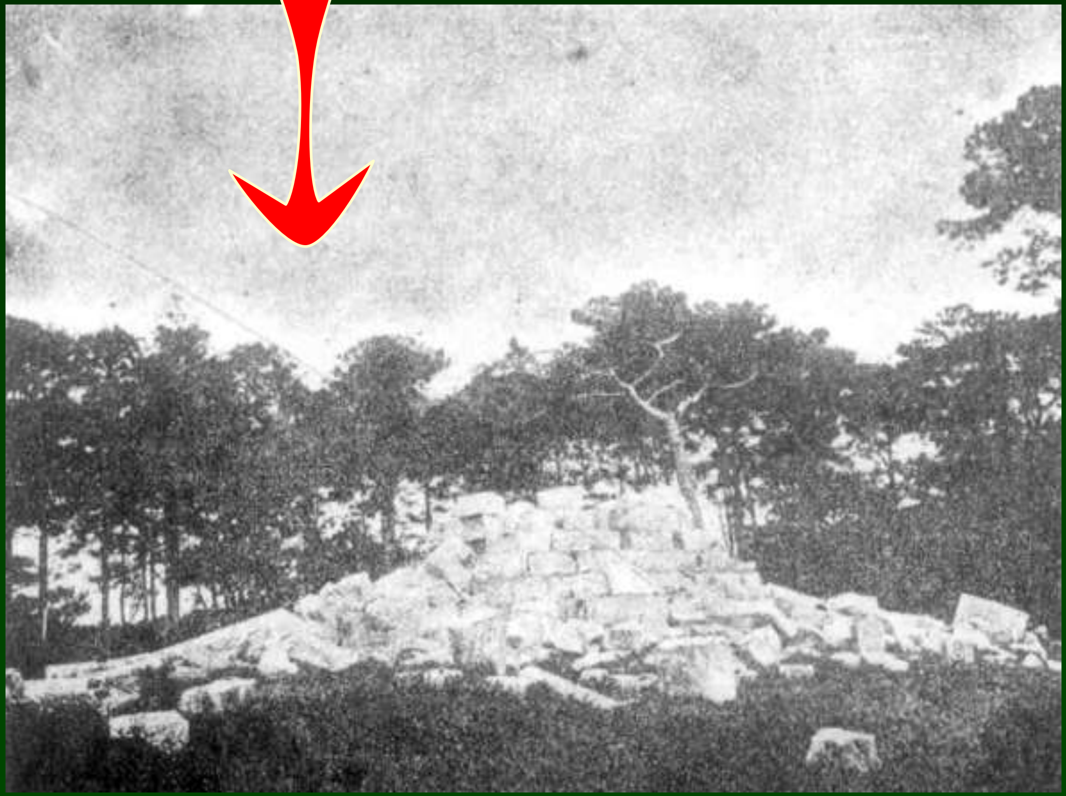


Manshai Bridge

GSI Memoirs, Oldham

1897 Assam Earthquake…





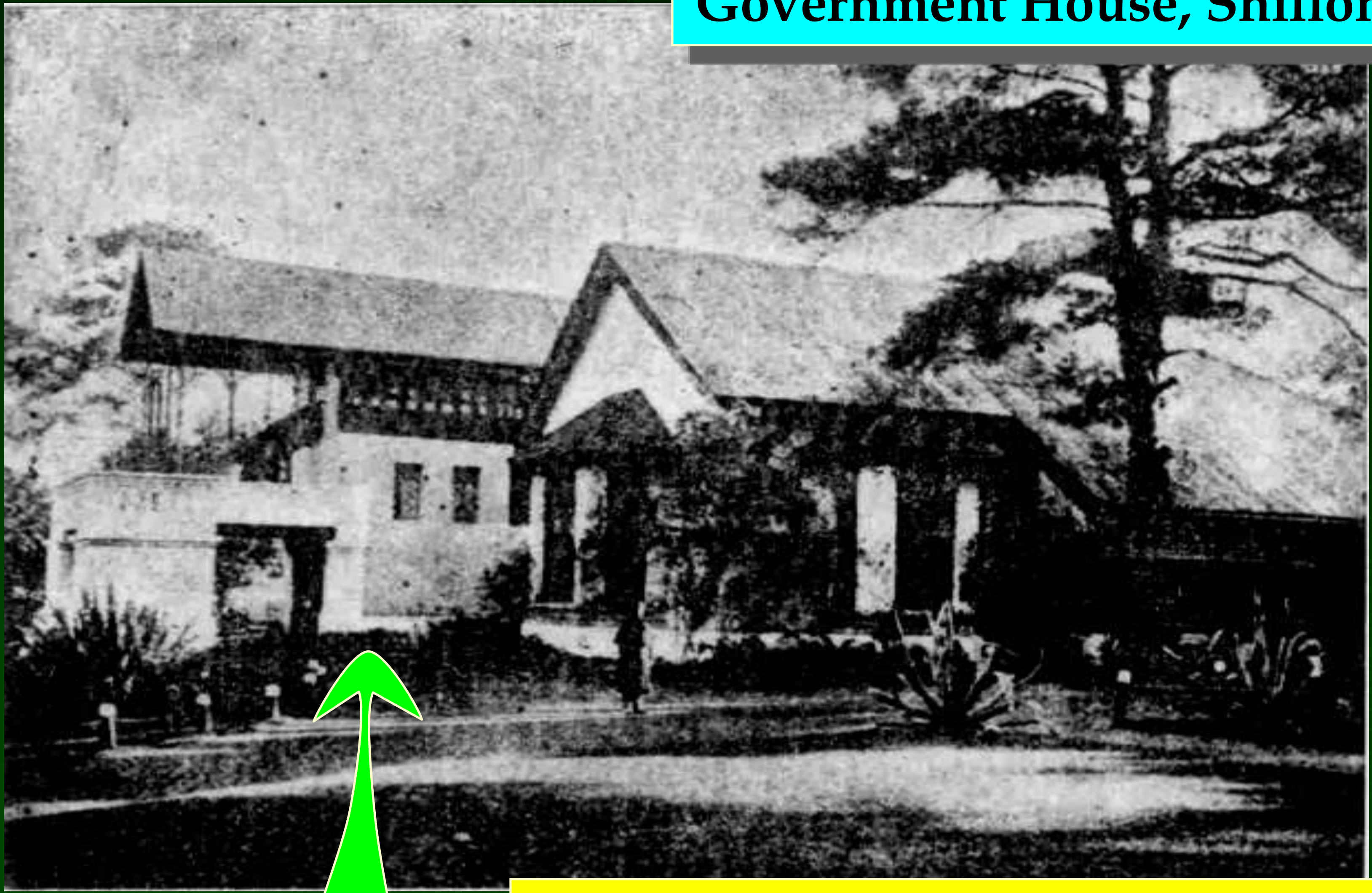
GSI Memoirs, Oldham

1897 Assam Earthquake...

GSI Memoirs, Oldham

1897 Assam Earthquake…

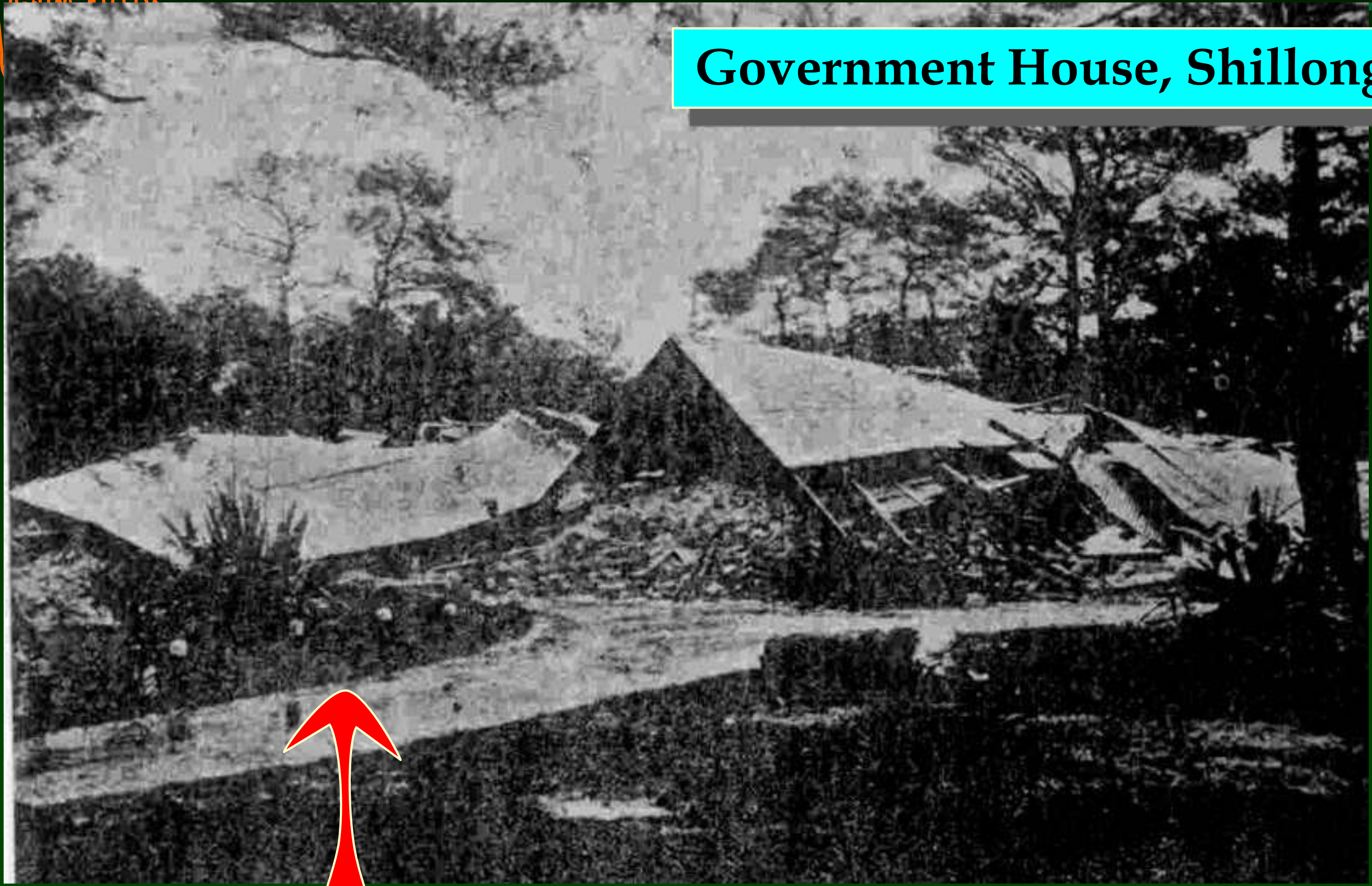
Government House, Shillong



before **the 1897 Assam Earthquake**

GSI Memoirs, Oldham

1897 Assam Earthquake…



Government House, Shillong

after **the 1897 Assam Earthquake**

GSI Memoirs, Oldham

1897 Assam Earthquake:

- **Stone Buildings**
  - ✓ *Leveled to ground*
- **Ekra-built Buildings**
  - ✓ *Wooden framework with walls of san grass covered in plaster*
  - ✓ *About half the buildings leveled to ground*
  - ✓ *Significant damage due to stone chimneys*
- **Plank Buildings**
  - ✓ *Wooden framework covered with planks*
    - ***No damages***
  - ✓ *Led to development of "Assam-Type" houses*
  - ✓ *Current housing status*

1905 Kangra Earthquake

- **4 April 1905**
- **Magnitude 8.6**
- **About 19,000 lives lost**
  - ✓ *Very low population density*
- **Maximum Intensity X around Kangra**
  - ✓ *Intensity at Dehradun VIII*
  - ✓ *Intensity between Kangra and Dehradun up to VI/VII*
  - ✓ *Initially thought of as two different earthquakes*

1934 Bihar-Nepal Earthquake

- **15 January 1934**
  - ✓ *Around 2:13pm*
- **Deaths**
  - ✓ *7253 in India and 3400 in Nepal*
- **Magnitude 8.4**
- **Maximum intensity X in about 80×20 miles**
  - ✓ *Intensity X also at Munger and in Kathmandu Valley (about 100 miles from main damage area)*

1934 Bihar-Nepal Earthquake…

- **Slump Belt**
  - ✓ *190 mile long, up to 40 miles wide*
  - ✓ *Excessive liquefaction*
  - ✓ *Buildings slumped into alluvium*
  - ✓ *Subsidence of embankments (roads/rails)*
  - ✓ *Uplift of bottoms in tanks*
  - ✓ *Fissures / emissions of sand and water*
    - ***one fissure : 15’ deep, 30’ wide, 900’ long!***

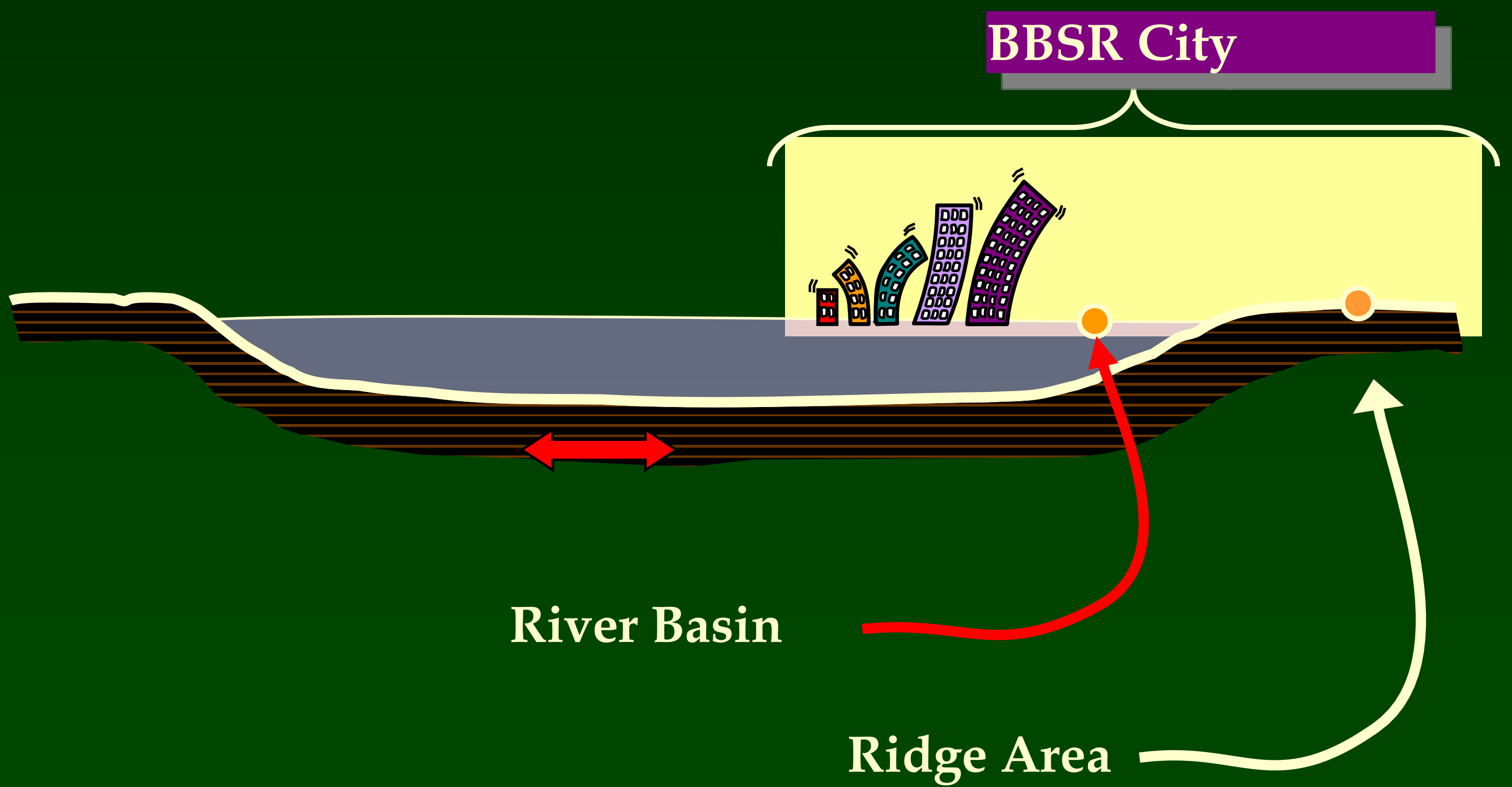
1934 Bihar-Nepal Earthquake…

- More damage and strong shaking at Munger and in Kathmandu valley in 1934 Bihar-Nepal Earthquake.

Isoseismal of 1934 earthquake
~ 130 km x 30 km area intensity X
(I to X Mercalli)

Looking Closely …

- **Effect of River Basin**
  - ✓ *More pronounced for structures with natural periods close to that of soil deposits*



1950 Assam-Tibet Earthquake

- **Magnitude 8.7**
- **Epicenter near Rima (Tibet)**
- **Maximum intensity XII**
- **Aftershocks M 7.0**
  - ✓ *More property loss in Assam than in 1897 earthquake*
- **Massive landslides**
  - ✓ *Blockade of rivers*
  - ✓ *Later, led to floods as dams burst one by one*

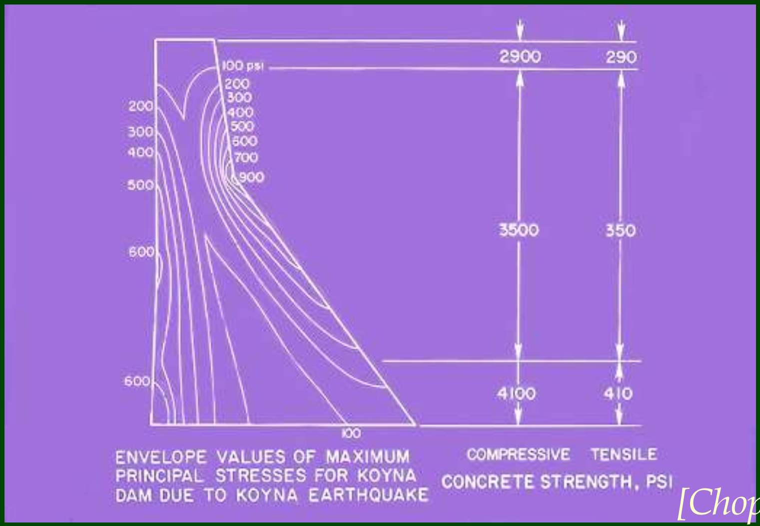
Some Recent Indian Earthquakes

Some Recent Indian Earthquakes

- **Moderate Earthquakes** *(M~6.5)*
  - ✓ *1967 Koyna*
  - ✓ *1988 Bihar-Nepal*
  - ✓ *1991 Uttarkashi*
  - ✓ *1993 Killari*
  - ✓ *1997 Jabalpur*
  - ✓ *1999 Chamoli*
  - ✓ *2011 Sikkim*
- **Large Earthquake** *(M~7.7)*
  - ✓ *2001 Bhuj*
  - ✓ *2005 Kashmir*
- **Great Earthquake** *(M~9.3)*
  - ✓ *2004 Sumatra*

1967 Koyna Earthquake

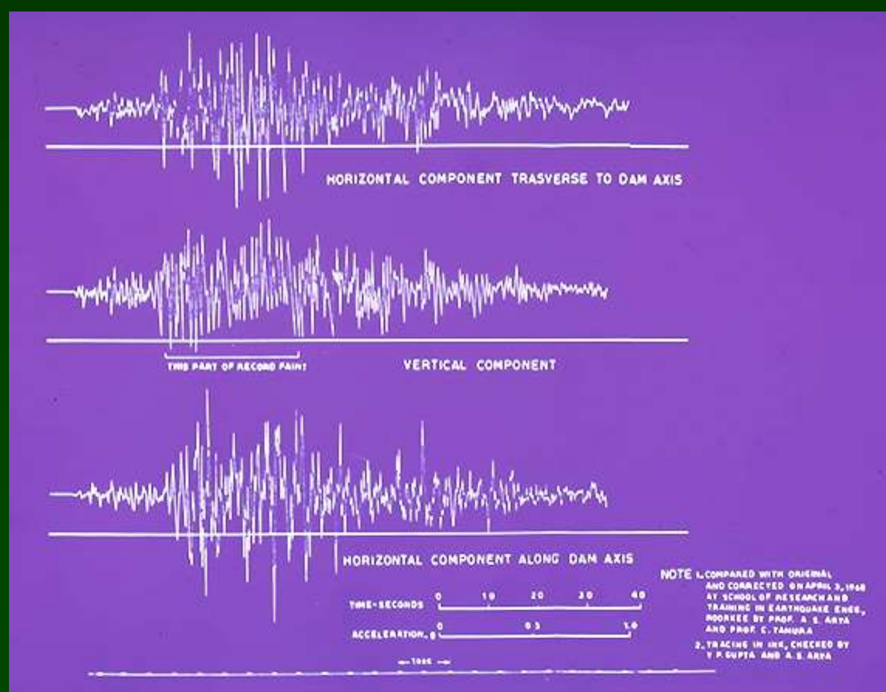
- **Magnitude ~ 6.5**
- **Maximum Intensity VIII**
- **Deaths: 200; Injuries: 1500**
- **Area considered non-seismic (Zone I of the prevalent zone map)**
- **Damage to dam, houses, other structures**



[Chopra, 2008]

1967 Koyna Earthquake

- **One strong motion record**
  - ✓ *In the gallery at mid-height of the dam*
  - ✓ *Peak vertical acceleration 0.3g*
  - ✓ *Peak horizontal acceleration 0.45g & 0.39g*
  - ✓ *Record not very reliable (faint)*



[Chopra, 2008]

1967 Koyna Earthquake…

- **Koyna Dam**
  - ✓ *103 m high concrete gravity type*
  - ✓ *Designed for 5%g (static load)*
  - ✓ *Damaged, but not disastrous*
  - ✓ *Retrofitted with new buttresses*
- **Reservoir-Induced Seismicity**
- **Changes in seismic zone map**

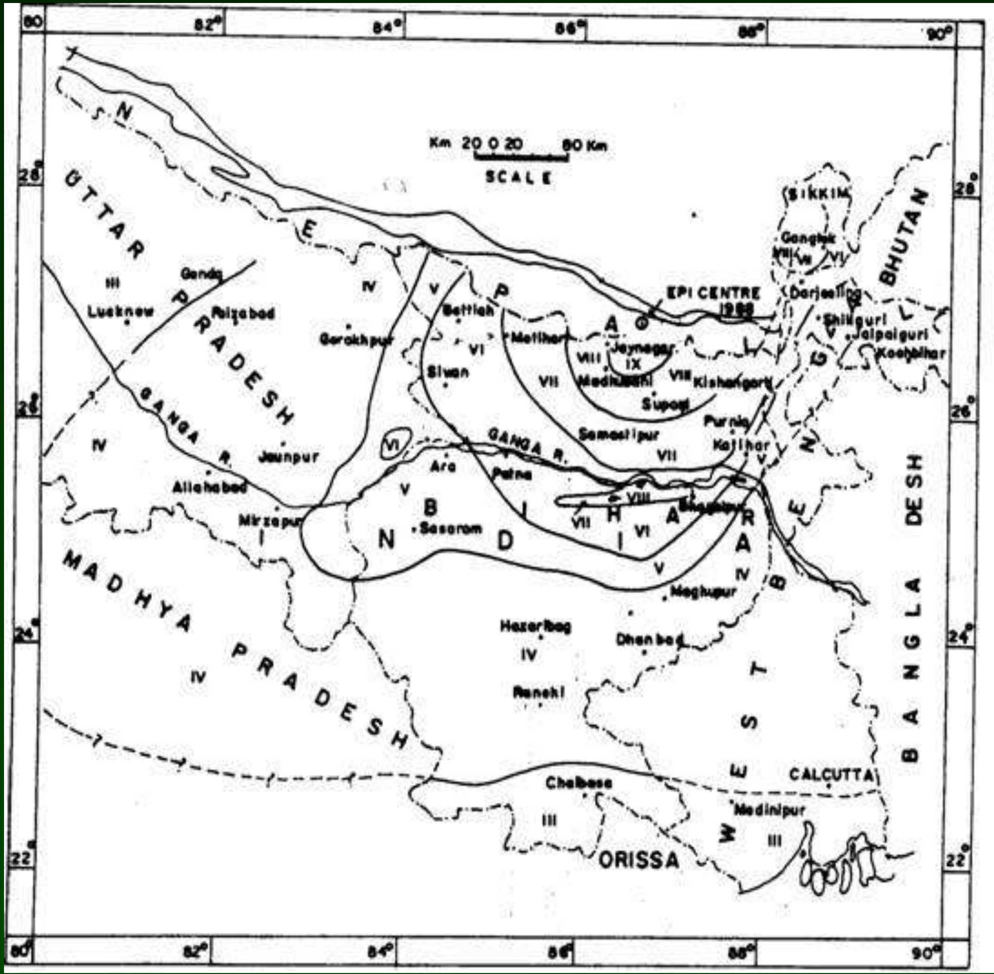
[Chopra, 2008]

1988 Bihar-Nepal Earthquake

- **21 August 1988 at 4:39am**
- **Magnitude 6.6**
- **Maximum Intensity VIII**
- **Deaths: 1004; Injuries: 16000**
  - ✓ *Summer time; Most people outdoors*
- **Same damage trend in Munger and Kathmandu as in 1934 earthquake**
- **Damage to buildings and bridges**
  - ✓ *Shaking induced*

1988 Bihar-Nepal Earthquake…

- **Liquefaction**
  - ✓ *Nominal*
  - ✓ *Damage to embankments*
- **Damage in Darjeeling and Sikkim**

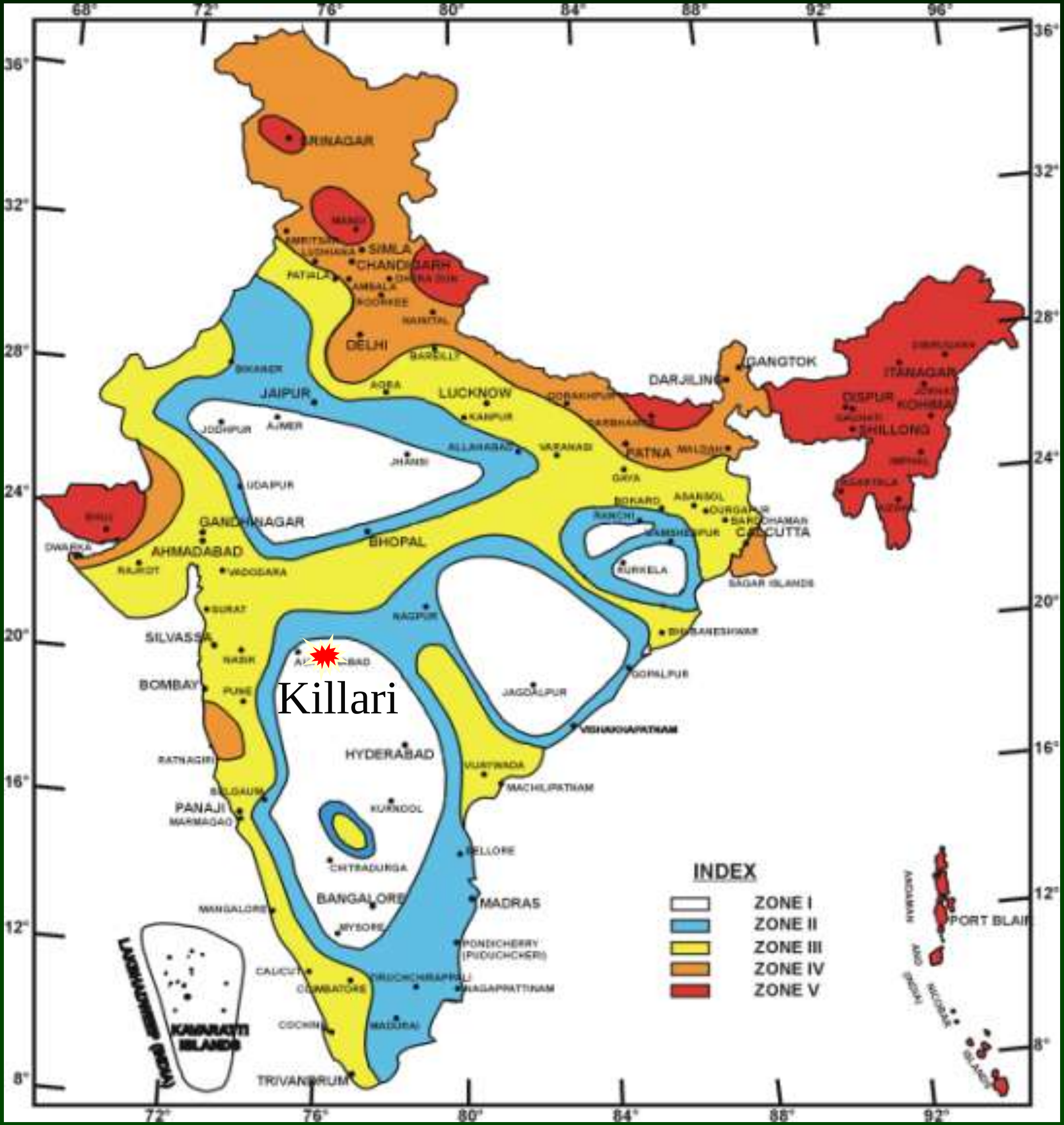


Isoseismal of 1988 earthquake

1993 Killari Earthquake

- **Magnitude 6.4**
- **Maximum Intensity VIII-IX**
- **Death toll ~10,000**
  - ✓ *Up to 35% in some villages*
  - ✓ *Earlier estimates up to 30,000*
- **Surface rupture**
  - ✓ *Intra-plate shallow focus earthquake*
- **Located in Seismic Zone I of the prevalent zone map!**
- **Astonishingly good rescue and relief**
  - ✓ *After 2 days*

1993 Killari Earthquake...



Location of Killari Earthquake and the prevalent Seismic Zone Map

1993 Killari Earthquake…

- **Damage in a limited area**
  - ✓ *20 km×20 km*
  - ✓ *No towns*
  - ✓ *Few modern structures*
- **Major cause of casualty in houses**
  - ✓ *Stone masonry in mud mortar*
  - ✓ *Very heavy roof*

1993 Killari Earthquake…

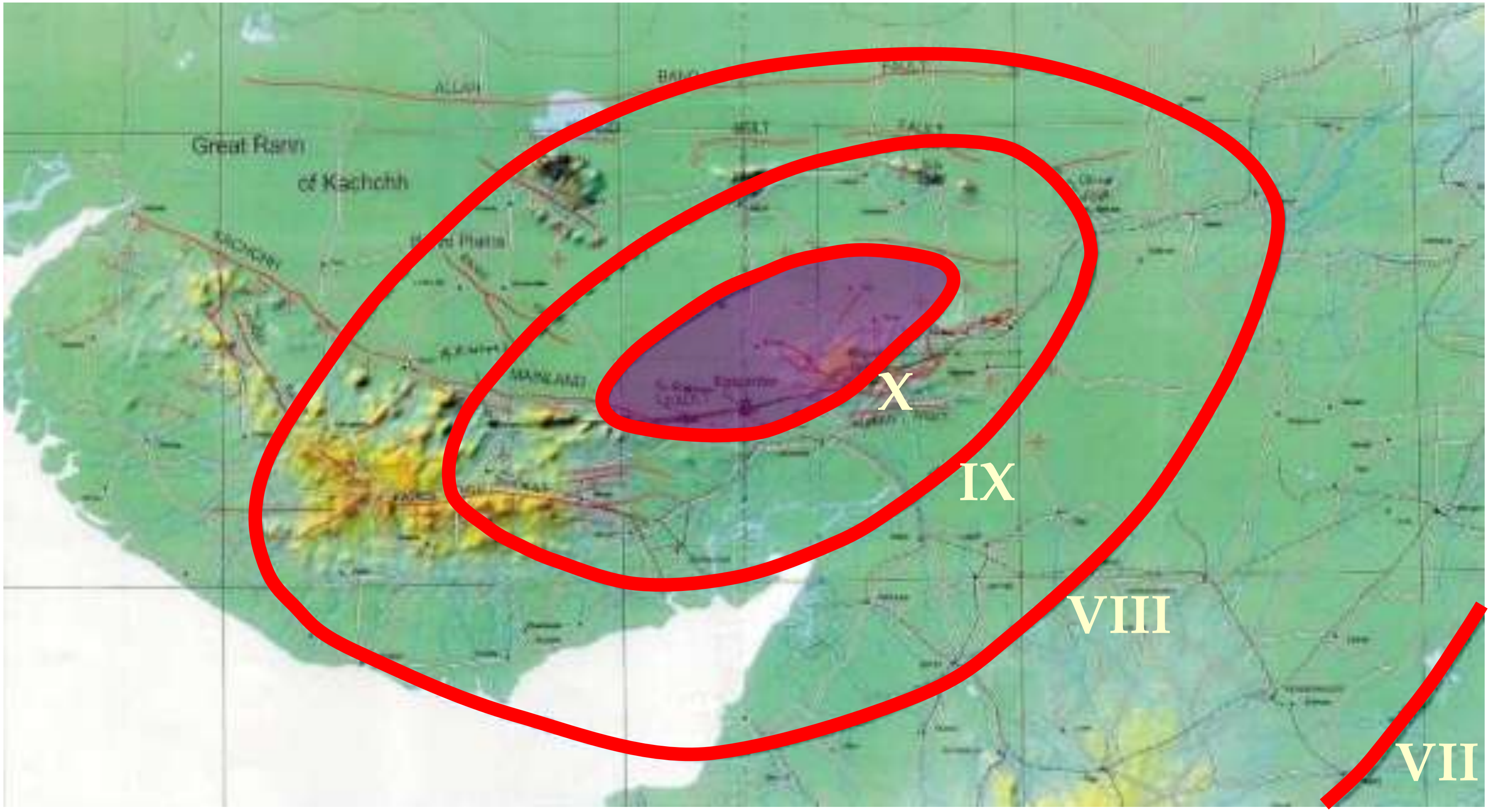
Collapse of Stone Masonry Houses

The experience of 2001 Bhuj EQ

2001 Bhuj Earthquake

- **Magnitude 7.7**
- **Maximum MSK Intensity X**
  - ✓ *Bhuj in Seismic Zone V of Indian seismic map*
- **8.46 am on 26 January 2001**
  - ✓ *More than 13,805 dead; 1,67,000 injured*
  - ✓ *300,000 houses destroyed; 700,000 houses damaged*
- **Numerous multistorey RC buildings collapsed**
  - ✓ *130 such buildings collapsed in Ahmedabad ~225km from epicenter (Seismic Zone III)*

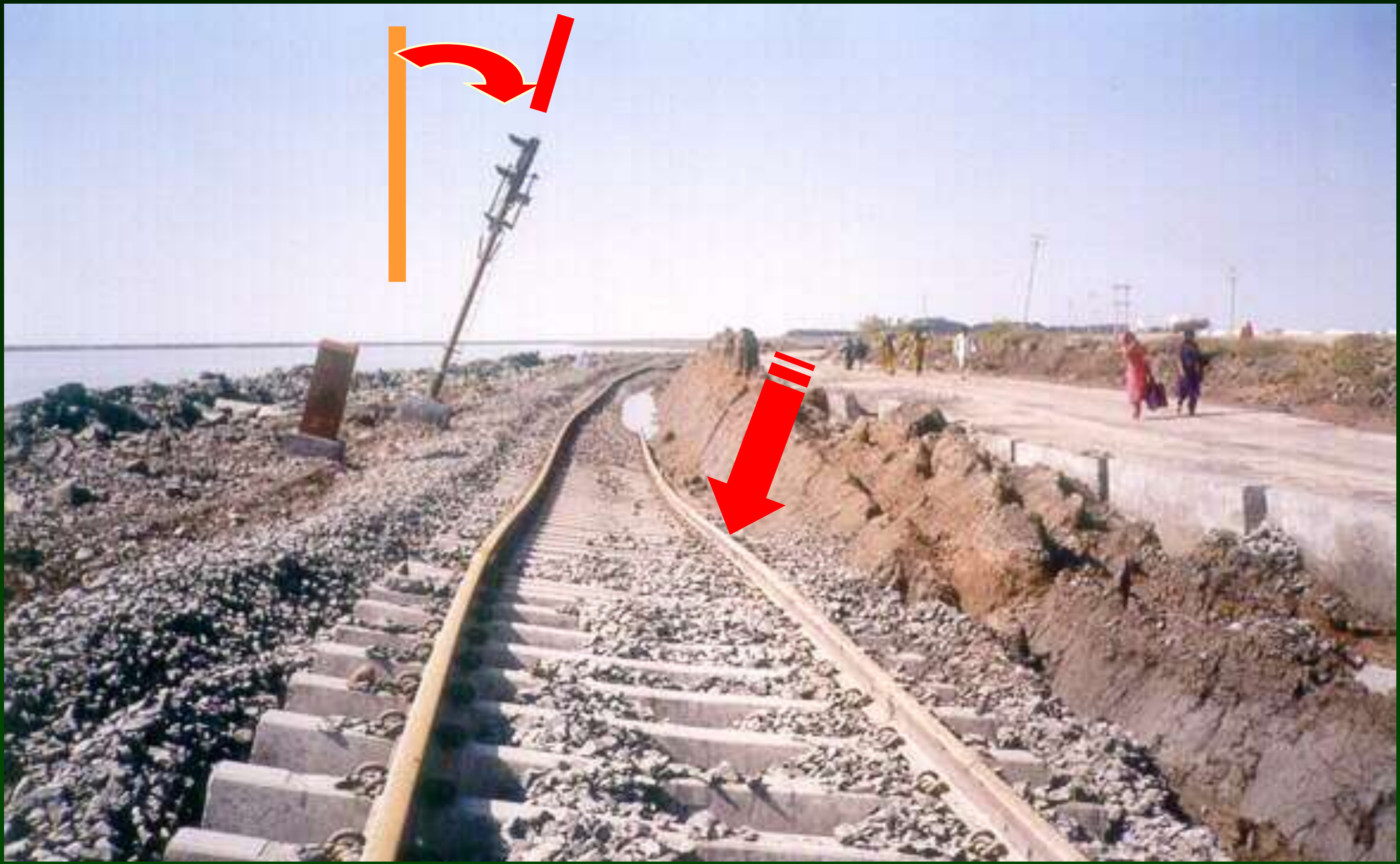
2001 Bhuj Earthquake…



Liquefaction...

Liquefaction...

Slope failures...



Earth dams

2001 Bhuj Earthquake…

The Damage…

@ cities

The Damage...

...stark contrasts

230mm wide columns

- *Maximise built-up area*
- *Vertical & plan Irregularities*

Floating Columns

Damage due to Floating Columns

Lack of Connection


ભચાઉ
भचाउ
BHACHAU

Schools...

