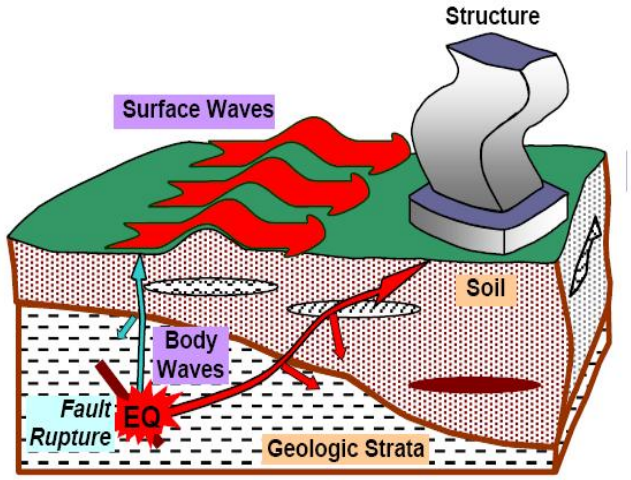
Water and Land Management Institute
Phulwarisarif, Patna

Induction Course for new JEs

EARTHQUAKE RESISTANT STRUCTURE



EARTHQUAKE EFFECTS

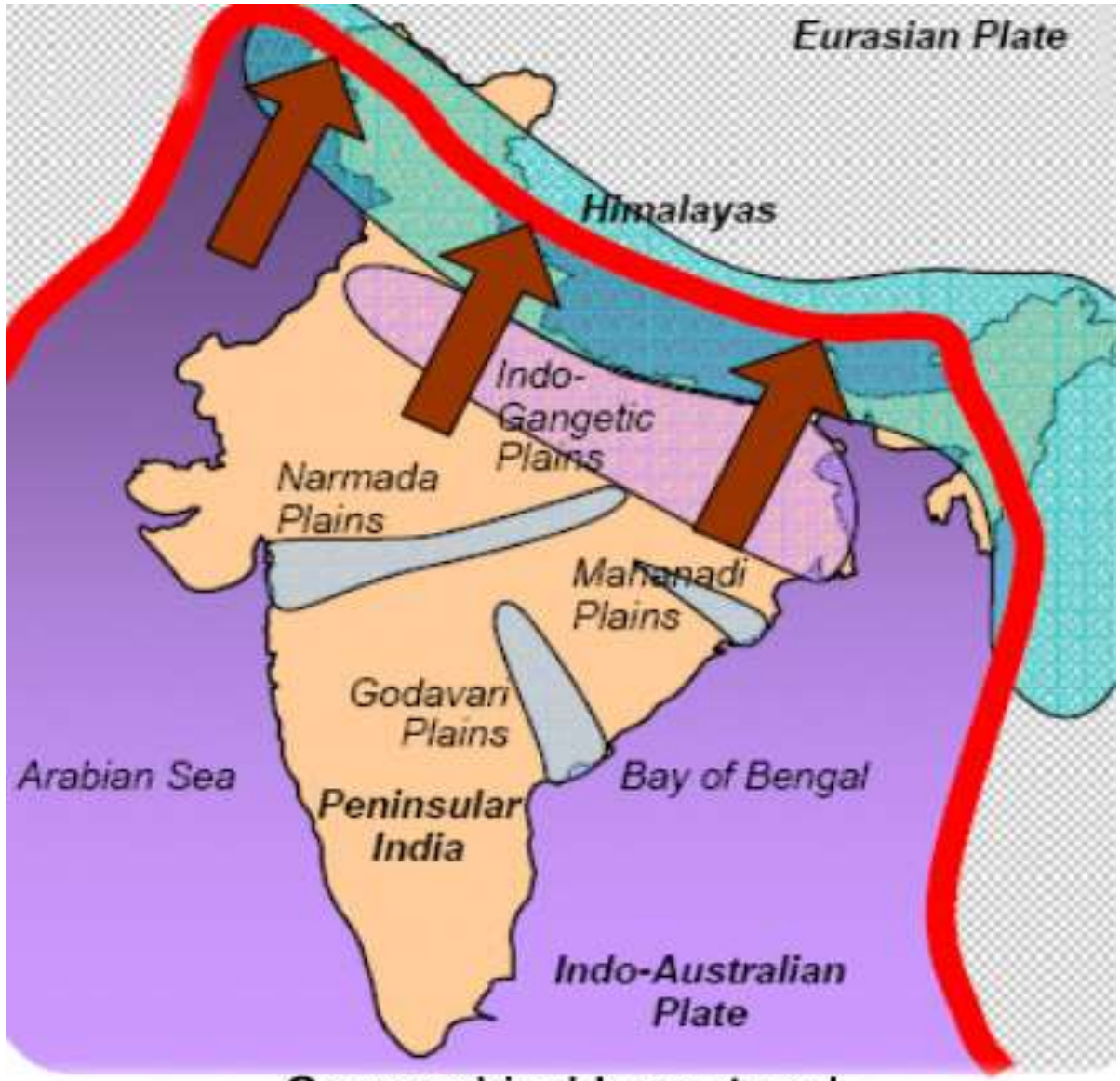
EARTHQUAKE IN HIMALAYAS

Subduction of Indo-Australian plate into Eurasian plate

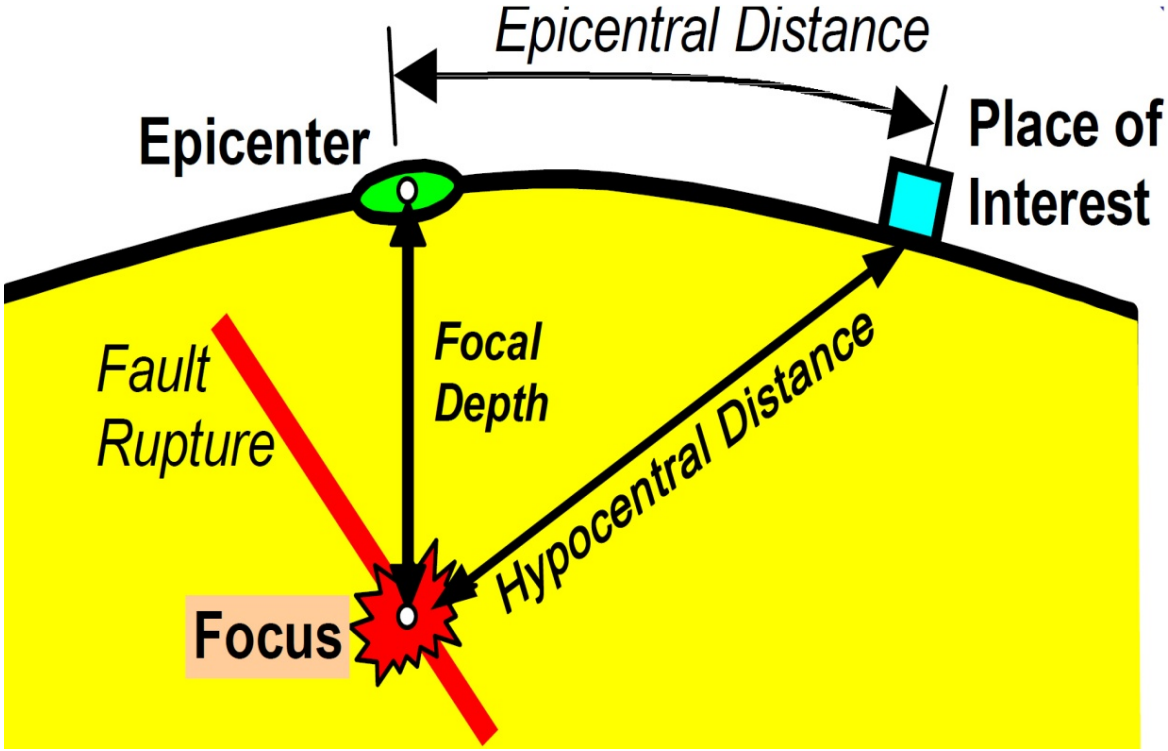
Heavily Compressed Rock

- **Enormous Strain Stored**
- **Suddenly Breaks**
- **Strain Energy Release**
- **Rapid Shaking of Earth**
- **Seismic Waves:**

नेपाल में भूकम्प के चलते बिहार प्रभावित होता है।



Geographical Layout and Tectonic Plate Boundaries in India



FOCUS / HYPOCENTER

धरती के अंदर, जहाँ चट्टान में विस्फोट के कारण भूकंप उत्पन्न हुआ।

EPICENTER:

फोकस के सीधे उपर, धरती के सतह पर का भौगोलिक स्थल।

MAGNITUDE : Size of Earthquake

Magnitude of Energy Released

Measured using Seismogram

- **Richter logarithmic scale : M1 to M10**
- **M3 से कम का भूकम्प हम महसूस नहीं करते।**

INTENSITY :

स्थल आकृति, संरचनाओं एवं मानव पर भूकम्प झटकों के प्रभाव।

MSK-scale I से **XII** तक भूकम्प तीव्रता दर्शायी जाती है।

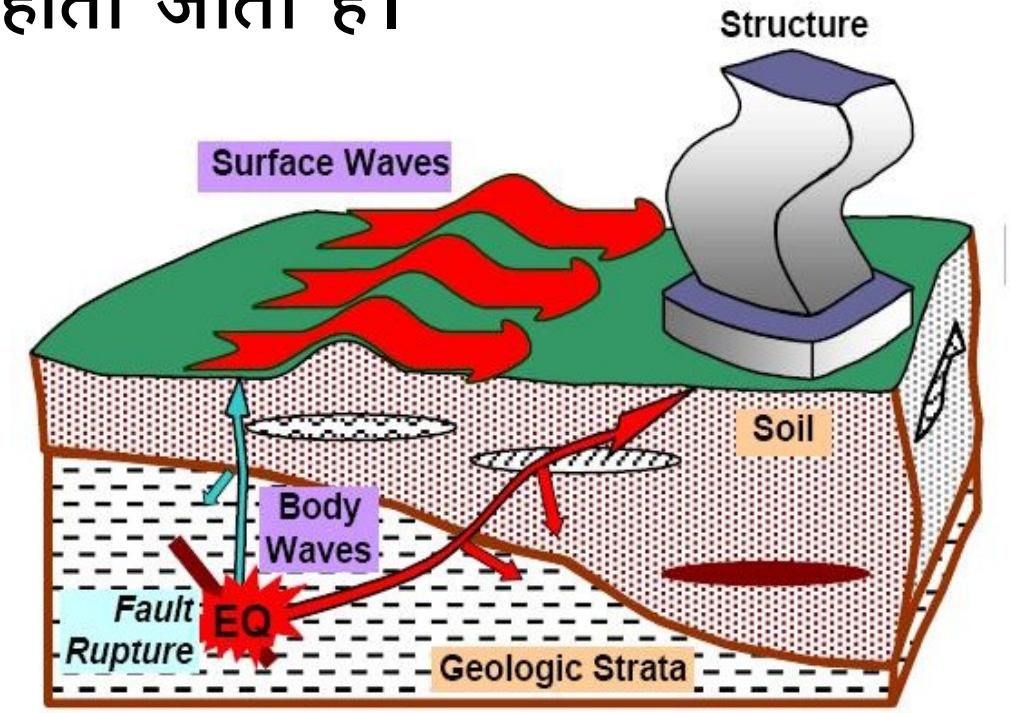
Epicentre क्षेत्र में अधिकतम तीव्रता रहती है

जो सभी दिशाओं में कम होती जाती है।

GROUND VIBRATIONS

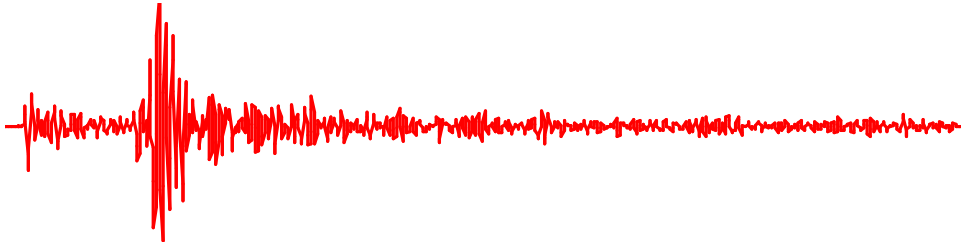
at any location depends on:

- **Magnitude of Earthquake**
- **Depth of Focus**
- **Distance from Epicenter**
- **Characteristics of Path travelled by Seismic Waves**
- **Soil Strata beneath the Structure**



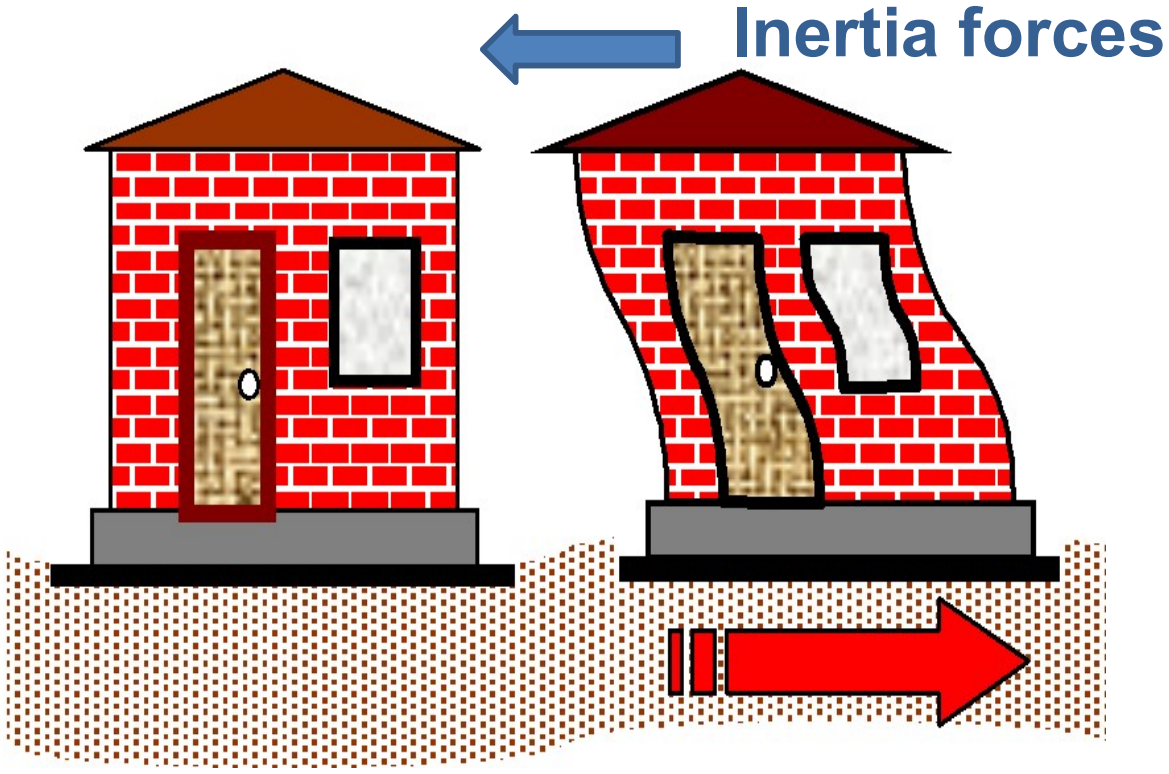
SEISMIC WAVES :