Precast School Buildings in Gujarat
Many Collapsed

Elevated Water Tanks

Elevated Water Tanks…

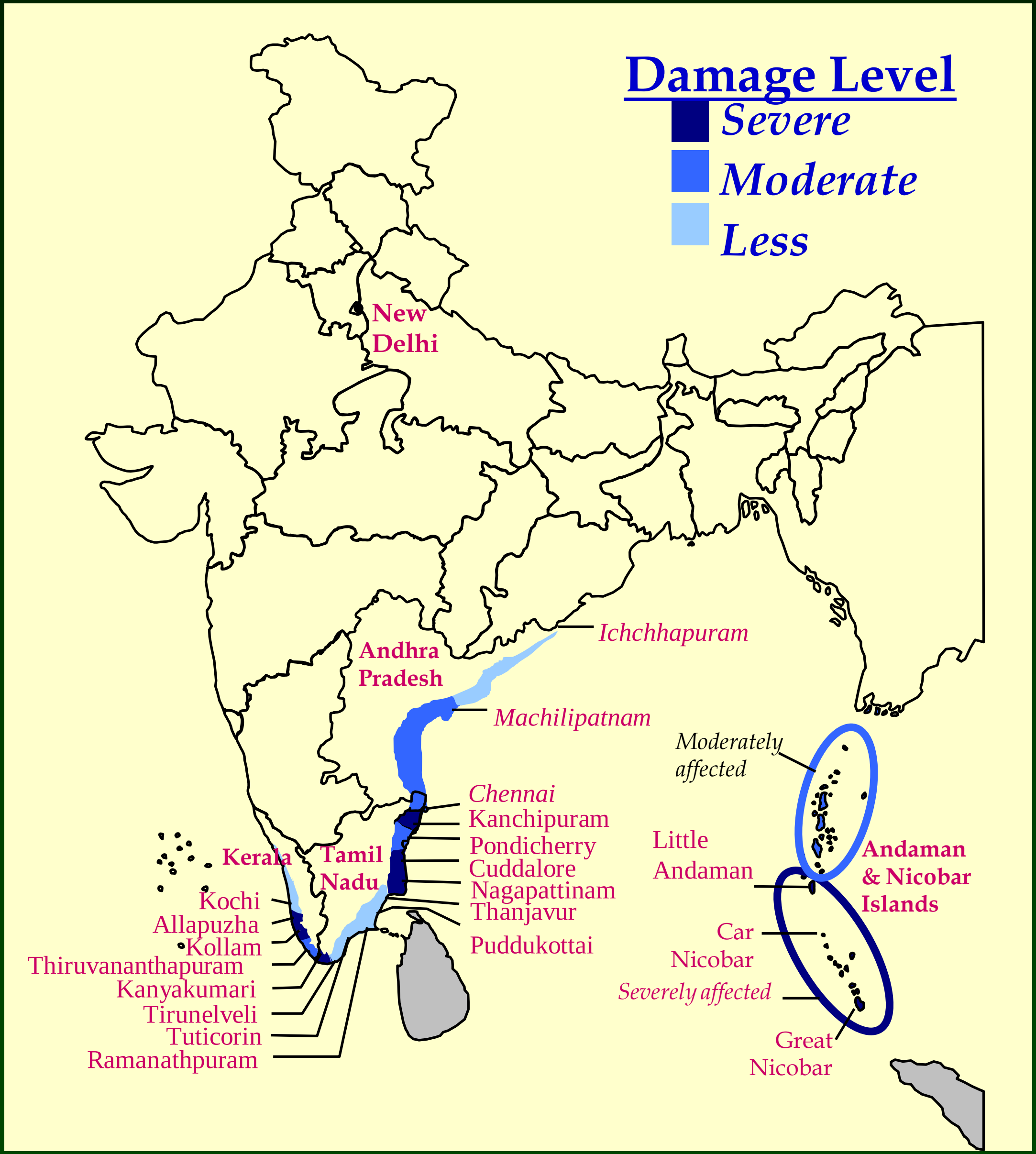
Shaft Supported Tank at Chobari

Elevated Water Tanks…

Frame Supported Tank at Manfera

2004 Sumatra Earthquake

- **Magnitude 9.3**
- **Massive tsunami in a number of countries**
- **Damages due to:**
  - ✓ *Tsunami*
  - ✓ *Earthquake Shaking*
- **Landscape changes**



Damage Level
Severe
Moderate
Less
New Delhi
Andhra Pradesh
Ichchhapuram
Machilipatnam
Moderately affected
Chennai
Kanchipuram
Pondicherry
Cuddalore
Nagapattinam
Thanjavur
Puddukottai
Little Andaman
Andaman & Nicobar Islands
Car Nicobar
Severely affected
Great Nicobar
Kerala
Tamil Nadu
Kochi
Allapuzha
Kollam
Thiruvananthapuram
Kanyakumari
Tirunelveli
Tuticorin
Ramanathpuram


AN01
C1595

2005 Kashmir Earthquake

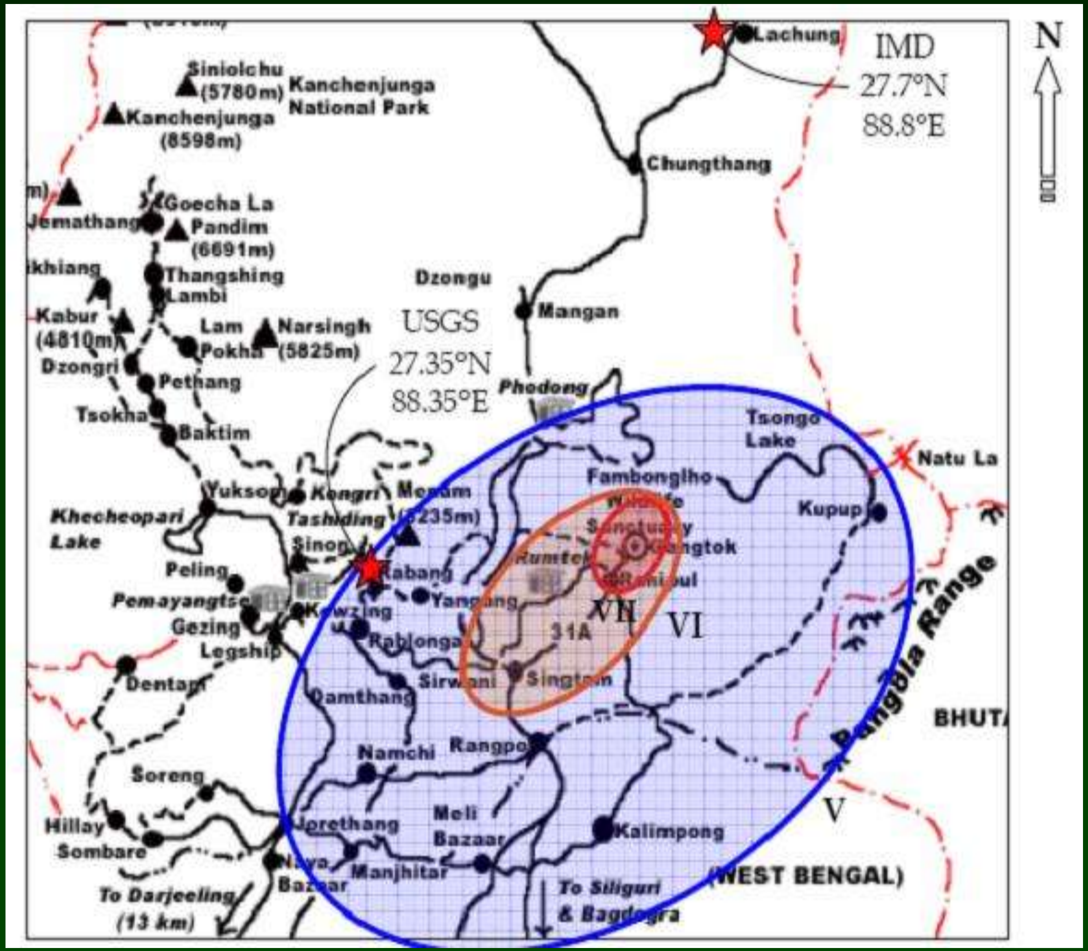
- **Magnitude 7.6**
- **In area shown as moderate seismicity in Pakistan zone map; as zone IV in Indian zone map**
- **The most disastrous earthquake on the Indian sub-continent**
  - ✓ *~13,000 dead in India, ~ 53,000 dead in Pakistan*
  - ✓ *~80,000 injured*
- **Maximum intensity: VIII-IX in Pakistan, VIII in India**
  - ✓ *Large deaths caused by poor constructions*

www.bbc.co.uk

www.bbc.co.uk

2006 Sikkim earthquake (Mw 5.7)

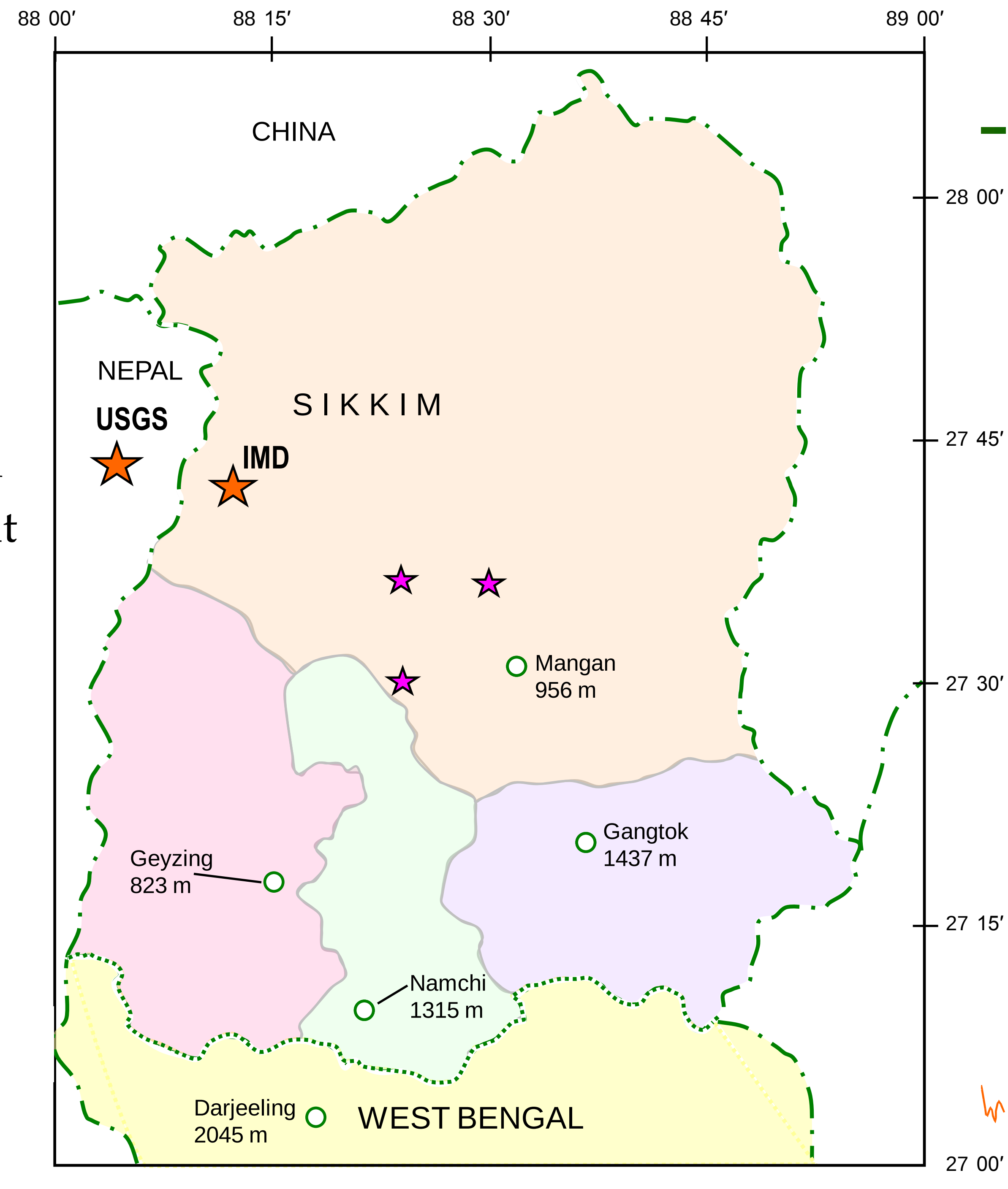
- Max. intensity VII
- Killed ~ 2 soldiers



Isoseismal of 2006 earthquake

2011 Sikkim Earthquake

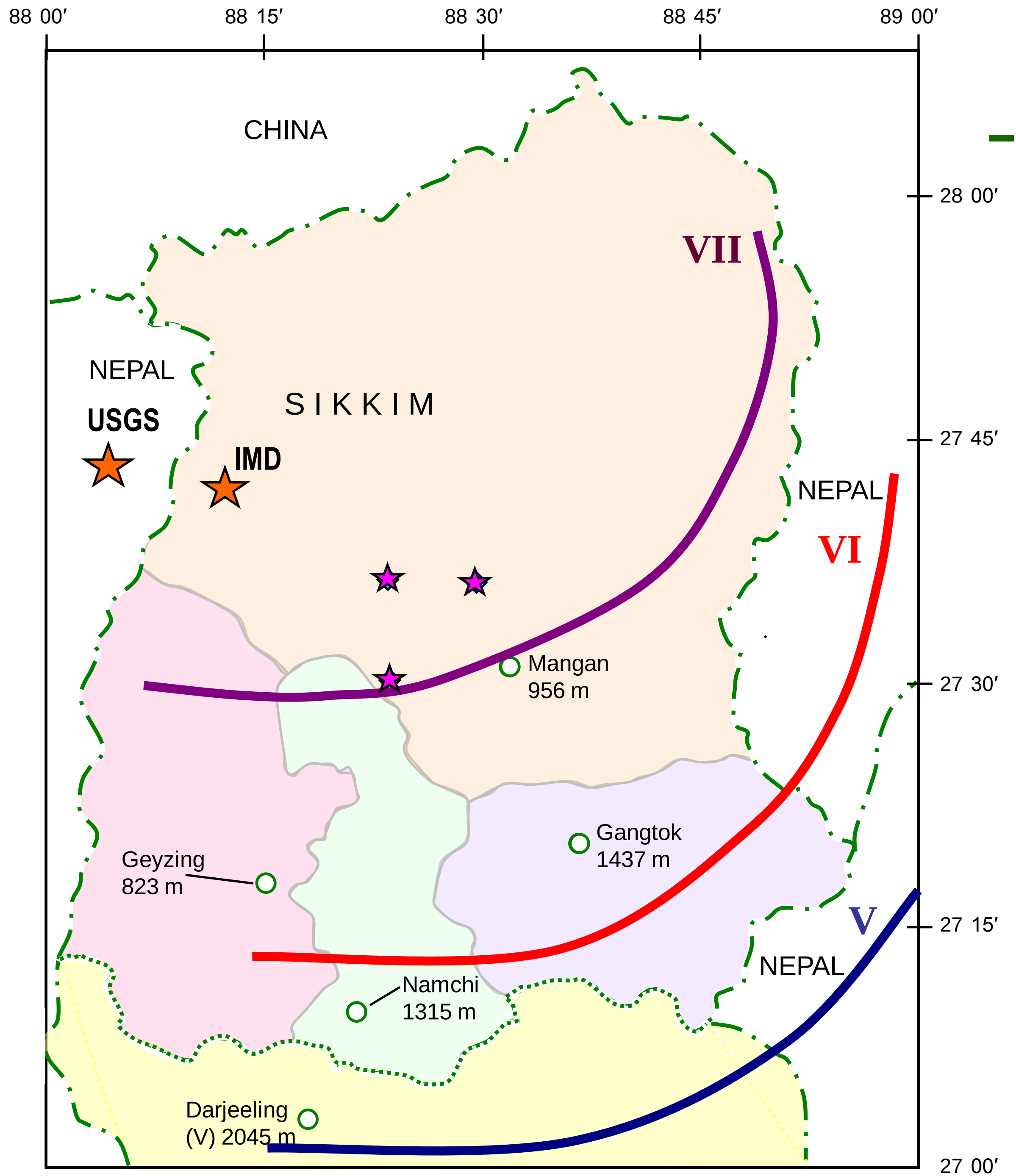
- M6.9 India-Nepal Border
- 18, Sept. 2011 at 6:10 pm
- 68 km NW of Gangtok at a depth of 19.7 km (USGS)
- Tremor lasted for 30-40 seconds
- 3 Aftershock- M5.7, M5.1 and M4.6



Statistics

- Total death toll : **136 in India**
  - **112 in Sikkim, 15 in West Bengal, 9 in Bihar**
  - **80% of total death in North District**
- 19 deaths in neighboring countries (Nepal, Tibet, Bhutan)
- Total estimated property loss: ~ **1 lakh crore**
- More than 300 landslides spreading over approx. 2400 sq. km area
  - **Roads connecting major towns got disrupted**

Shaking Intensity on MSK Scale



A Distant View …

A Closer View …

And… without technological inputs??

Performance of Buildings…

Failure of column reinforcement

5- storey building at Lumshey Bastey

Performance of Buildings…

9- storey building at Balwakhani

Performance of Buildings…

Collapsed building colliding with adjacent one at Balwakhani

After the Earthquake …

Demolition of 9- storey building at Balwakhani

Retrofitting of the adjacent building

Retrofitting of Buildings…

Balwakhani, Gangtok (March 2012)

Retrofitting of Buildings…

Gangtok, Balwakhani

Performance of Buildings…

- Secretariat building
  - constructed in 1979

Failure of concrete block masonry cladding

Damage to state secretariat building at Tashiling, Gangtok

Performance of Buildings…

Splicing Near Beam-Column Joint

Damage to state secretariat building at Tashiling, Gangtok

Performance of Buildings…

Offset in Beam

Damage to state secretariat building at Tashiling, Gangtok

Performance of Buildings…

- Mild steel bar as main reinforcement
- Poor quality of concrete

Damage to State secretariat building at Tashiling, Gangtok

Performance of Buildings…

- Poor quality hollow concrete blocks for infill walls

Damage to State secretariat building at Tashiling, Gangtok

After the Earthquake …

Demolition of Historical Tashiling Secretariat, Gangtok

Performance of Buildings…

Construction of Annexe to Tashiling Secretariat, Gangtok

Performance of Buildings…

Construction of Annexe to Tashiling Secretariat, Gangtok

Performance of Buildings…

Construction of Annexe to Tashiling Secretariat, Gangtok

Performance of Buildings…

Construction of Annexe to Tashiling Secretariat, Gangtok

Performance of Buildings…

Construction of Annexe to Tashiling Secretariat, Gangtok

Aerial view of Chungthang

Performance of Buildings…

Pan-caking failure of school cum residential building at Chungthang

Performance of Buildings…

Collapse of appendage in a 3 storey building at Chungthang

Performance of Buildings…

- Out-of-Plane Failure of Infill
- Severe damage in column of ground floor

Severe damage in a 5 storey building at Chungthang

Performance of Buildings…

Out-of-Plane Failure of Infill in SMIT buildings

Performance of Buildings…

Out-of-Plane Failure of Infill of SDM Quarter at Chungthang

Performance of Buildings…

Column failure due to poor detailing in government quarter at Chungthang

Performance of Buildings…

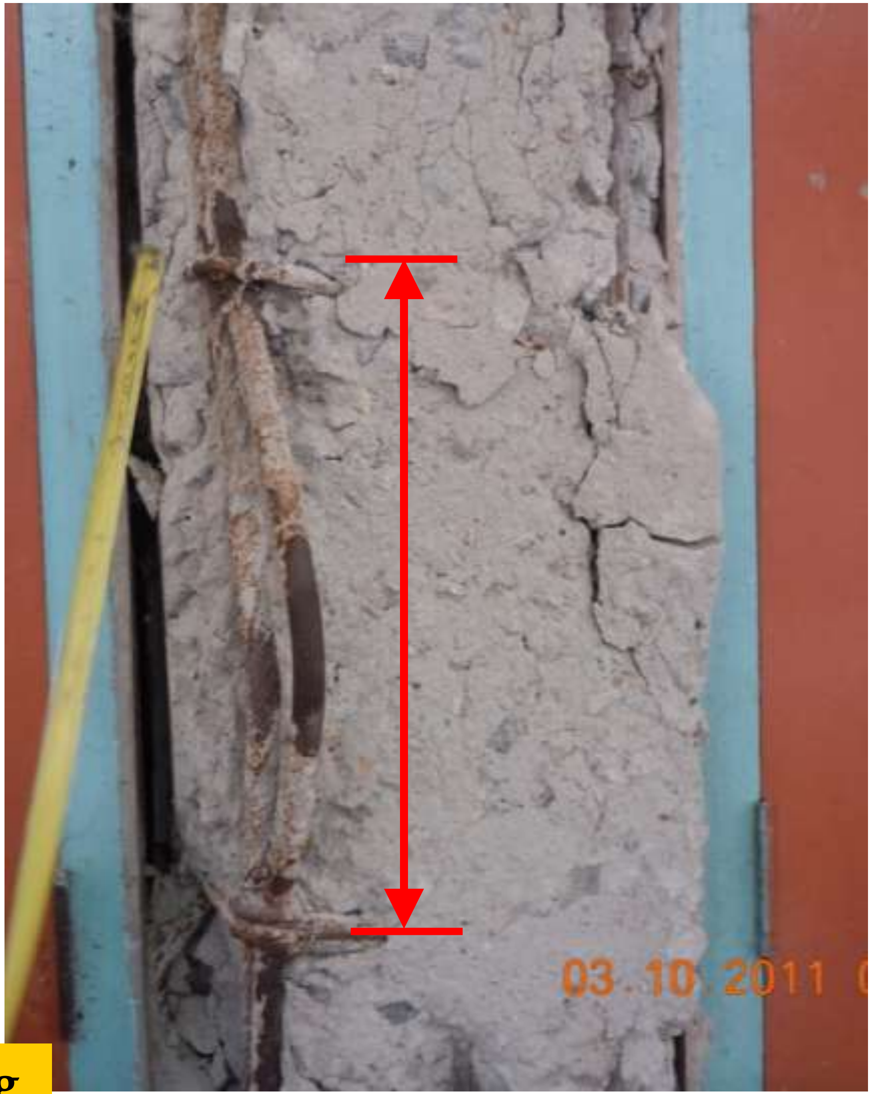
- **Inadequate confining reinforcement**
- **Cold Joint – *Topi Construction***

Column failure at government quarter building at Chungthang

Performance of Buildings…

Large Spacing b/w Stirrups

> 250 mm



Failed column of a building in Chungthang

Performance of Buildings…

Opening of
Stirrup; 90 hook

Failed column of a building in Chungthang

Performance of Buildings…

Minor damages in Police headquarter building at Gangtok

Performance of Buildings…

- Out of plane failure of inner walls
- Shear cracks in exterior walls

L Shaped Hotel building, suffered considerable damage at Lachung

Performance of Buildings…

Minor cracks in walls in Holly cross school at Tadong, Gangtok

Performance of Buildings…

Minor cracks and delamination of plaster in staff quarters of TNA at Gangtok

Performance of Buildings…

- **Older Block (60 year old)**
  - Ikra infill
  - RC frame
  - **Negligible damage**

Tashi Namgyal Academy at Gangtok

Performance of Buildings…

Timber wall

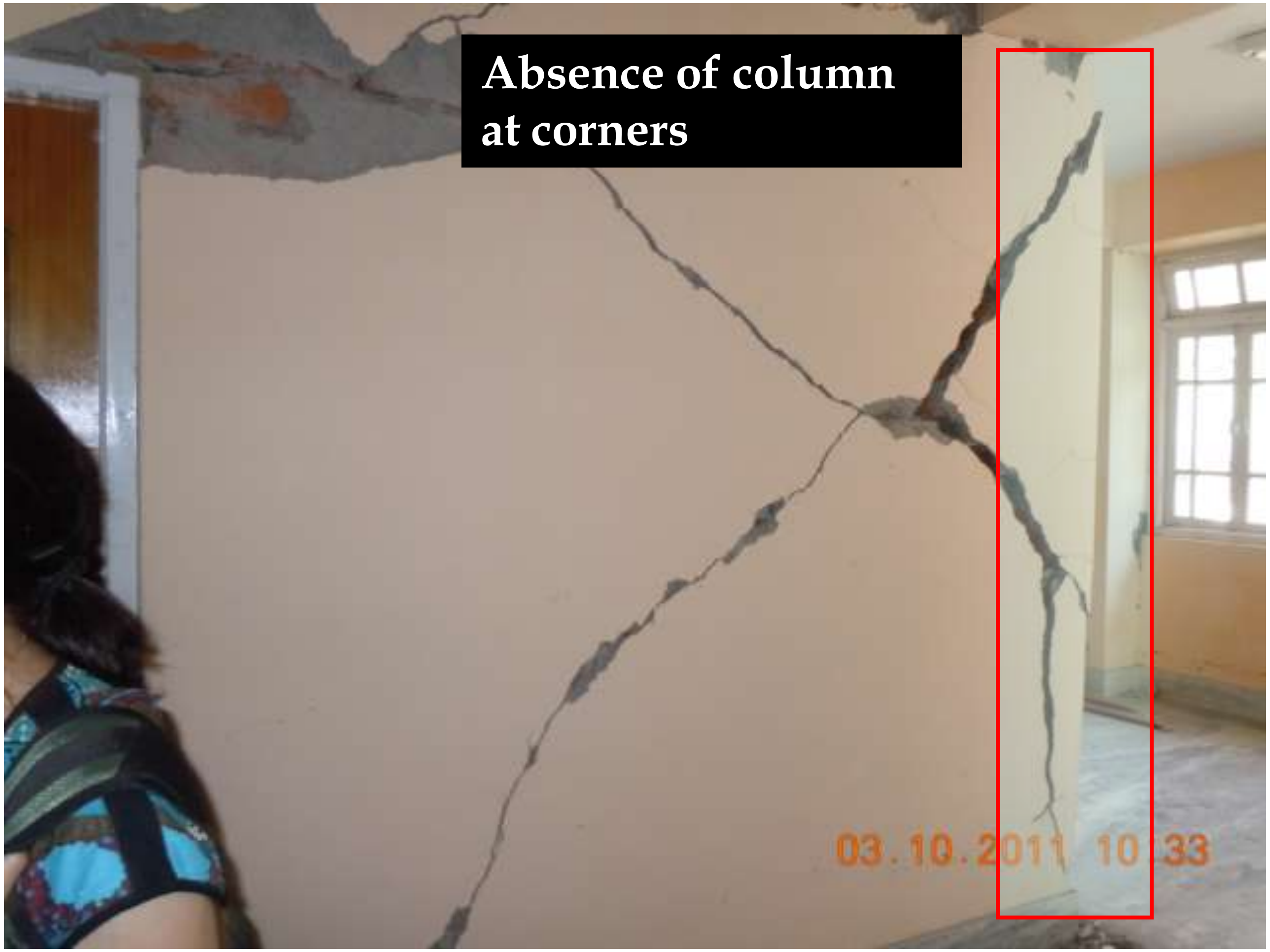
Brick on edge

Half-brick thick wall

Concrete blocks

In-situ concrete

Performance of Buildings…



Shear failure and detachment of wall at corner in a building, Chungthang

Performance of Buildings…

Damage to exterior unsupported wall on the cantilever projections in two of the buildings at Chungthang

Materials in Practice

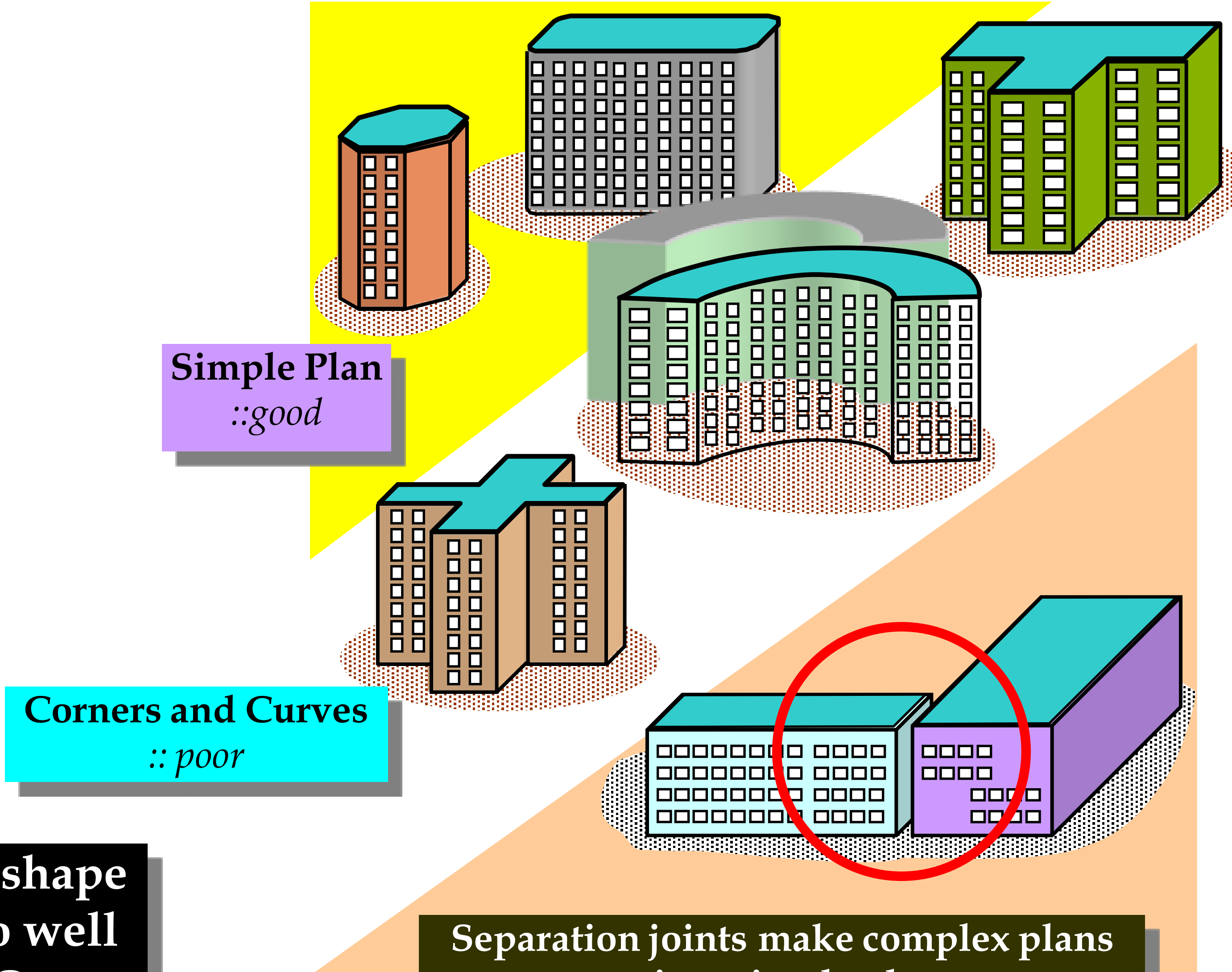
Quality control of materials

- Thin concrete blocks
- Poorly graded aggregate
- Rounded aggregate
- Poor quality of sand
- No control on w/c ratio in concrete
- No control over mixing of concrete

Earthquake Resistant RC Frames

Seismic Configuration

- Shape

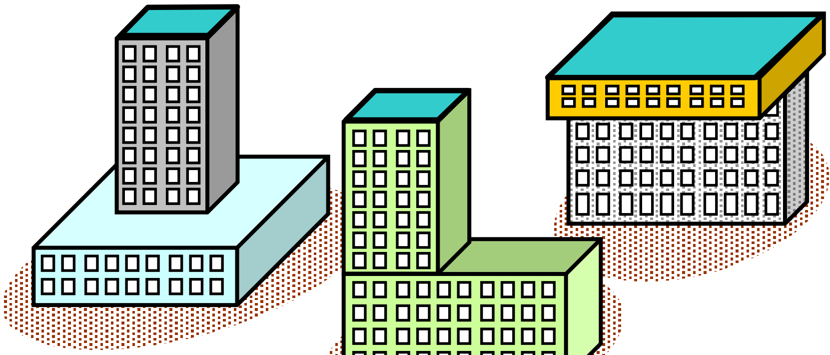


Simple plan shape buildings do well during EQs

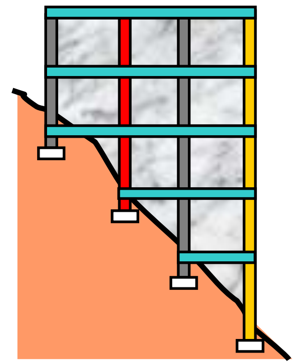
Separation joints make complex plans into simple plans

Seismic Configuration…

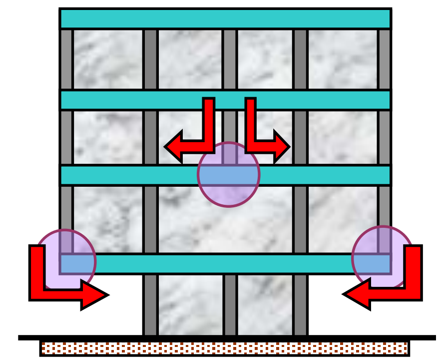
- Indirect load path



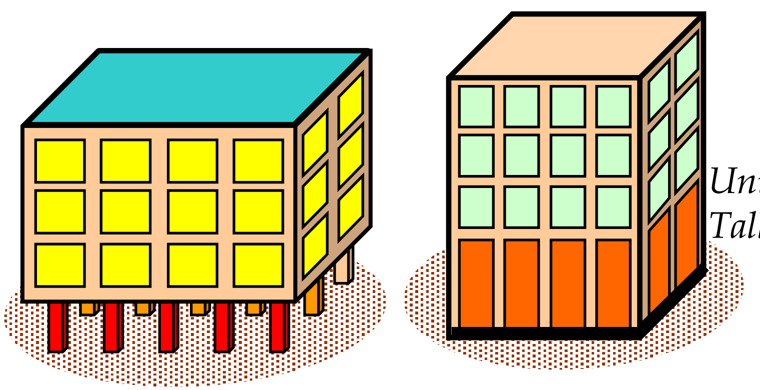
Setbacks



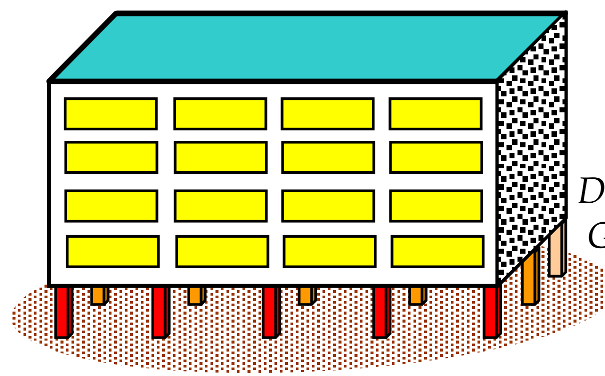
Slopy Ground



Hanging or Floating Columns



Weak or Flexible Storey

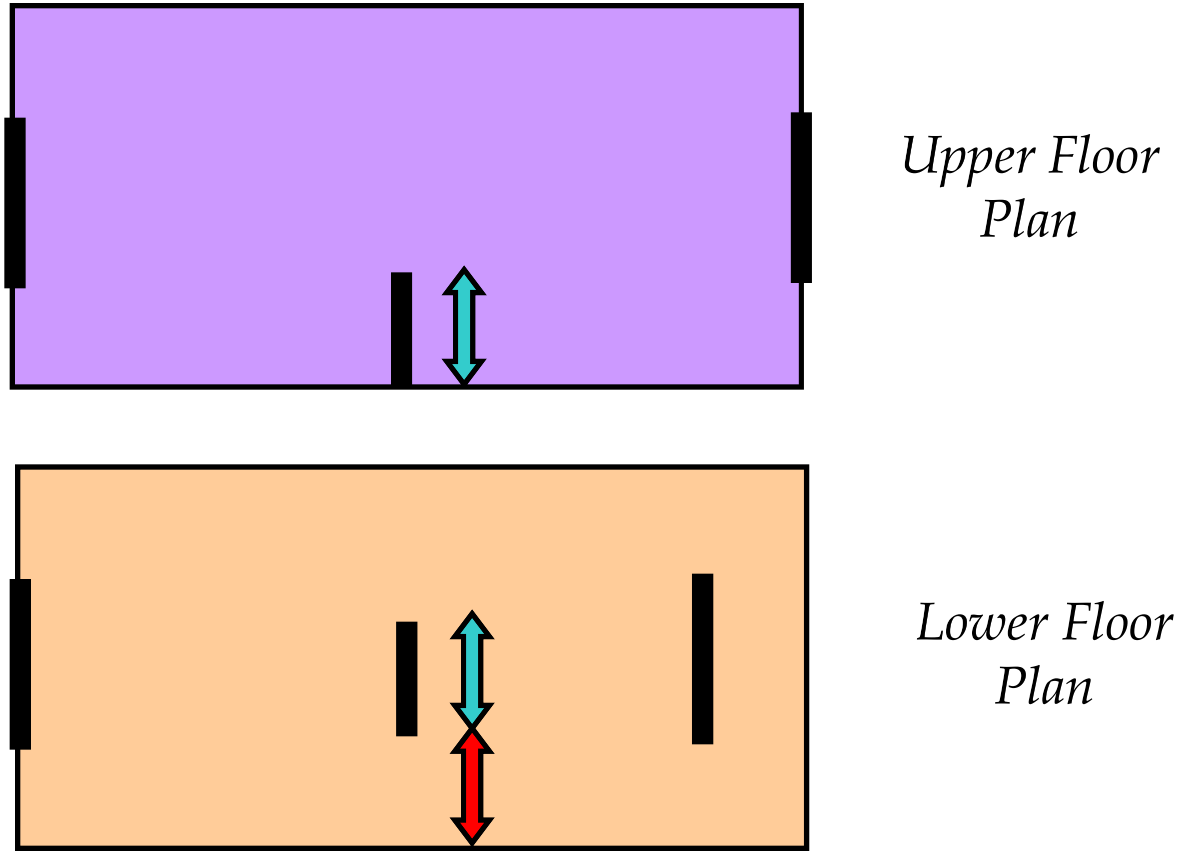


Discontinuing Structural Members

Sudden deviations in load transfer path along height lead to poor performance

Building Configuration…

- In-plane Discontinuity in Lateral Load Resisting Elements



Importance of Configuration

- Henry Degenkolb,
  a noted Earthquake Engineer of USA

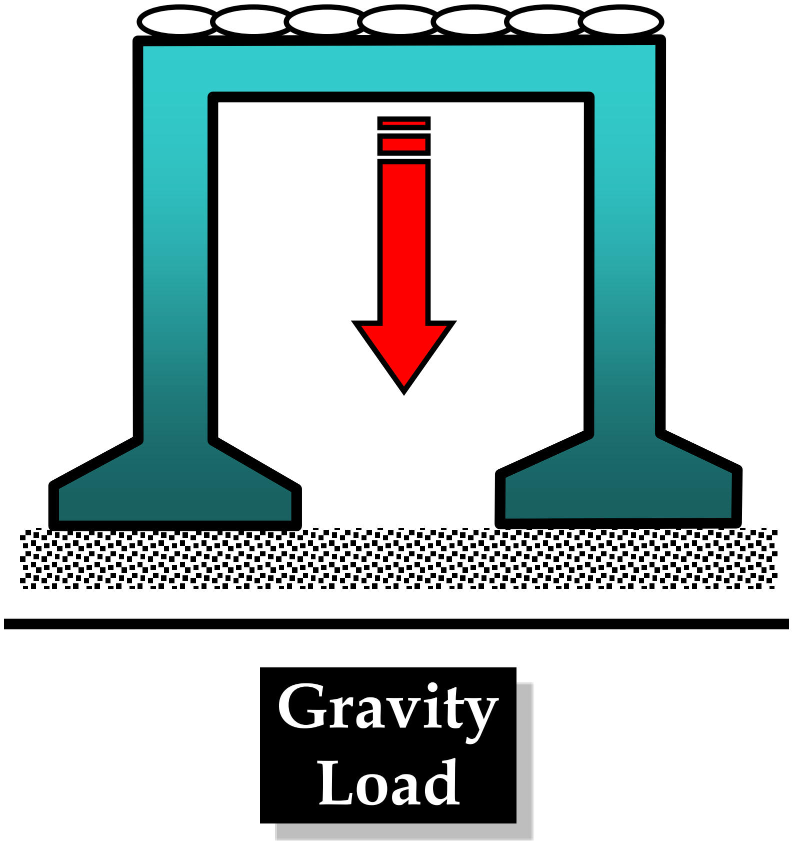
  - Aptly summarised the intense importance of seismic structural configuration in his words:

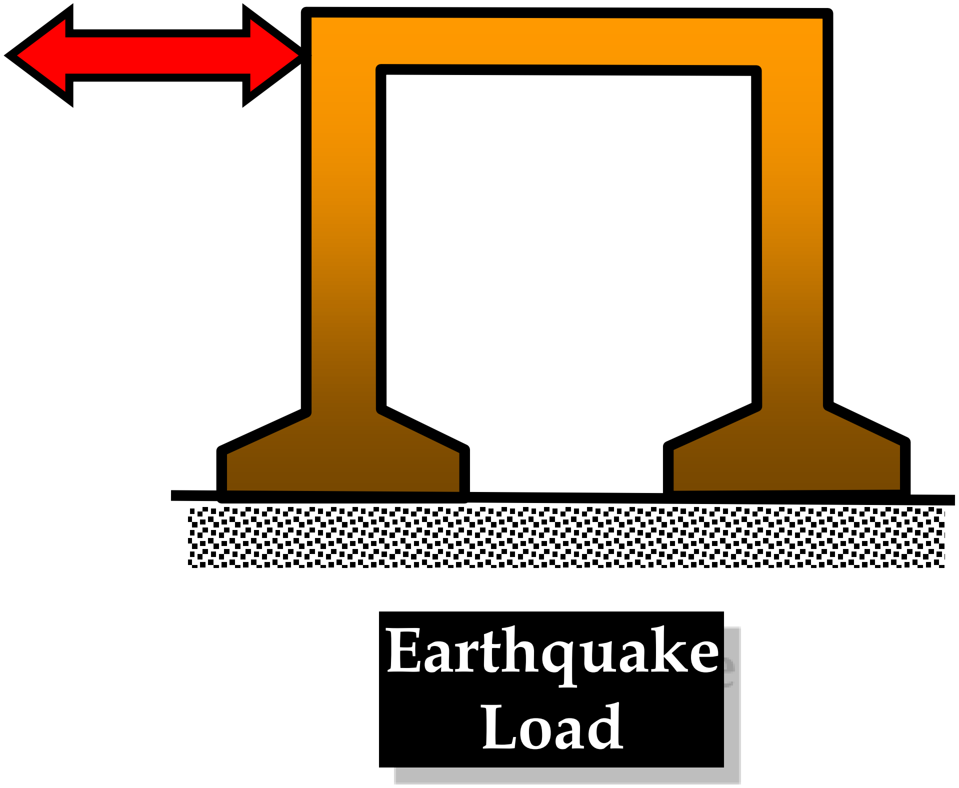
"If we have a poor configuration to start with,
all the engineer can do is to provide a band-aid
- improve a basically poor solution as best as he can.

Conversely, if we start-off with a good configuration and reasonable framing system, even a poor engineer cant harm its ultimate performance too much."

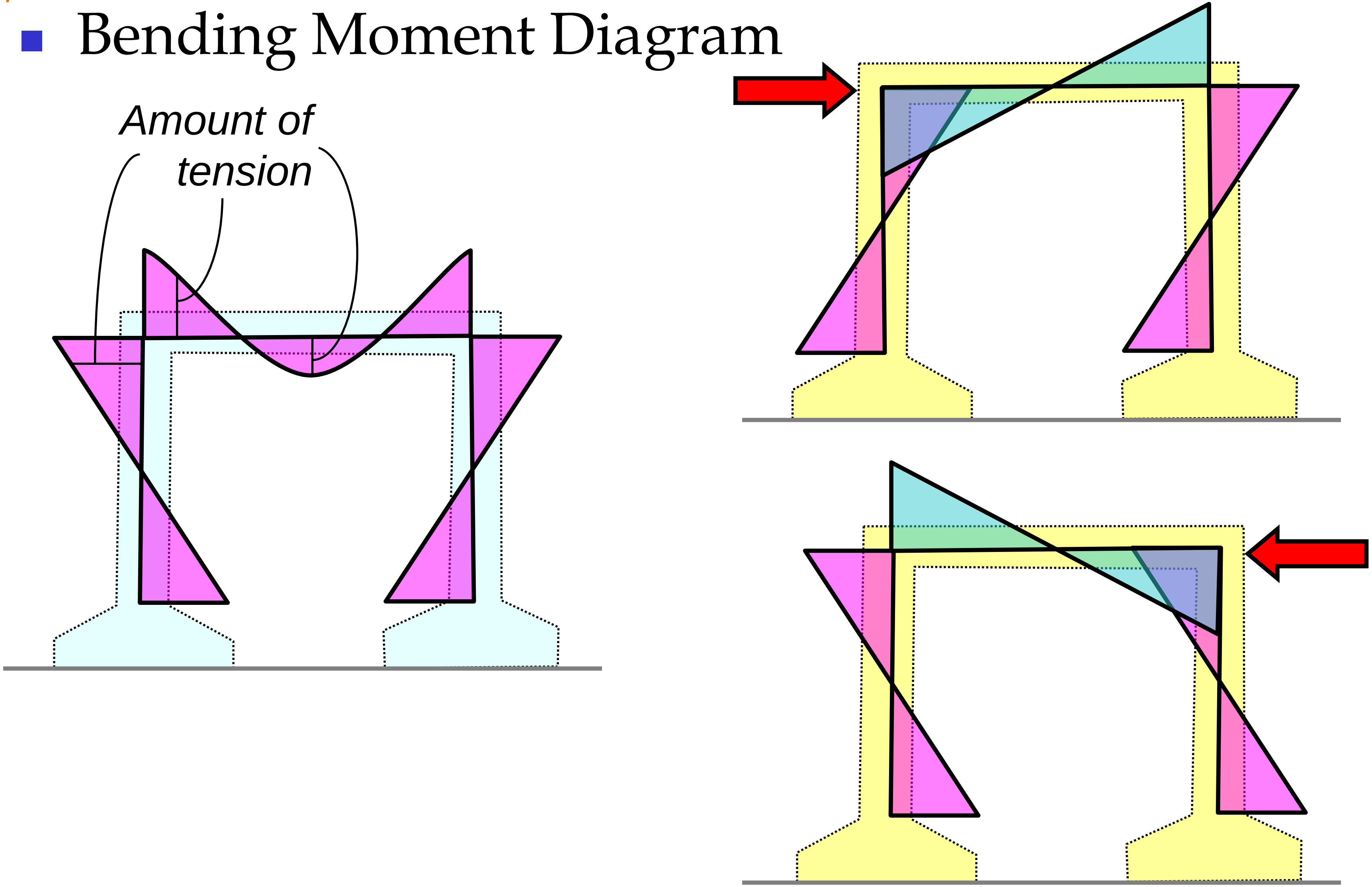
Seismic behaviour of RC Frames

- Influence of Loading Type

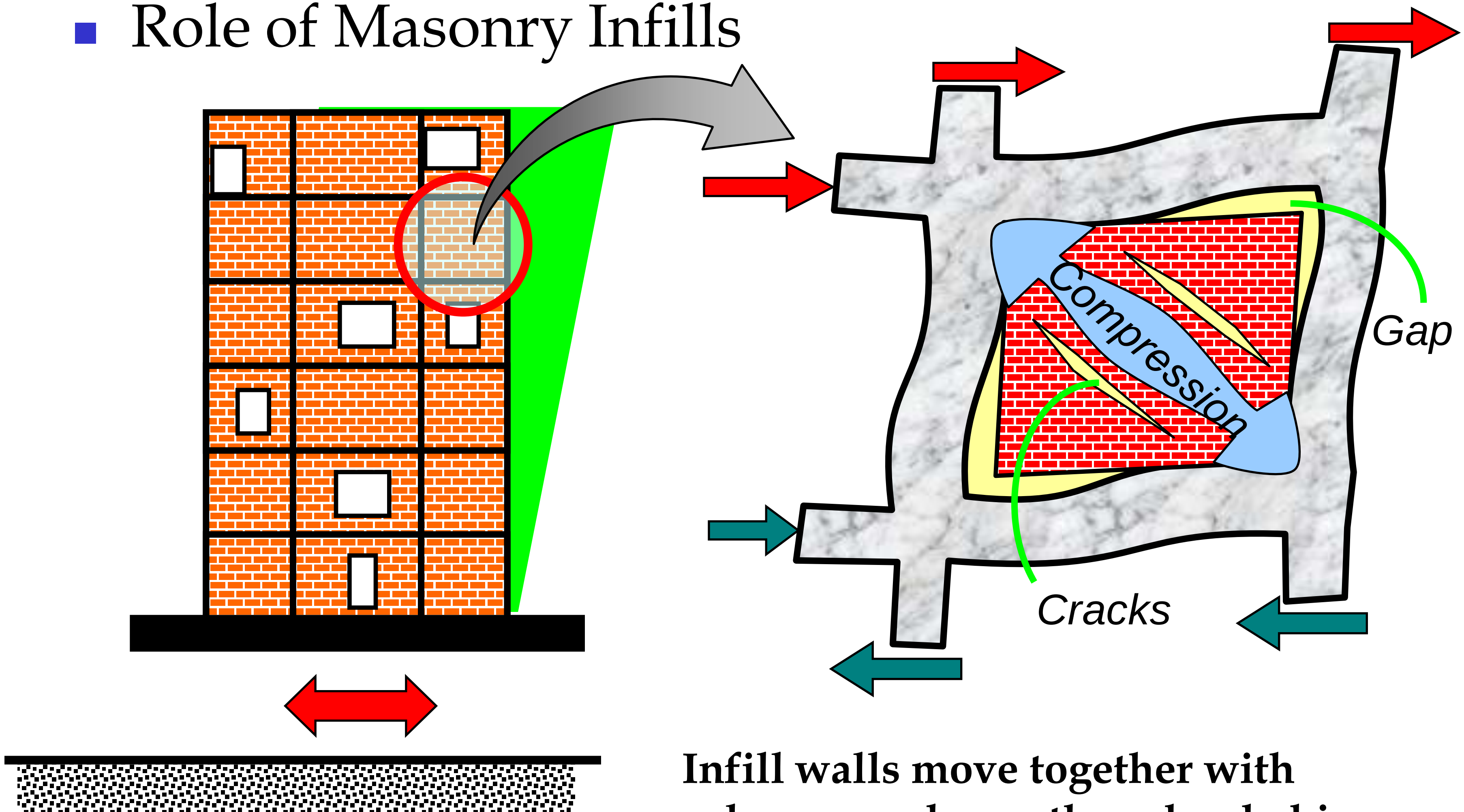




- Bending Moment Diagram



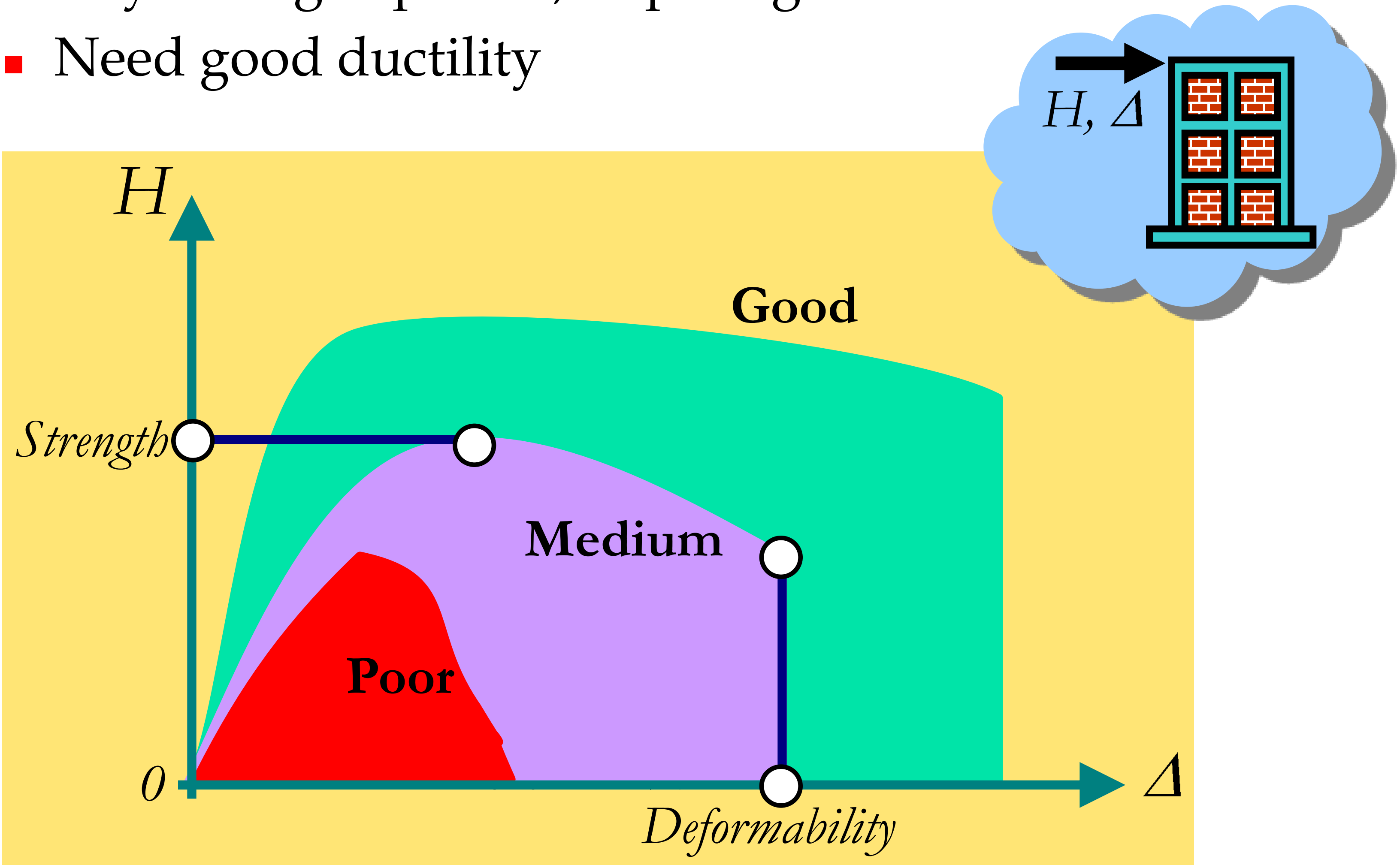
- Role of Masonry Infills



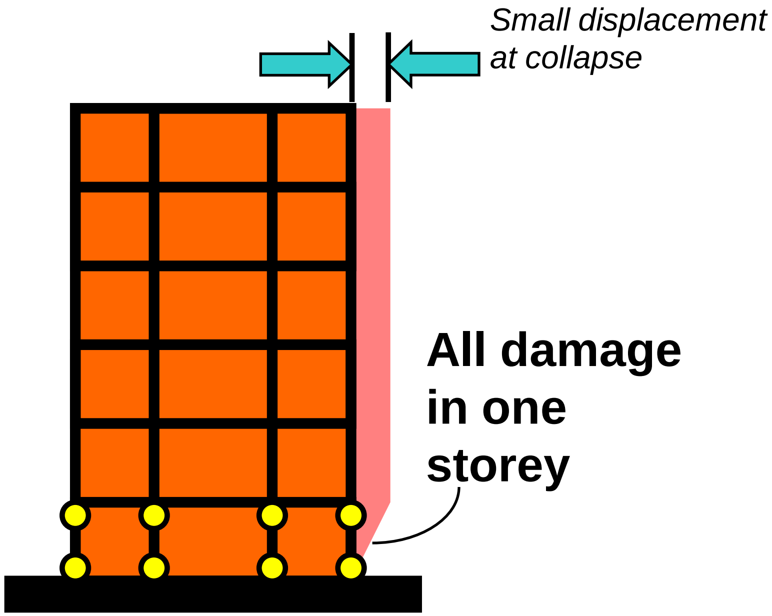
Infill walls move together with columns under earthquake shaking