Body Wave, Surface wave

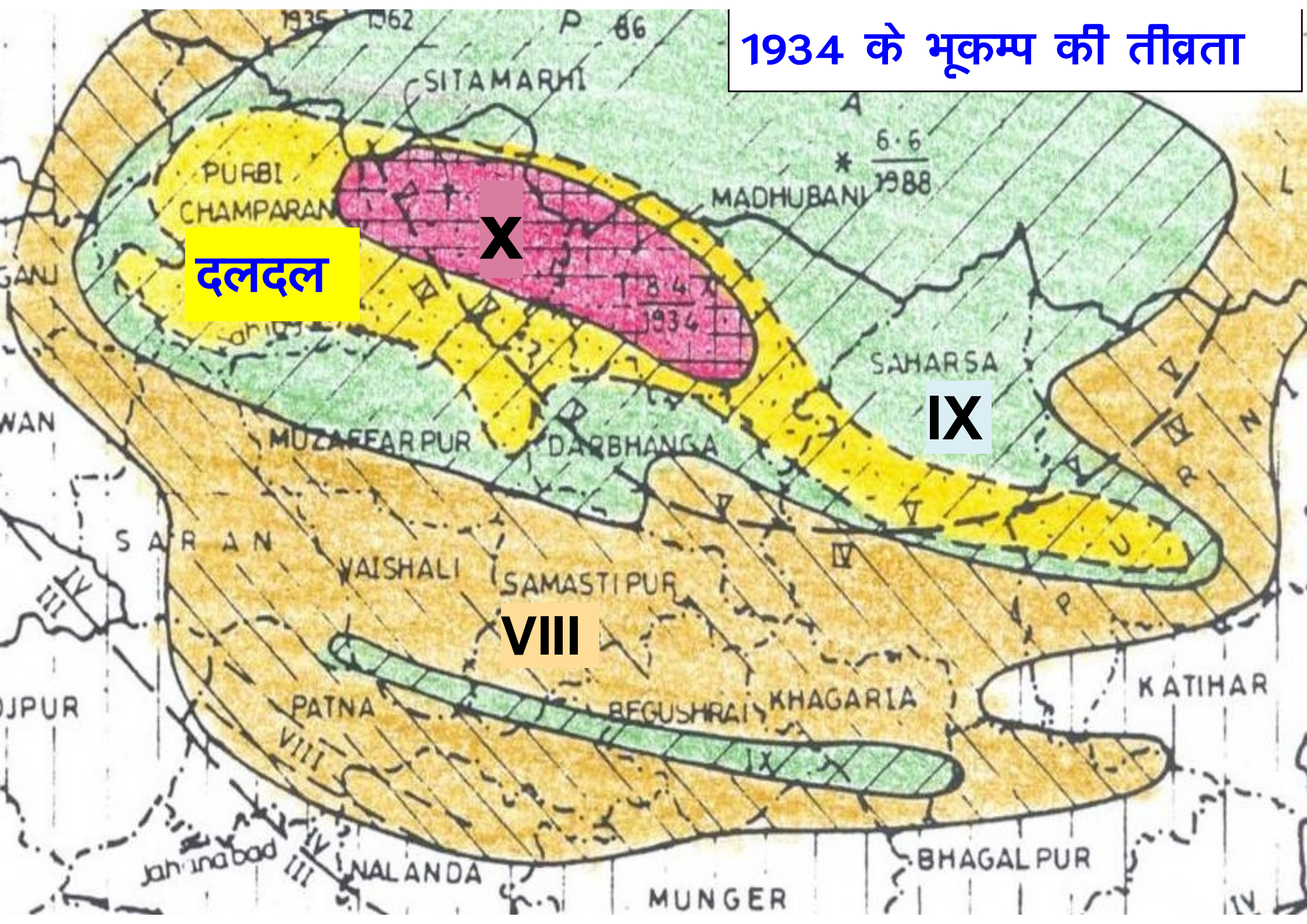


OSCILLATION OF STRUCTURE DURING EARTHQUAKE

- भूकम्प तरंग के कारण जमीन का तल डोलता है।
- संरचना के नींव और निचले भाग जमीन के साथ चलते हैं।
- Inertia के कारण भवन के उपरी भाग अपने मूल जगह पर रह जाते हैं।
- उपरी भाग पर विपरीत दिशा में inertia force लगता है।
- और संरचना डोलने लगता है।



- संरचना की दीवारें या पिलर छत को खींचकर रखते हैं।
- इससे कमजोर दीवारें या पीलर झुककर टूट सकते हैं।


1934 के भूकम्प की तीव्रता
SITAMARHI
PURBI CHAMPARAN
MADHUBANI
SAHARSA
MUZAFFARPUR
DARBHANGA
VAISHALI
SAMASTIPUR
BEGUSHRAI
KHAGARIA
KATIHAR
PATNA
NALANDA
BHAGALPUR
MUNGER
दलदल
X
IX
VIII

1934 के भूकम्प में क्षति

मुंगेर में क्षति

क्षतिग्रस्त रेल पुल

क्षतिग्रस्त रेल–लाईन

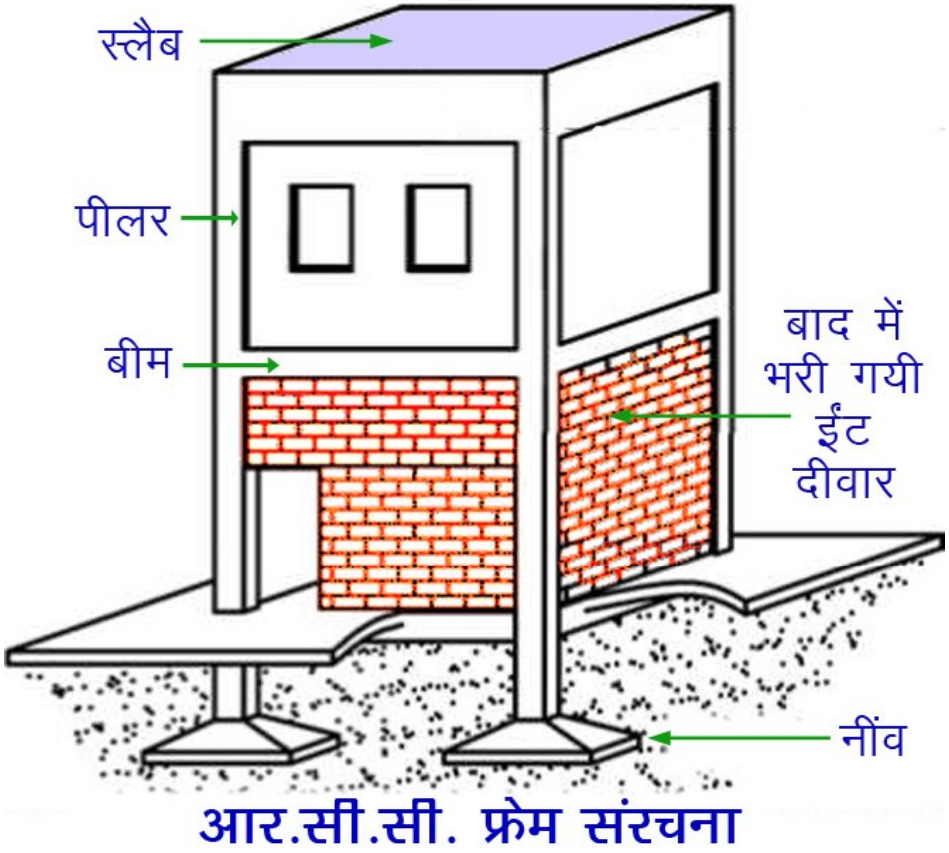
राजनगर, मधुबनी के क्षतिग्रस्त भवन

EARTHQUAKE RESISTANT DESIGN PHILOSOPHY

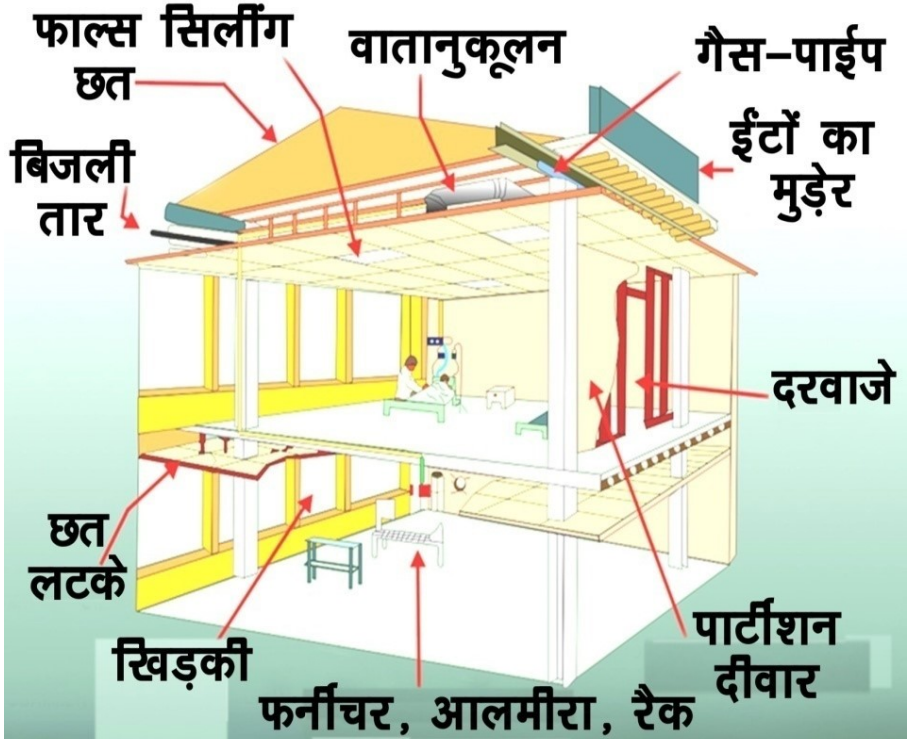
MCE & DBE

- **Maximum Considered Earthquake (MCE)**
  - **Extreme earthquake event, PGA, Z**
  - **Has very low probability of occurrence**
  - **Must not result in excessive casualties or damages**
  - ***2% probability to exceed in 50 years***
  - ***Return period 2500 years***
- **Design Basis Earthquake (DBE)**
  - **Moderate earthquake event, Z/2**
  - **Has moderate probability of occurrence**
  - **Must result in moderate and repairable damage**
  - **Must result in very few casualties**
  - ***10% probability to exceed in 50 years***
  - ***Return period 475 years***

STRUCTURE & NON-STYRUCTURAL ELEMENTS



आर.सी.सी. फ्रेम संरचना



STRUCTURE :

Bears Vertical and Horizontal forces and transmits the forces to the foundation

NON-STRUCTURE ELEMENTS :

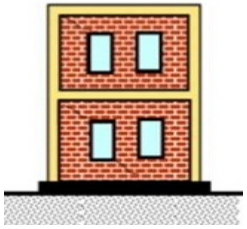
Accessories and Utilities fixed with the structure

EQ RESISTANT DESIGN PHILOSOPHY

- बारबार आनेवाले गौण भूकम्प (< DBE) के दौरानः

  संरचना क्षति : नहीं

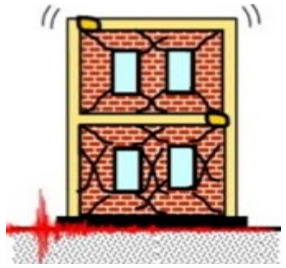
  गैर–संरचना क्षति : न्यून



- यदा–कदा आनेवाले मध्यम भूकम्प (= DBE) के दौरानः

  संरचना क्षति : न्यून, मरम्मति योग्य

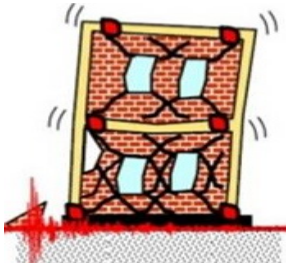
  गैर–संरचना क्षति : काफी, हटाने योग्य



- आसाधारण शक्तिशाली भूकम्प (MCE) के दौरानः

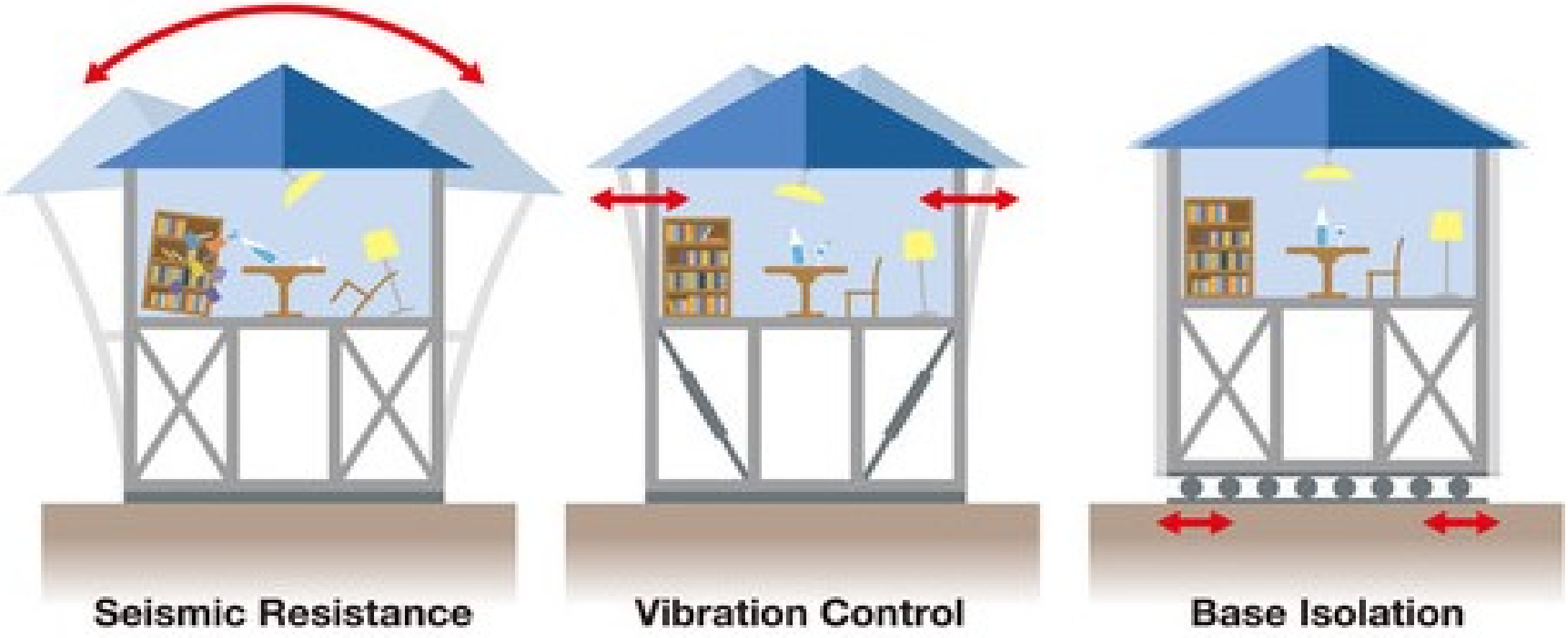
  संरचना क्षति : काफी,

  परन्तु, संरचना ढ़हना नहीं चाहिए।



SOLUTIONS FOR EARTHQUAKE RESISTANCE

1. Seismic strengthening
2. Energy absorbing devices, dampers
3. Base isolation technique

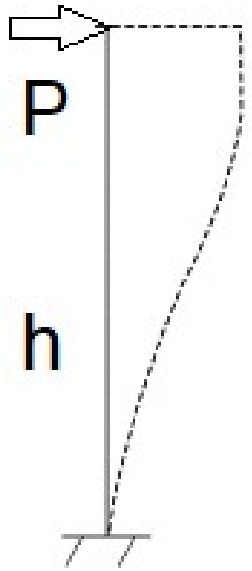


IMPROVING EARTHQUAKE RESISTANCE

STIFFNESS OF COLUMN

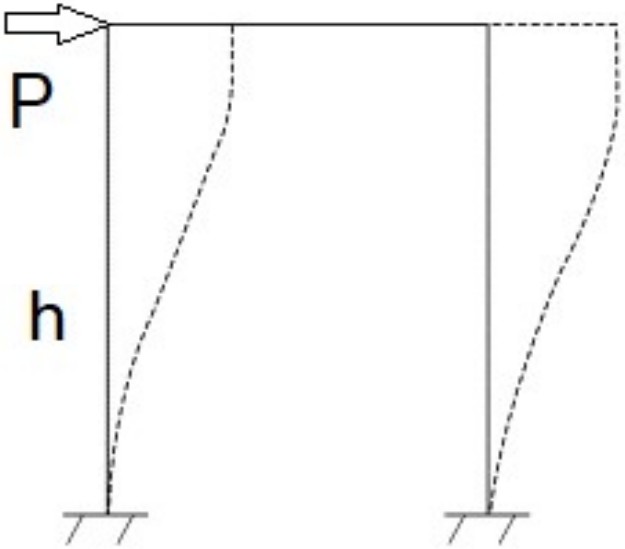
STIFFNESS : Force required for unit deflection