Ductile Frame Design

- Since yielding expected, require good inelastic behaviour
  - Need good ductility

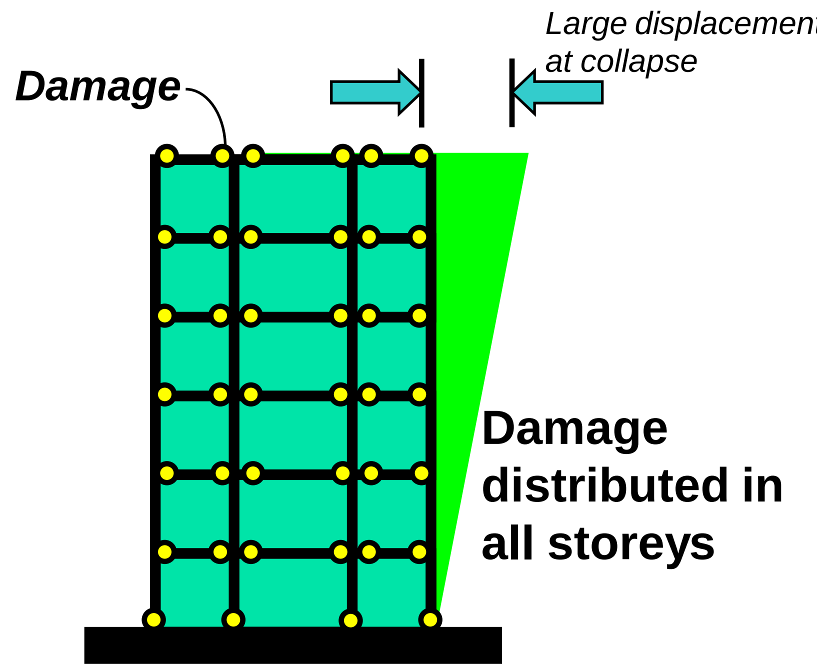


- Overall Collapse Mechanisms



(*Weak Column* Strong Beam)
:: **SWAY Mechanism**

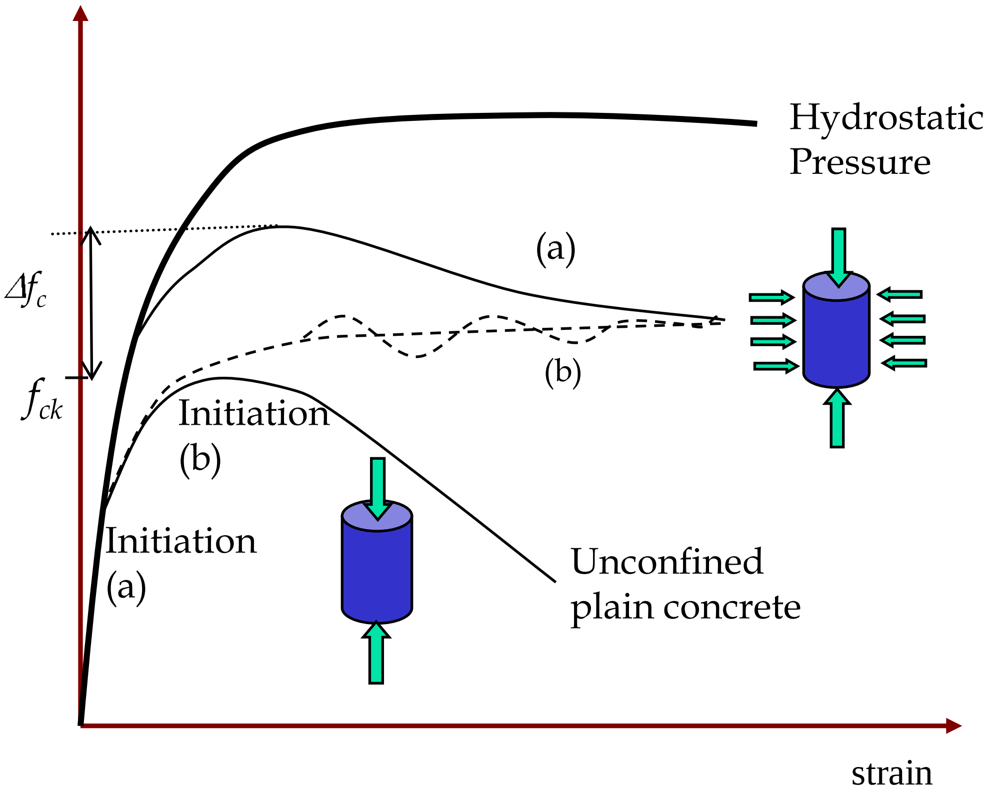
Poor



(*Strong Column* Weak Beam)
:: **BEAM Mechanism**

Good

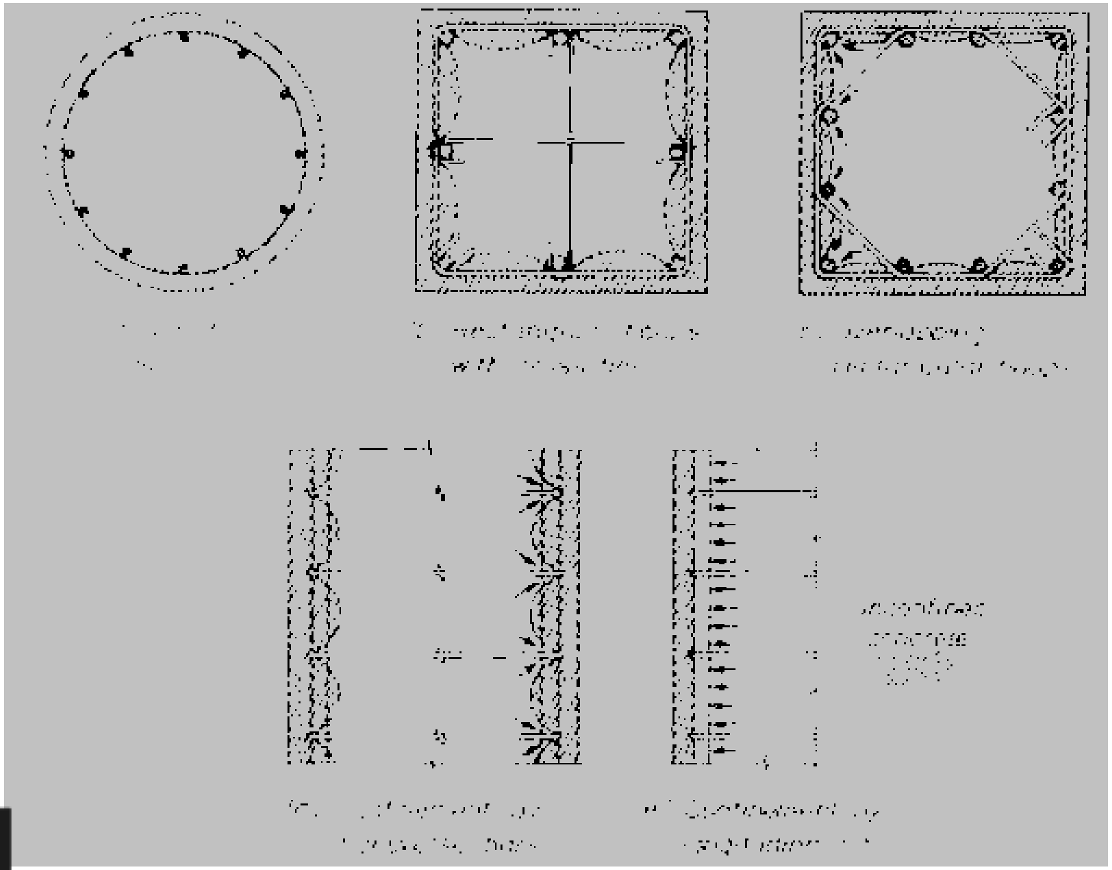
Confinement of Concrete



$$f'_{cc} = f'_c + 4.1 f_1$$

Compressive strength is increased by ~ 4 times of the confining pressure

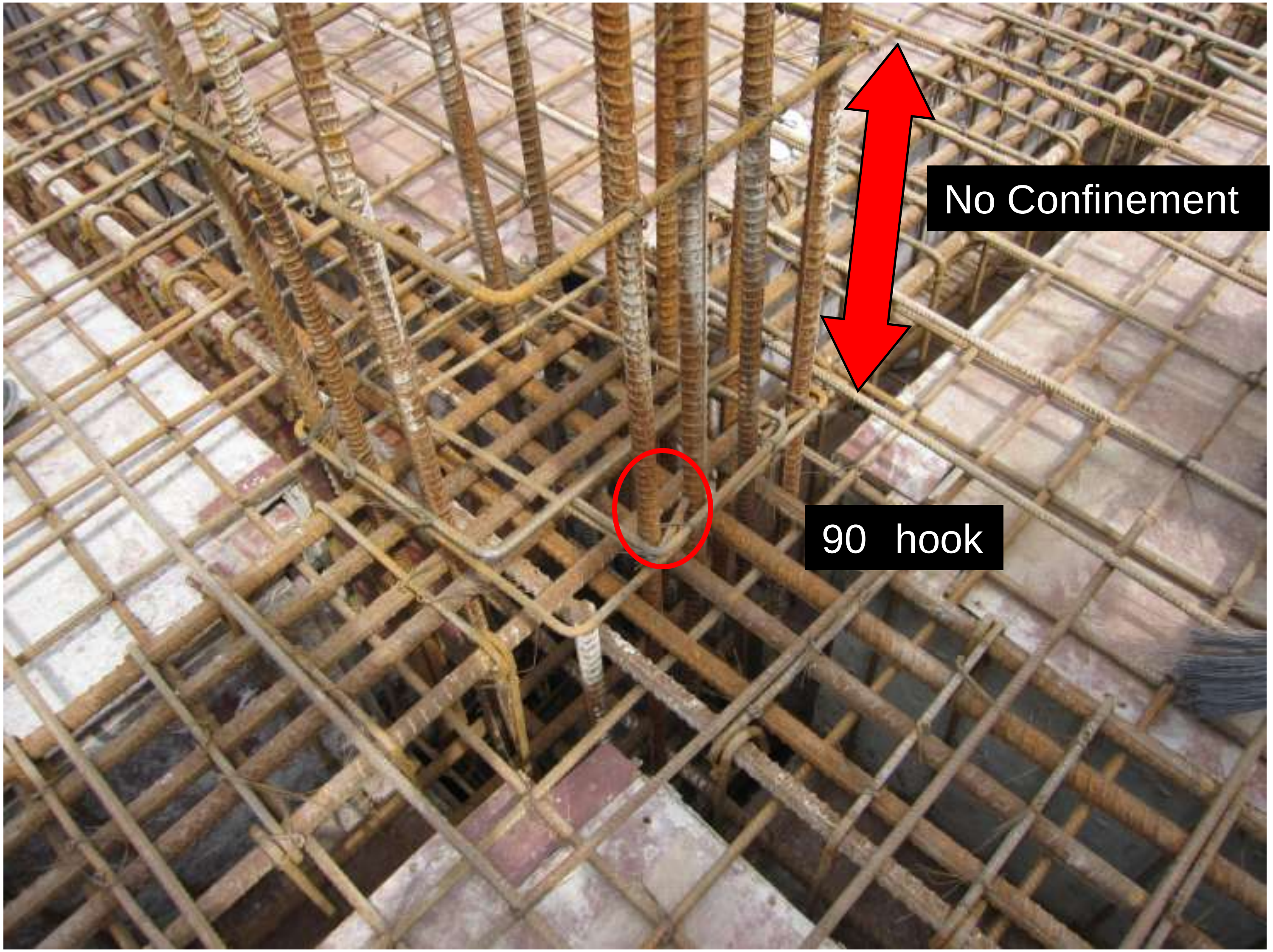
- Confinement of column sections by transverse and longitudinal steel



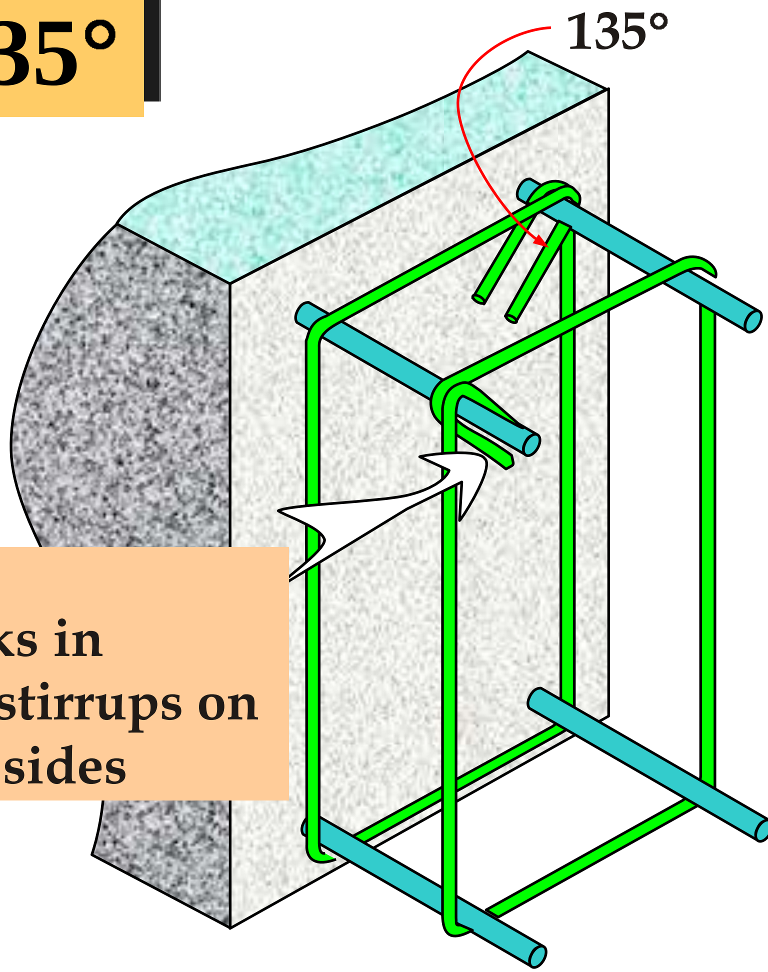
Paulay and Priestley, 1992


Maladieis & Remedies …

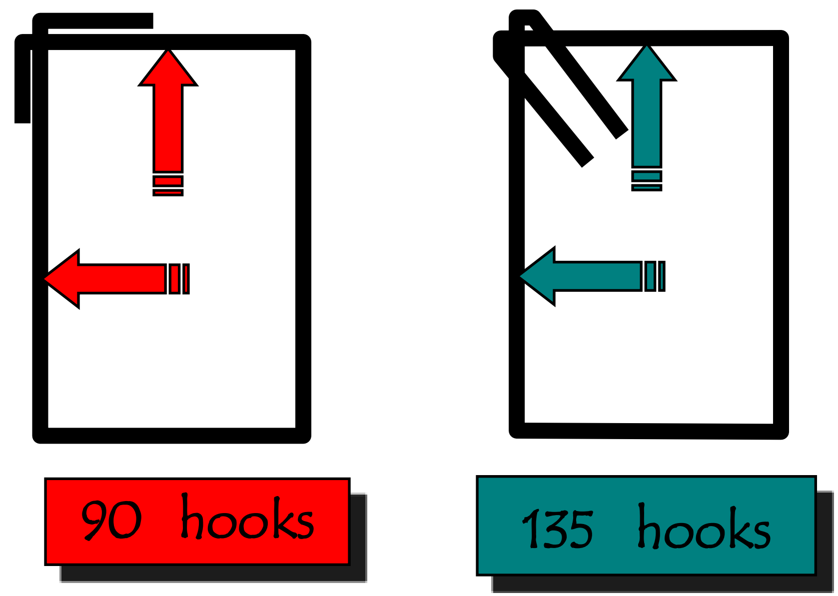
Prevalent Practices



135°



The ends of stirrups are bent at 135°. Such stirrups do not open during strong earthquake shaking.



Preferred:
135° hooks in adjacent stirrups on alternate sides

Lack of Confinement

Improper Splicing

5mm bars

90 degree hooks

Large spacing

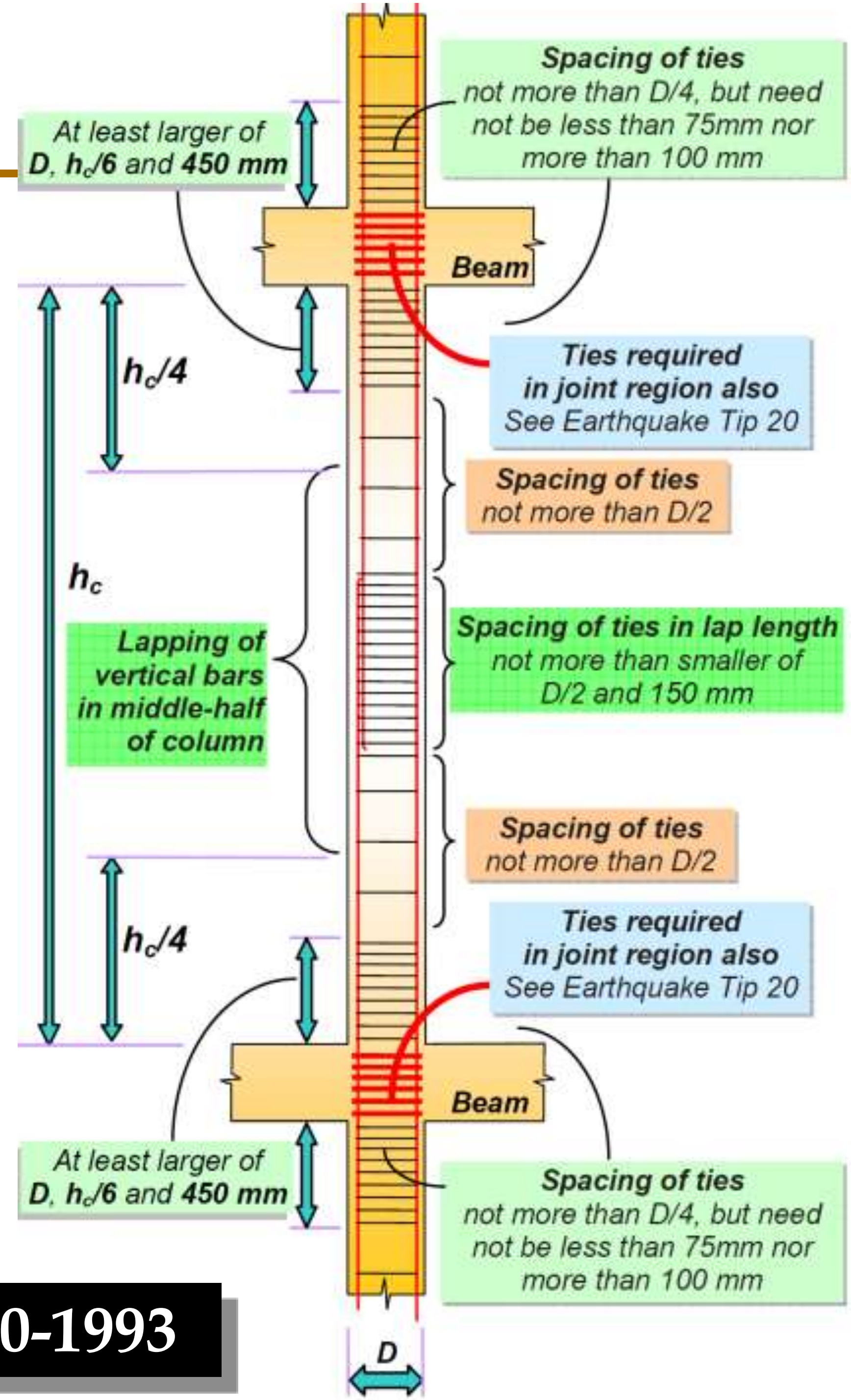
Lack of Confinement !!

Column Reinforcement

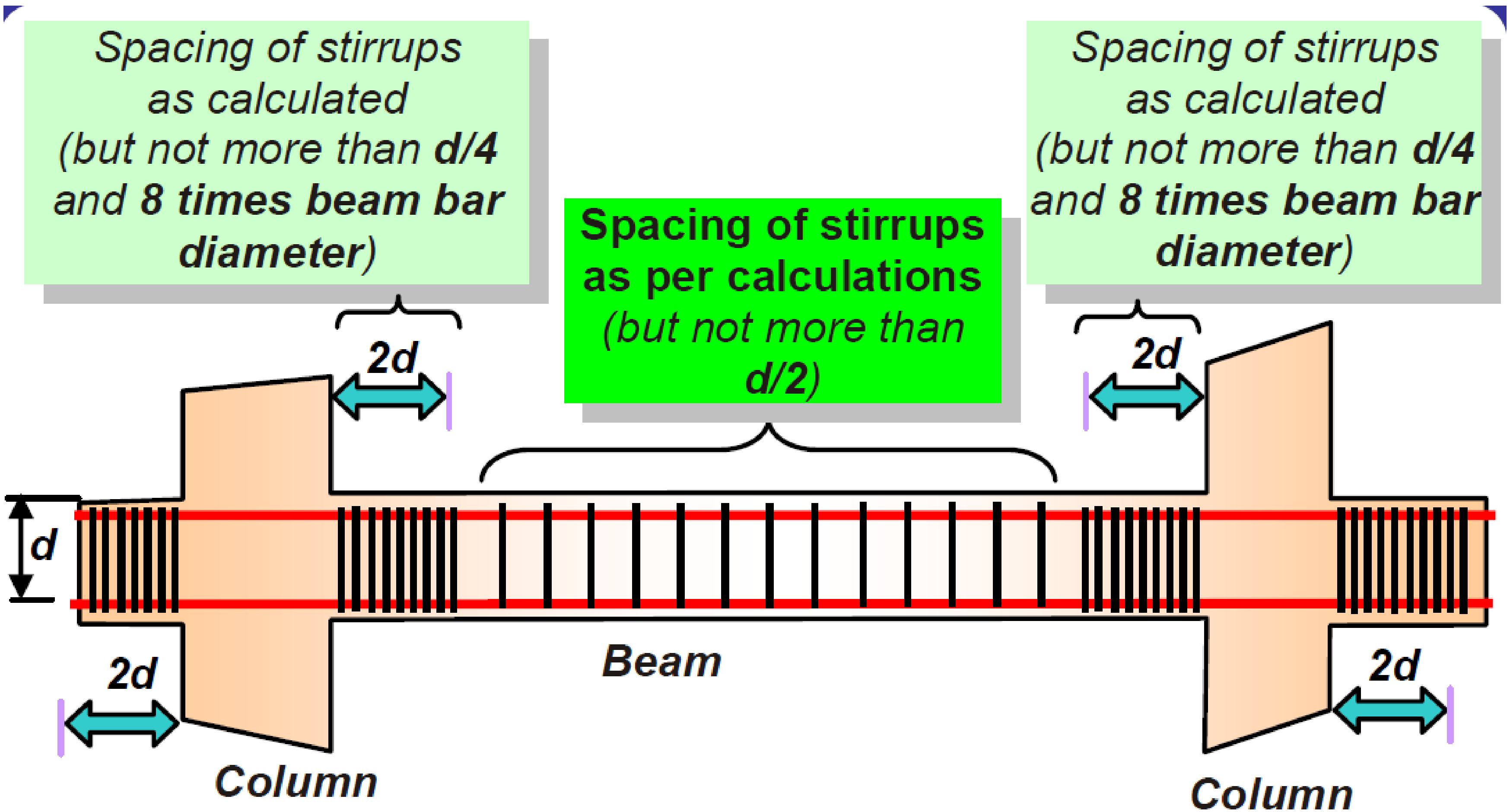
- Spacing of ties not more than D/2
- Special confining reinforcement at column ends
  - ✓ Spacing < D/4, not more than 100 mm

- The lap length should be provided only in middle half of column and not near its top and bottom ends.
- Minimum lap length is 50 times the bar diameter

IS 13920-1993



Beam Reinforcement : Vertical Stirrups

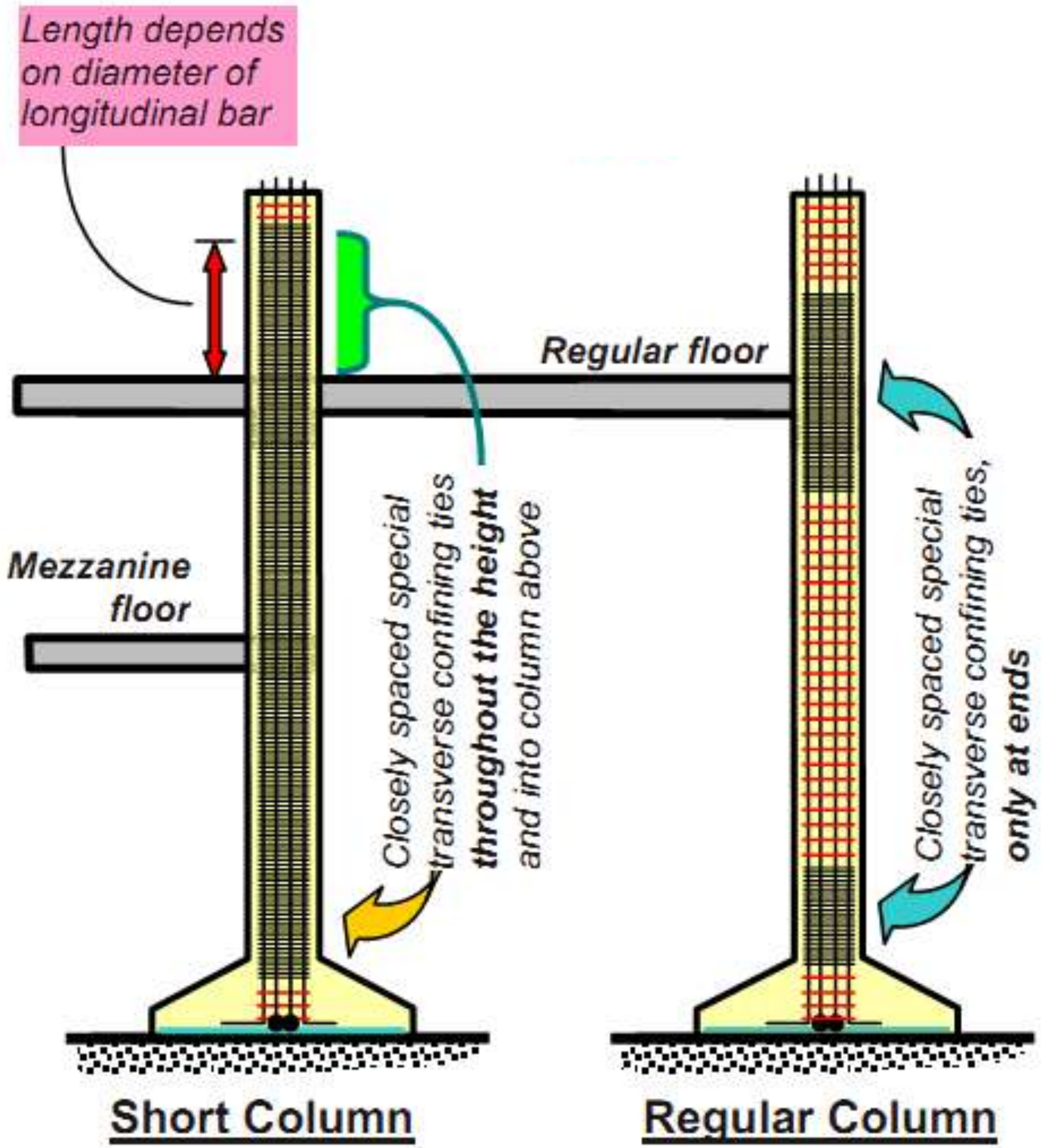


IS 13920-1993

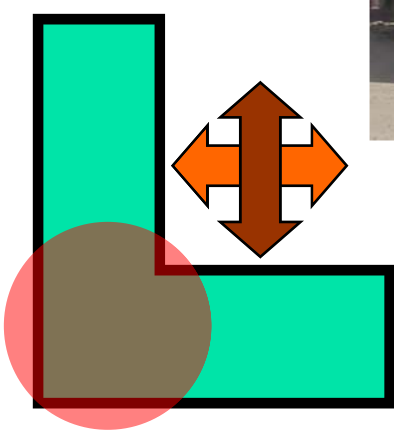
Beam-Column Joint

Absence of confining reinforcement

Special confining reinforcement to be provided over full length of the column.

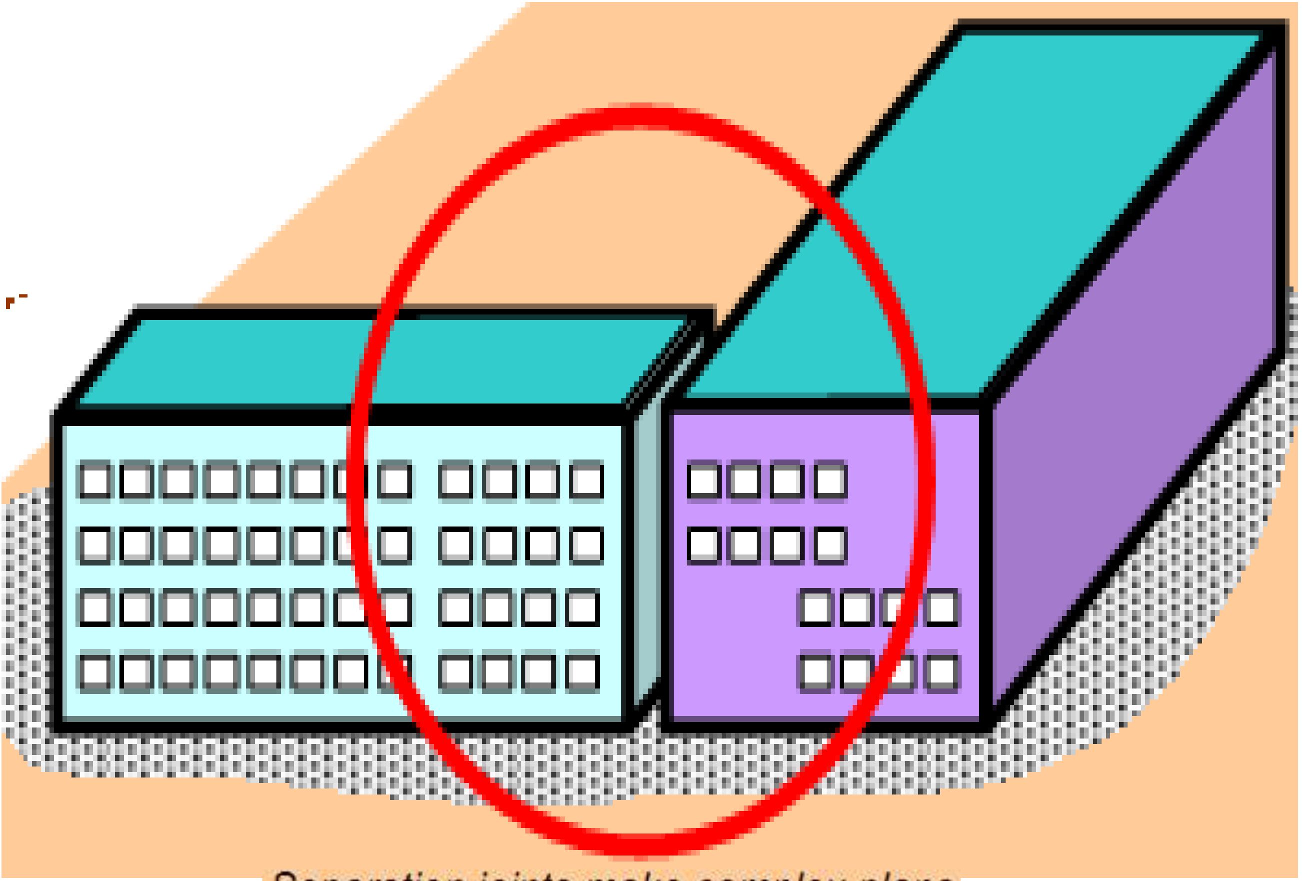


Prone to Damage
ROYAL OAKS
HOTEL ORCHID



Buildings with Corners

Correct way of construction

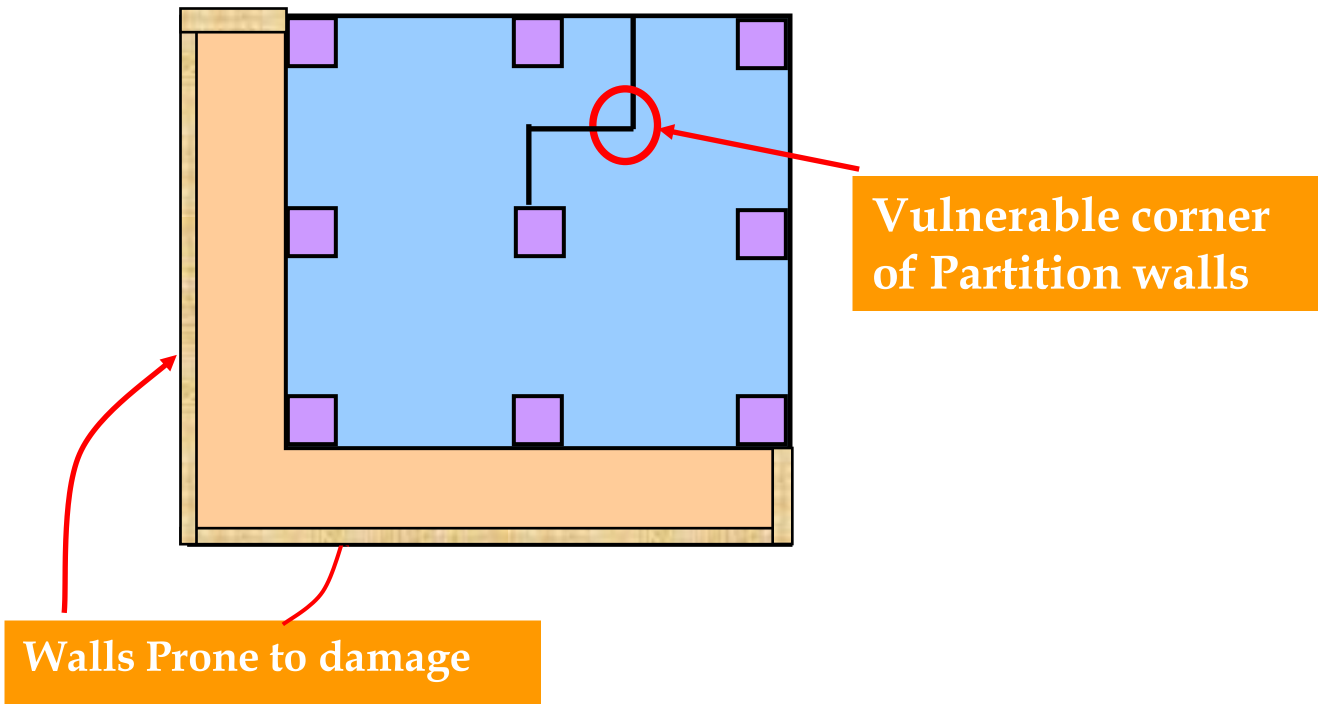


Separation joints make complex plans into simple plans

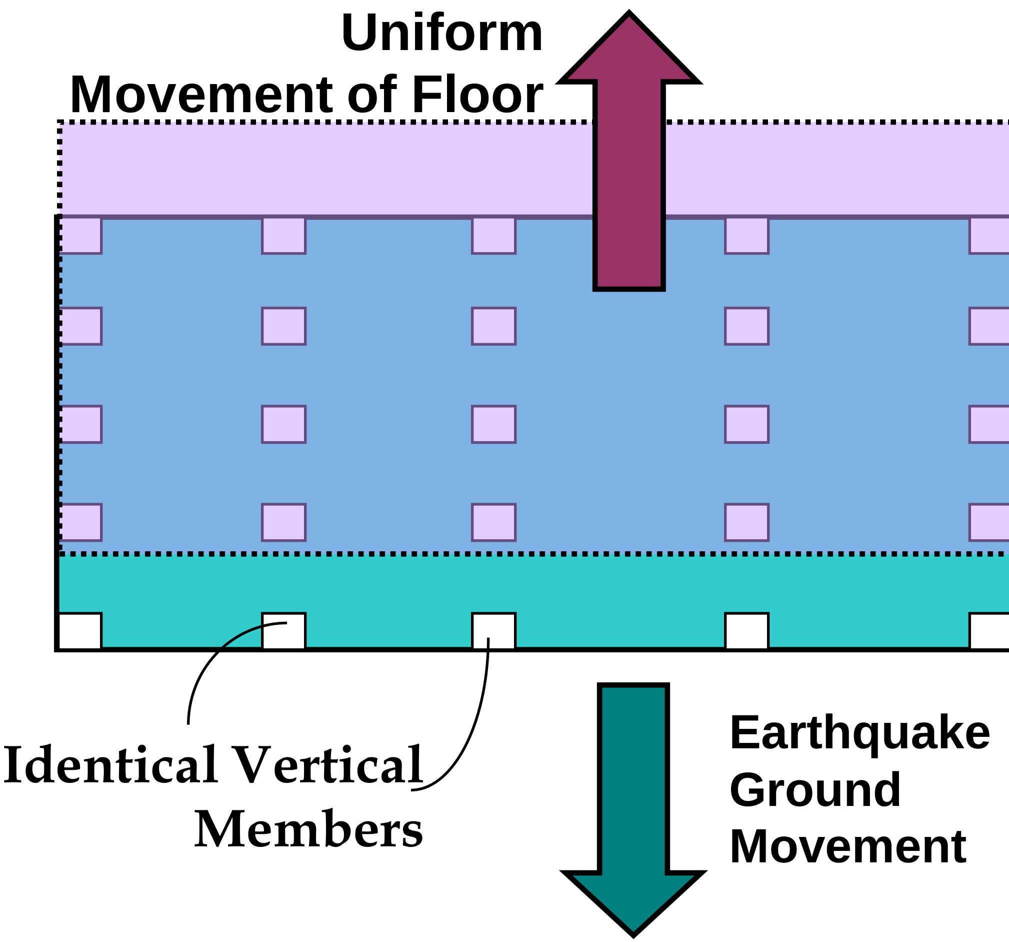
Unsupported wall on cantilever projection

Absence of column at corner

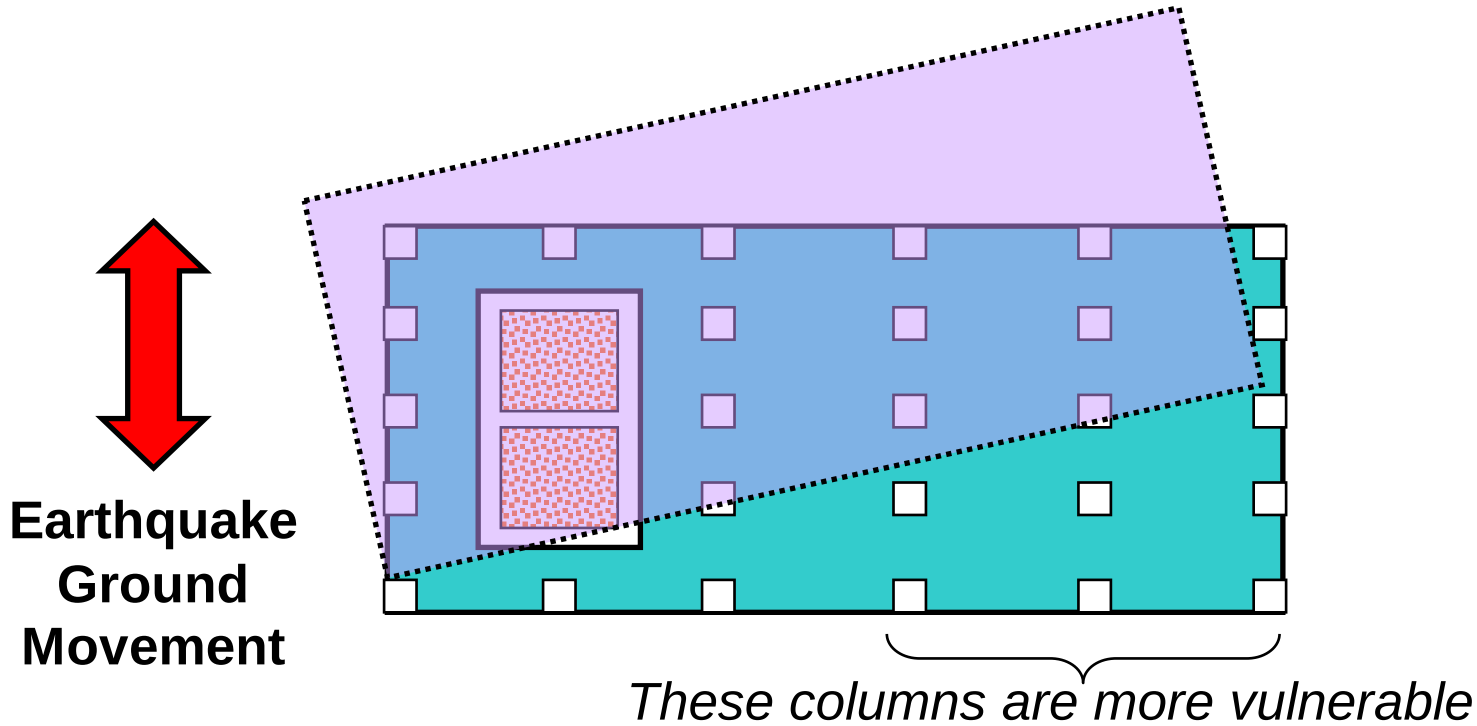
- Mushroom like construction, “floating wall” and corner view
- Outer wall prone to damage due to lack of stiffness



By ensuring that buildings are symmetric in plan

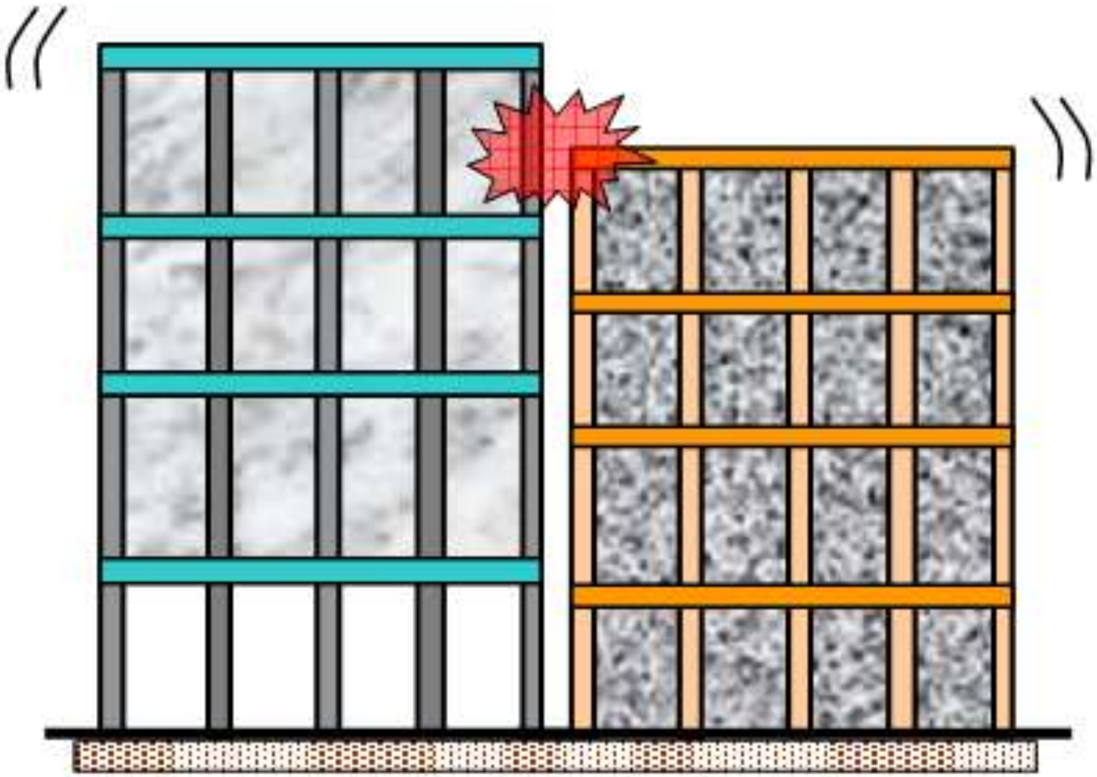


Different portions at the same floor level move horizontally by different amounts.