COLUMN UNDER HORIZONTAL FORCE



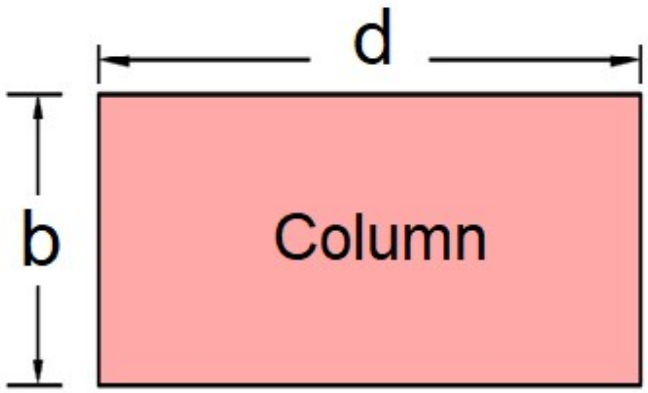
Cantilever

$3EI/h^3$



FRAME

$12EI/h^3$



$I = bd^3/12$

Stiffness is more when Larger size of column is placed along EQ force P

GENERAL PRINCIPLES

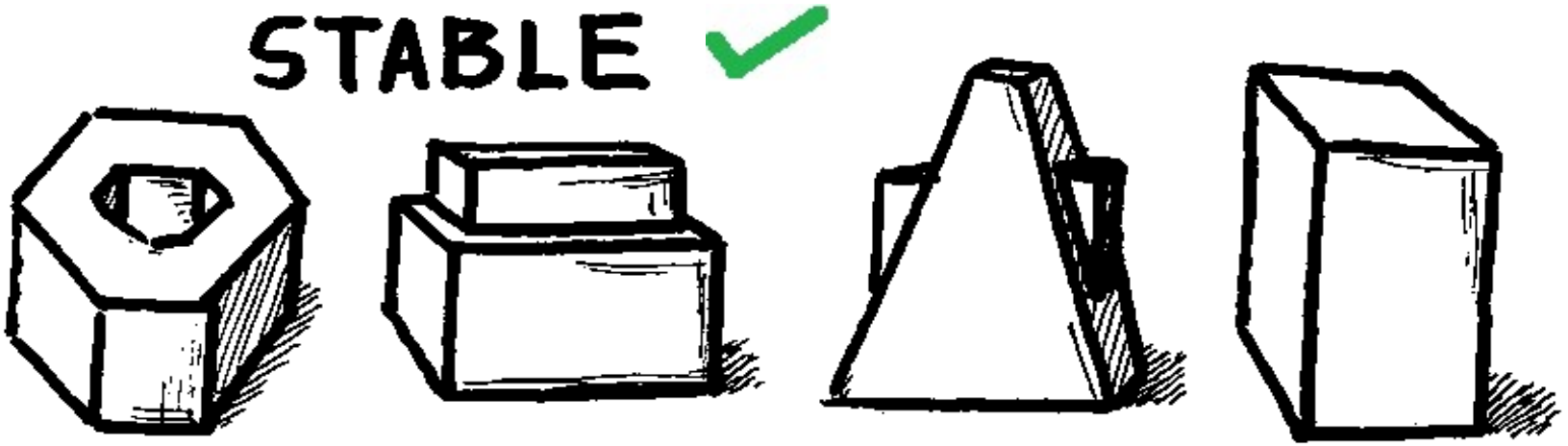
- **LIGHT WEIGHT** Particularly roof and upper storeys
- **GEOMETRY** Simple circular or rectangular Plan
- **SYMMETRY** In plan & elevation, mass and stiffness
- **LOAD PATH** Simple & shortest, top to foundation
- **LATERAL STRENGTH : Sufficient carrying capacity**
- **INTEGRITY:** Al portions of building tied together
- **REDUNDANCY:** Extra Structural members
  At least 3 columns in a row
- **DUCTILITY : Large inelastic deformations without breaking**

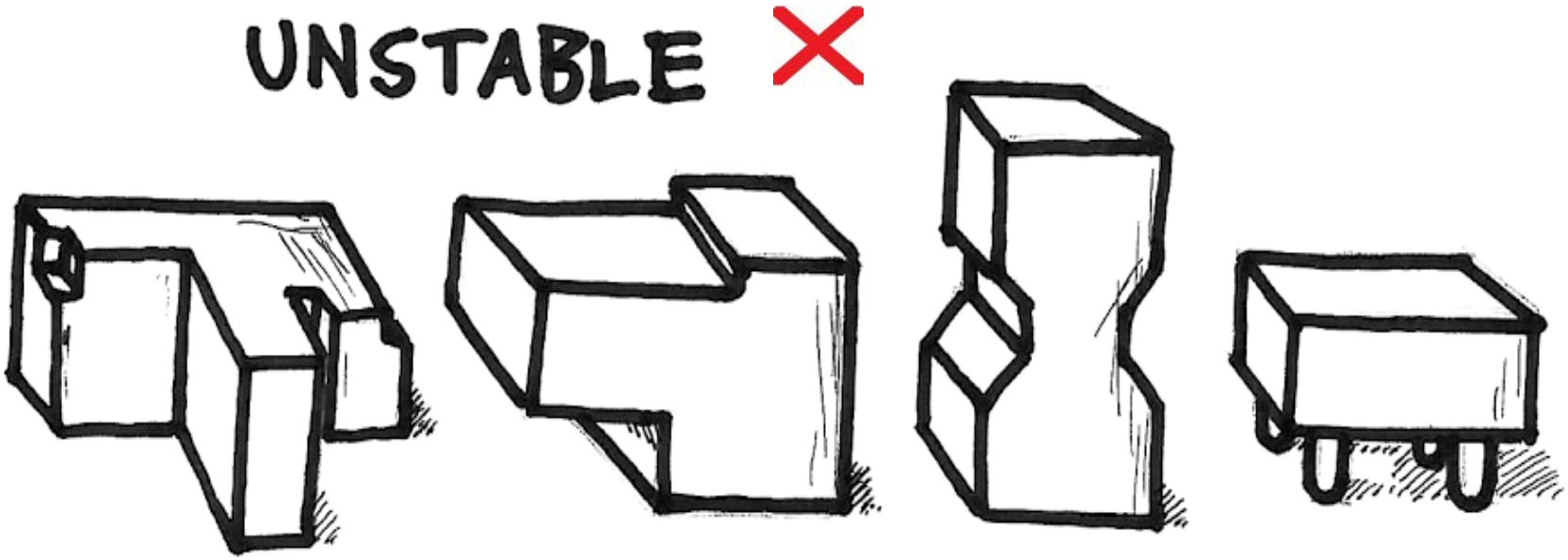
OTHER ASPECTS

- **Projecting parts**
  - Avoid as for as possible
- **Protection of Building contents**
  - Non structural components
  - Architectural elements
  - Building services
- **material properties:**
  - High strength to weight ratio
  - Ductility
- **Foundation:**
  - On firm and uniform ground

BUILDING CONFIGURATION

STABLE - UNSTABLE

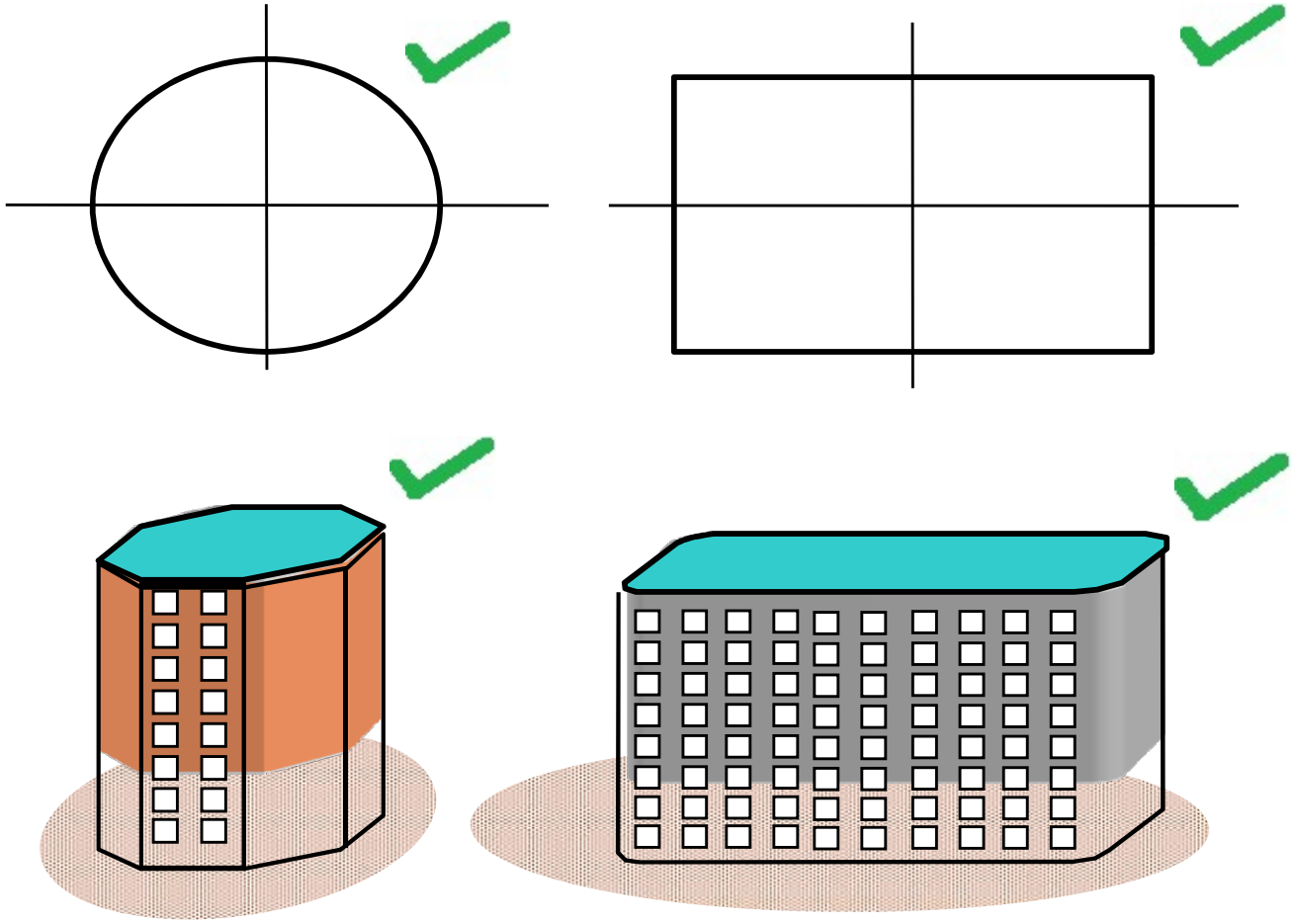




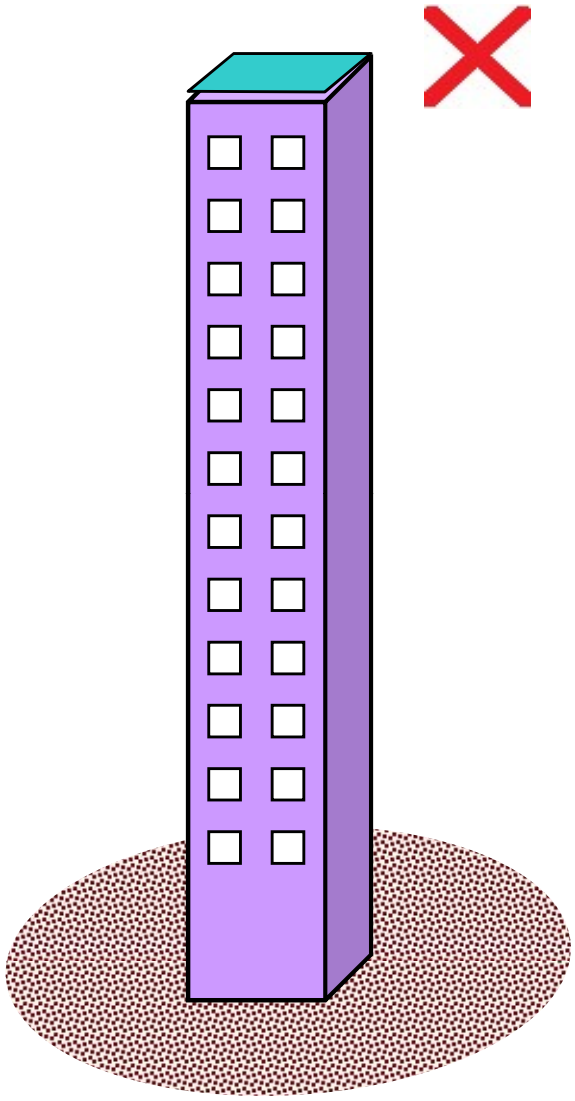
SIMPLE, COMPACT & SYMMETRICAL PLAN

GOOD SEISMIC PERFORMANCE

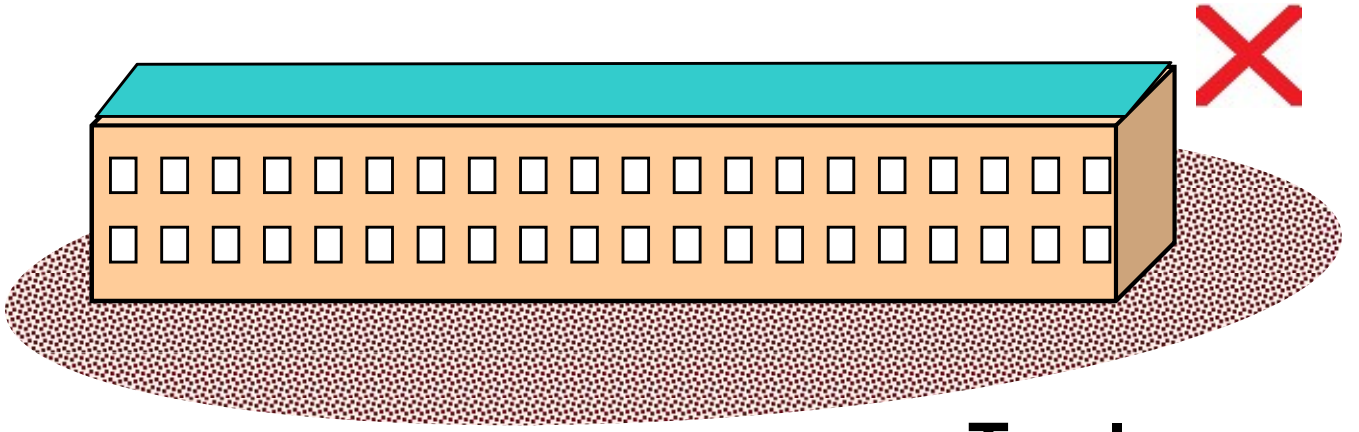
- Predominantly bending deformation under Earthquake loads
- Less torsion or twisting behavior about vertical axis.