Pounding between adjacent buildings

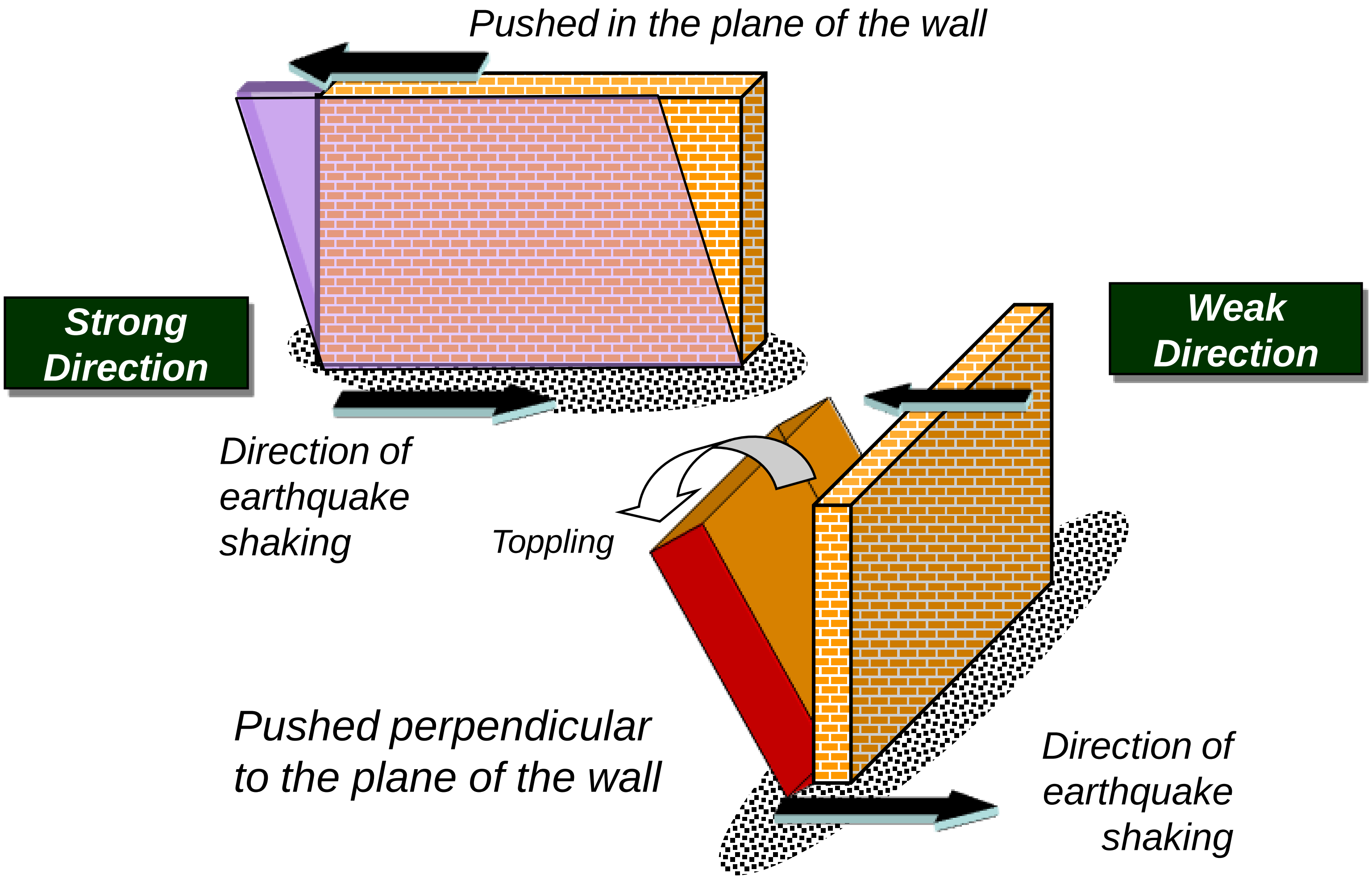
Pounding between adjacent building blocks due to inadeqaute seismic gap



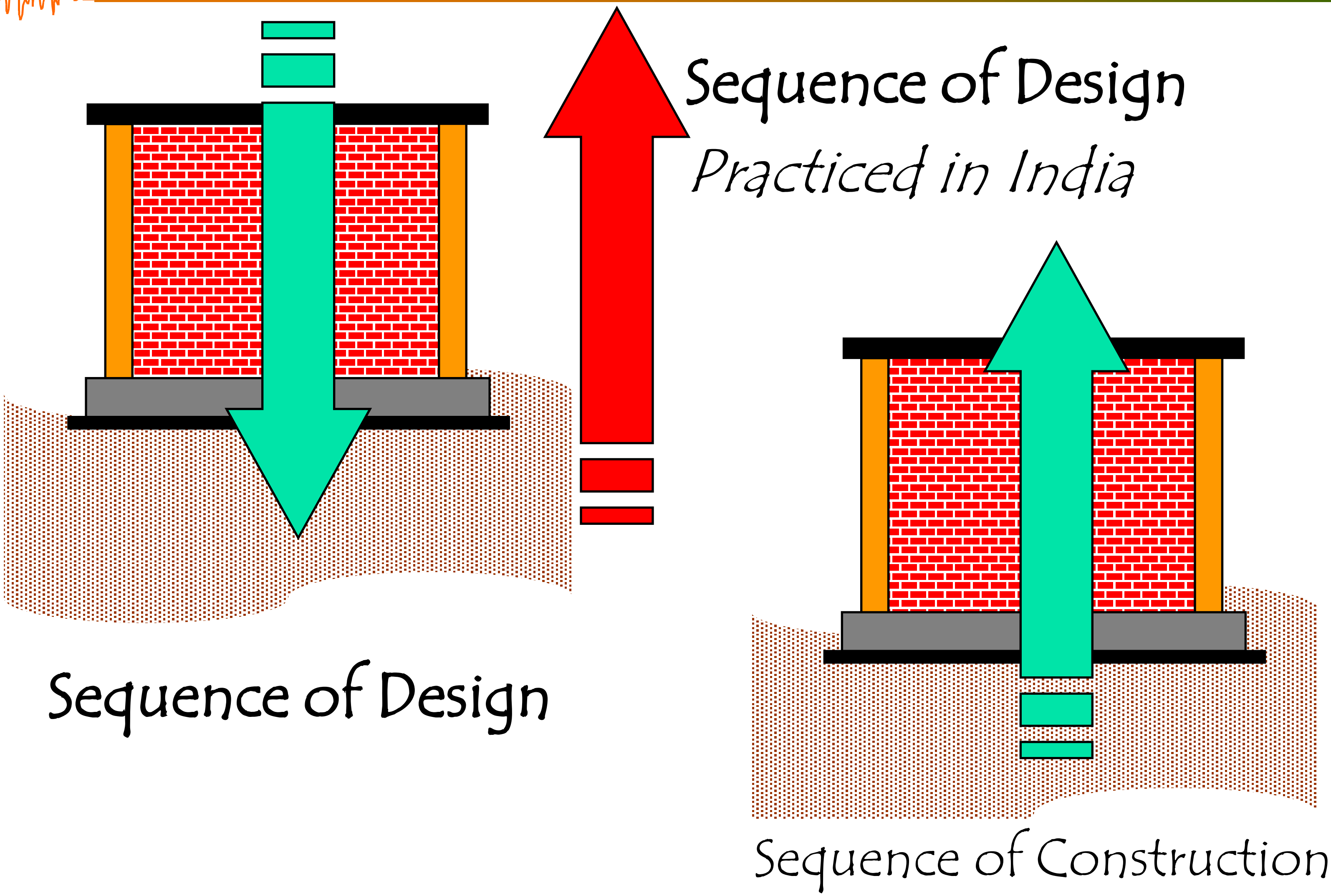
Sufficient gap at least 50 mm per storey for regular 3-4 storey building.
Else do fancy dynamics!

Out-of-plane failure of infill wall

In-plane failure of infill wall



Brittle masonry walls are weak in direction perpendicular to its plane


Sequence of Design
Practiced in India
Sequence of Design
Sequence of Construction

Engineer's Role

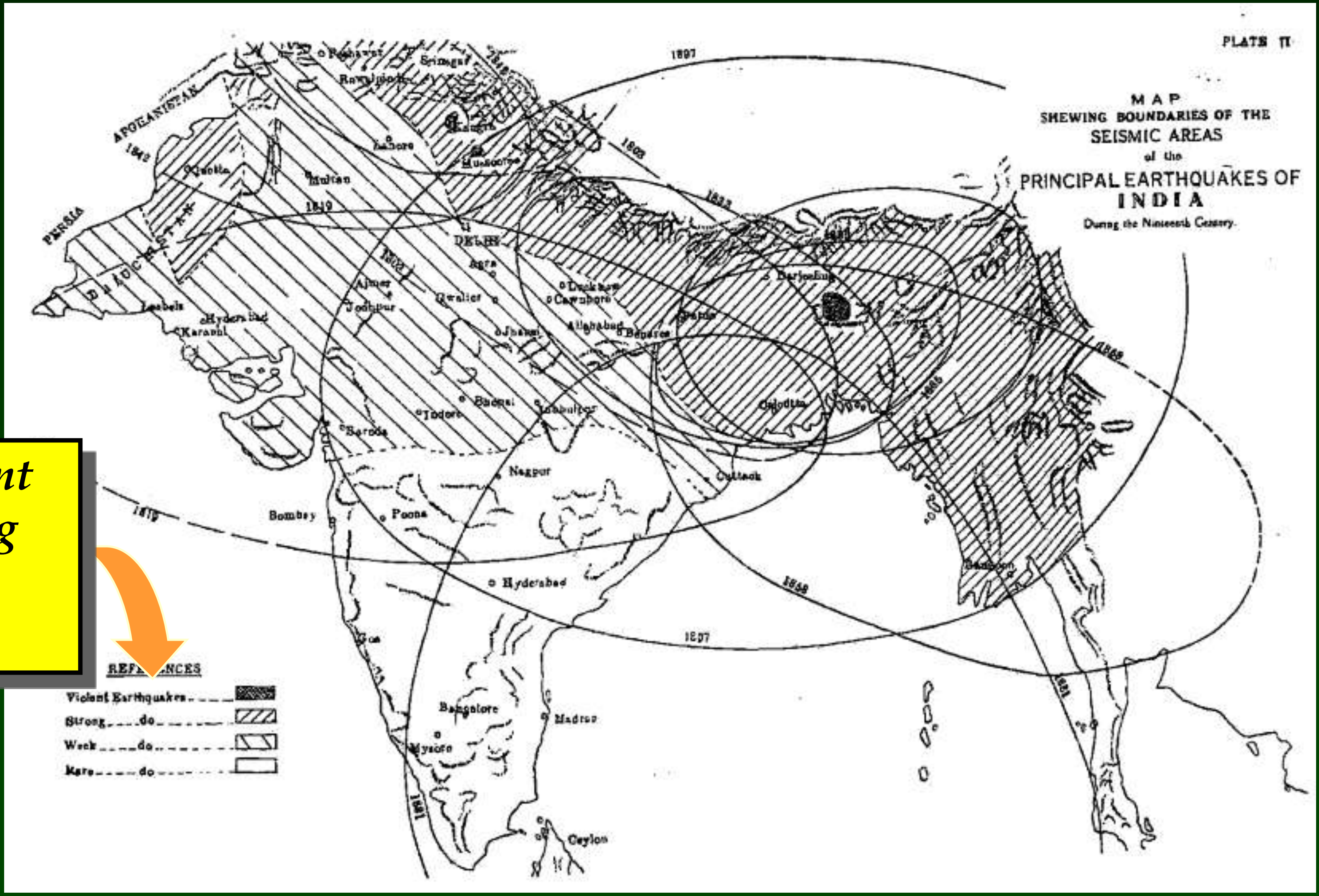
Preparedness as a key to disaster mitigation

Seventy Five Years Ago in India …

- 1931 Mach earthquake (M7.4) in Baluchistan
- S L Kumar (28 year age at that time) designed earthquake resistant quarters for railway staff
- In 1933, Kumar published a paper on this work, and recommended a zone map

Seventy five years ago in India …

- *Early Zone Map (Kumar, 1933)*



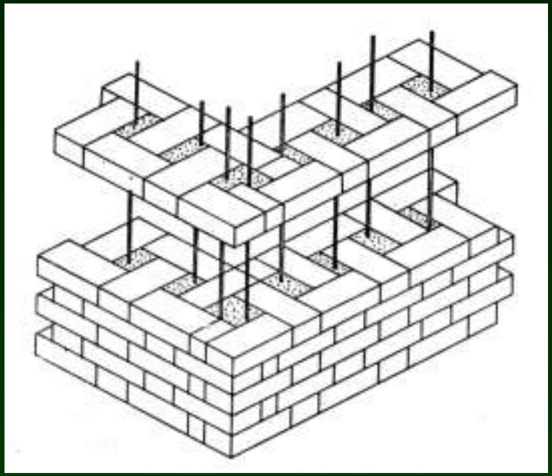
- *Violent*
- *Strong*
- *Weak*
- *Rare*

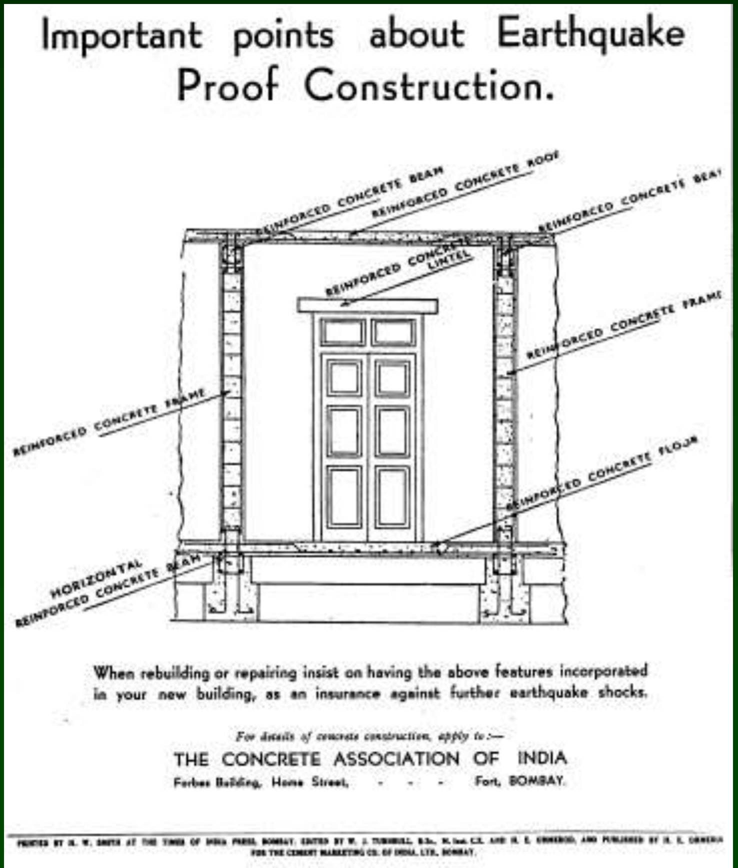
Seventy five years ago in India …

- **1935 Quetta earthquake**
  - ✓ *M7.6; max intensity X; ~20,000 persons killed*
- **Performance of quarters designed by Kumar**
- **Massive reconstruction after Quetta earthquake by military, railways, and civil authorities**
- **Code developed**; lintel, plinth and roof bands for masonry buildings
- **Earthquake of 1941 (intensity VIII to IX) proved efficacy of these constructions**

Lost in the Shelves…

- **Novel masonry bond known as Quetta Bond invented for reinforced masonry using solid units**

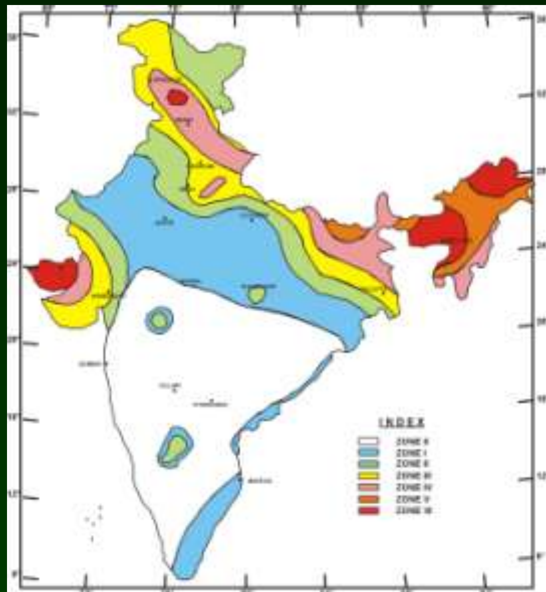




The Indian Concrete Journal, 1934

The Seismic Hazard

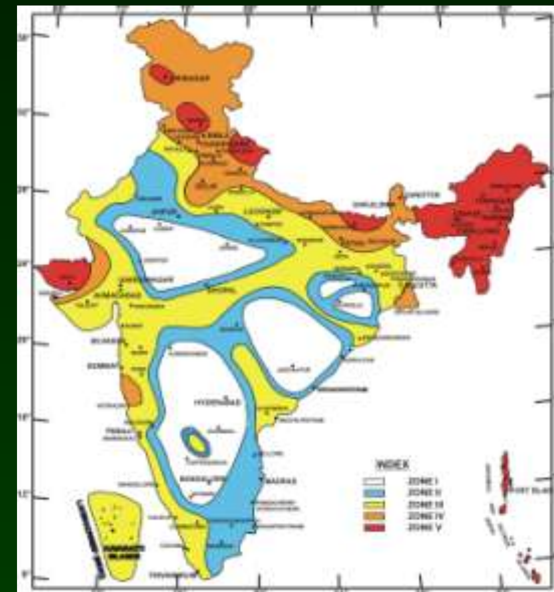
1962



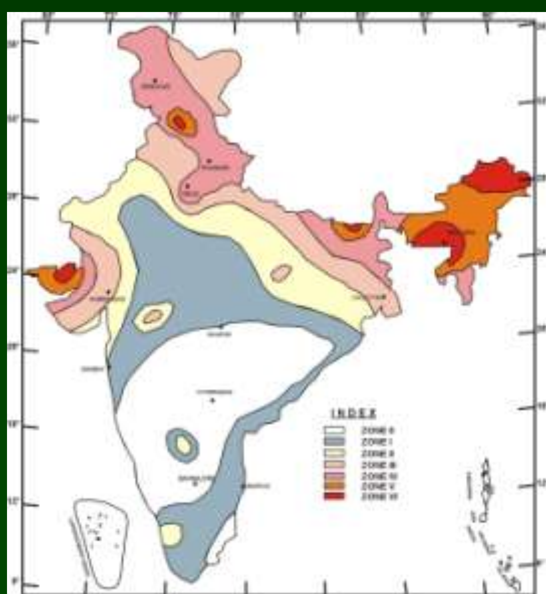
1970

1975

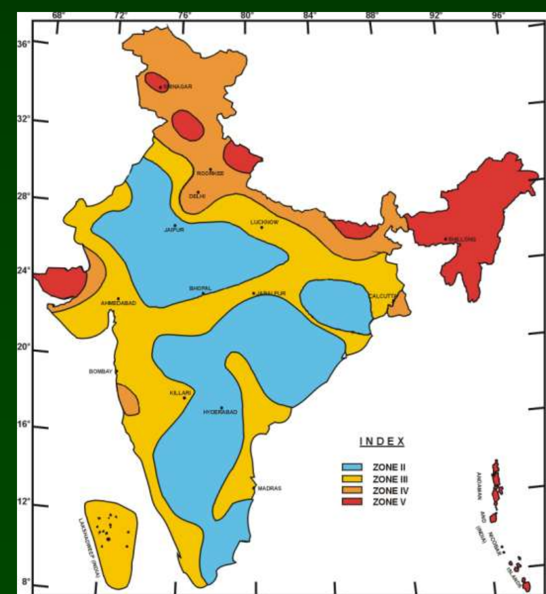
1984



1966



2002

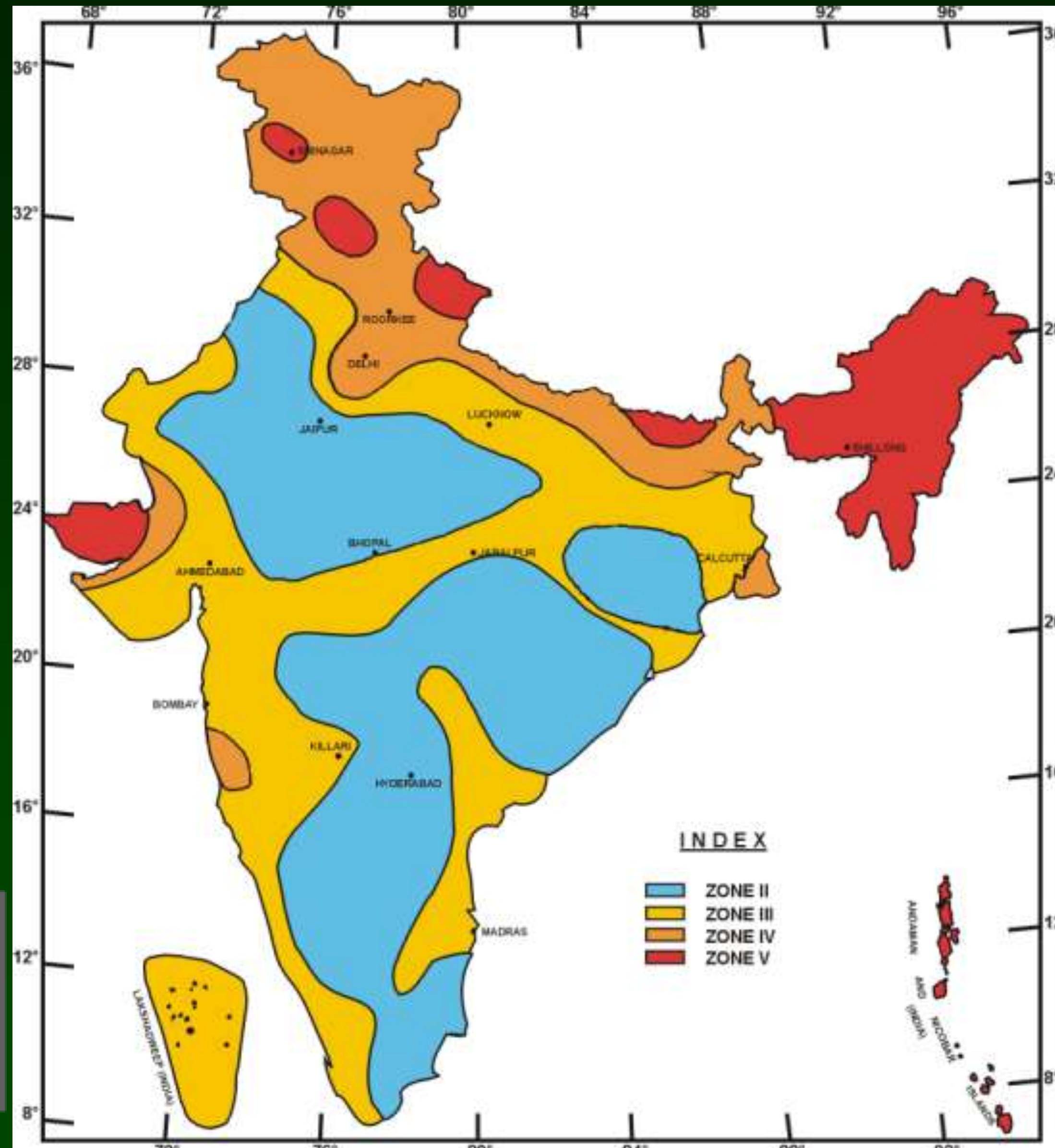


The Seismic Hazard…

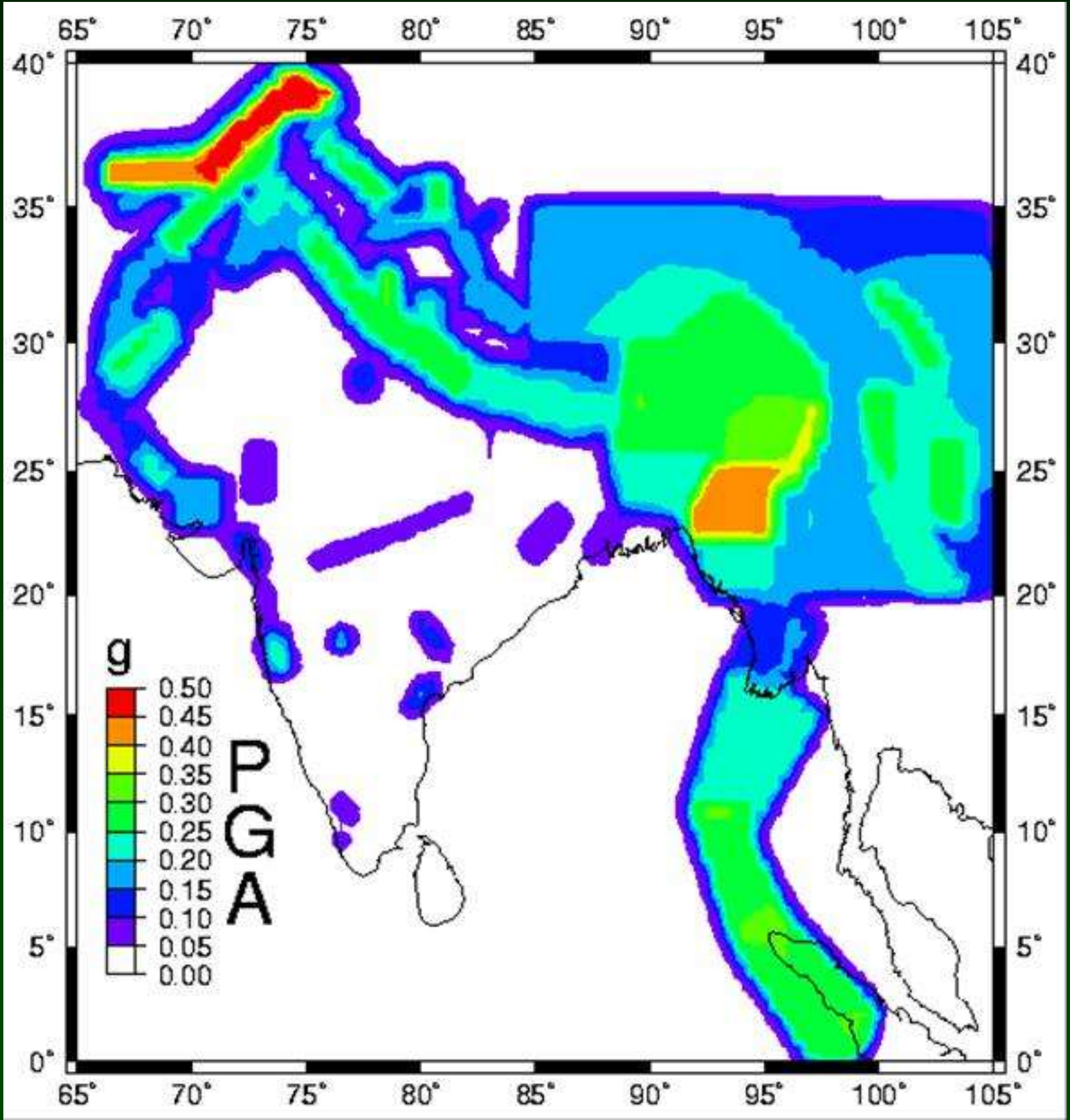
Zone Factor, *Z*

II	0.10
III	0.16
IV	0.24
V	0.36

~60% India's land area under
Moderate-to-Severe Seismic Hazard



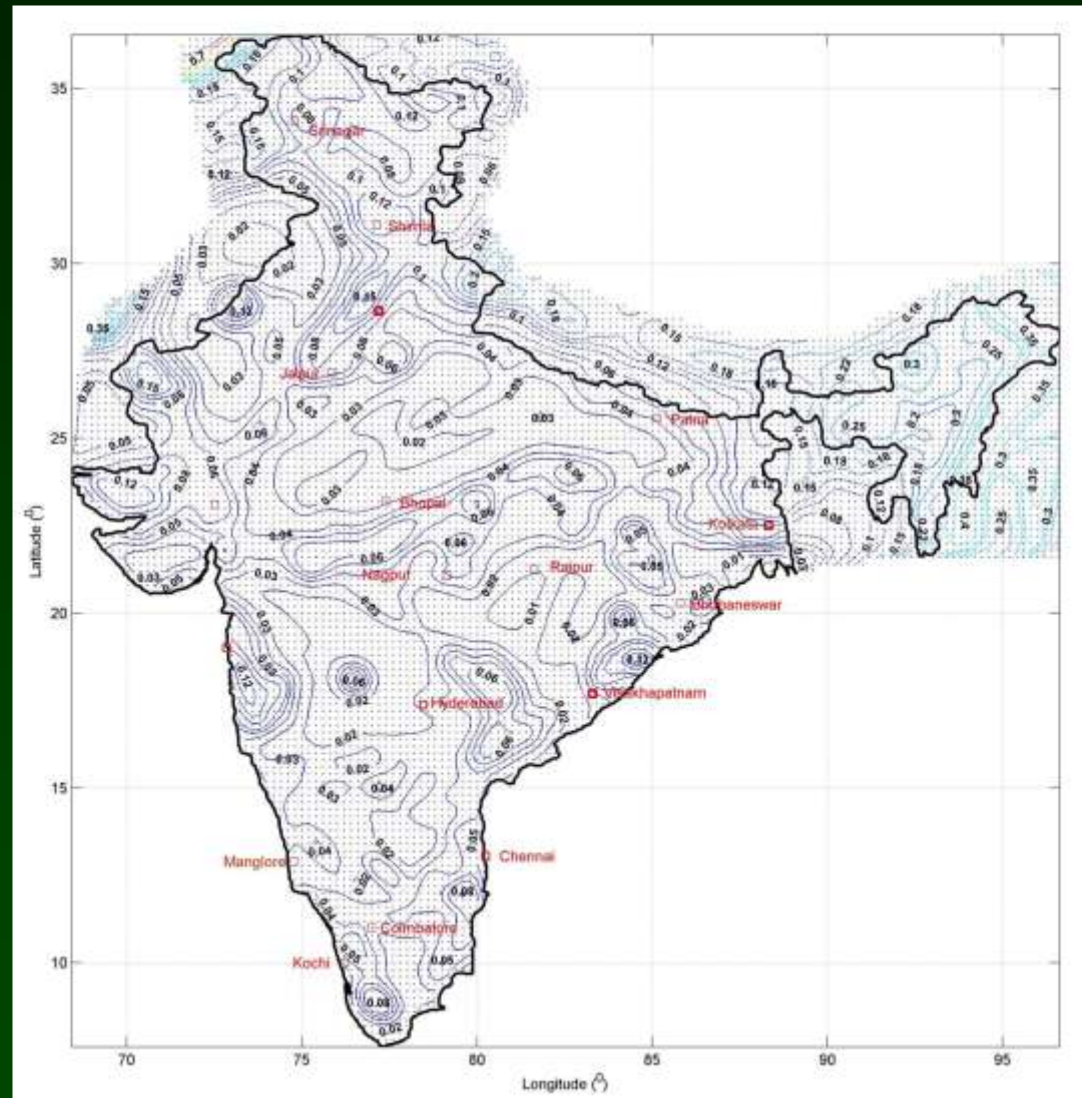
The Seismic Hazard…



GSHAP

Probabilistic map

The Seismic Hazard…



NDMA

Probabilistic map

10PE50 (500 yr RP)

The Indian Earthquake Problem

Early gains were lost …

- It was possible ~75 years back to construct earthquake resistant houses in India
- Formal research and teaching started at Roorkee ~45 years back
- First formal seismic code: 1962
- Why disasters like 2001 Gujarat despite such early gains?

RC Frame Buildings in India…

RC Frame Buildings in India…

- 230mm Columns

RC Frame Buildings in India…

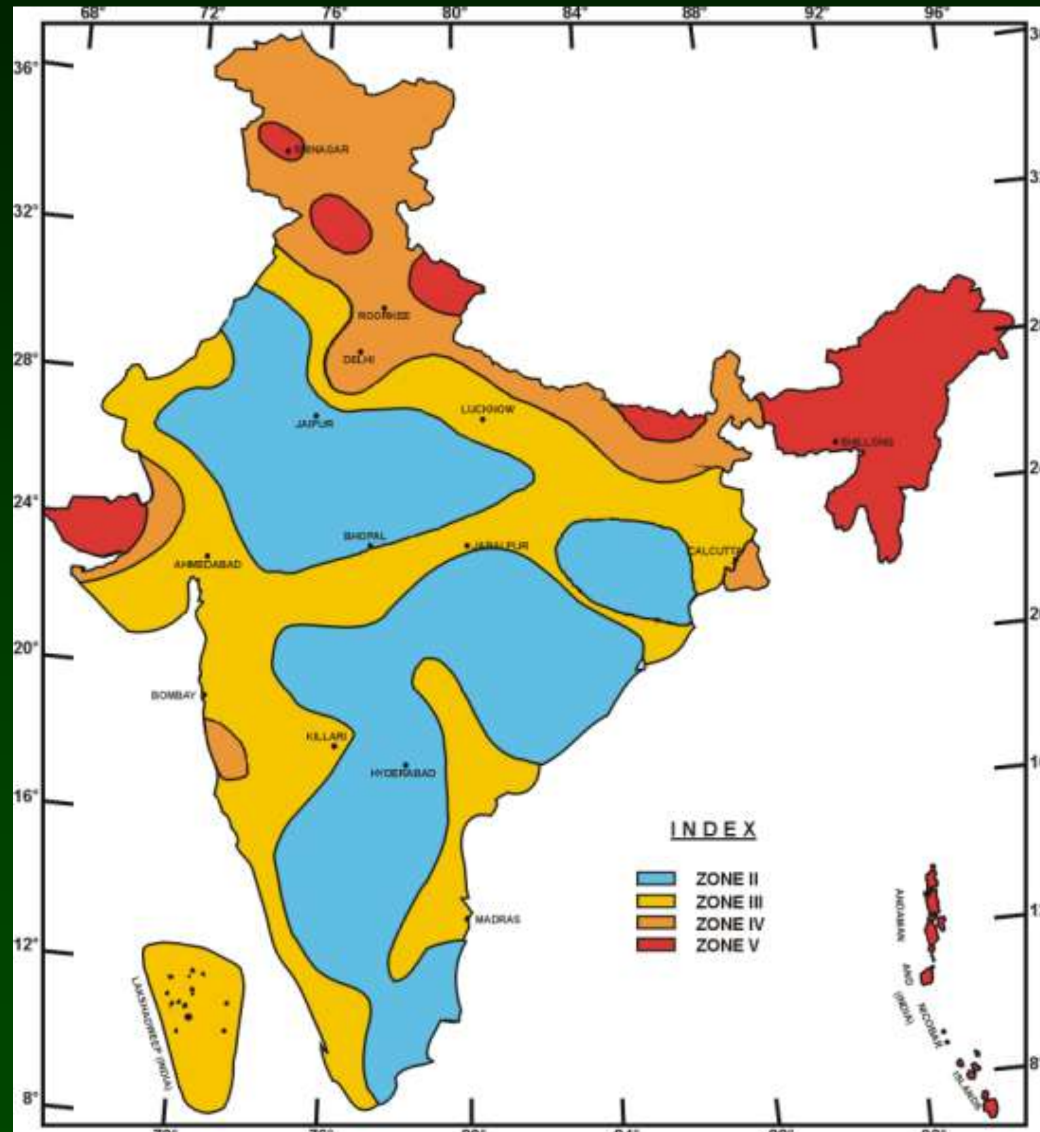
The 230mm Syndrome

RC Frame Buildings in India…

The 230mm Syndrome

Kanpur City :
Earthquake Risk Scenario

The Truth...!!

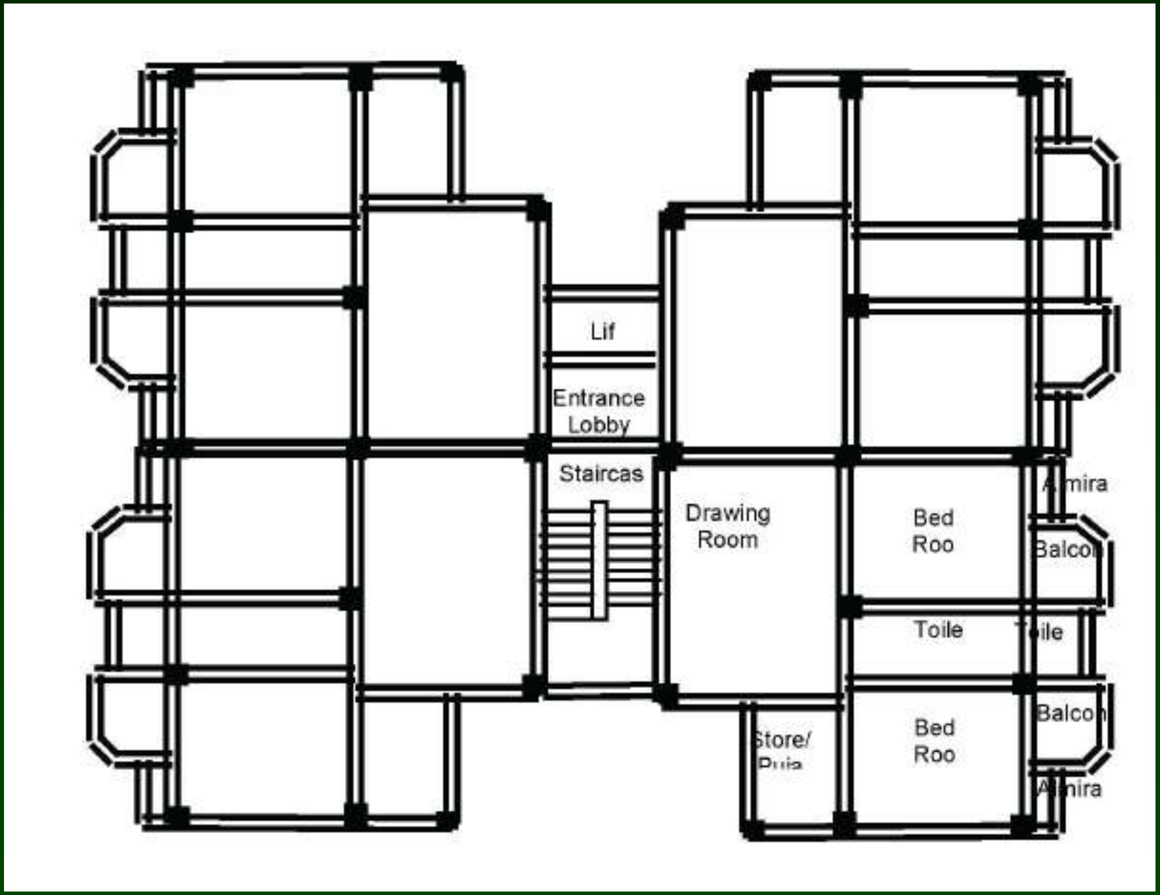


Kanpur lies in Zone III

Same as Ahmedabad & Bhubaneshwar

The Truth…!!

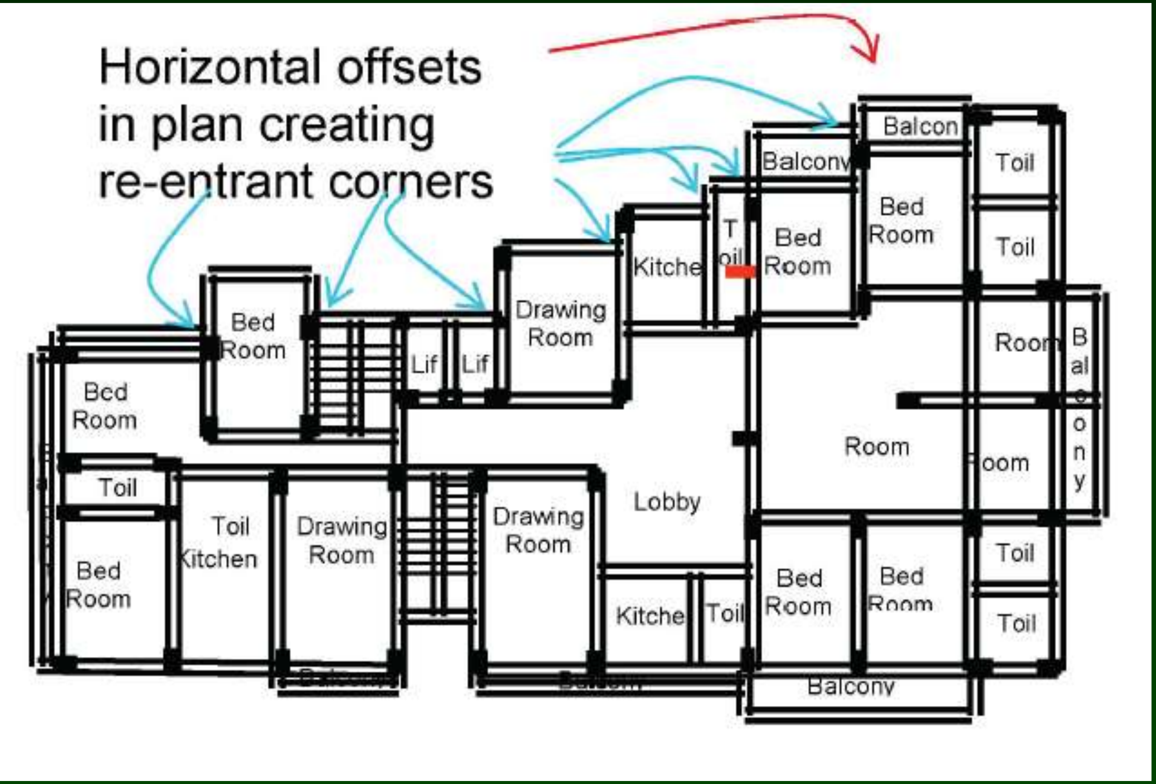
- **Multi-storied buildings**



[Jain, 2005]

The Truth…!!

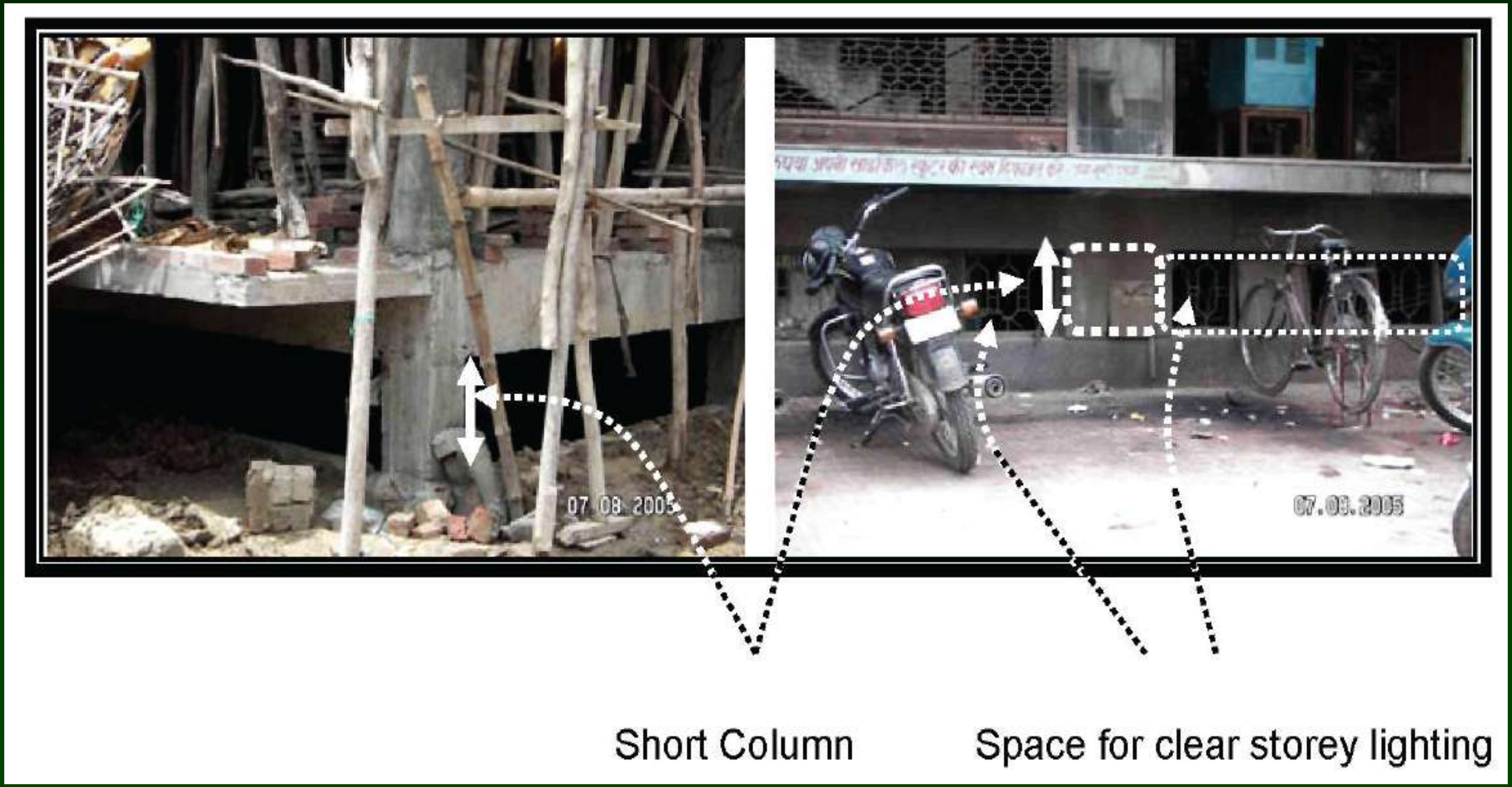
- **Multi-storied buildings**



[Jain, 2005]

The Truth…!!

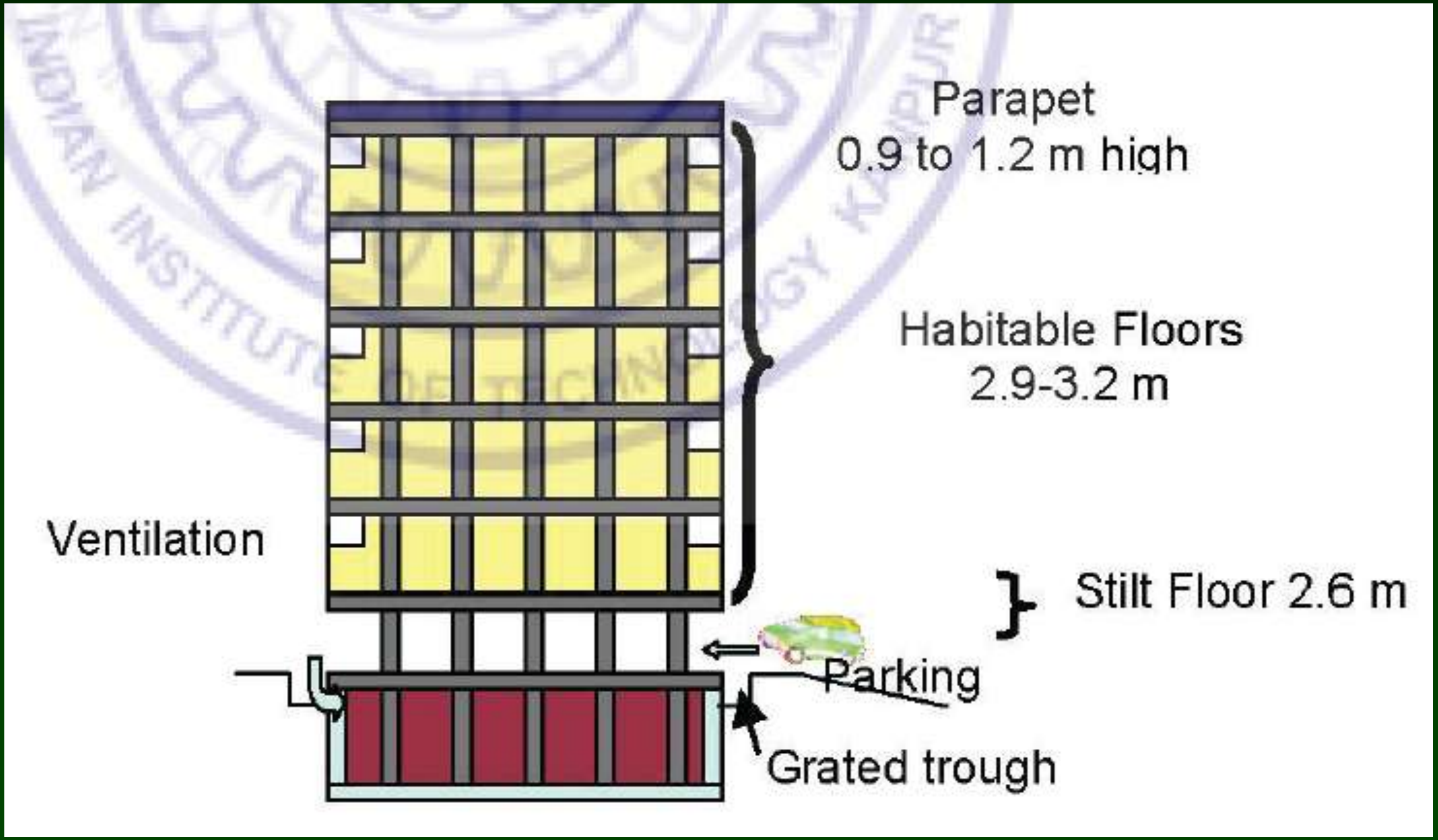
- **Multi-storied buildings**



[Jain, 2005]

The Truth…!!

- **Multi-storied buildings**



[Jain, 2005]

The Truth…!!

- **For 30 multi-storied buildings**
  - ✓ *No building passed the preliminary check of seismic strength evaluation as per BIS code*
  - ✓ *75% had serious configuration related problems*
    - ***82% - Short column Effect***
    - ***64% - Torsion***
    - ***61% - Soft Storey***
    - ***50% - Geometry***
    - ***43% - Adjacent Buildings***

[Jain, 2005]

Ad-hoc Retrofit Activities
:Panicked Response

After the Earthquake …

Retrofitting of Damaged RC Columns, Rumtek

After the Earthquake …

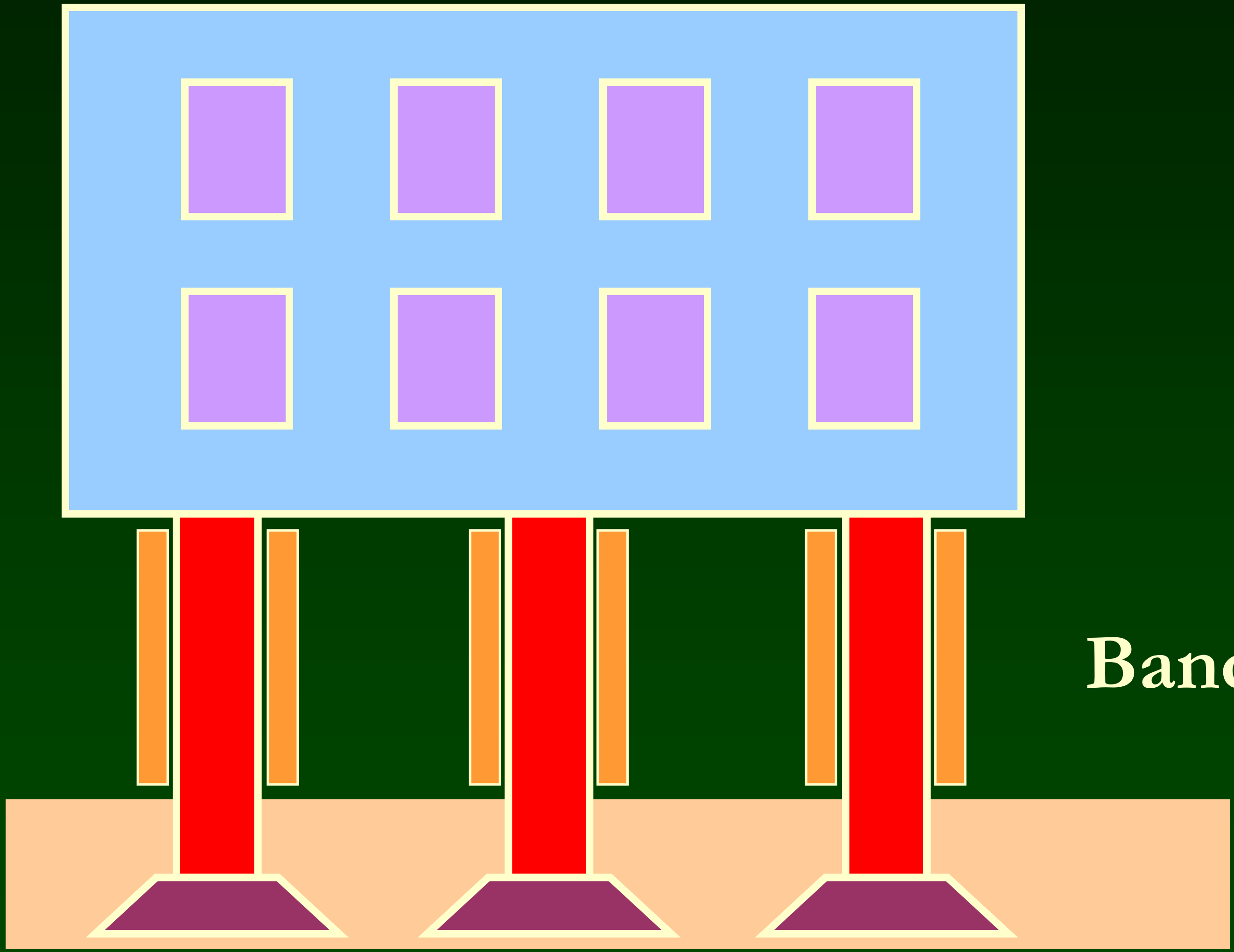
Retrofitting of Damaged RC Columns, Rumtek

1997 Jabalpur Earthquake…

Ajanta and Nalanda Apartments

The frenzy...

The frenzy...



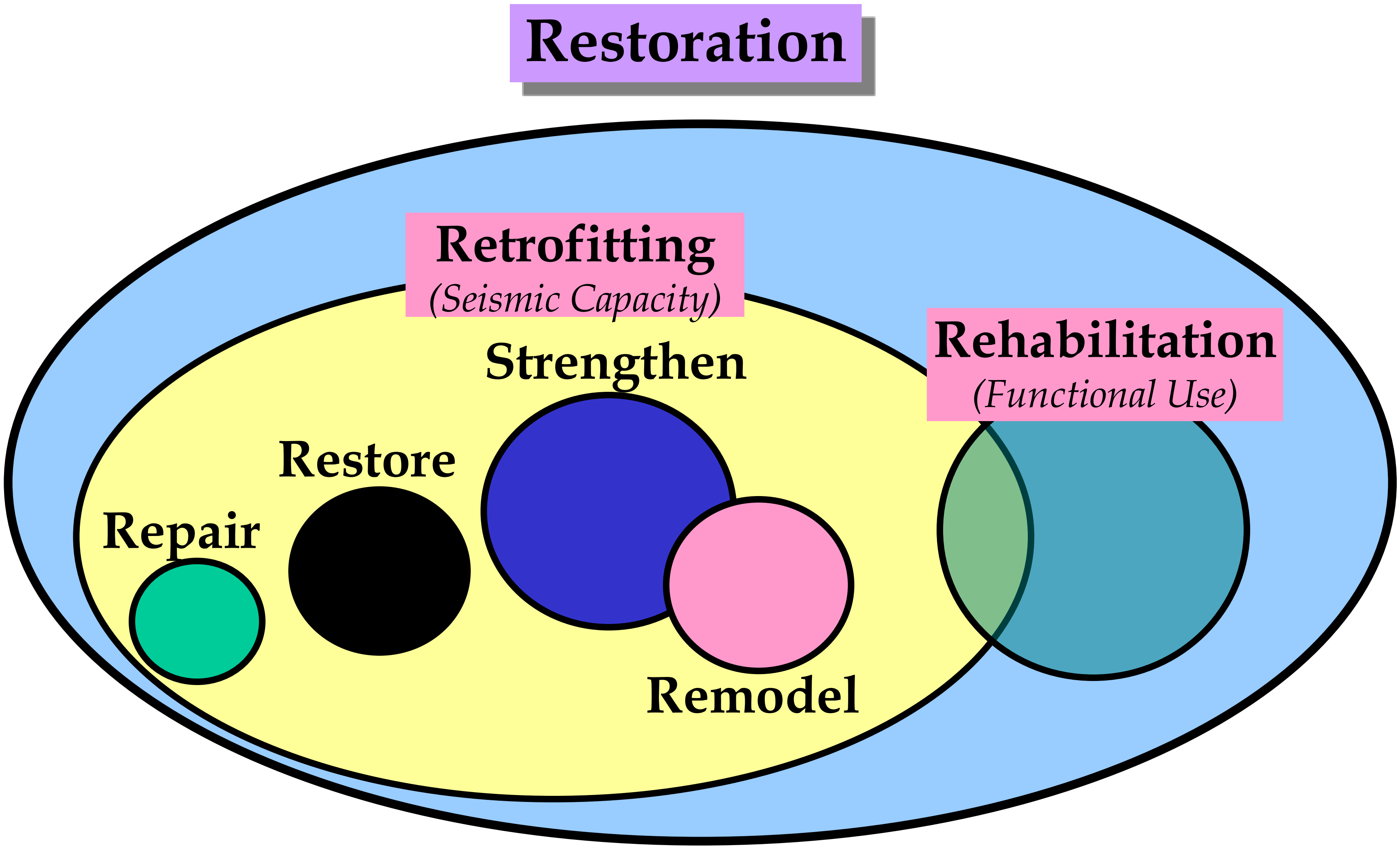
Band Aid…??

Masonry Infills

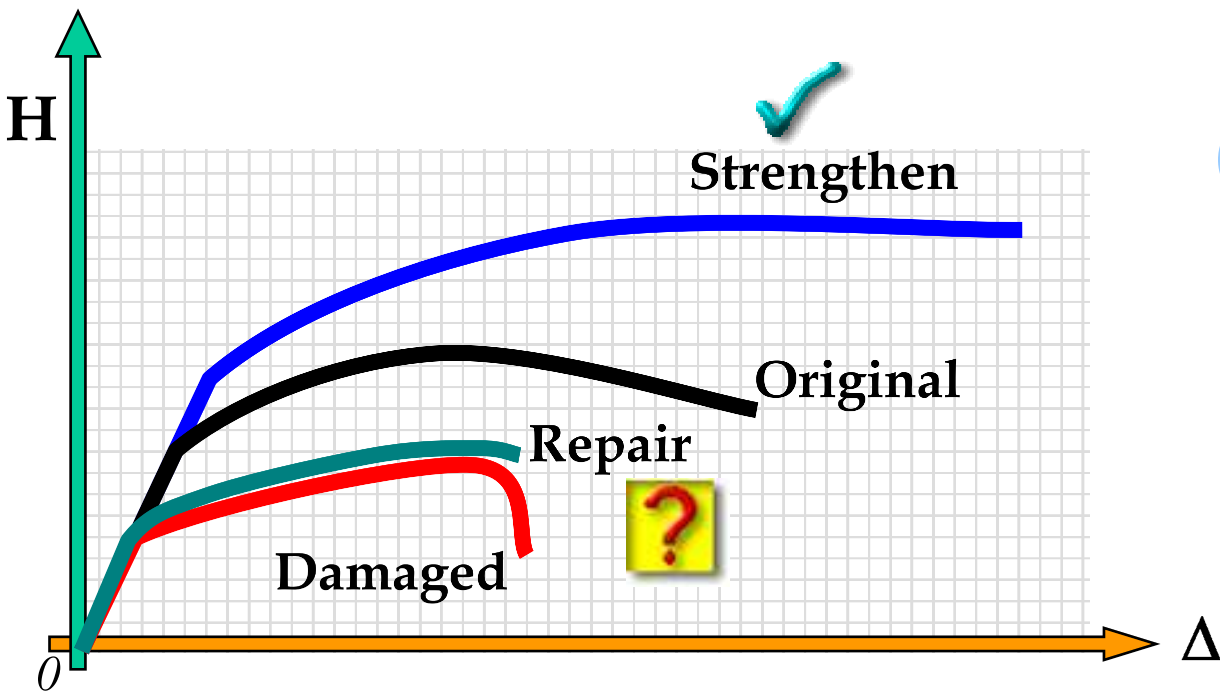
Seismic Strengthening

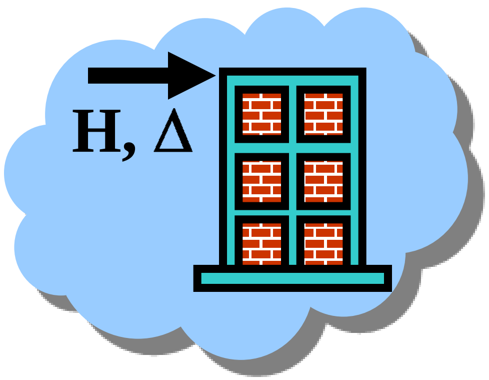
- **Reasons for Deficiency**
  - *Up-gradation of seismic design requirements*
  - *Deficiencies in design codes*
  - *Advancements in engineering knowledge*
  - *Lack of understanding by designers*
  - *Damaged during past EQs*
  - *Learning from experience*
  - *Gap between design & construction*

Restoration of Buildings

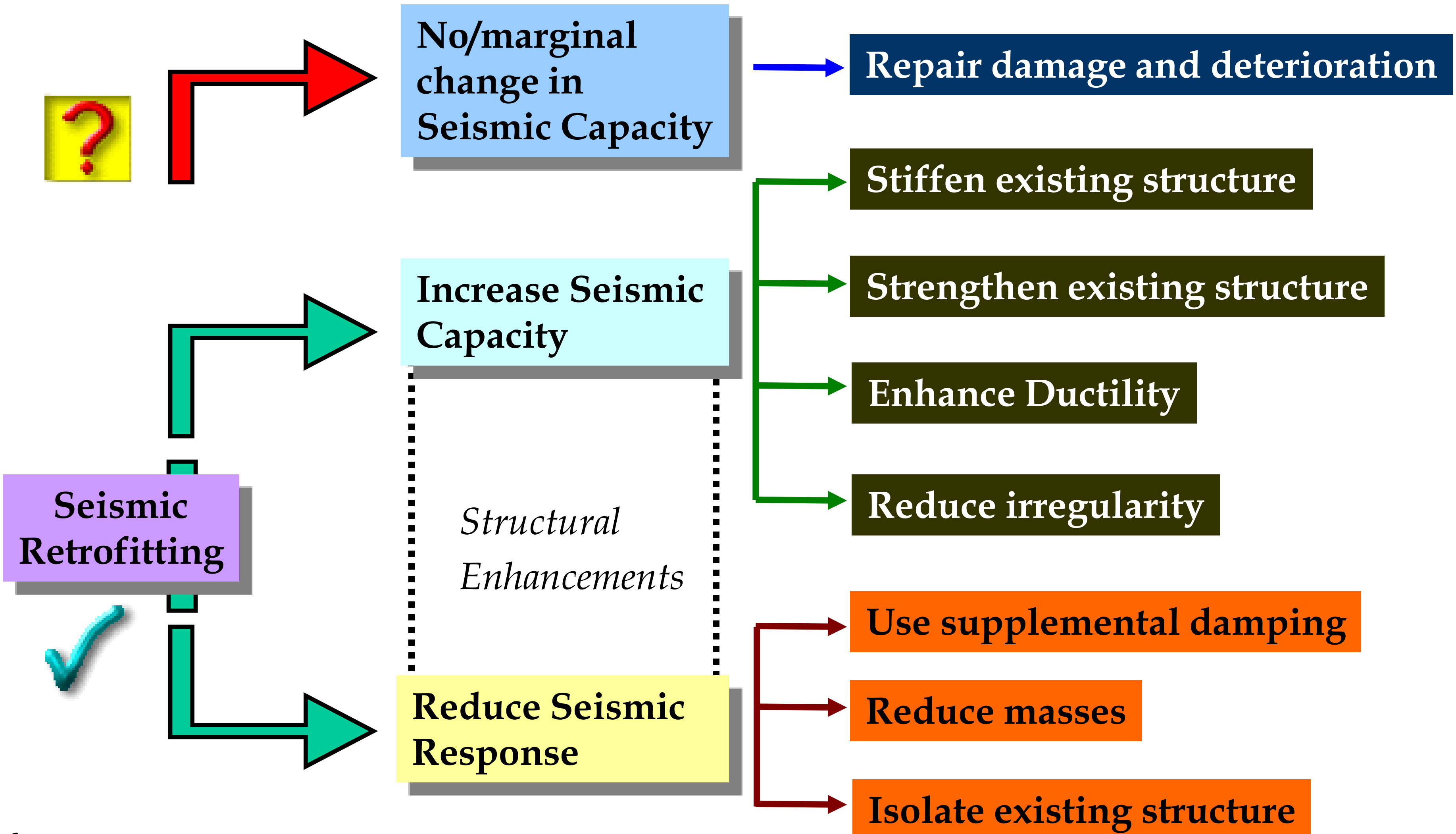


- **THREE Levels of Improvement**
  - *Repair (Cosmetic modifications)*
  - *Restore (Original performance)*
  - *Strengthen (Higher performance)*

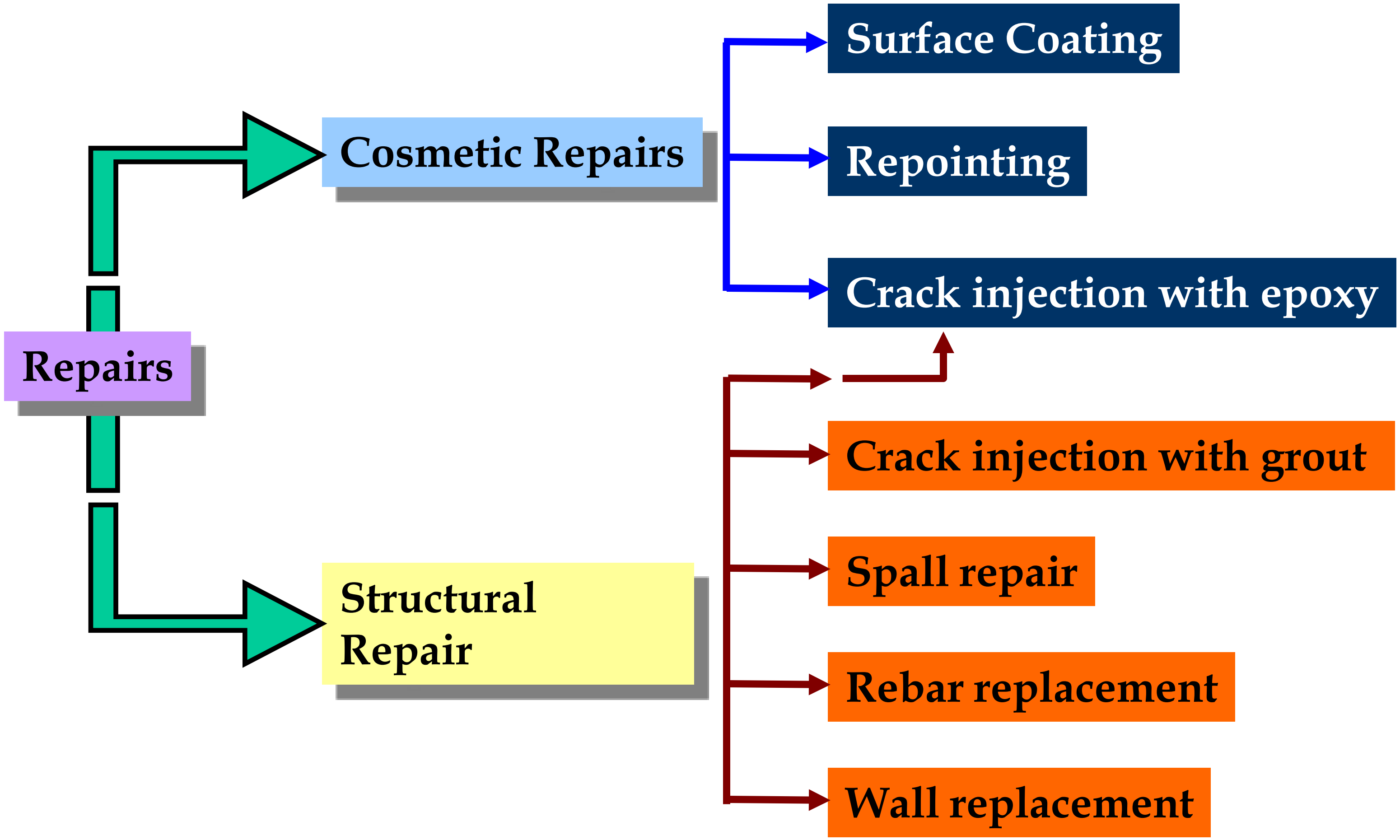




- **Retrofitting Strategies & Measures**



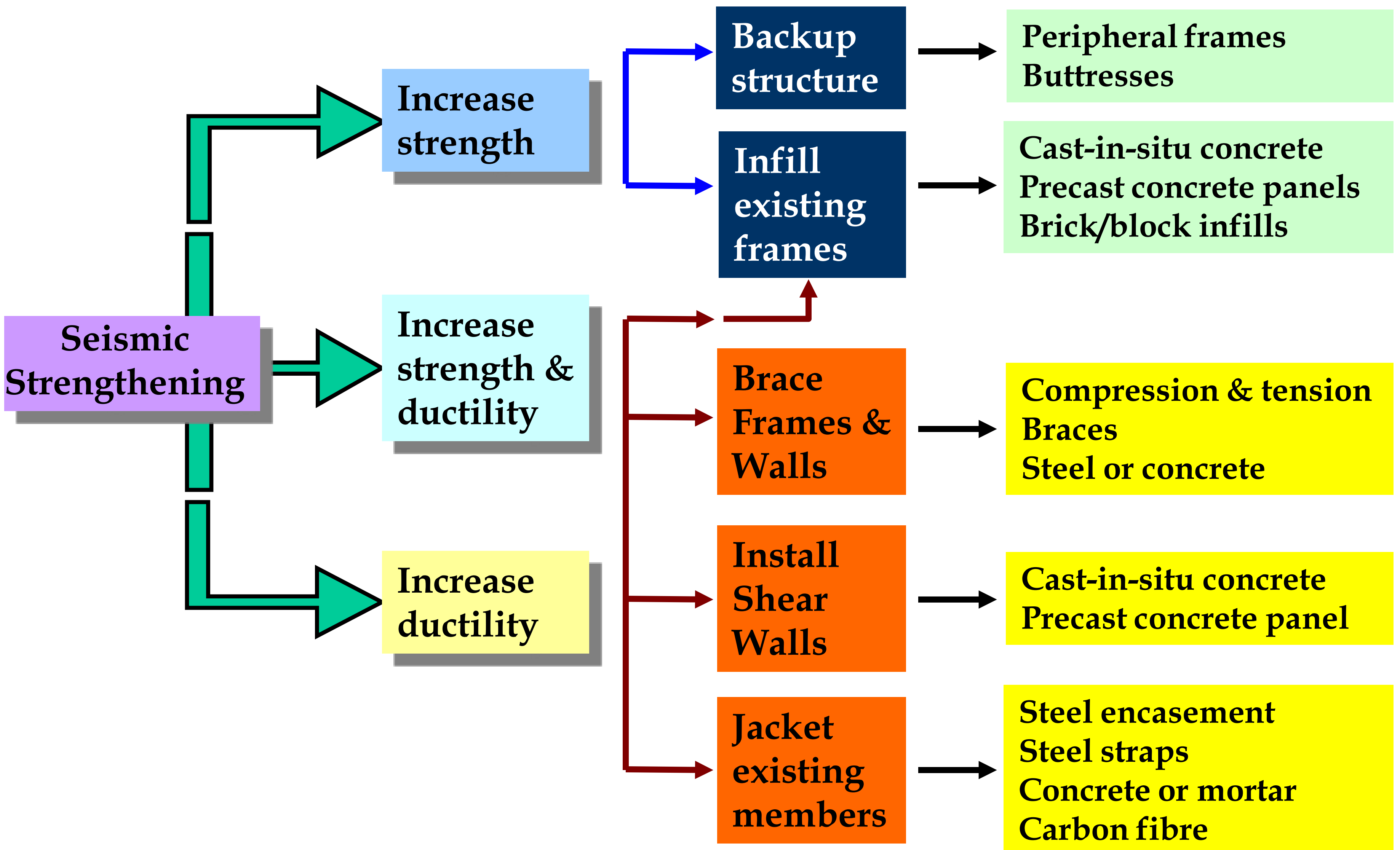
Repair Methods



Cosmetic repairs *only improve the visual appearance of component damage and may restore non-structural properties (weather protection) but any structural benefit is negligible.*

Structural repairs *intends to restore structural properties.*

Seismic Strengthening Methods



- **Steel Bracing for Masonry Walls**

University of California

@ Berkeley

Steel Bracing

Steel Bracing

Masonry Infills

Steel Bracing

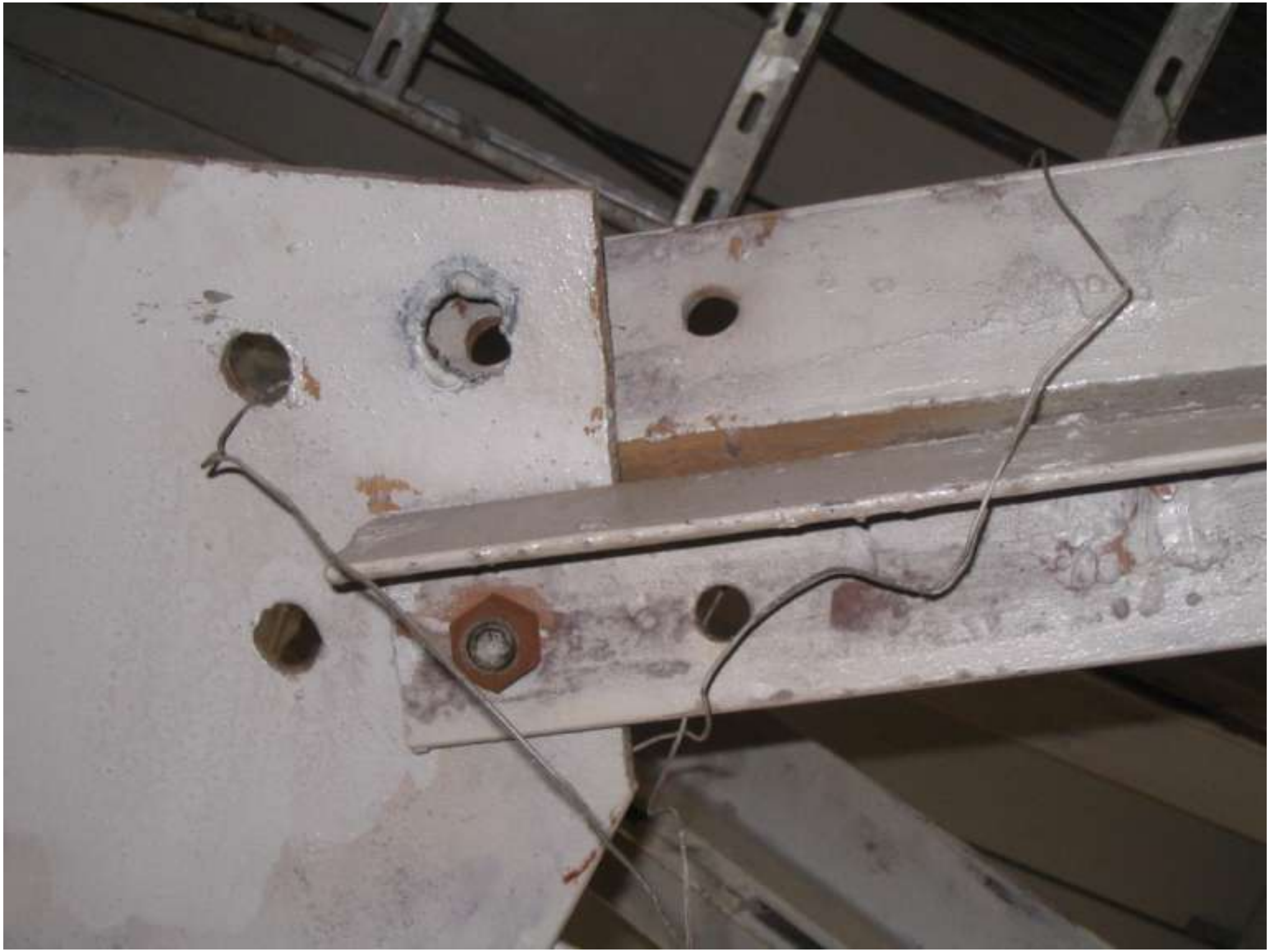
Example Building

Building

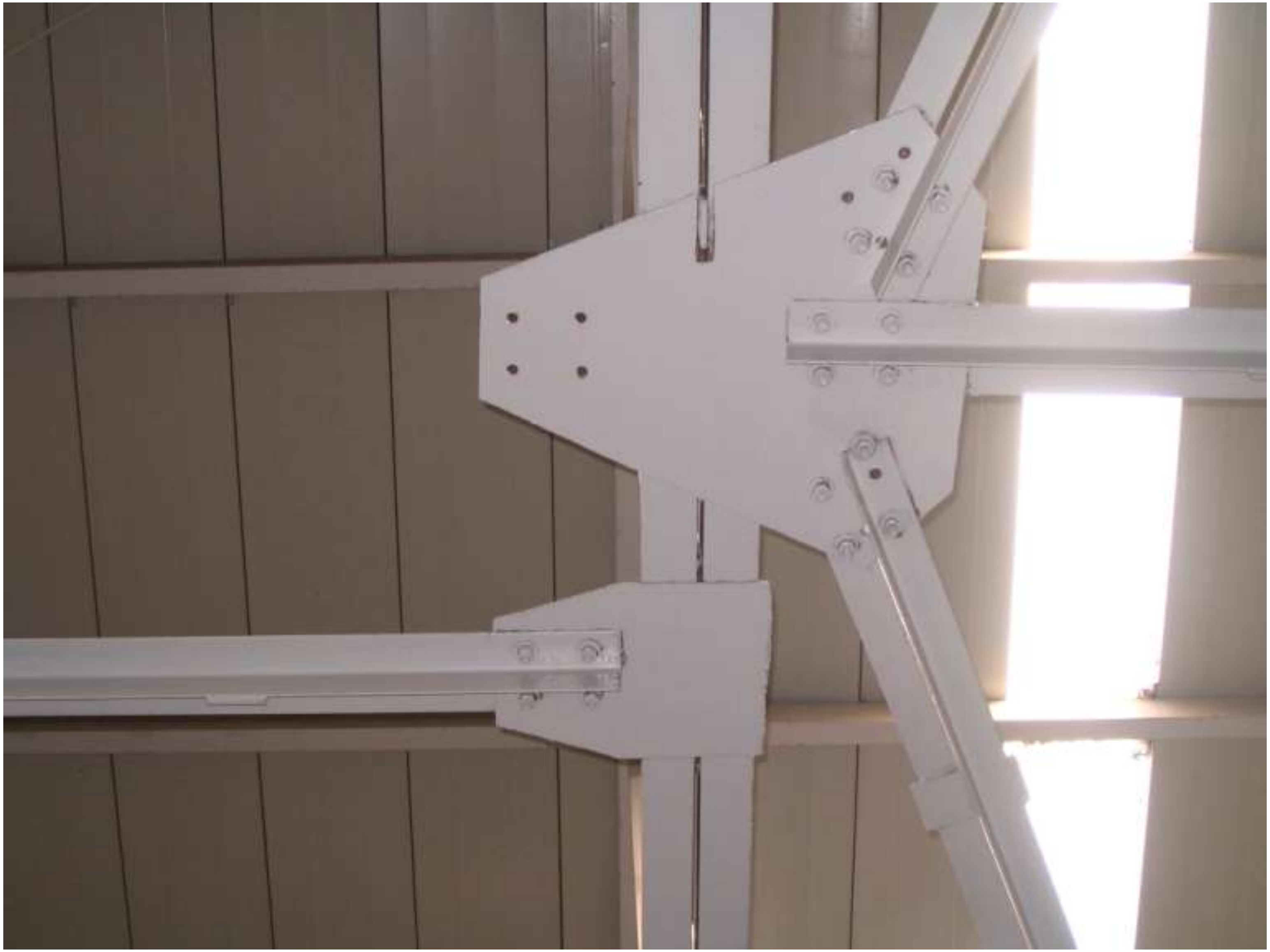
Building

Building

Building



Building

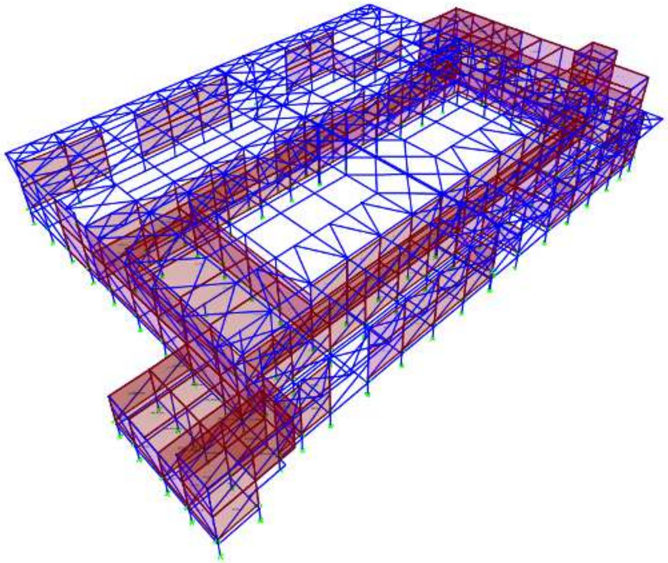


Four areas of concern

- In-plane shear strength and stiffness especially of "window" walls
- Diaphragm shear capacity to transfer forces and rigidity to limit deflections
- Out-of-plane stability of slender walls
- Structural integrity such that entire structure behaves as single unit

Remedial Measures

- Buttress walls and braced frames, shear walls
- Adequate shear capacity and new in-plane members will reduce deflections
- New bracing elements to reduce slenderness
- In-plane bracing of diaphragm



Linear dynamic procedure (LDP) analysis using SAP 2000

Seismic Evaluation:

Allowable seismic drifts (FEMA 356):

- 2.0% for the concrete frame
- 0.5% for unreinforced masonry

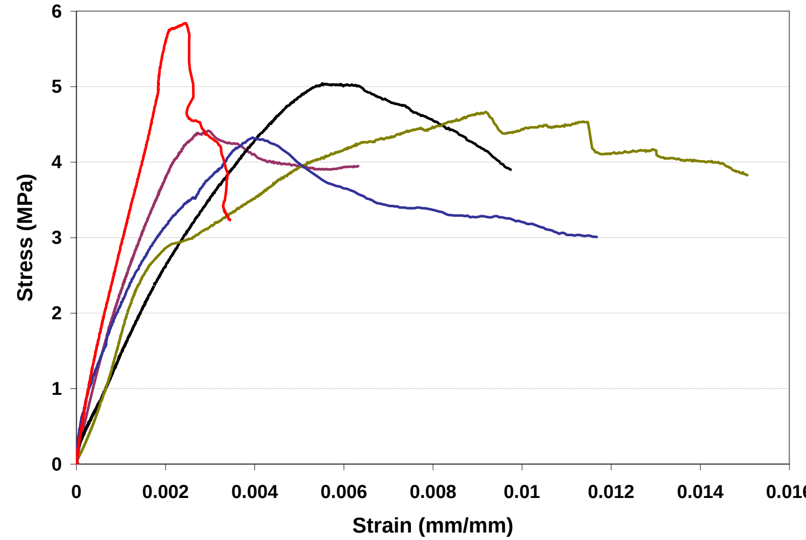
Demand over Capacity Ratio indicated:

- 100% columns failed in shear
- 98% columns failed in flexure
- 97% of beams failed in shear
- 21% of beams controlled by flexure failure