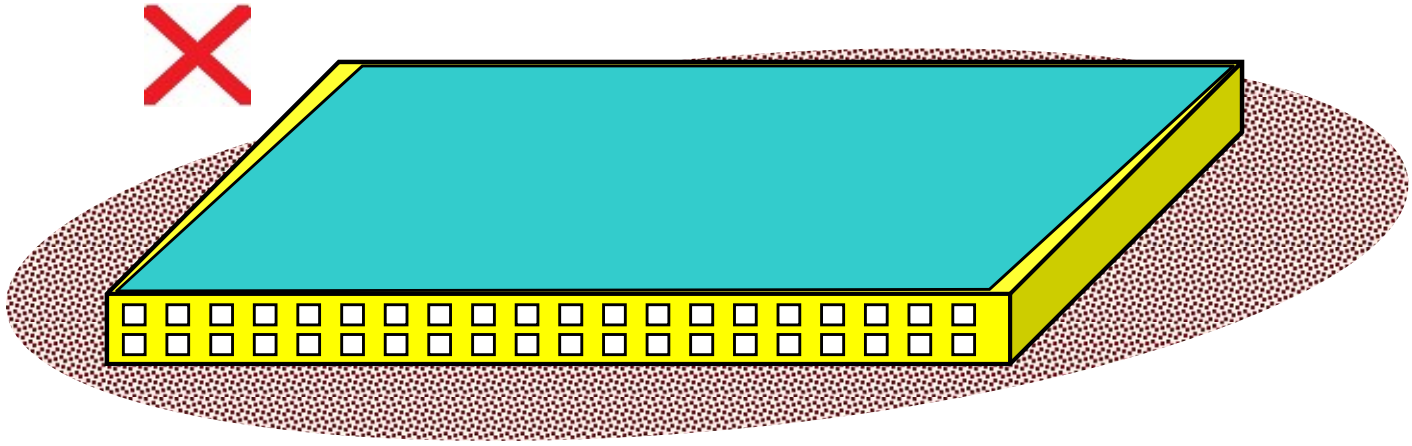
OVERALL SIZE : POOR



Too tall

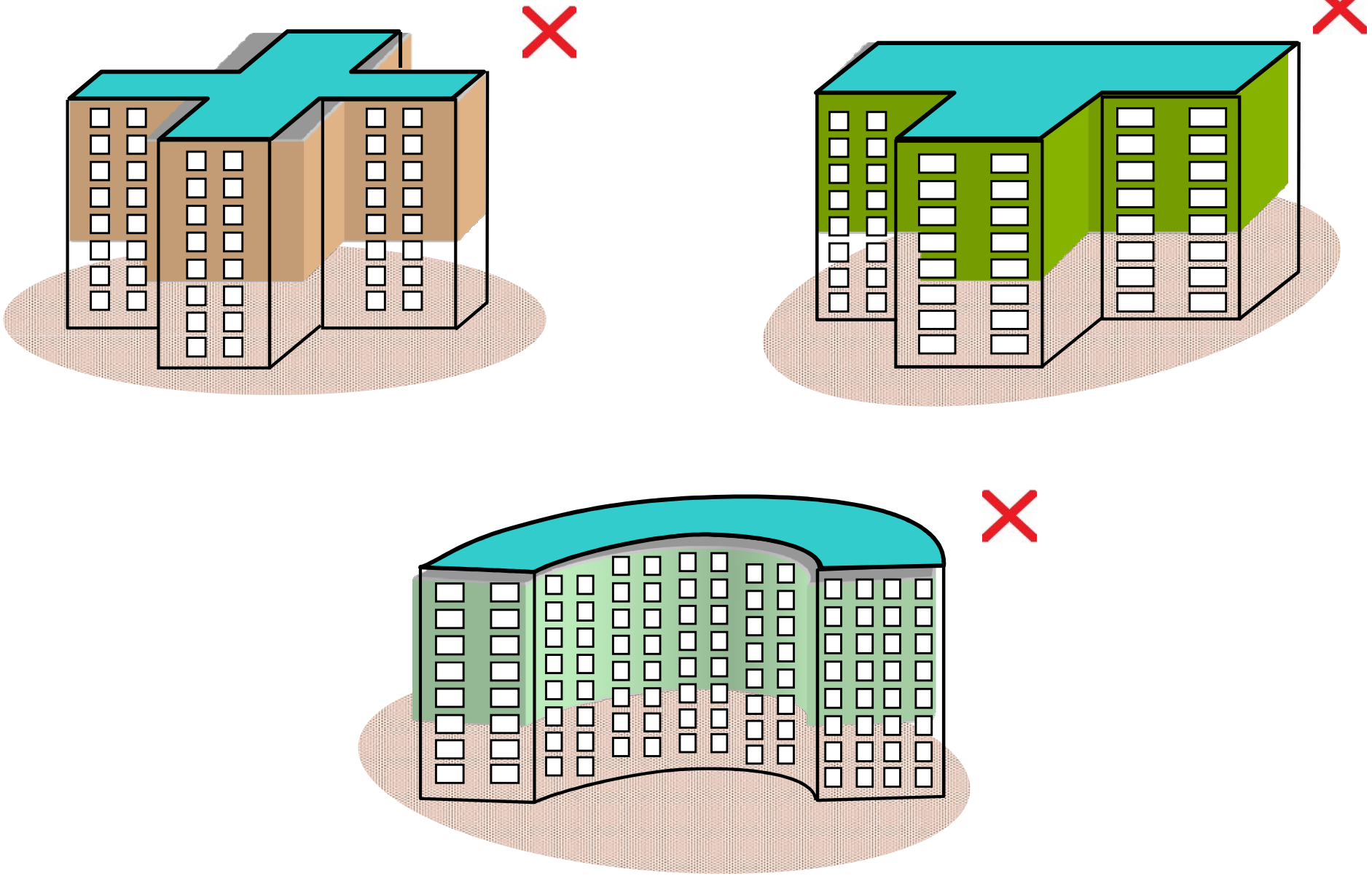


Too long

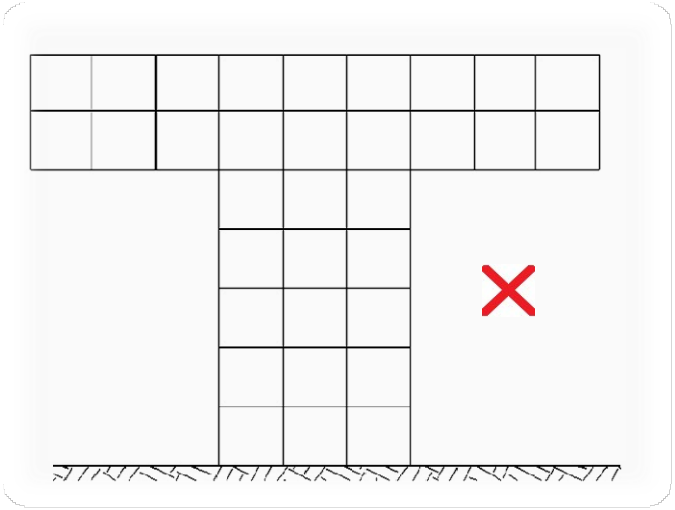


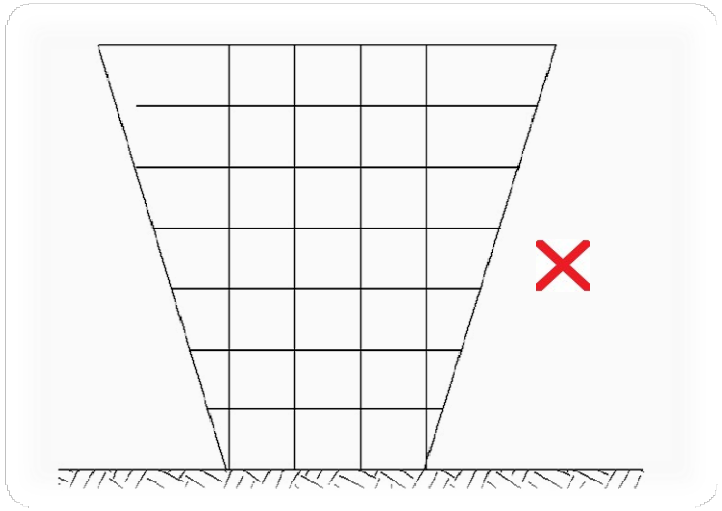
Too large in plan

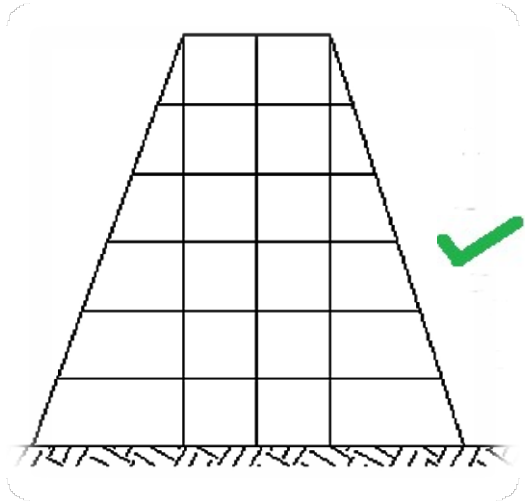
CORNERS AND CURVES : *POOR*



ELEVATION







Enlarged top stories

Pyramid Elevation

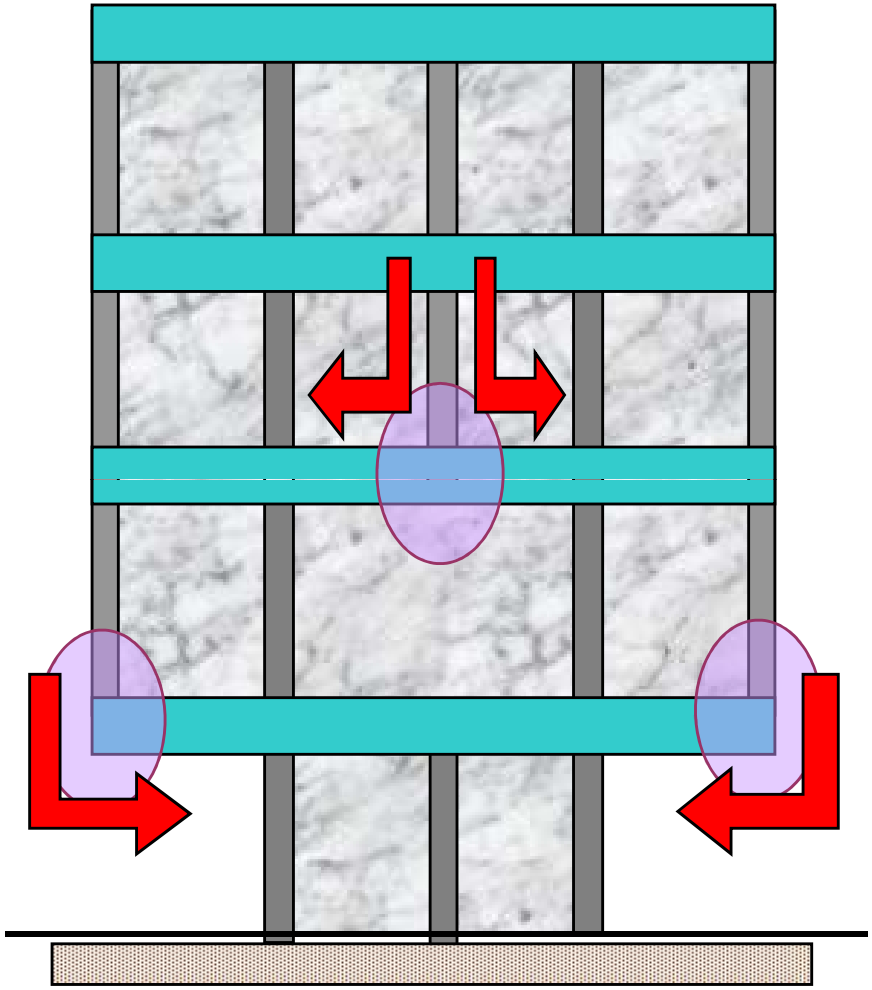
Problematic

- **Problem of stability :**