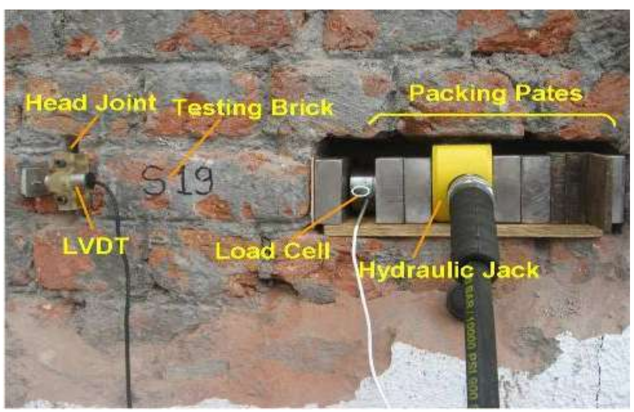
Assessment – Retrofit required

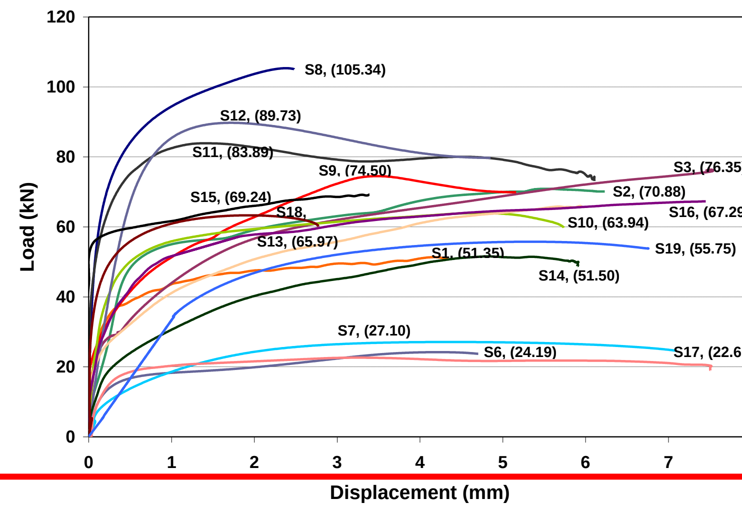
Lab and In-situ Test on Masonry

Five Brick prism test

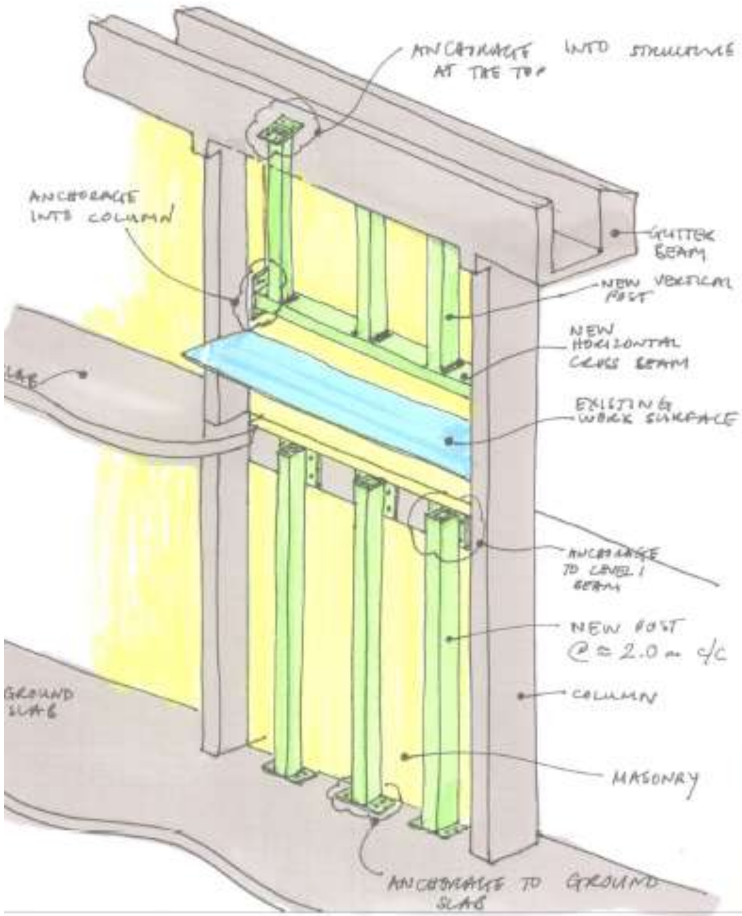


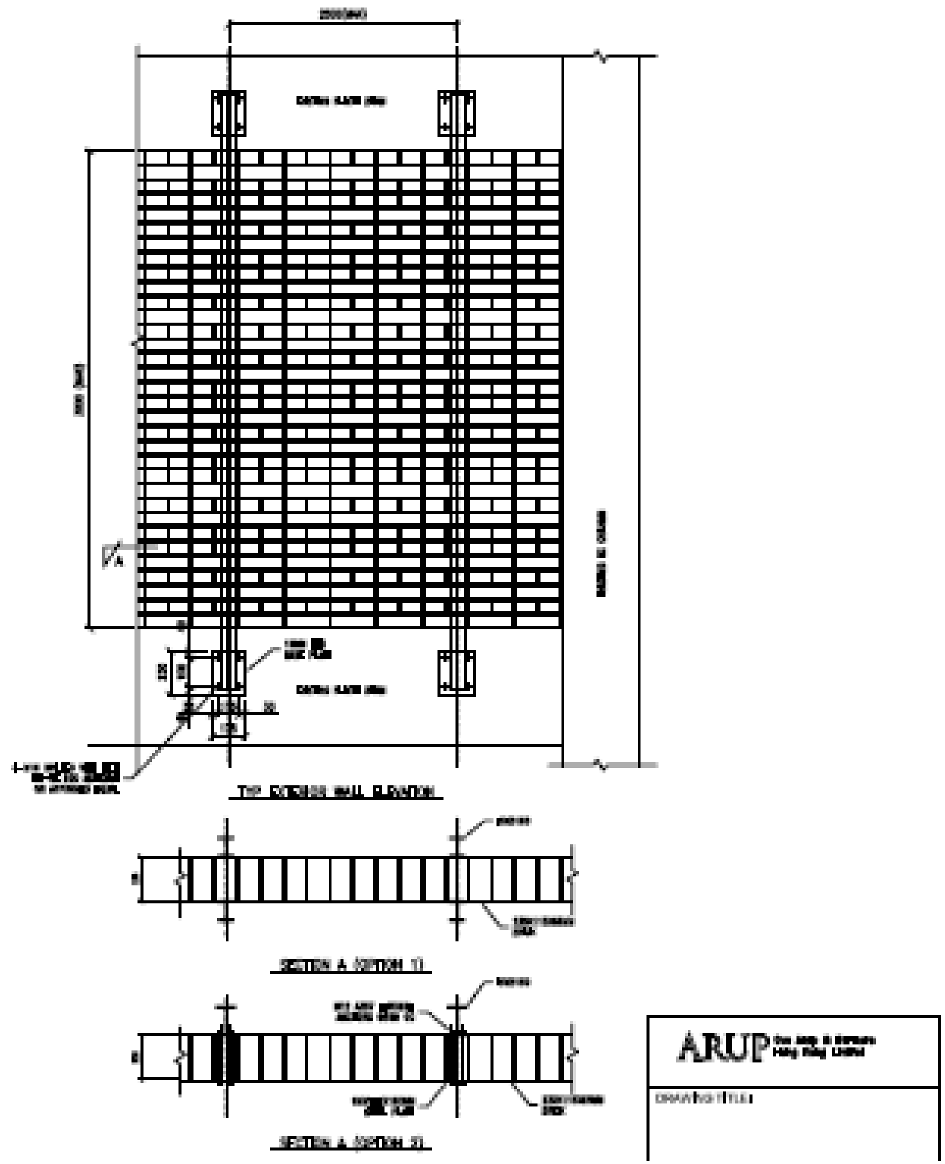
In-situ shear tests



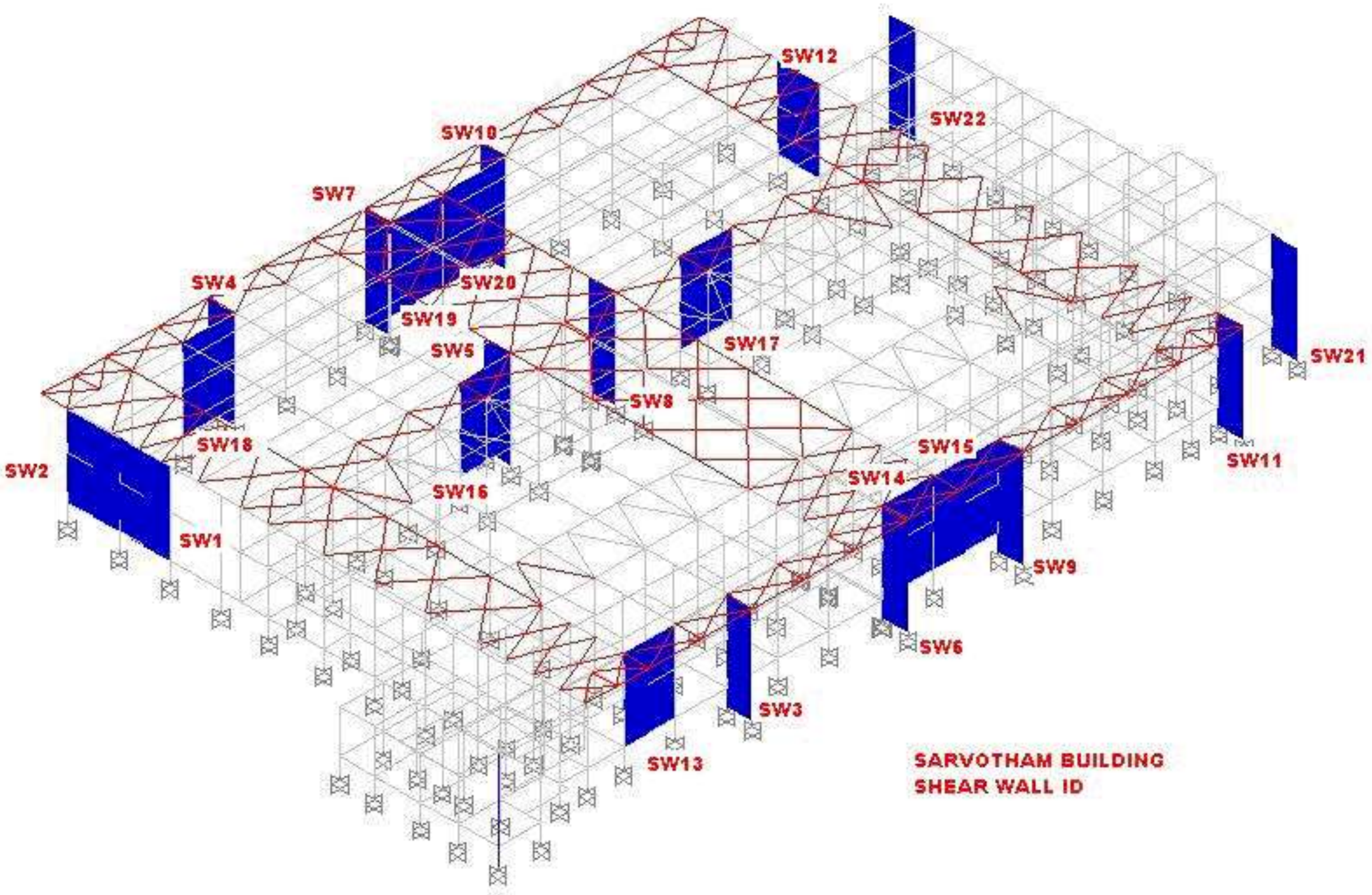


Out-of-plane retrofit





implementation



implementation

implementation

implementation

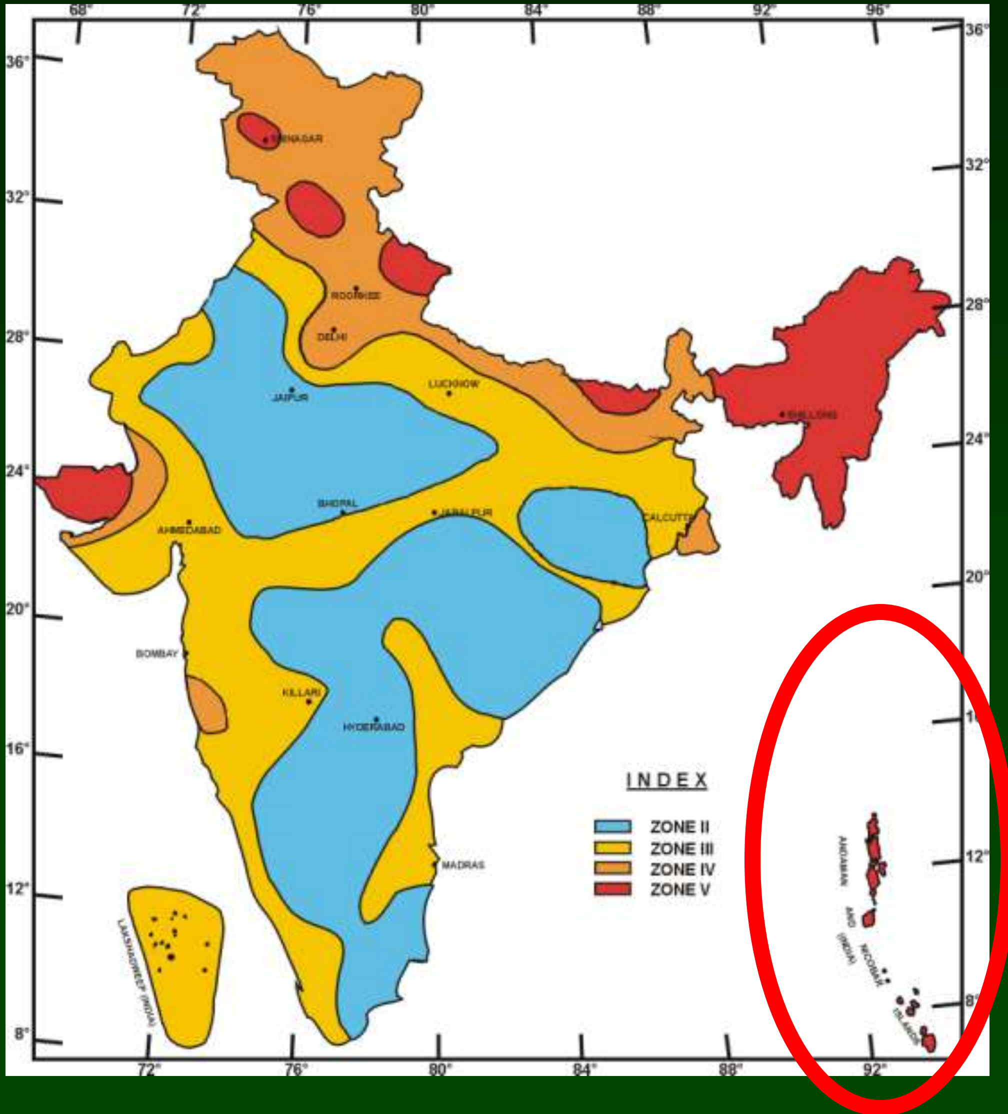
implementation

Earthquakes
in Andaman & Nicobar Islands

2004 Sumatra earthquake repeats lessons not learnt from 2002 Diglipur earthquake

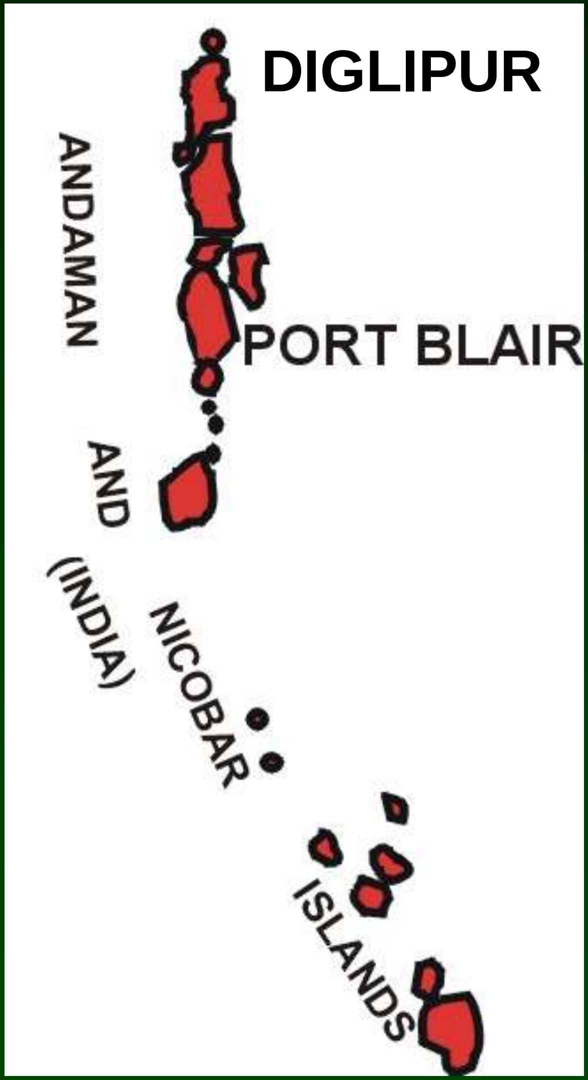
The Seismic Hazard

- **Seismic Zones**
  - ✓ *Four Seismic Zones*
  - ✓ *V :: Most Severe*

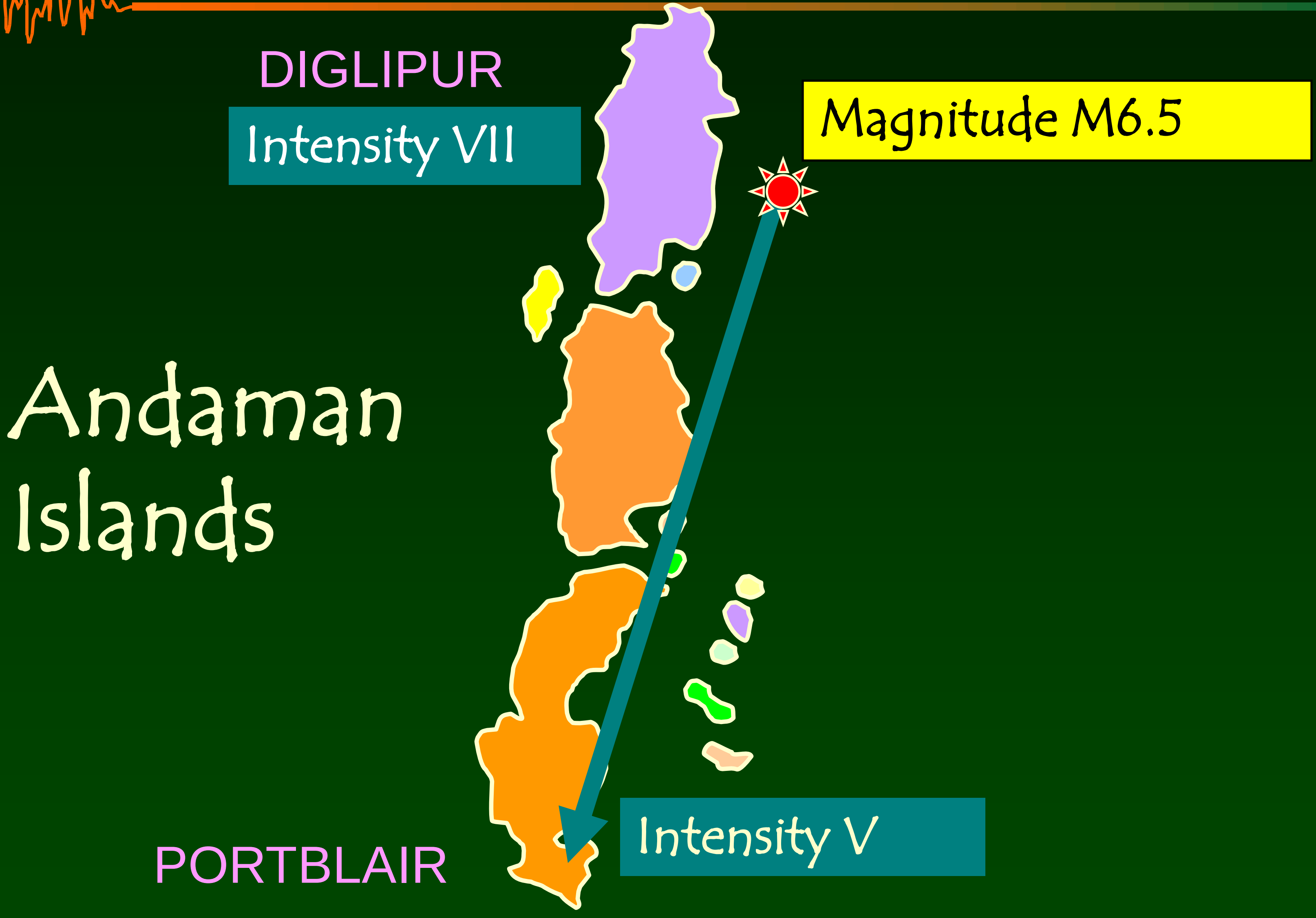


- Seismic Zone V

  All Islands

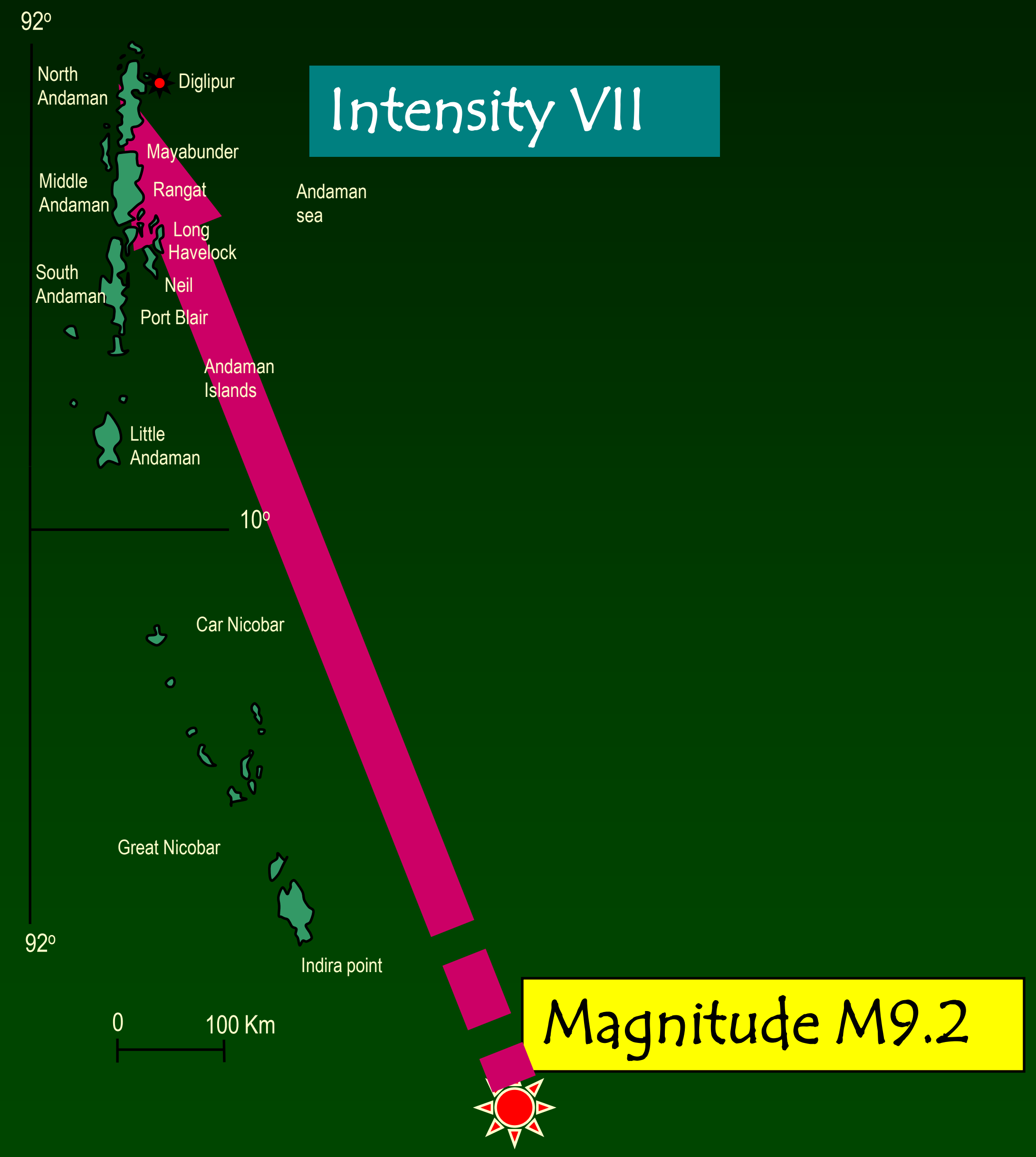


2002 Diglipur Earthquake… Magnitude *versus* Intensity …



2004 Sumatra-Andaman Earthquake

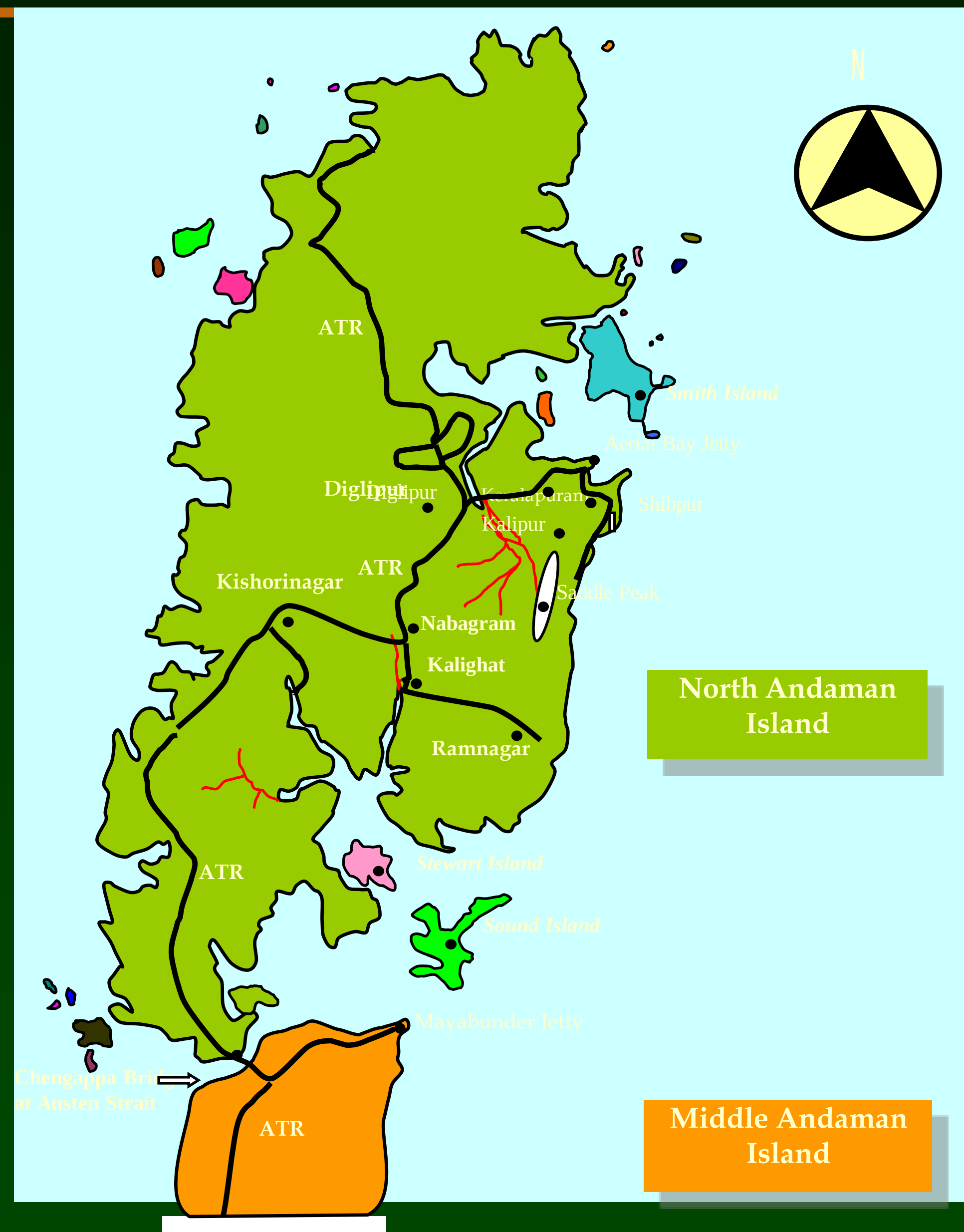
Andaman& Nicobar Islands



Study Region

North Andaman Islands

Affected in both2002 and 2004 earthquakes



Modern Constructions: Load bearing brick and Reinforced Concrete

2002


2004

2002

2002

2004


2002


2004

2004

2002


2004

2004

Austen-Creek Bridge
On ATR connecting two major population centres: Diglipur and Portblair

2002


2002

2002

"Inadequate seating of bridge deck over piers and abutments is a serious concern for its safety during a stronger earthquake in future. The bearings are simple neoprene pads which are far from satisfactory for a bridge located in seismic zone V. Bridge deck restrainers are the minimum that need to be provided to ensure that the spans are not dislodged from the piers in future earthquakes."

2002


2004

2004

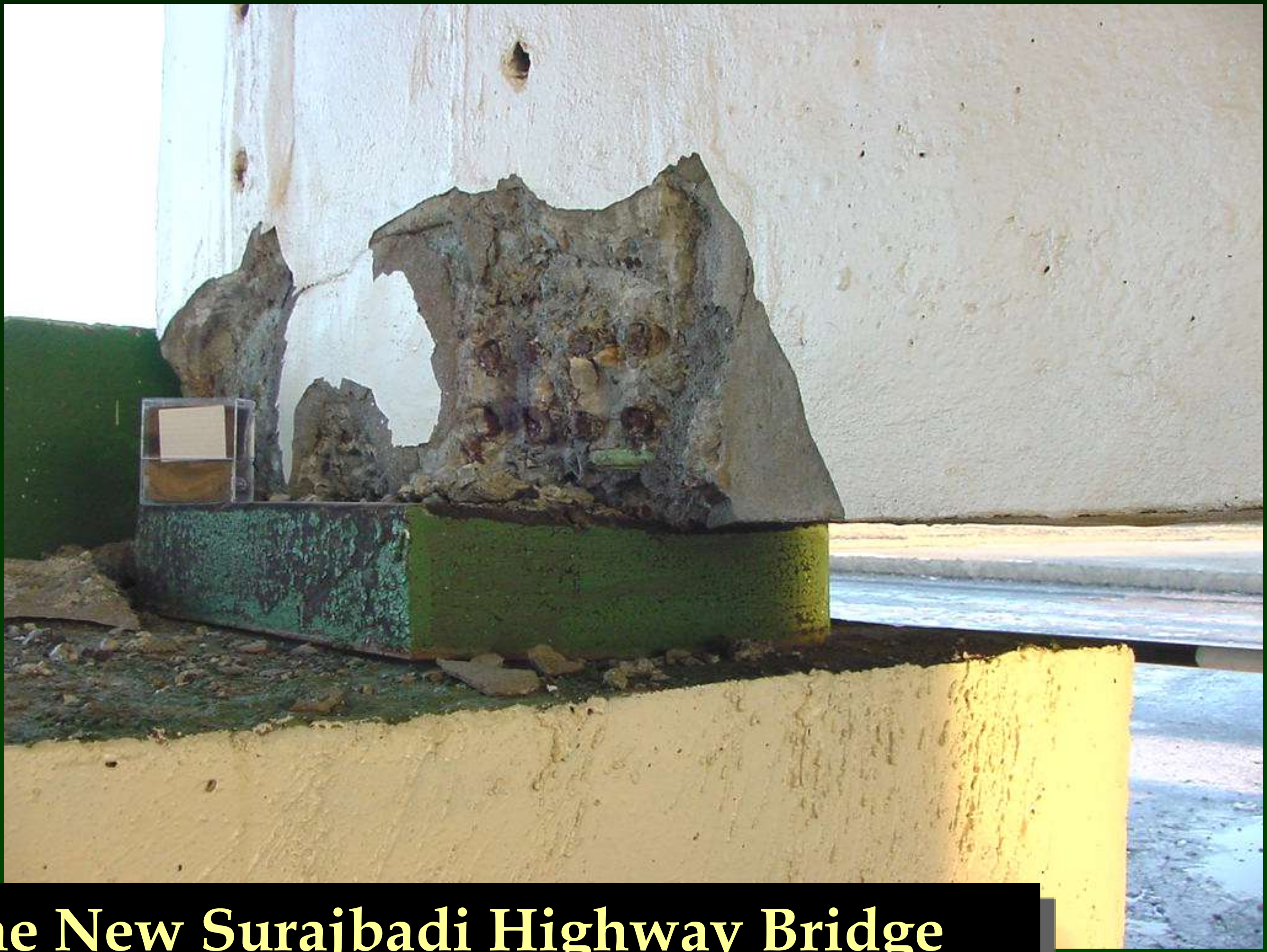
Bridges

The Old Surajbadi Highway Bridge
Balanced Cantilever Multi-Span Concrete Bridge

The New Surajbadi Highway Bridge
Longitudinal pounding of decks

bridges...

BRIDGES…



The New Surajbadi Highway Bridge
Jumping of Girders and damage

BRIDGES…

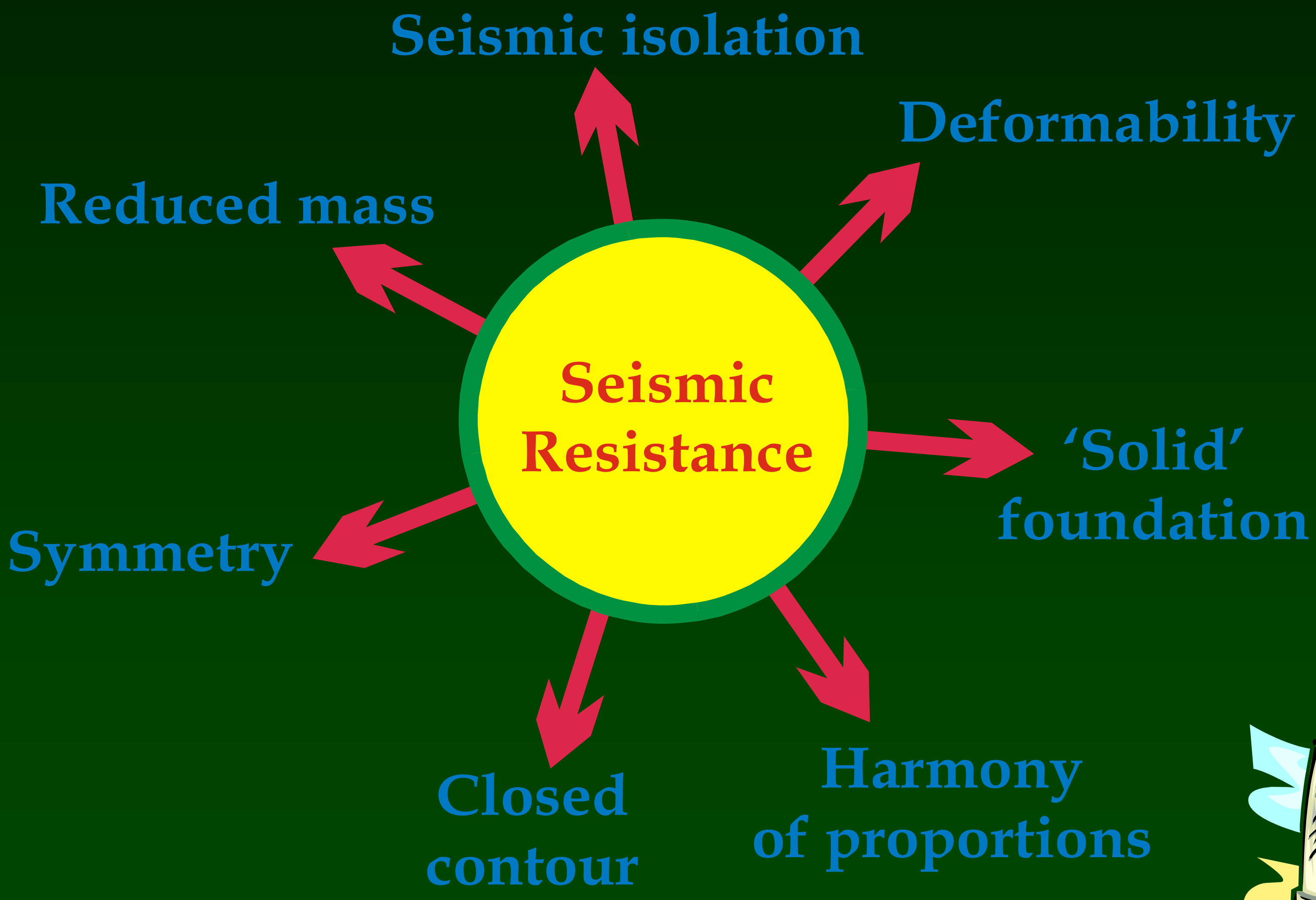
Modern RC Highway Bridge at Vondh
Poor Configuration of bed blocks

Performance of Traditional Housing Typology

Wisdom of Ancient Architects

- Structures standing even after 5000 years indicate their perfection in construction and ability to withstand earthquakes and other forces of nature
- We may not know the exact thoughts of ancient architects and builders regarding seismic protection and how they generalized the past experience
- May not have considered earthquake loads as a separate entity from dead, live, wind or snow loads, as we do today.
- Considerable insight can be gained by analyzing the ancient structures from present day knowledge of earthquake resistance of structures

Seven Principles of Seismic Resistance



Traditional masonry for proven earthquake resistance:

***Dhajji-dewari* system of timber laced masonry for confining masonry in small panels**

***Taq* system of embedding timber logs in thick walls**

Traditional Masonry
Building Earthquake Resistance

Traditional masonry for proven earthquake resistance

Widely used throughout the world in seismically threatened regions

Colombage-France

***Gaiola*-Portugal**

***Fatchwerk*-Germany**

Traditional Masonry
Building Earthquake Resistance

Institute's new building for Medical Research at Naggar


THE EARTHQUAKE PROOF DHAJJI DIWAR CONSTRUCTION.

Built in 1932

Confined Masonry

Building Earthquake Resistance

Institute's new building for Medical Research at Naggar

This method of construction is known here as the dhajji diwar construction and has proved to be the best, if not even the only, method of construction that resists earthquakes, which used to be quite frequent in this region. Most of the Government buildings in Dharmsala for instance, are built in this style and have proved to be the best. It is interesting that in its essential principle this mode of building rather resembles the steel structure of modern skyscrapers, with the difference of course that wooden beams are used instead of steel girders. Thus the wisdom of the people in its own way found the best solution, how to give the utmost binding strength and rigidity with the local material available. The

Present Status

Confined Masonry

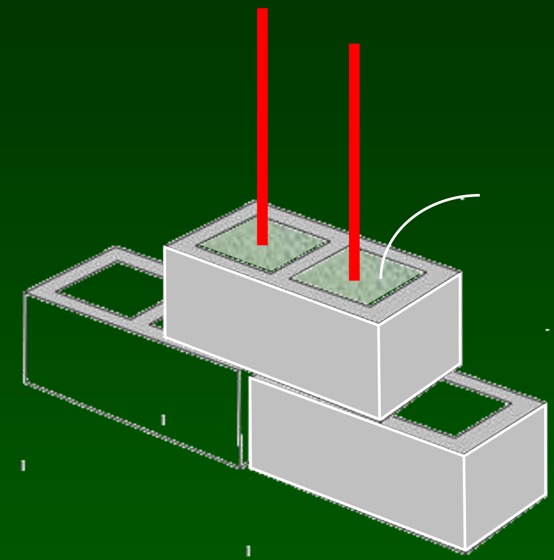
Building Earthquake Resistance

Traditional masonry for proven earthquake resistance

Mixed construction involving *dhajji-dewari* and dressed/undressed stone masonry and brick masonry

Reinforced Masonry

Building Earthquake Resistance



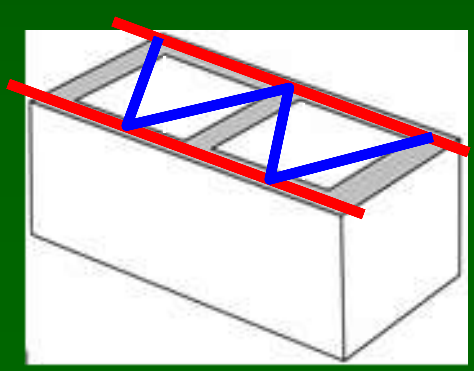
Appropriate bricks and blocks to receive reinforcements

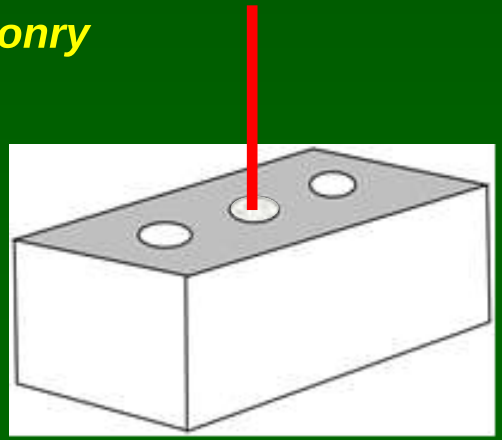
Masonry bond such as Quetta

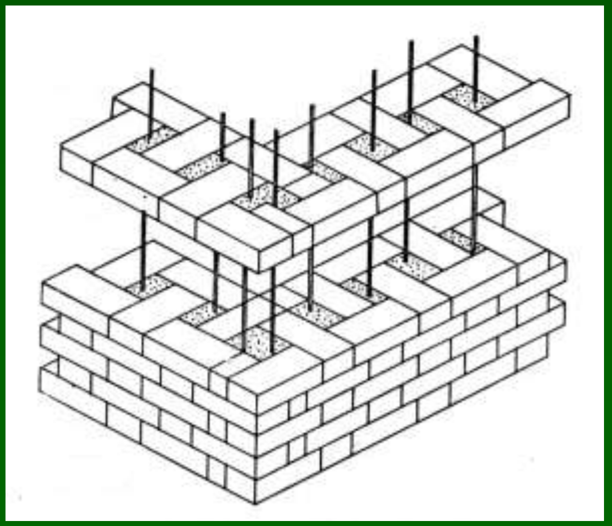
Code provisions

Verification studies

Reinforcement in masonry



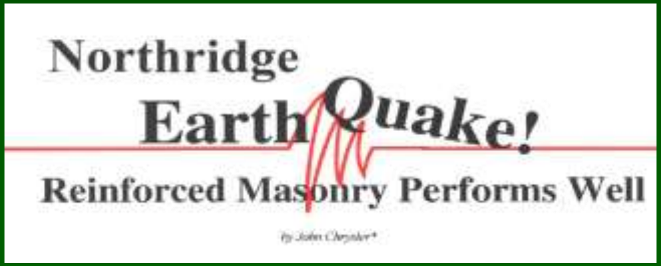




Reinforced Masonry
Building Earthquake Resistance

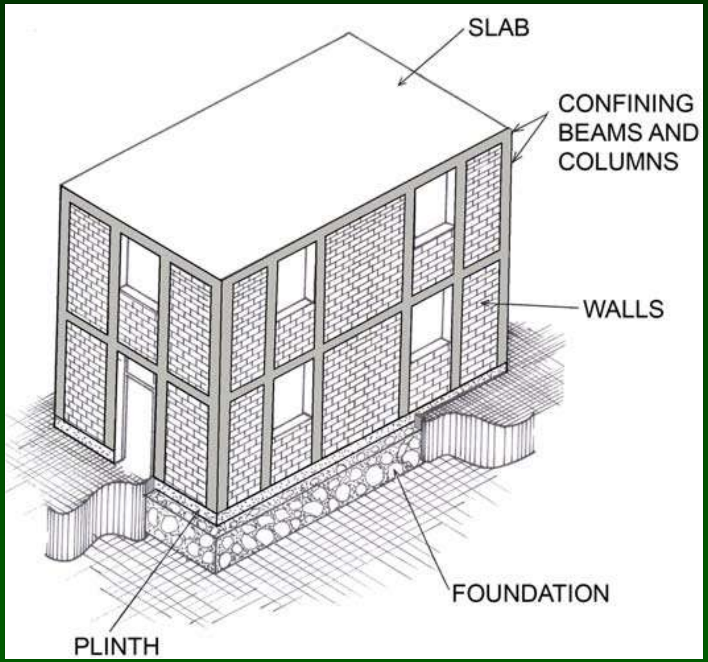
Masonry can be earthquake resistant by using proper amount of reinforcement

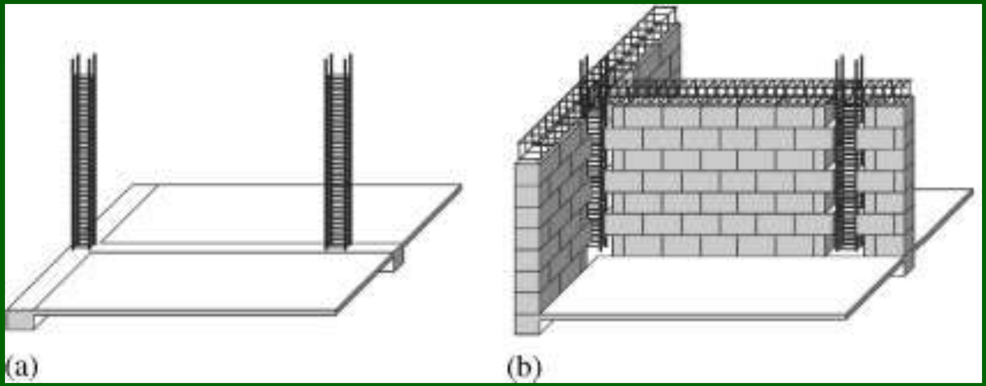
Reinforced masonry is most suitable for low-rise structures.

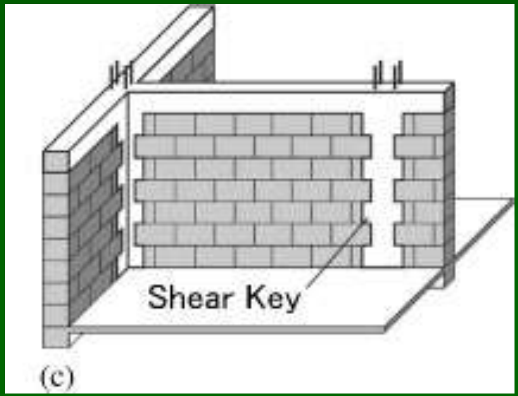


New Confined Masonry

- Close to traditional construction practices
- Low in intricacies of modern technology
- Inherent earthquake resistance
- Perform satisfactorily in resisting earthquake loads
- Good for low-rise buildings in India



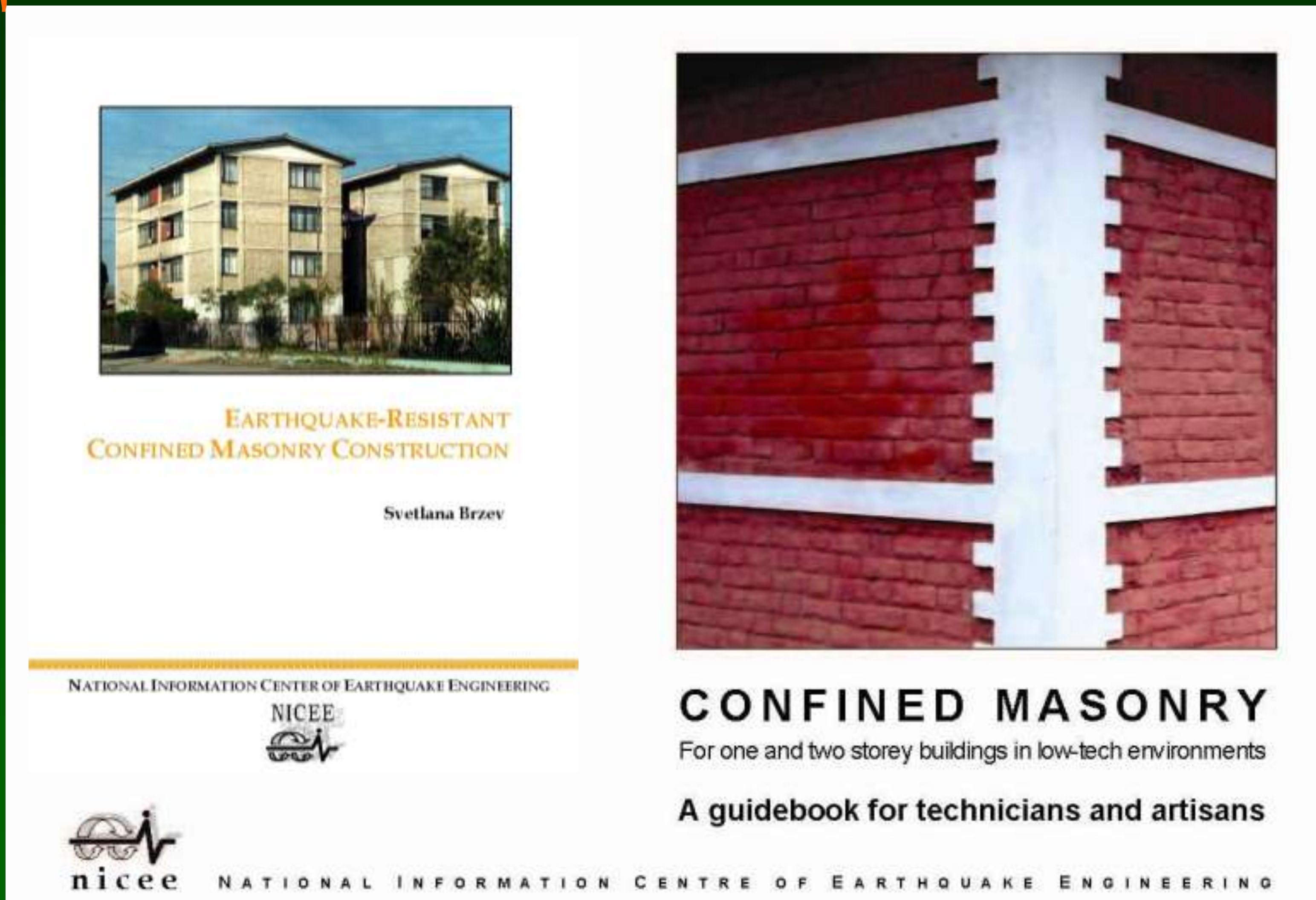




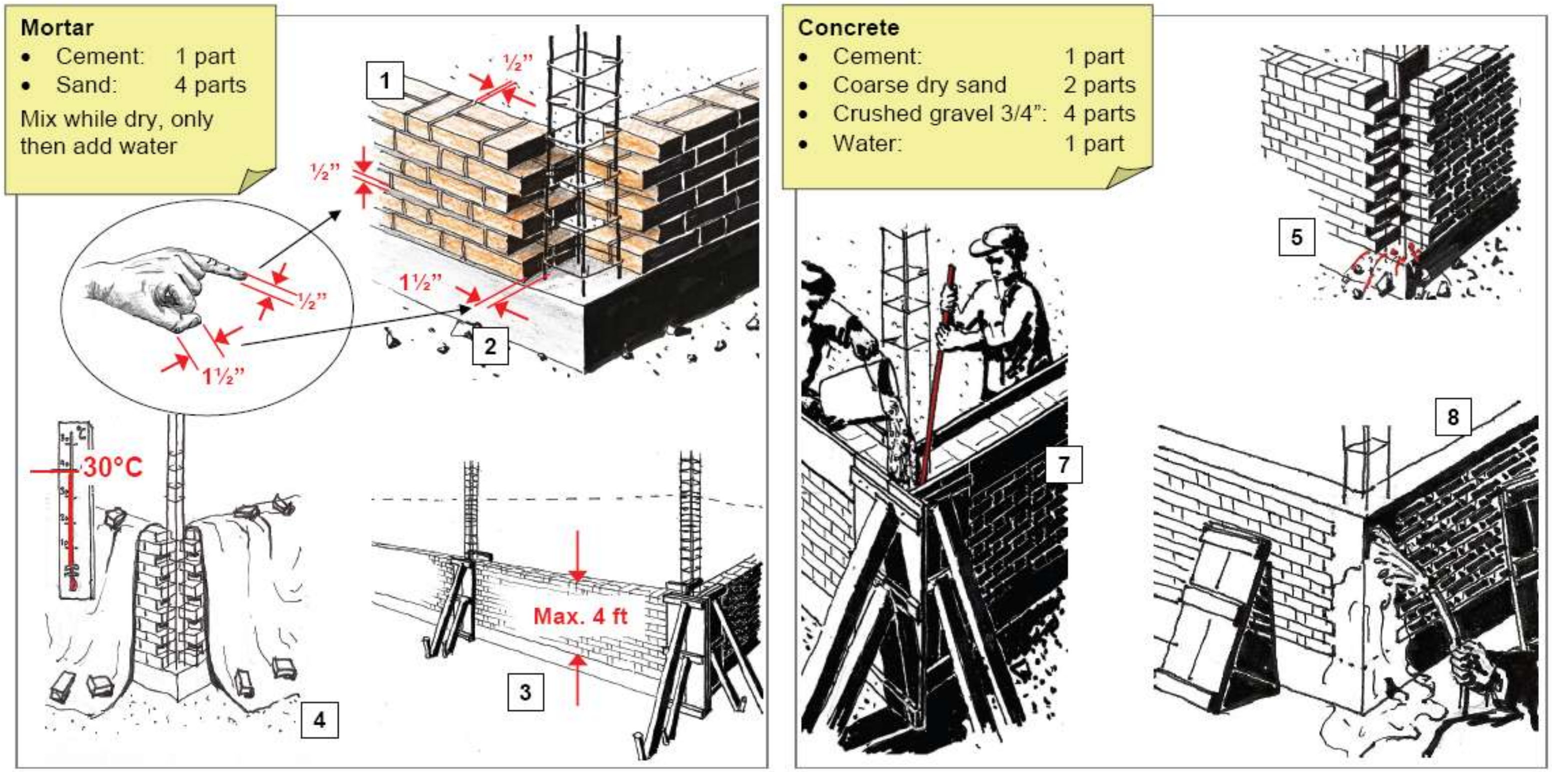
Confined Masonry Buildings in Peru

[Quinn, Peru]

Confined Masonry…



Confined Masonry…



1. Mortar beds and joints must not be thicker than ½ inch.
2. Keep end bricks 1½" away from the stirrups to leave room for the concrete of the tie-columns.
3. Don't build higher than 4 feet per day.
4. Protect the wall in warm weather with a plastic sheet or wet cloth so the mortar will not dry out.
5. Clean the column space of all rubbish before adding the formwork.
6. Pour the concrete for the bands and the columns at the same time.
7. Compact the concrete vigorously with a stick to get the air pockets out of the mix. Also, hammer against the formwork to compact the concrete. Don't add water to make concrete 'go down'.
8. Water the concrete twice a day for at least 3 more days. Cover with a plastic sheet in summer or in a dry climate.

8. Tie-columns

Traditional Building Typology

Innovative structural systems offer new possibilities

Traditional structures show that earthquake protection is a rather wider concept than mere reinforcement and use of strong materials

Need to develop novel building typologies for enhanced seismic performance using systems of proven performance

Development of rational design guidelines and their validation of design using experimental and analytical simulations

Window of opportunity!

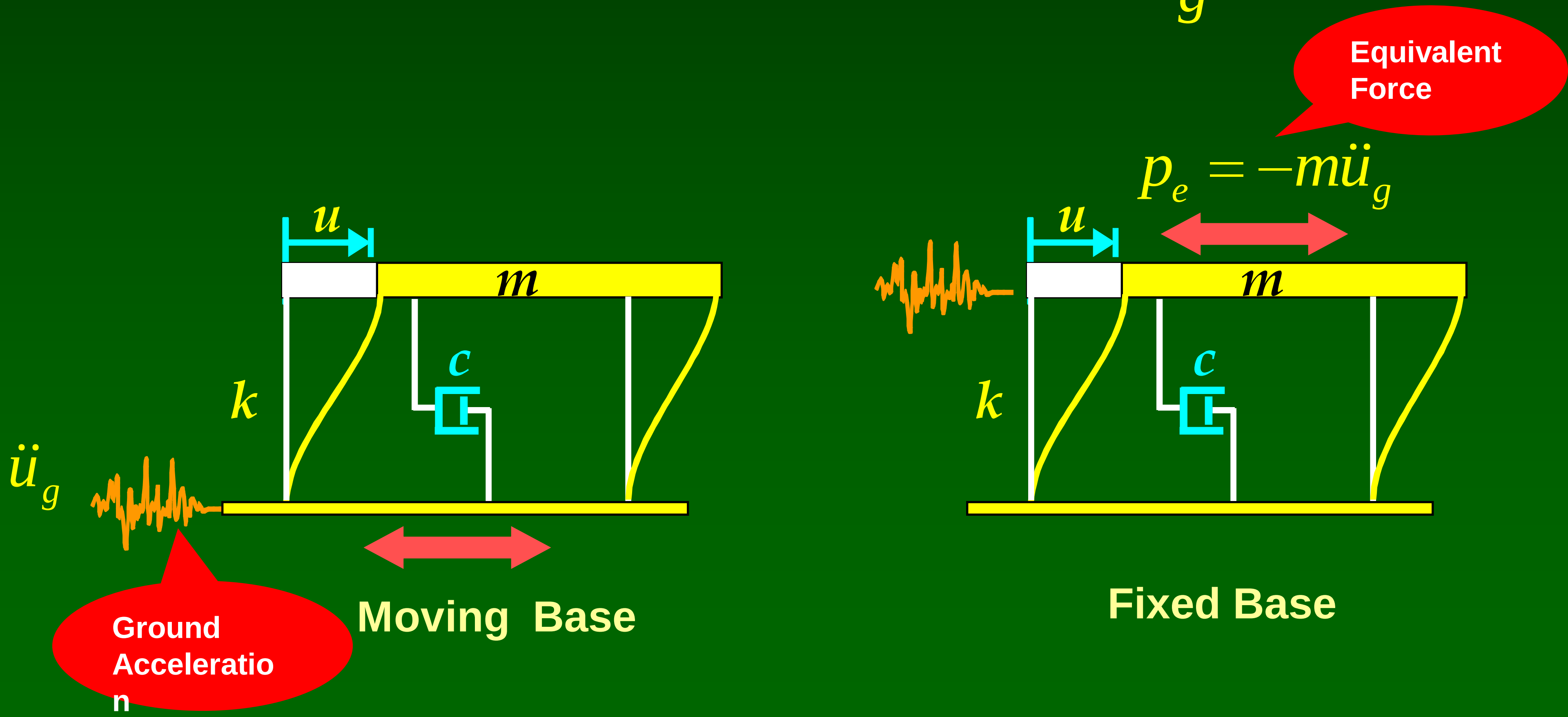
Experimental Earthquake Engineering

Earthquake Response

Equation of motion

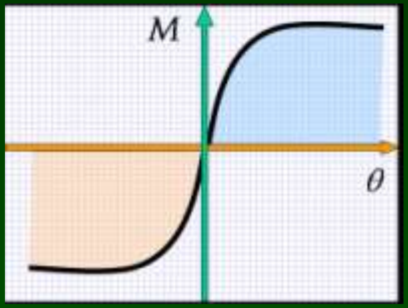
Single Degree of Freedom System

$$m\ddot{u} + c\dot{u} + ku = -m\ddot{u}_g$$

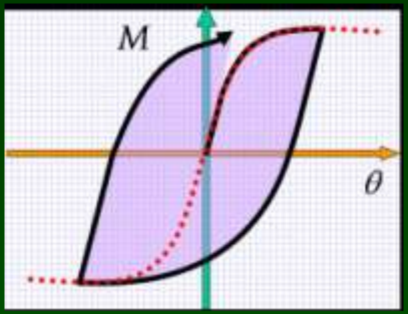


Experimental Simulation
Validation of design

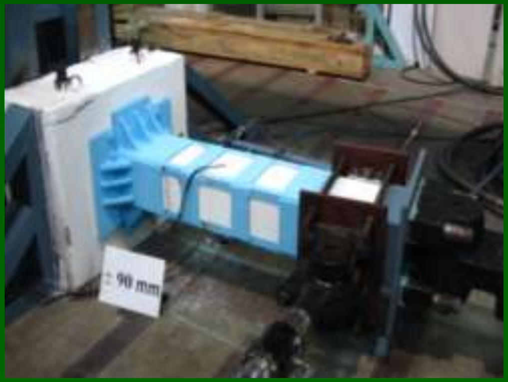
- Behavior of structures and materials under dynamic loads is very crucial
- Accurate analytical models are difficult
- Monitoring of real life prototypes is nearly impossible
- Low-cost experiment techniques

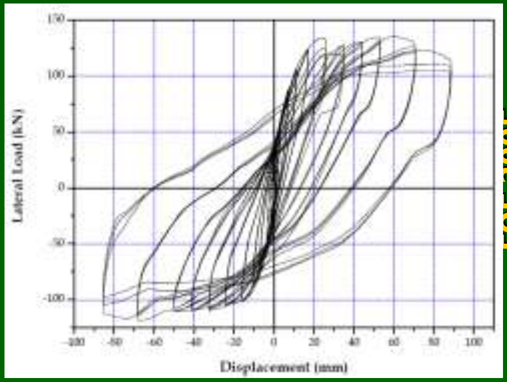


Monotonic



Cyclic





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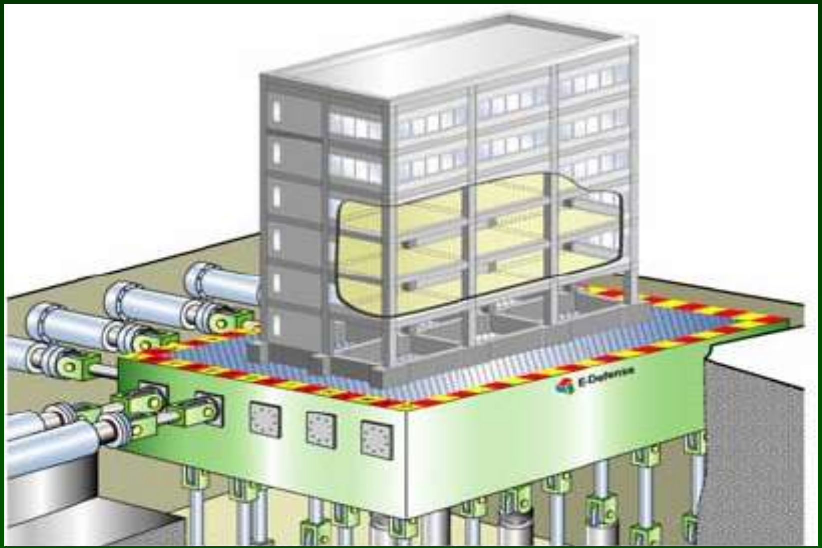
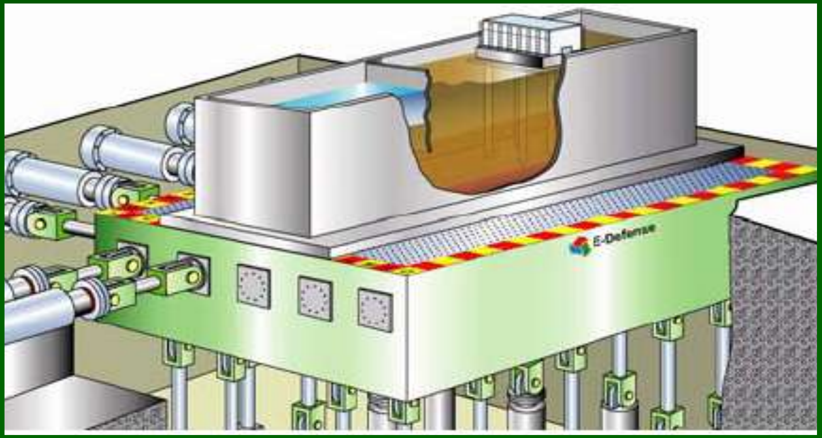
Shake Table Test

Realistic Simulation of Seismic Environment

World's Largest Shake Table
NIED, Miki City, Japan

Payload – 1200 ton
Size – 20 x 15 m
Max. acceleration – 1g
Max. velocity – 2 m/s
Max. displacement – 1 m





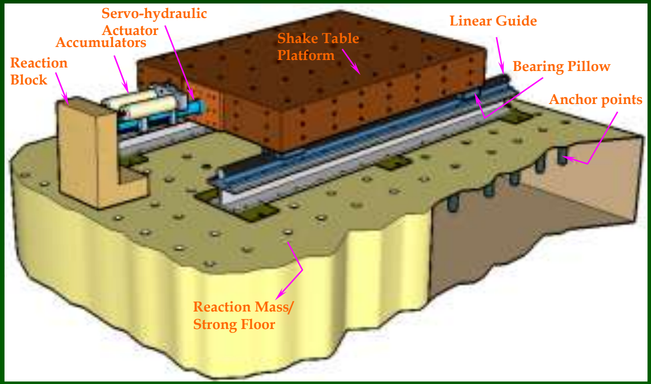
FOE 2005

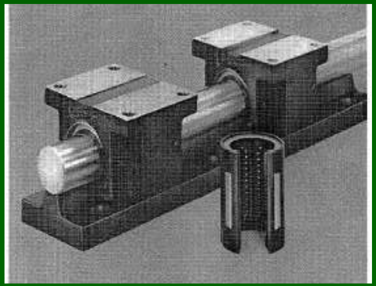
Shake Table Test

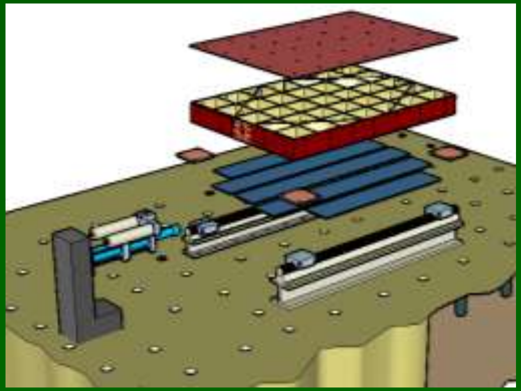
Realistic Simulation of Seismic Environment

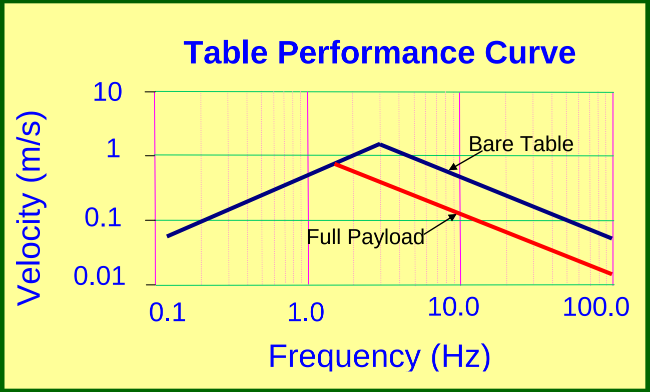
Shake Table at IIT Kanpur

- Payload – 4 ton
- Size – 1.2 x 1.8 m
- Max. acceleration – 5g
- Max. velocity – 1.5 m/s
- Max. displacement – 0.15 m









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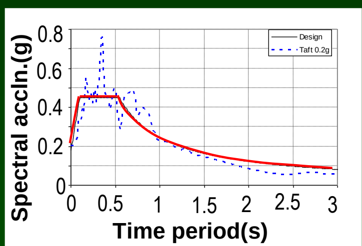
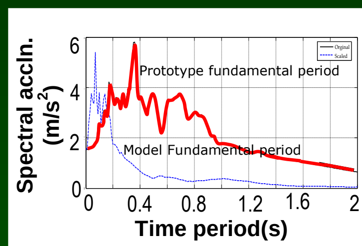
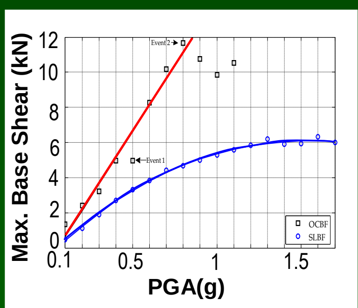
Shaking Table Studies of Shear-Link Braced Frame

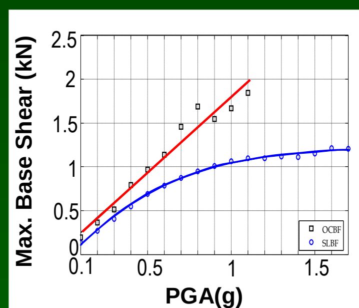
Validation of Novel Concept and Design

Aluminium Shear Link Damper

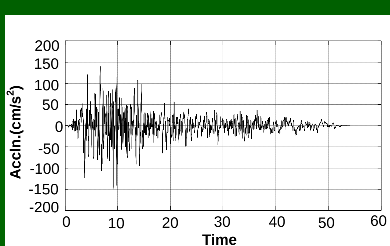




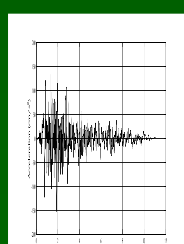




Increasing Severity



Taft Motion



Taft Motion applying a scale factor of 1/24

SLBF Specimen Mounted on the Shaking Table

FOE 2005

Shaking Table Studies of Shear-Link Braced Frame

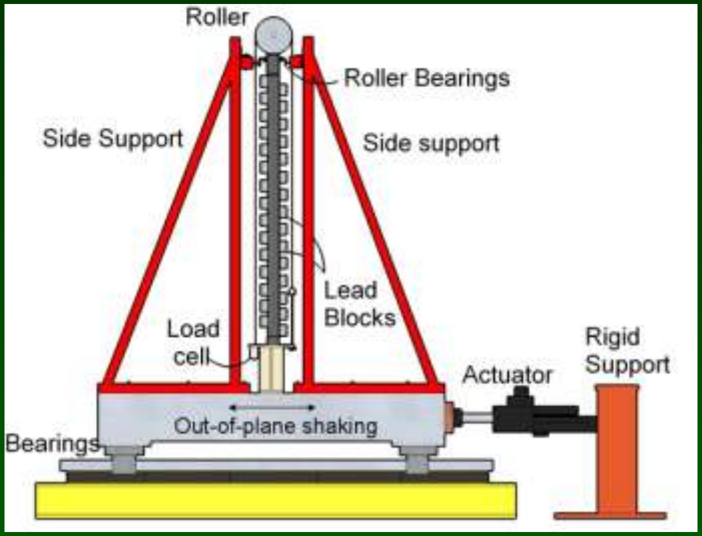
Validation of Novel Concept and Design

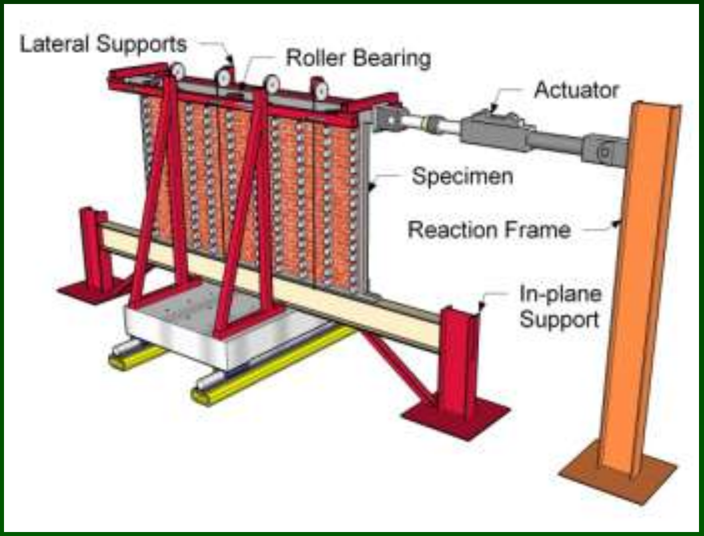
Aluminium Shear Link Damper

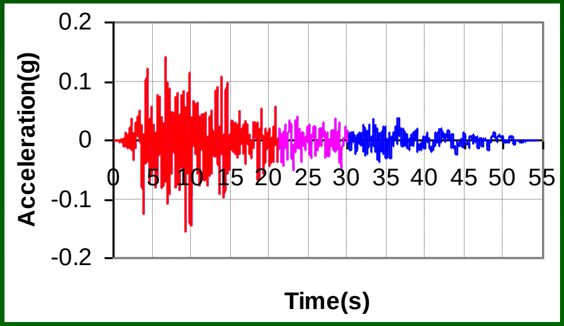
Taft
1.6g

Combined In-plane and Out-of-plane studies
Verifying Seismic Behaviour

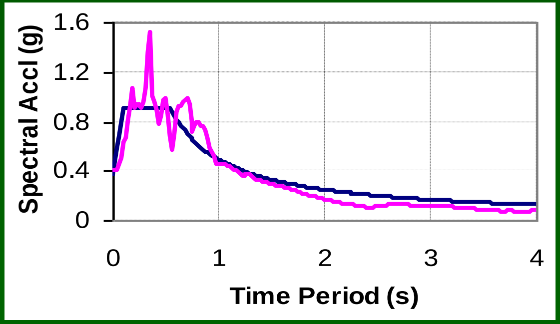
Enhancing Capacity of Confined Masonry

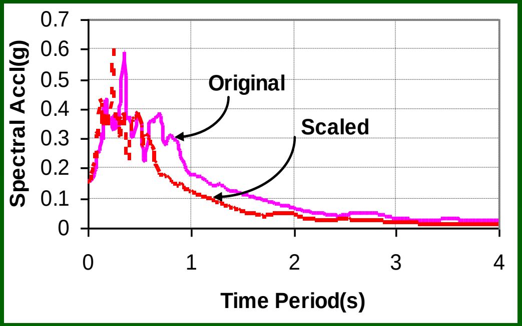






Original, Curtailed and scaled Taft Motions



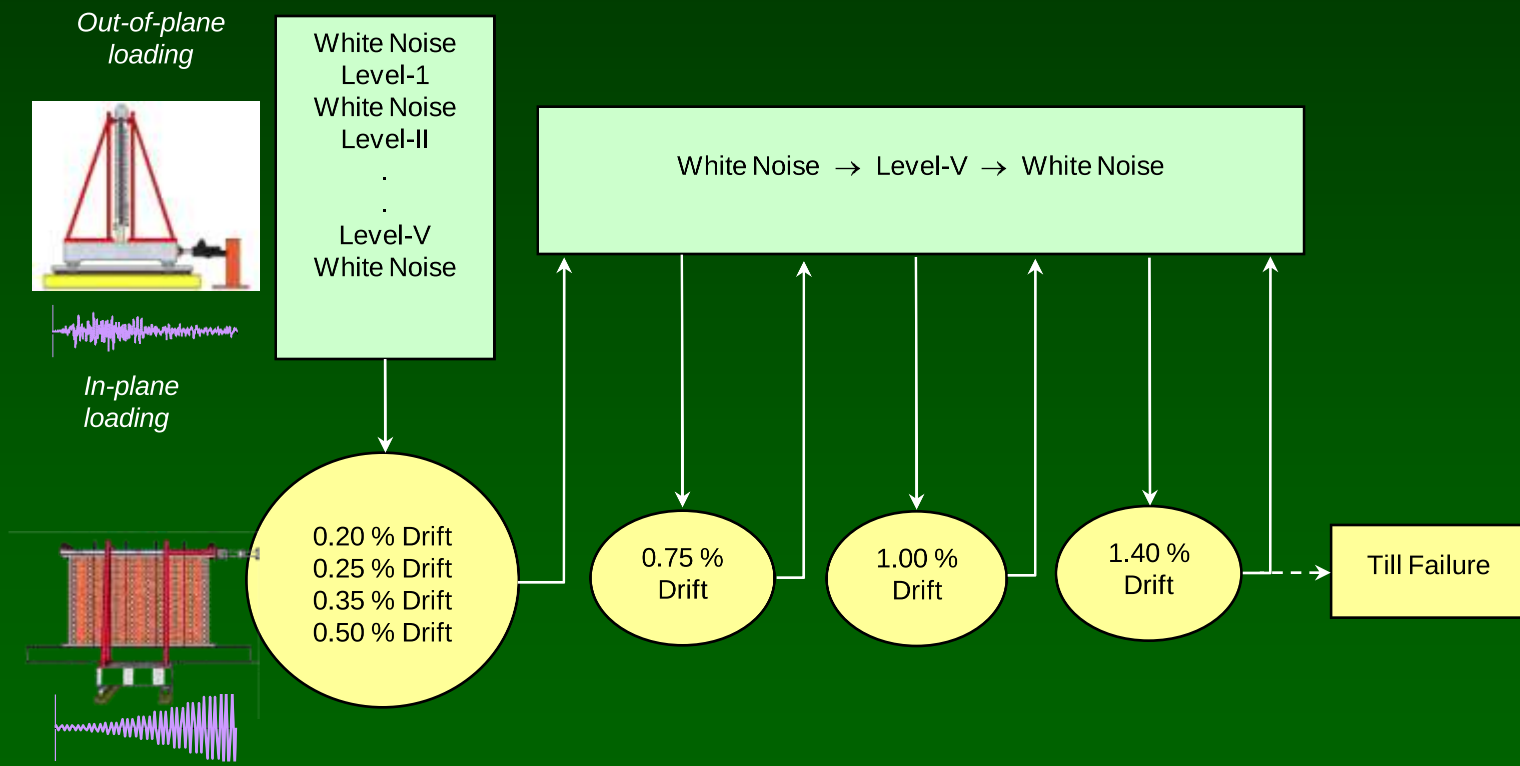


Response Spectra Comparison

Shaking Table Studies of Shear-Link Braced Frame

Verifying Seismic Behaviour

Loading Sequence Followed



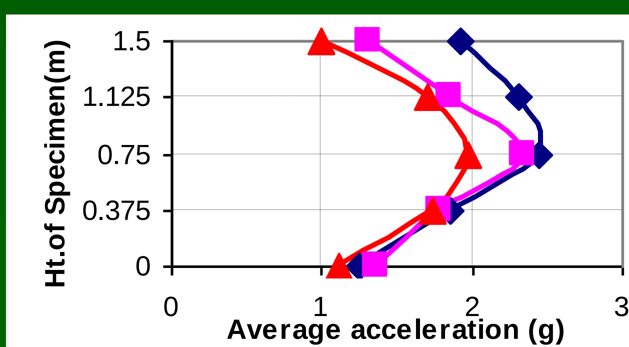
FOE 2005

Combined In-Plane and Out-of-Plane Studies

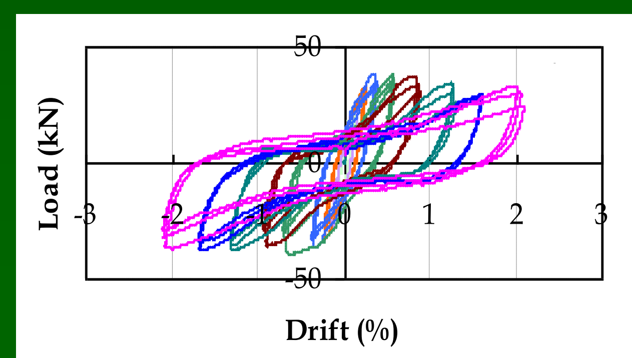
Verifying Seismic Behaviour

Confined Masonry Behaviour

Out-of-plane Acceleration



In-plane Hysteresis



FOE 2005

Combined In-Plane and Out-of-Plane Studies

Verifying Seismic Behaviour

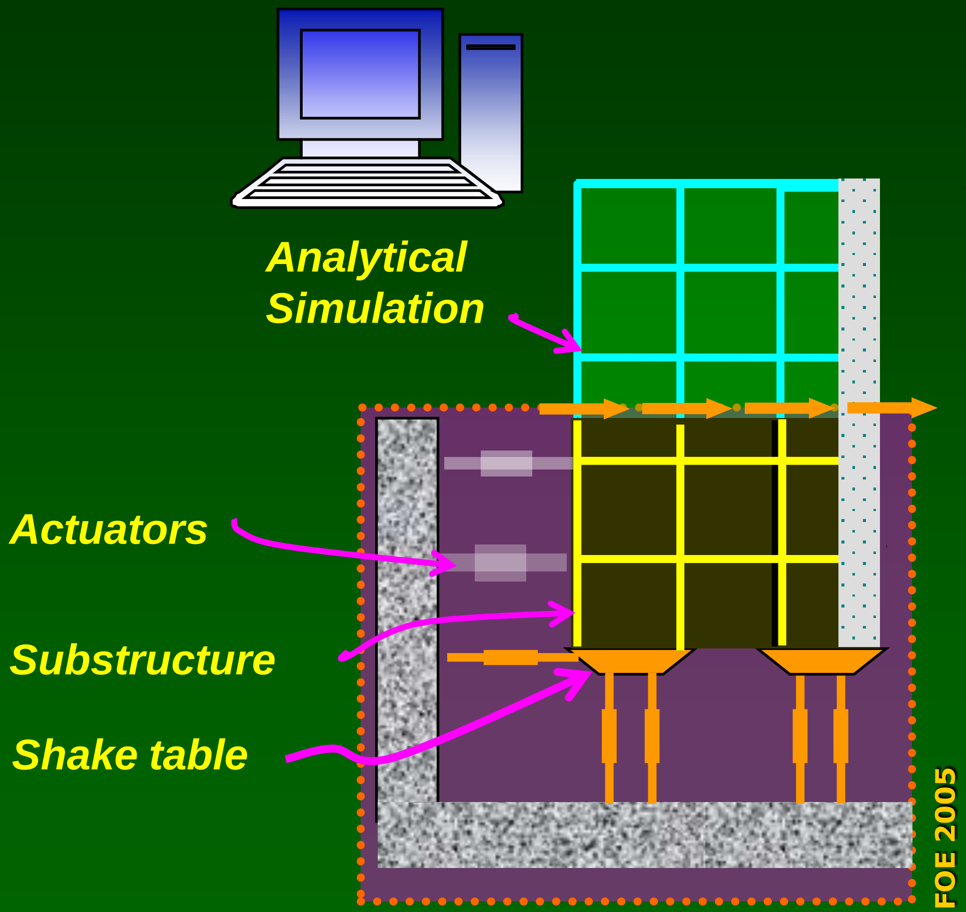
Confined Masonry Behaviour

FOE 2005

Real Time Hybrid Test
Using best of both Worlds!

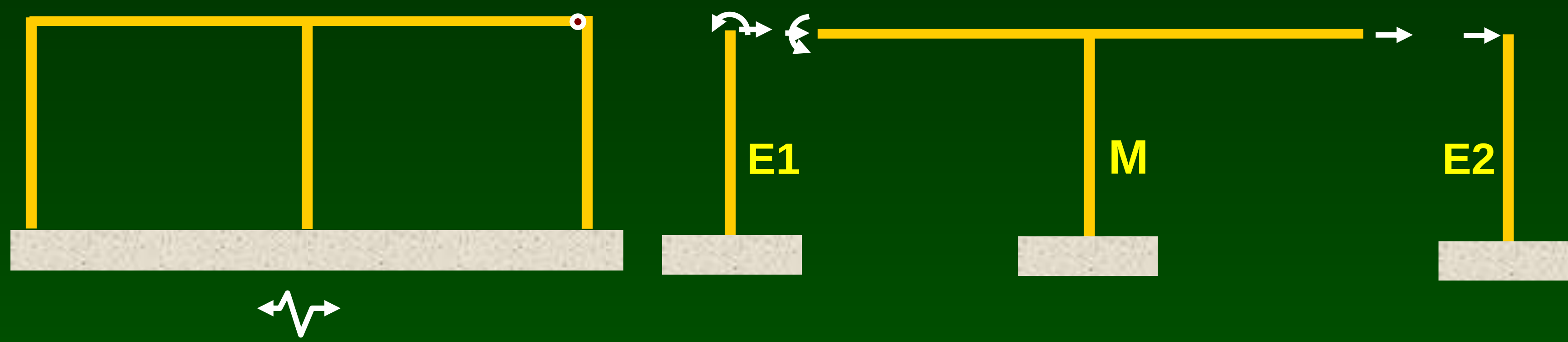
Combined use of shake tables, actuators, reaction wall and computational engines for simulation

Utilizes low-cost experimental set-up and higher resolution analytical simulation



Linked Multi-Site Testing

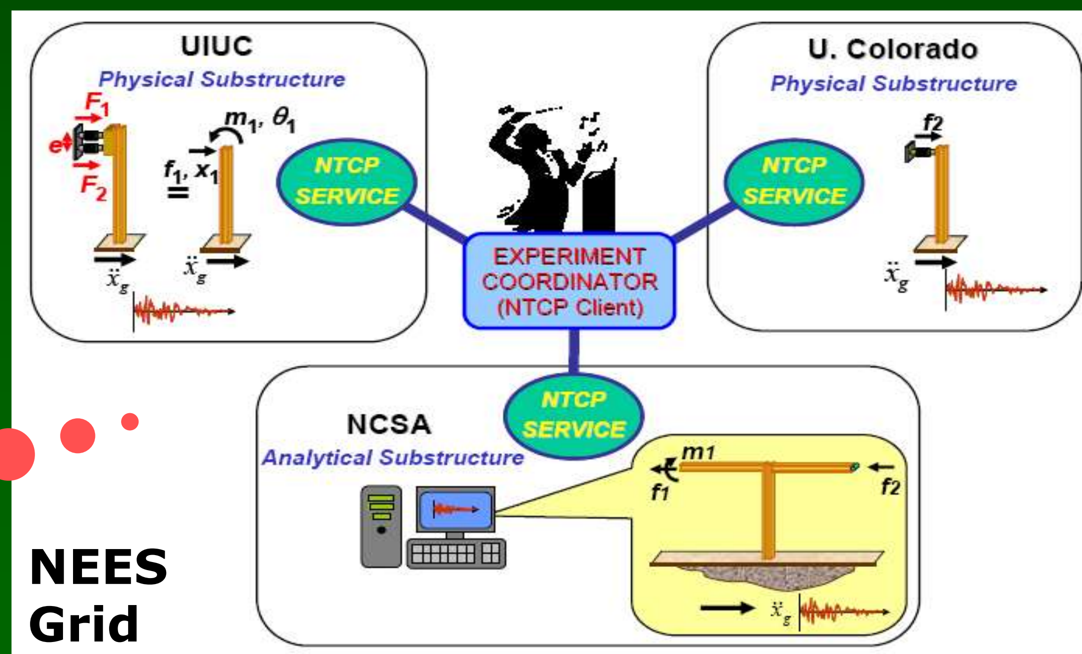
Distributed physical and analytical simulation



Internet latency

Synchronization of remote controllers

15 s ground motion completed in 5 hr with 1500 cycles of data exchange



FOE 2005

Advanced Sensor Technology
Measurement of data and visualization

Conventional wired sensors

Wireless and Non-contact sensors

Full field measurement

Fast synchronous data acquisition

Digital video images correlated with data

Data repository with uniform markup

Tele-operation

Web-streaming and tele-presence

FOE 2005

Concluding Remarks

Earthquake need not be deadly & destructive!

Earthquake-resistant structures are key elements

Need to develop novel techniques for enhanced seismic performance

Validation of design using low-cost physical and higher-resolution analytical simulations

Improved control and network protocols for realistic earthquake simulations

FOE 2005

Success of Design!

PEER, Richmond, CA

Ductile Column

Non-Ductile Column

Ductile Column

FOE 2005

Hurdles to Seismic Safety

Elements for Risk Reduction

- **Seismic Codes**
- **Competent professionals to implement codes**
  - ✓ *Supporting materials for codes*
  - ✓ *Training of engineers*
- **Implementation of codes**
- **Enforcement mechanisms for codes**
- **Demand for safety**
  - ✓ *Awareness generation*
  - ✓ *Higher priority for safety*

Structural Engineering Practice

- **Lack of competence-based licensing of structural engineers**
- **Associated checks and balances are lacking**
  - ✓ *Code of ethics*
  - ✓ *Responsibility and liability*

Construction Industry

- **Several internationally-competitive construction companies**
- **Yet, decay of small-scale construction industry**
- **Indian masonry was world renowned a century ago:**
  - ✓ *Today it is difficult to find competent masons for small jobs*

Seismic Codes

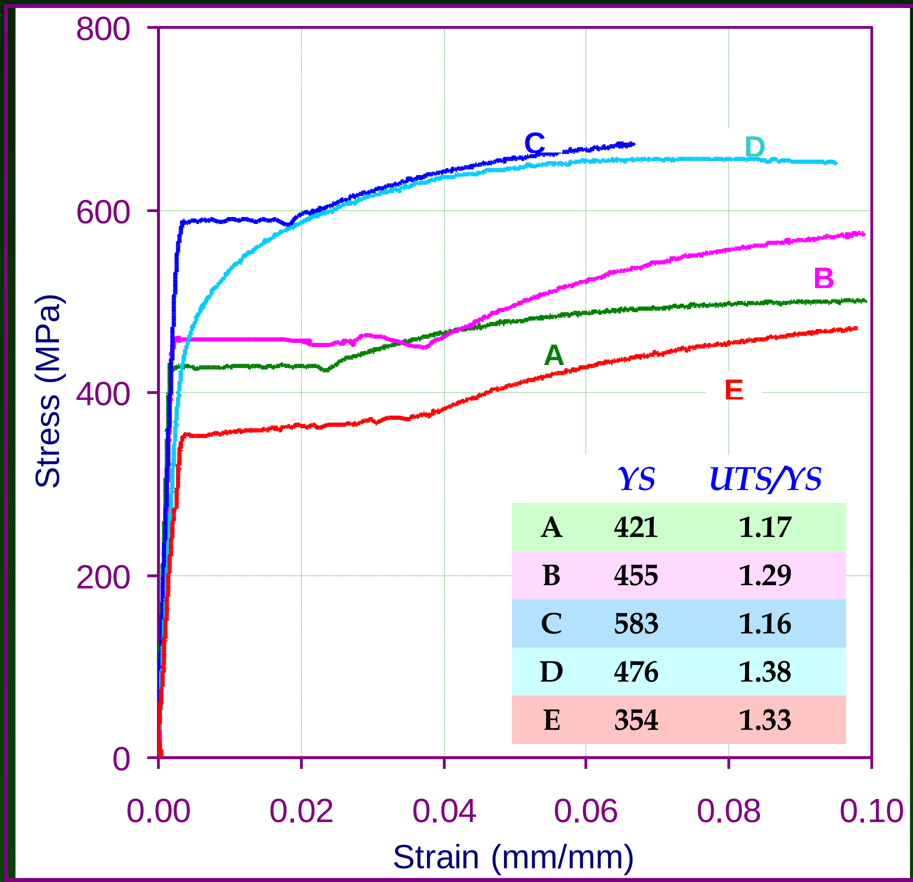
- **IS:1893 (Main code; design seismic force)**
  - ✓ *1962,1966, 1970, 1975, 1984, and 2002*
- **IS:4326 (Seismic design of buildings)**
  - ✓ *1967, 1975, 1993*
- **IS:13920 (Ductile detailing of RC structures)**
  - ✓ *1993*
- **Three codes on non-engineered buildings**

Reinforcing Steel Code

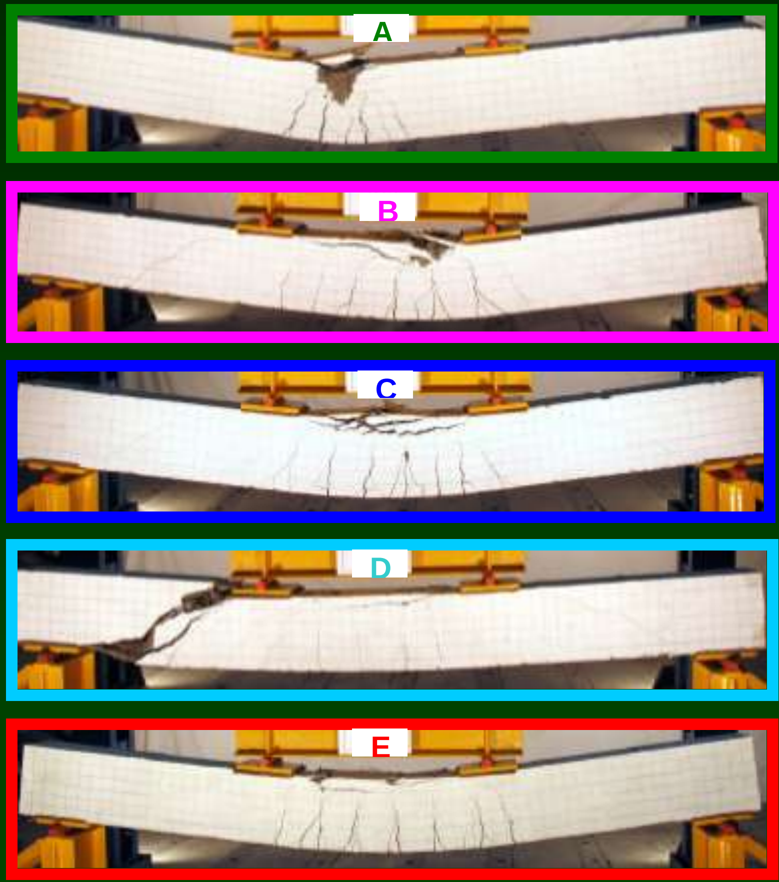
- **IS:1786-2008**
  - ✓ *New revision introduces D class bars*
  - ✓ *Supposedly for earthquake resistant construction*
  - ✓ *Deficient and misleading as it does not have provisions about upper limit on YS and large UTS/YS ratio*
  - ✓ *May lead to unexpected brittle shear failure mode and poor energy dissipation*

Reinforcing Steel Code

- **IS:1786-2008**



	YS	*UTS/YS*
A	421	1.17
B	455	1.29
C	583	1.16
D	476	1.38
E	354	1.33



Bar B with adequate YS and high UTS/YS ratio is the best.

Competence of engineers

- Engineering curriculum did not cover earthquake engineering
- Not many opportunities for professional engineers for training (until 1992)

Recent Initiatives

Agenda on Codes

- **A number of studies on codes started at IITK around 1986**
- **Numerous papers in Indian journals**
- **A number of draft codes and commentaries**
  - ✓ *IS:13920 emerged out of one of these*
  - ✓ *IS:1893 new provisions in 2002*
  - ✓ *Code on Seismic Evaluation and strengthening*
  - ✓ *Water tank code (not yet implemented)*

Codes Project of GSDMA

- **To review codes and develop commentaries / handbooks**
  - ✓ *Earthquake codes*
  - ✓ *Wind codes*
  - ✓ *Fire codes*
- **Executed by IITK with participation of several institutions**
  - ✓ *IIT Roorkee*
  - ✓ *VNIT Nagpur, NIT Jalandhar, MSU Baroda, …*

GSDMA Codes project contd…

- **Earthquake codes, commentaries and explanatory handbook (solved examples) on**
  - ✓ *IS:1893 (Part 1) : Buildings Code*
  - ✓ *IS:13920 : Ductile design of RC structures*
  - ✓ *IS: 1893 (Part 2) : Liquid storage tanks*
  - ✓ *IS: 1905 : Masonry code (with focus on seismic design)*
  - ✓ *New code on seismic evaluation and retrofitting of buildings*
  - ✓ *Seismic design of earth dams and embankments*
- **All documents on www.nicee.org for anyone to download**

Training of Engineers

- **A series of one-week trainings for professional engineers started in 1992.**
- **Philosophy:**
  - ✓ *To share everything and hold back nothing*
  - ✓ *Trainees should not have to come back to resource persons for consultancy*
  - ✓ *Compensate resource persons adequately*
    - ***Training not an opportunity for business development by the resource persons***
  - ✓ *Only 2 to 3 resource persons*
  - ✓ *Detailed notes*
    - ***Copy of every transparency to each participant before the lecture***

Training of Engineers …

- **Unprecedented successes**
  - *Class size*
    - ***~ 100 persons (before 2001 earthquake)***
    - ***~ 200 persons (after 2001 earthquake)***
  - *Conducted in numerous places in India, and in Nepal and Bhutan*
  - *About 30 courses since 1992*
- **Both ways learning experience**
  - *Professionals brought their practical issues; at times solutions*
- **Created tremendous networking and goodwill**

Discussion Workshops

- **Round-Table Discussion Workshops at IITK**
  - ✓ *Earthquake Resistant Construction in Civil Engineering Curriculum, 1996*
  - ✓ *Development of Earthquake Engineering Industry in India, 1998*
  - ✓ *Confined Masonry as alternative building typology, 2006*
- **Summary of discussions published in Indian journals**
- **Clarity of issues emerged**
- **Several recommendations implemented**
- **Created networking with other academics and those in industry**

National Information Centre of Earthquake Engineering

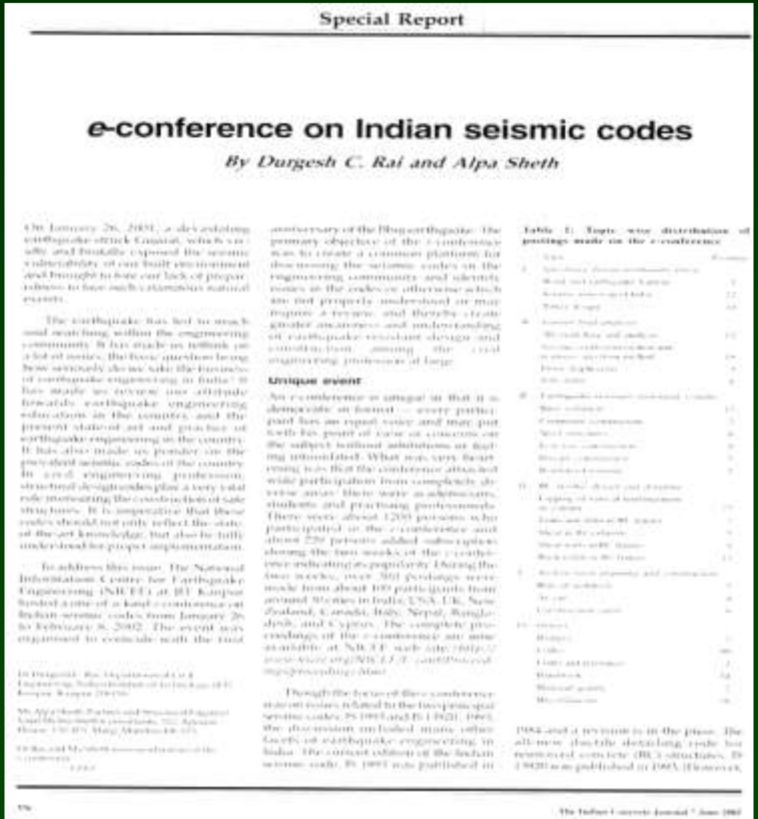
- **Original objectives to collect and disseminate literature and information in Earthquake Engineering**
  - ✓ ***A library oriented project initially***
- **After 2001 earthquake, many other outreach activities taken up**
- **Web site: www.nicee.org**
- **Electronic mailing list of 3000+ interested professionals**
- **Some requests received and entertained from other developing countries**
- **Literature supplied on request at no charge**
- **Visits by interested persons facilitated for literature review**

NICEE ACTIVITIES

- **Acquisition of Publications**
- **Supply of Literature**
- **Literature Review Workshops**
- **Publication and Distribution of Publications**
- ***Earthquake Engineering Practice* – A Quarterly Periodical**
- **Distance Education Products**
- **Translations into Local Languages**
- **E-Conferences**
- **Short Course**
- **Web Site**
- **Electronic Newsletter**
- **Email Listing**

Electronic Medium for Conferences and Continuing Education

- **E-Conference on Seismic Codes (January 2002)**
- **E-Conference on Professional Issues (August 2002)**
- **E-Course on Seismic Code IS:1893 (January 2003)**



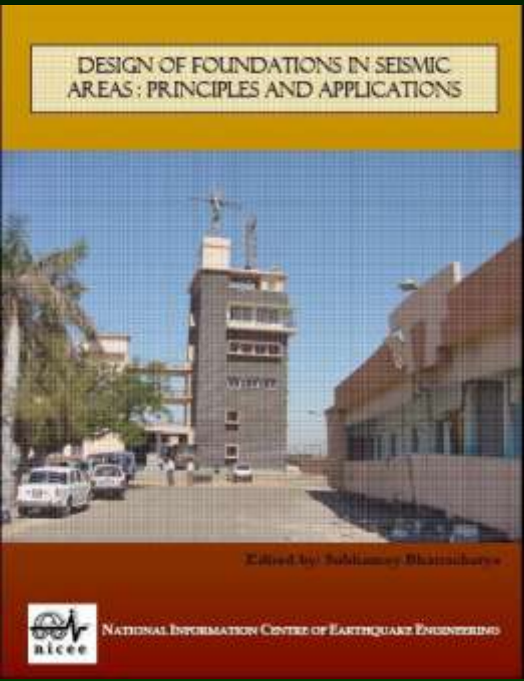
Special Report

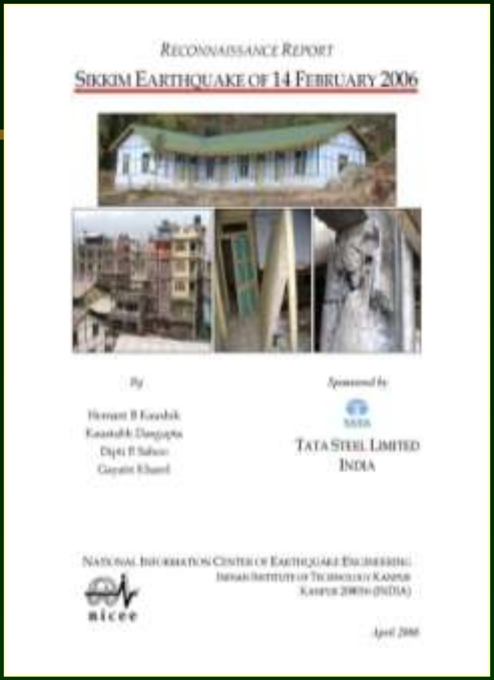
e-conference on Indian seismic codes

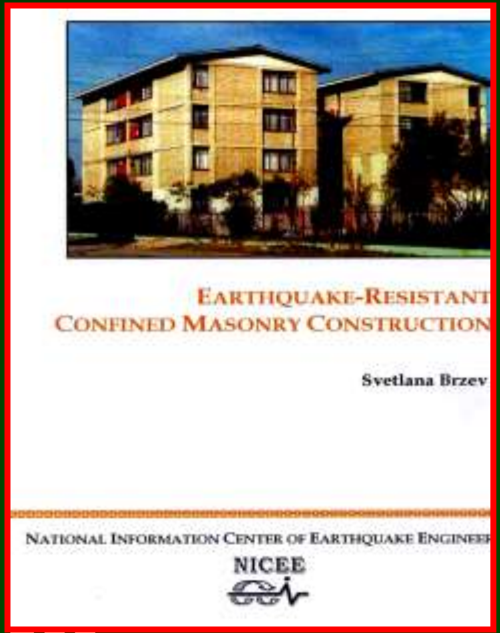
By Durgesh C. Rai and Alpa Sheth

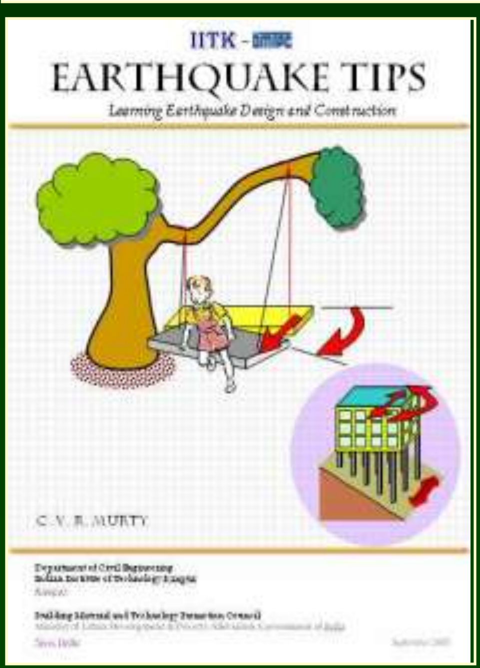
Unique event

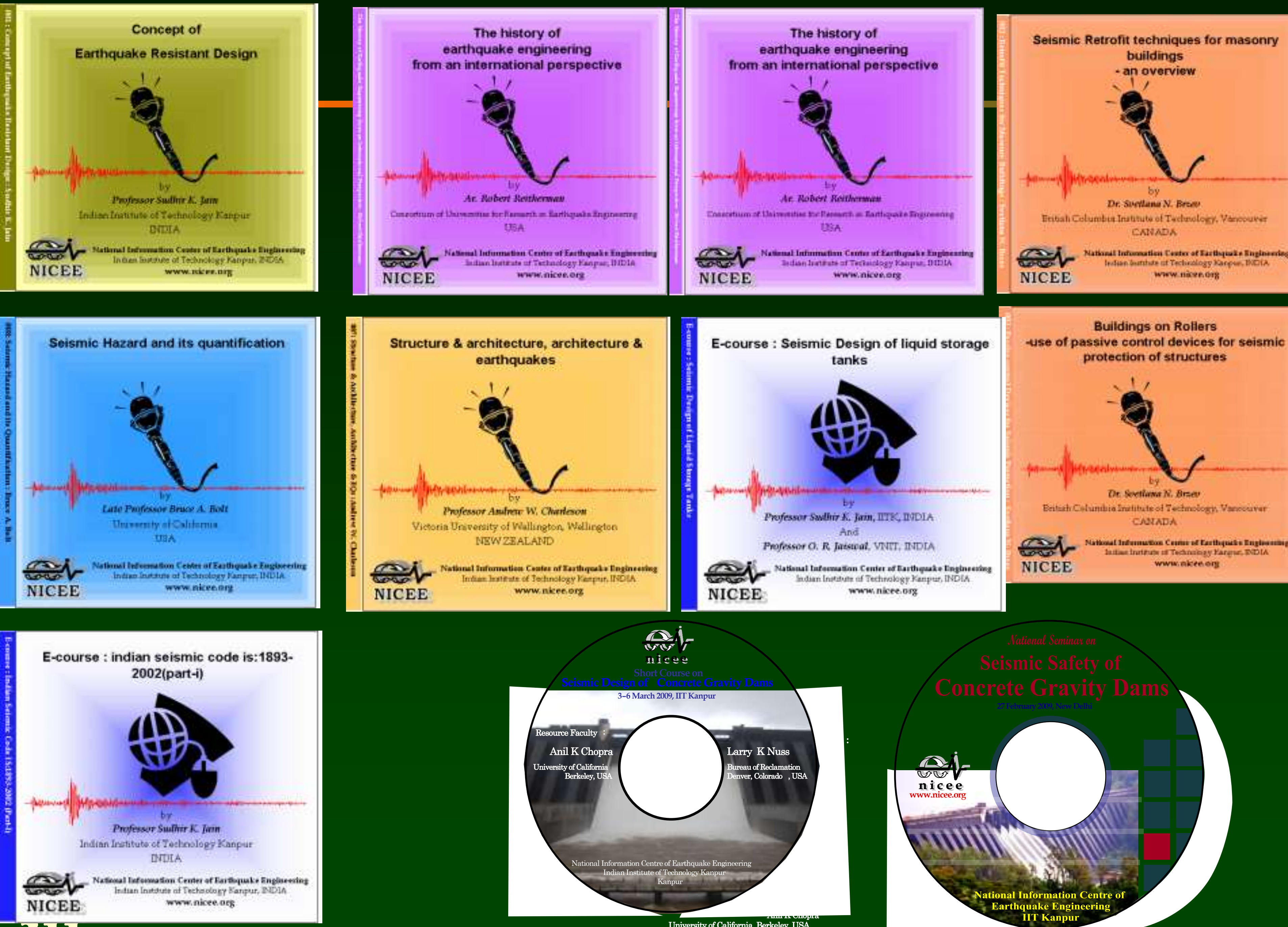
Publications










Concept of Earthquake Resistant Design
by Professor Sudhir K. Jain
Indian Institute of Technology Kanpur
INDIA
The history of earthquake engineering from an international perspective
by Ar. Robert Reitherman
Consortium of Universities for Research in Earthquake Engineering
USA
Seismic Retrofit techniques for masonry buildings - an overview
by Dr. Svetlana N. Brzev
British Columbia Institute of Technology, Vancouver
CANADA
Seismic Hazard and its quantification
by Late Professor Bruce A. Bolt
University of California
USA
Structure & architecture, architecture & earthquakes
by Professor Andrew W. Charleson
Victoria University of Wellington, Wellington
NEW ZEALAND
E-course : Seismic Design of liquid storage tanks
by Professor Sudhir K. Jain, IITK, INDIA
And
Professor O. R. Jaiswal, VNIT, INDIA
Buildings on Rollers -use of passive control devices for seismic protection of structures
by Dr. Svetlana N. Brzev
British Columbia Institute of Technology, Vancouver
CANADA
E-course : indian seismic code is:1893-2002(part-i)
by Professor Sudhir K. Jain
Indian Institute of Technology Kanpur
INDIA
NICEE
National Information Center of Earthquake Engineering
Indian Institute of Technology Kanpur, INDIA
www.nicee.org
nicee
Short Course on
Seismic Design of Concrete Gravity Dams
3-6 March 2009, IIT Kanpur
Resource Faculty :
Anil K Chopra
University of California
Berkeley, USA
Larry K Nuss
Bureau of Reclamation
Denver, Colorado , USA
National Information Centre of Earthquake Engineering
Indian Institute of Technology Kanpur
Kanpur
University of California, Berkeley, USA
National Seminar on
Seismic Safety of Concrete Gravity Dams
27 February 2009, New Delhi
nicee
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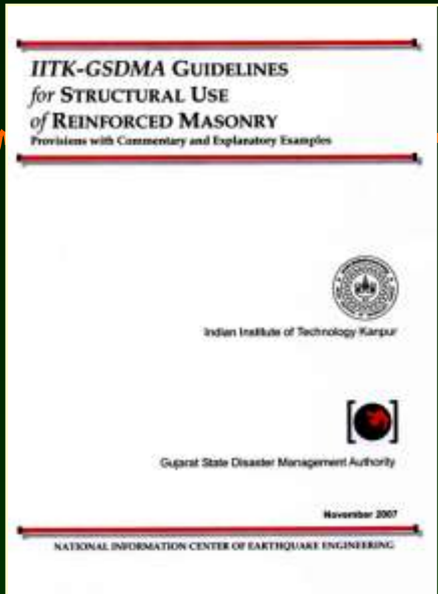
National Information Centre of Earthquake Engineering
IIT Kanpur



IITK-GSDMA GUIDELINES for STRUCTURAL USE of REINFORCED MASONRY

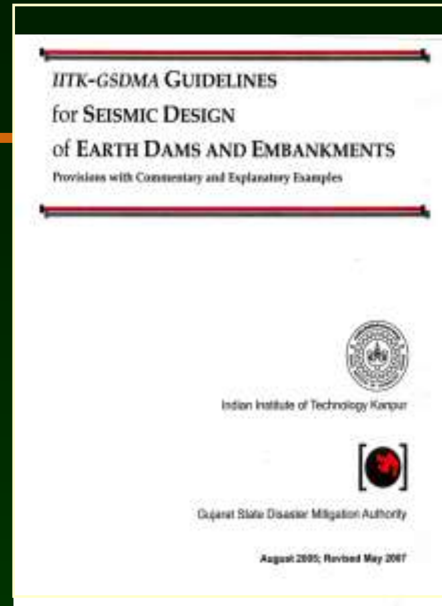
Provisions with Commentary and Explanatory Examples

Indian Institute of Technology Kanpur

Gujarat State Disaster Management Authority

November 2007

NATIONAL INFORMATION CENTER OF EARTHQUAKE ENGINEERING



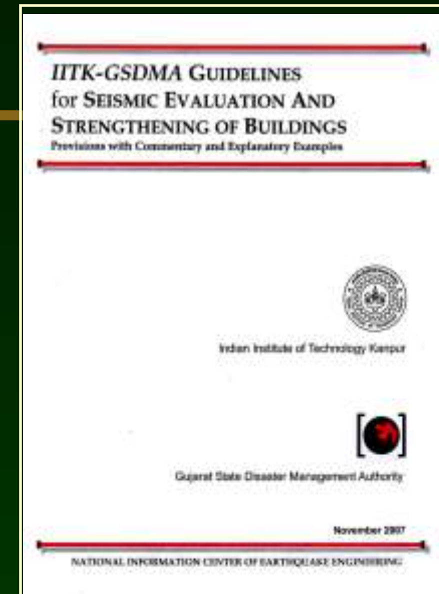
IITK-GSDMA GUIDELINES for SEISMIC DESIGN of EARTH DAMS AND EMBANKMENTS

Provisions with Commentary and Explanatory Examples

Indian Institute of Technology Kanpur

Gujarat State Disaster Mitigation Authority

August 2005; Revised May 2007



IITK-GSDMA GUIDELINES for SEISMIC EVALUATION AND STRENGTHENING OF BUILDINGS

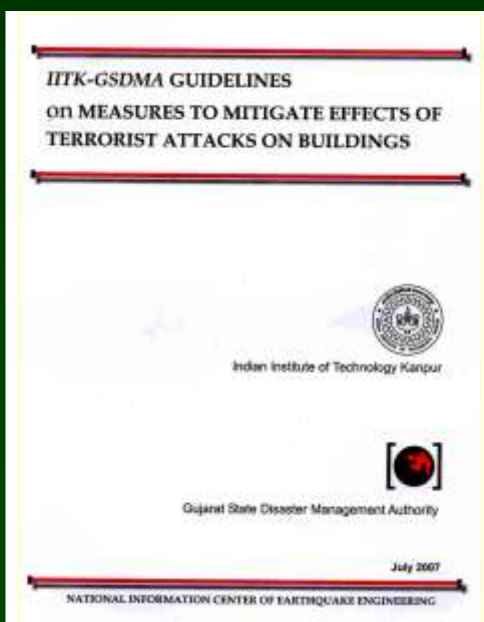
Provisions with Commentary and Explanatory Examples

Indian Institute of Technology Kanpur

Gujarat State Disaster Management Authority

November 2007

NATIONAL INFORMATION CENTER OF EARTHQUAKE ENGINEERING



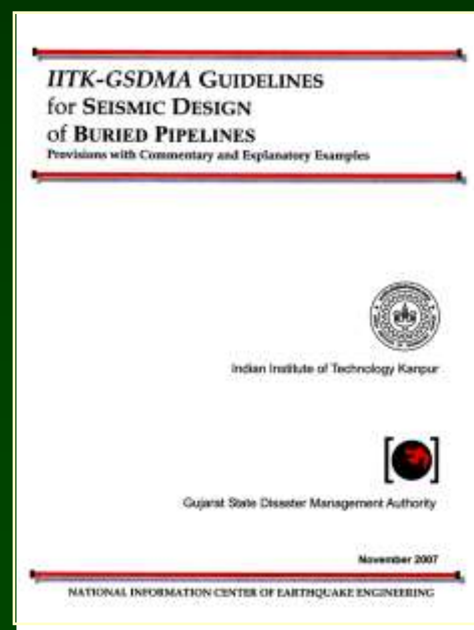
IITK-GSDMA GUIDELINES on MEASURES TO MITIGATE EFFECTS OF TERRORIST ATTACKS ON BUILDINGS

Indian Institute of Technology Kanpur

Gujarat State Disaster Management Authority

July 2007

NATIONAL INFORMATION CENTER OF EARTHQUAKE ENGINEERING



IITK-GSDMA GUIDELINES for SEISMIC DESIGN of BURIED PIPELINES

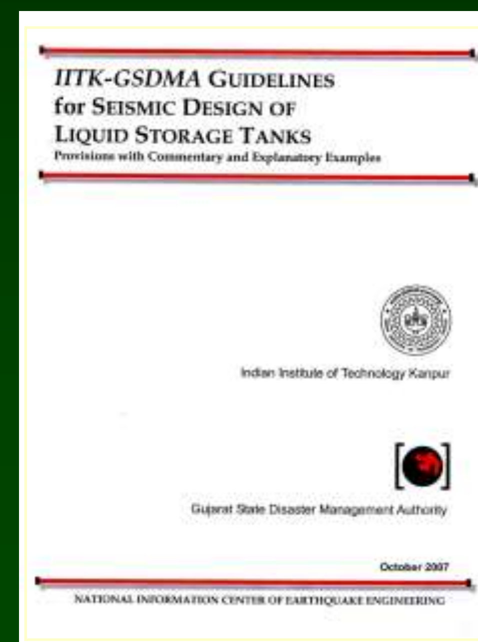
Provisions with Commentary and Explanatory Examples

Indian Institute of Technology Kanpur

Gujarat State Disaster Management Authority

November 2007

NATIONAL INFORMATION CENTER OF EARTHQUAKE ENGINEERING



IITK-GSDMA GUIDELINES for SEISMIC DESIGN OF LIQUID STORAGE TANKS

Provisions with Commentary and Explanatory Examples

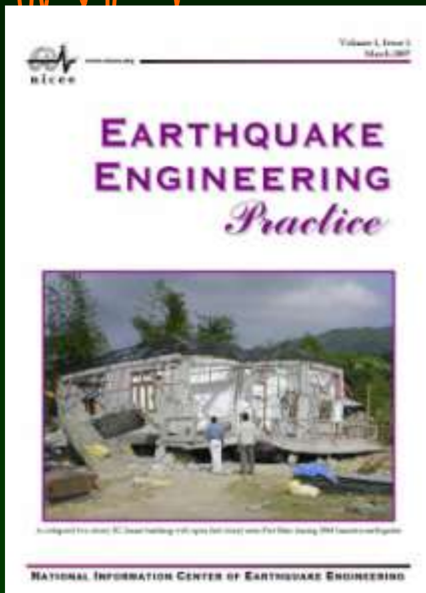
Indian Institute of Technology Kanpur

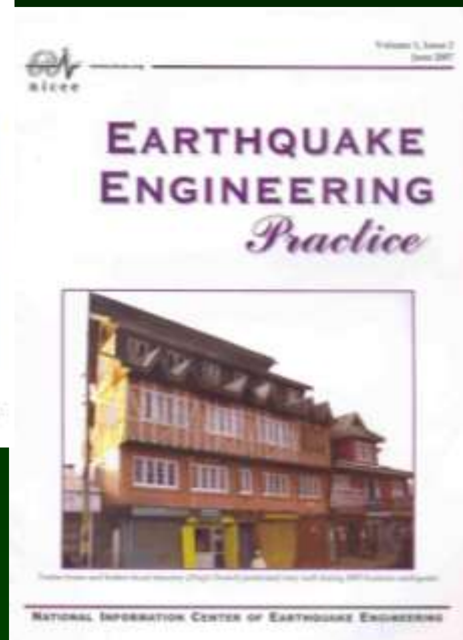
Gujarat State Disaster Management Authority

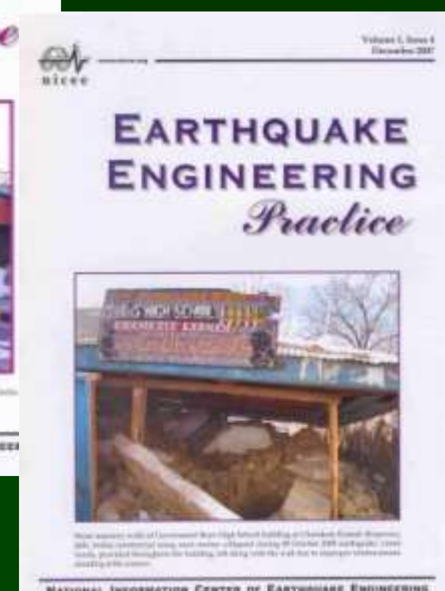
October 2007

NATIONAL INFORMATION CENTER OF EARTHQUAKE ENGINEERING

Earthquake Engineering Practice:
A Quarterly Periodical

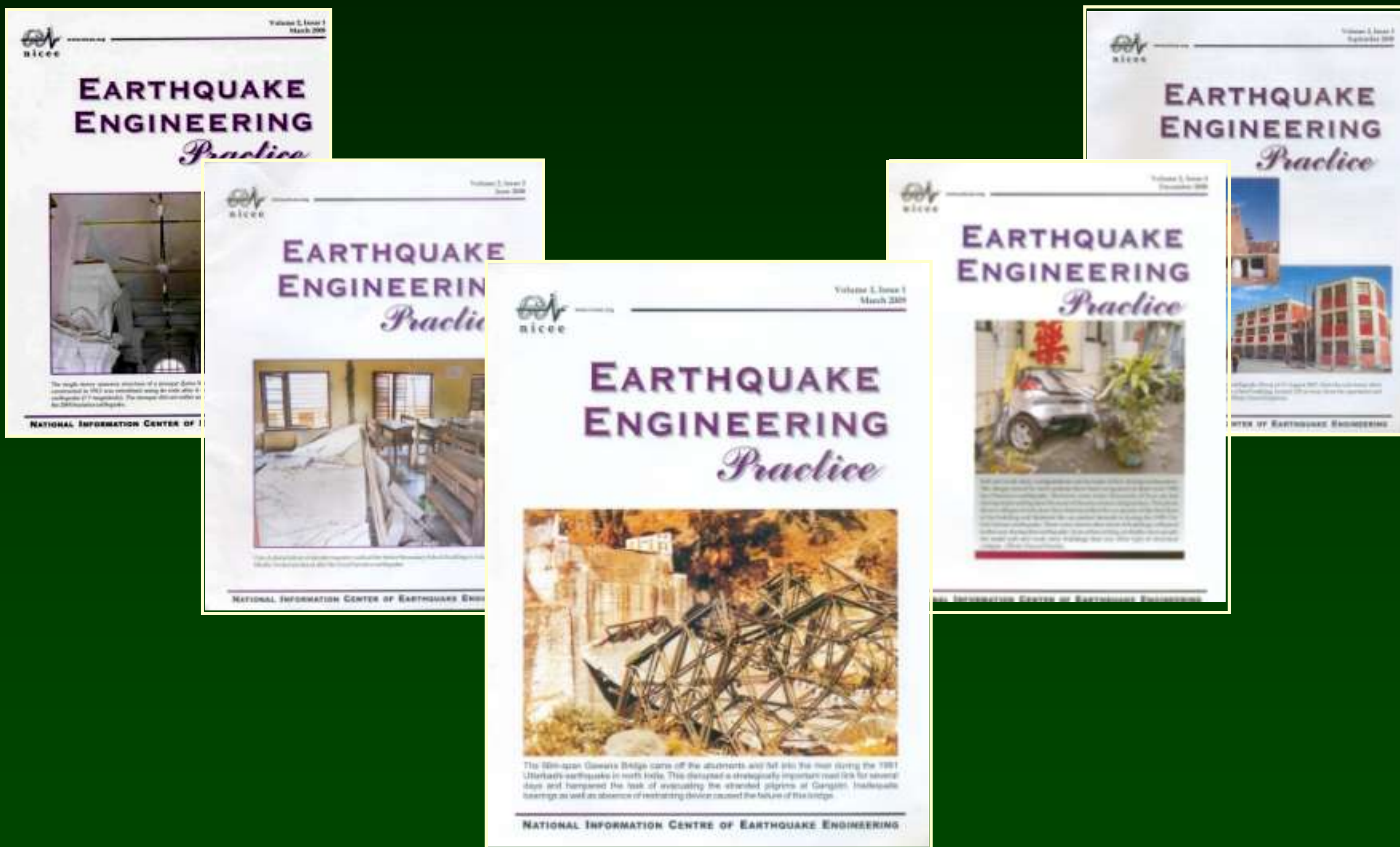




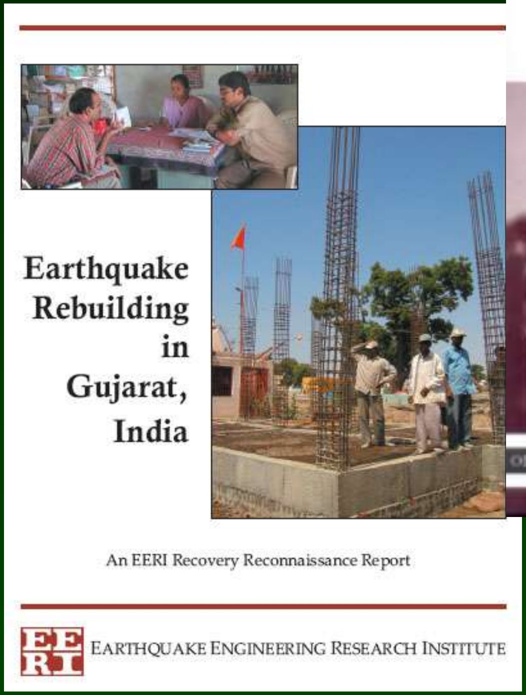


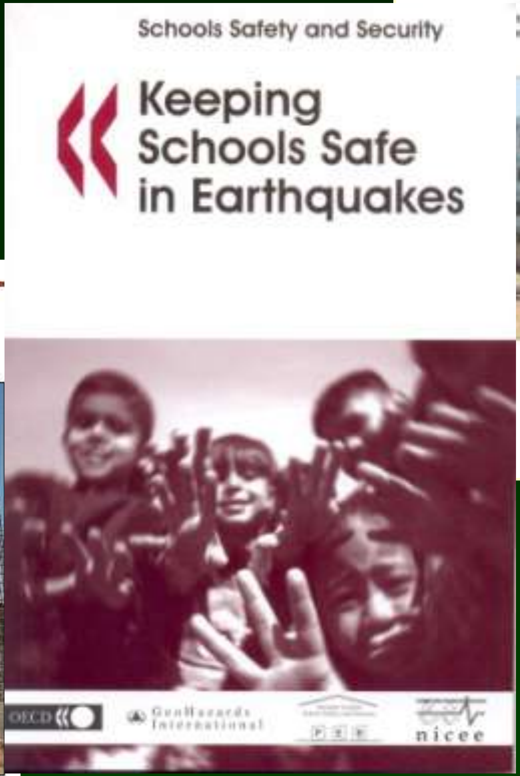
Earthquake Engineering Practice:

A Quarterly Periodical



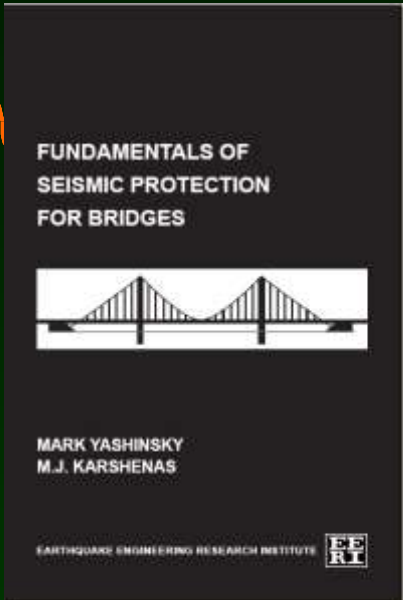

Seismic Conceptual Design of Buildings – Basic principles for engineers, architects, building owners, and authorities

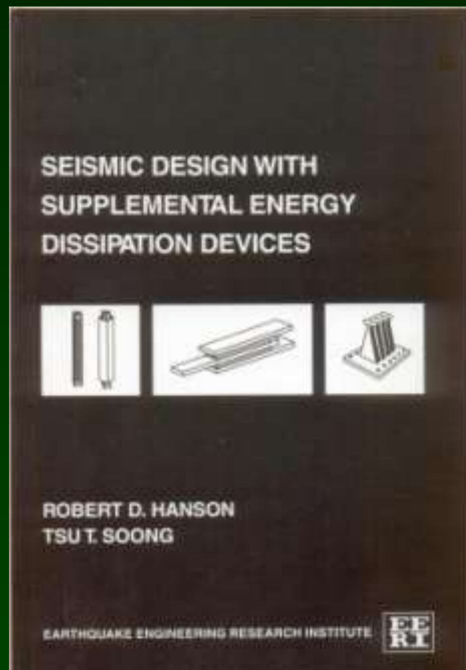

Earthquake Rebuilding in Gujarat, India
An EERI Recovery Reconnaissance Report
EERI
EARTHQUAKE ENGINEERING RESEARCH INSTITUTE

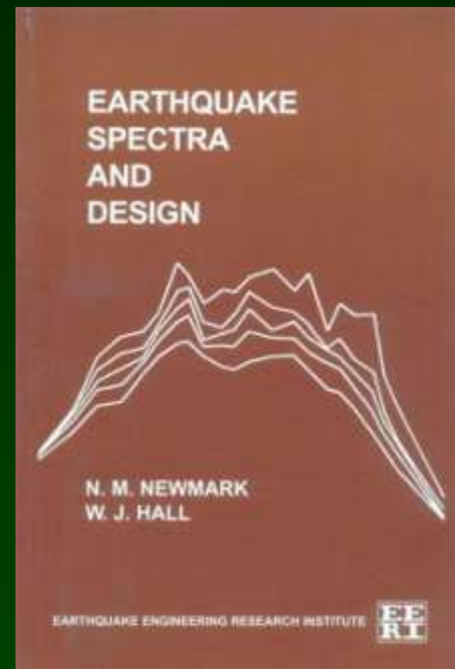

Schools Safety and Security
Keeping Schools Safe in Earthquakes
OECD
GeoHazards International
nicee

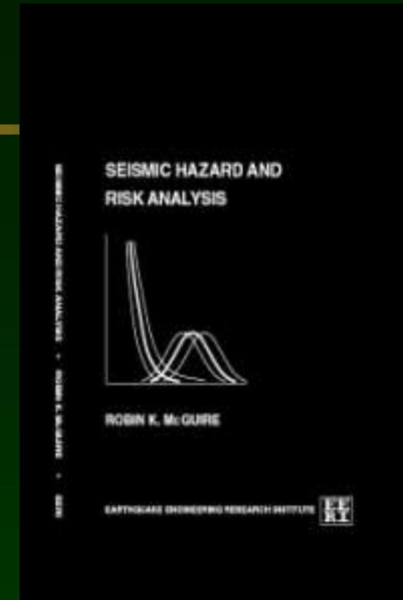

AT RISK:
The Seismic Performance of Reinforced Concrete Frame Buildings with Masonry Infill Walls
A Tutorial Developed by a committee of the
World Housing Encyclopedia
EERI

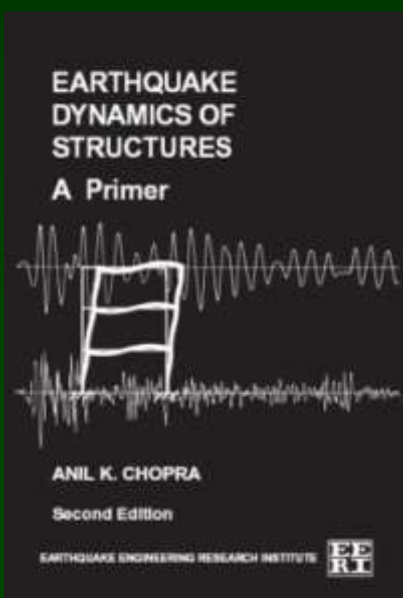
EERI Monographs

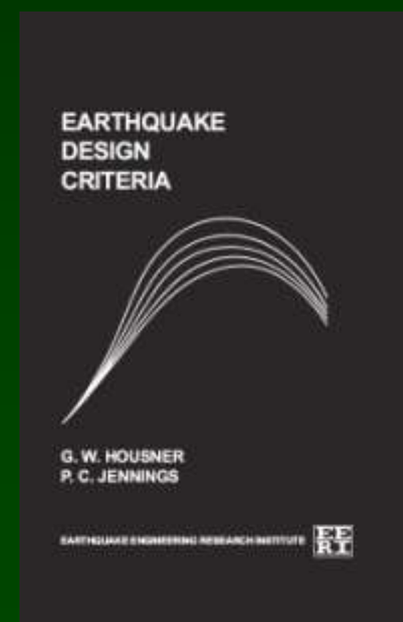












Large Scale Testing Facility @ IITK

Pseudo dynamic testing

Realistic simulation of earthquake effects for Prototype-size structures

Integrated Reaction Floor-Wall System

Post-tensioned wall

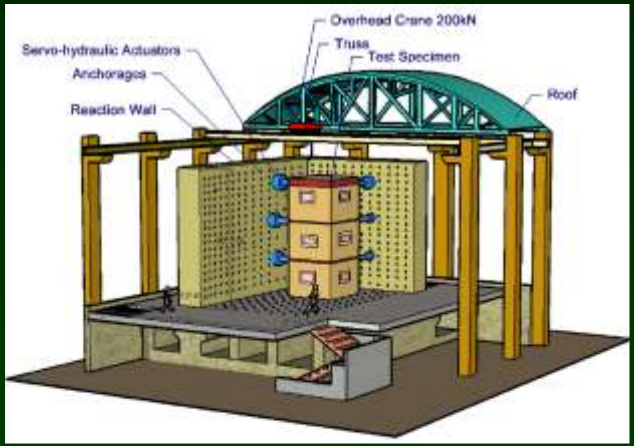
State-of-Art specs

Design

In-house conceptual design

Under Construction

Extension of existing structural engineering lab



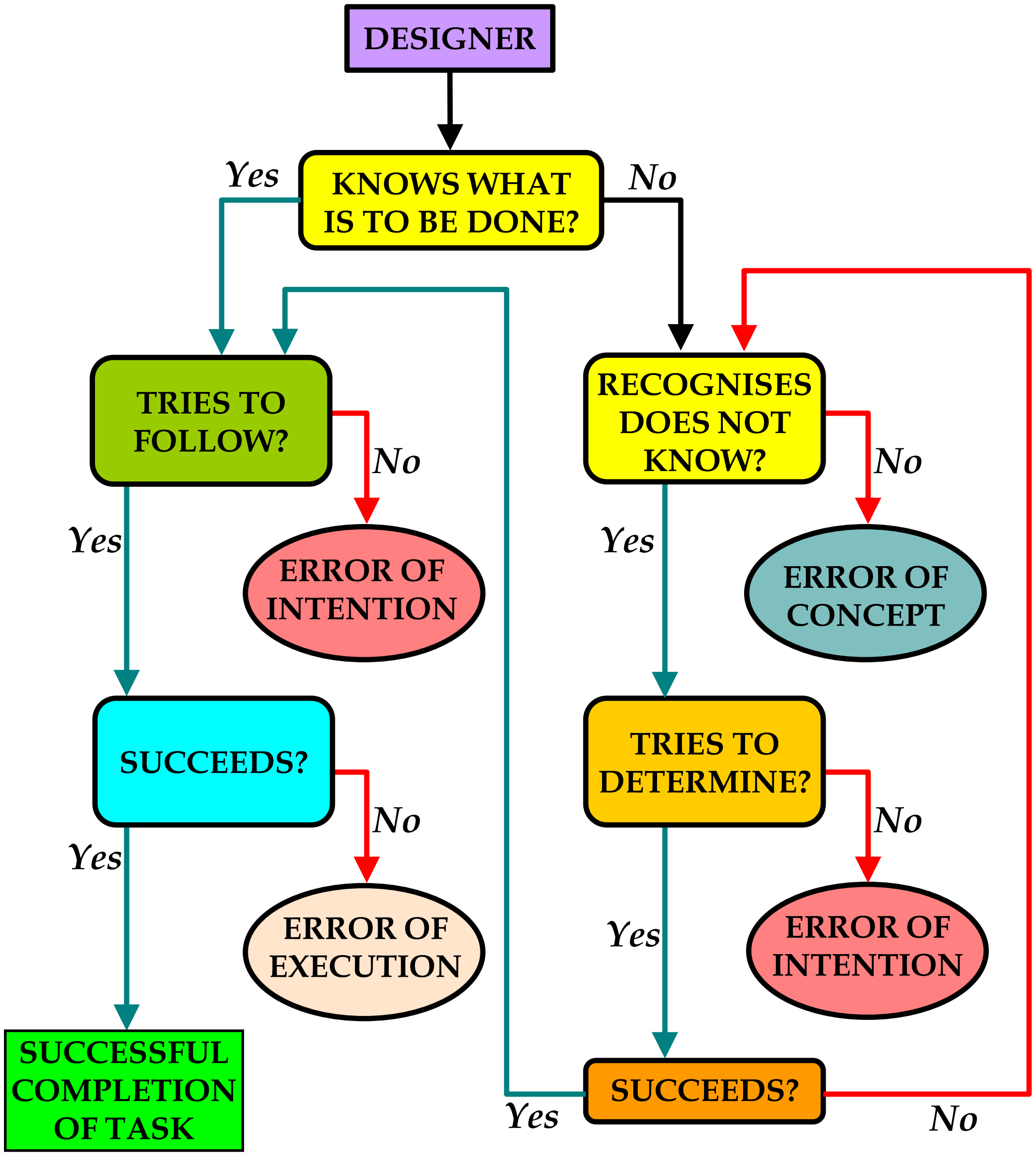
10mx15mx5.0m box girder floor
10m wall with 2.5m thick wall
2MN at each anchors 0.6m apart

In the end …

- **A lot is happening in India, but it is still too little for needs of a large and diverse country**
- **Fortunately, there is a positive slope of the activities and**
  - ✓ *Things look far more hopeful today than was the case few years back*
- ***Please share in our enthusiasm by visiting***

www.nicee.org

The Professional Choices…



Alternate Paths with regard to acceptable practices *(Nowak and Arafah, 1994)*

Long-term human response to EQ

Stage	Time	Event	Reaction	
			Positive	*Negative*
1	0-1 minute	Major Earthquake		*Panic*
2	1 minute – 1 week	Aftershocks	*Rescue and Survival*	*Fear*
3	1 week – 1 month	Diminishing aftershocks	*Short term repairs*	*Allocation of blame – builders, designers, officials, etc.*
4	1 month – 1 year		*Long term repairs, and action for higher standards*	
5	1 year – 10 years			*Diminishing interest*
6	10 years – The next time			*Reluctance to meet costs of seismic provisions, research, etc. Increasing non-compliance with regulations*
7	The next time	Major Earthquake	Repeat stage 1-7	

Key, 1988

In Closure…

The Disaster Equation

Disaster = Unmitigated Risk

Risk

= Hazard × Vulnerability

Moderate

NO Seismic Design

Implications

- **Recurrence of Earthquakes**
  - ✓ *World average:*
    - ***For every event of M>8.0, ~ 100 M>6.0 events***
  - ✓ *India:*
    - ***High frequency of great earthquakes***
    - ***Low frequency of moderate earthquakes***
  - ✓ *Moderate earthquake create awareness and lead to improvements in construction at "low" human cost*
  - ✓ *Performance of buildings and infrastructure not satisfactory in recent Indian earthquakes*

Implications…

- ✓ *M>8.0 earthquakes in Himalaya expected*
  - ***Will cause great disaster in cities of Indo-Gangetic Plains***
- ✓ *Orders of magnitude more constructions today than in 1897 or 1934*
- ✓ *Major Indian cities are vulnerable*
  - ***Many cities in North India are prone to great Himalayan events and moderate local events***

Implications…

- 2001 Bhuj and 2011 Sikkim Earthquakes
  - ✓ ***Shaking : Moderate Intensity***
  - ✓ ***Damage :***
    A preview to
    Potential Disaster during THE BIG ONE
- Urgent Need
  to reduce Vulnerability of Structures
  for Seismic Risk Mitigation

Elements of Seismic Safety

Knowledge of hazards

Earthquake Resistant Friendly Architecture

Quality Materials

Seismic Design and Detailing

The Final Question…

Will we continue to build these in a hurry?

The Final Question…

And… without technological inputs??

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