  .. High Centre of gravity
  .. Heavy overturning moments
- **Uneven foundation pressure and Foundation tilting**
- **Avoid in high seismic zone**

Ideal shape

- **Low center of gravity**
- **Symmetry**

INDIRECT LOAD PATH: POOR



Hanging or Floating Columns

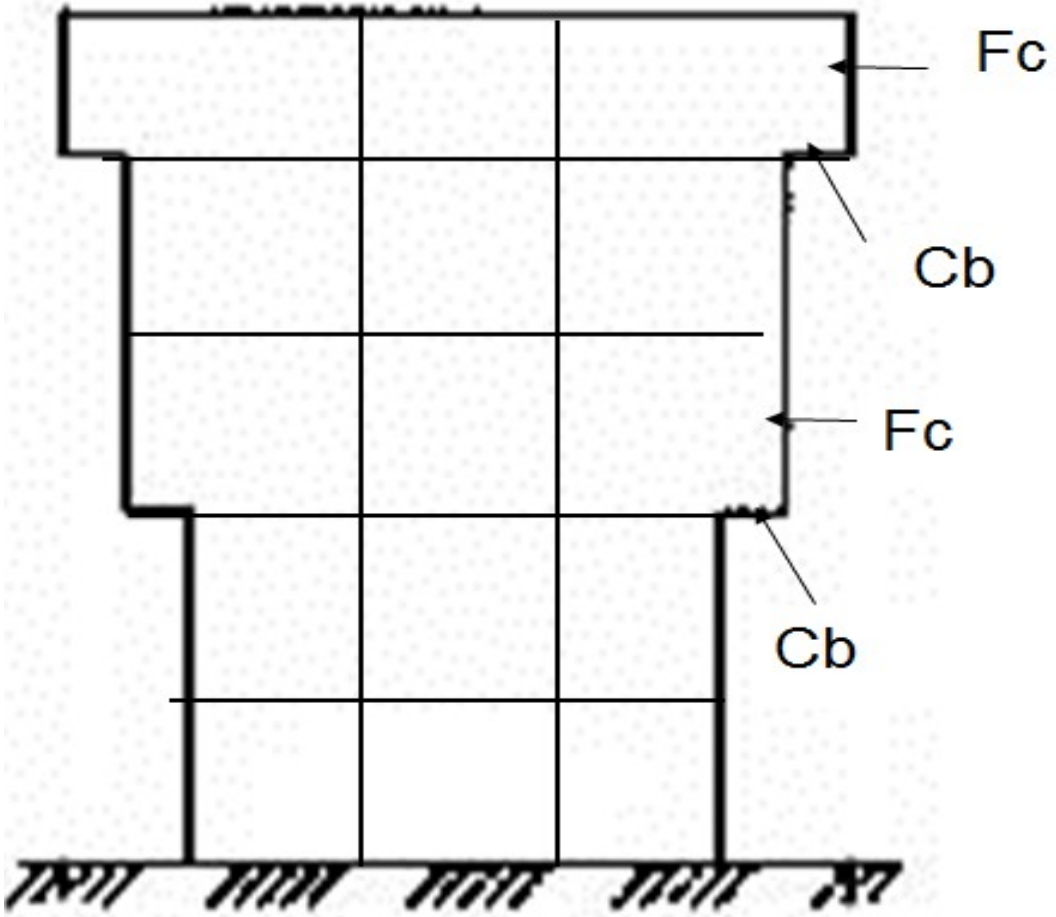
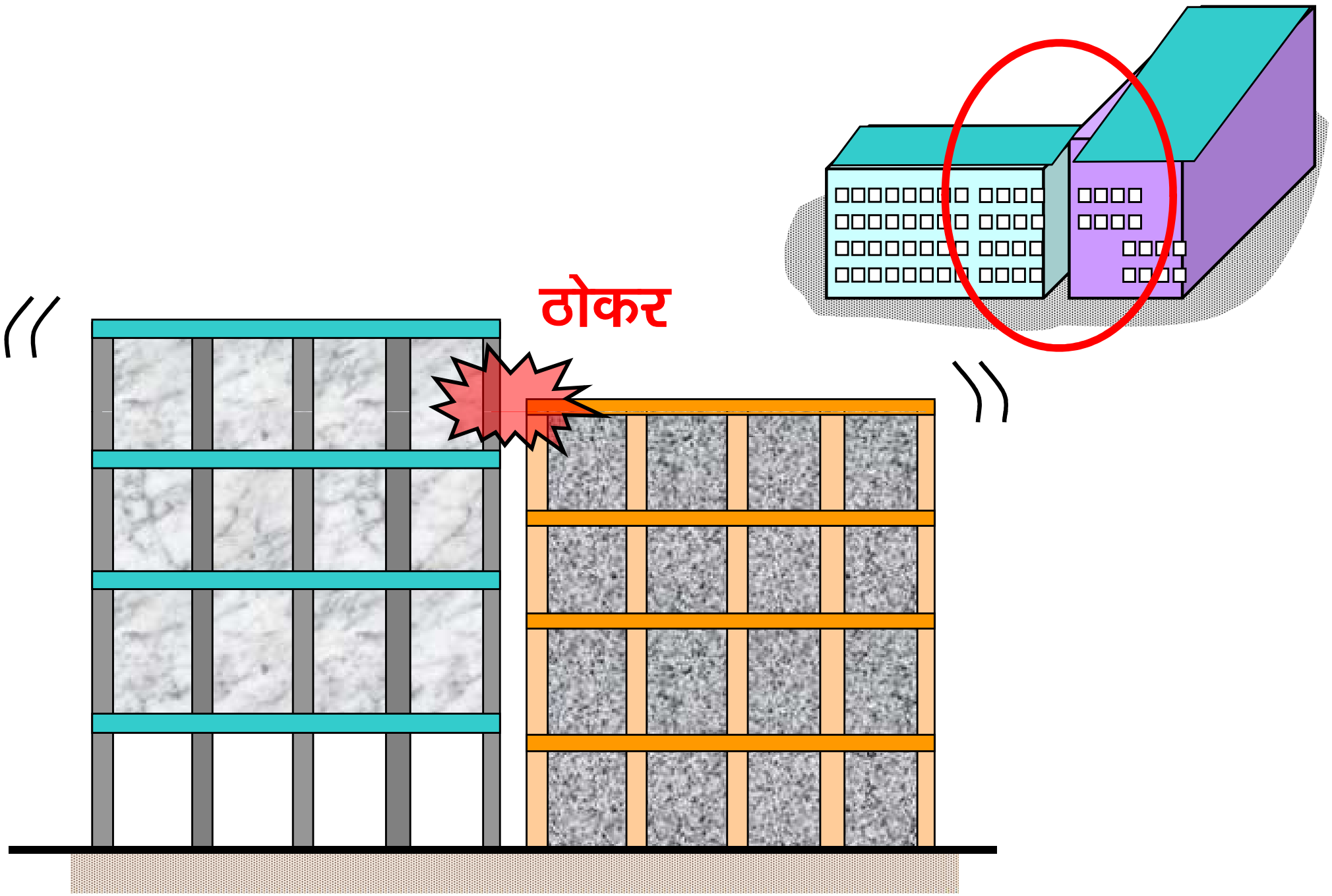


Fig.:-Floating columns
Fc= Floating Columns
Cb= Cantilever Beams

GAP BETWEEN BUILDINGS

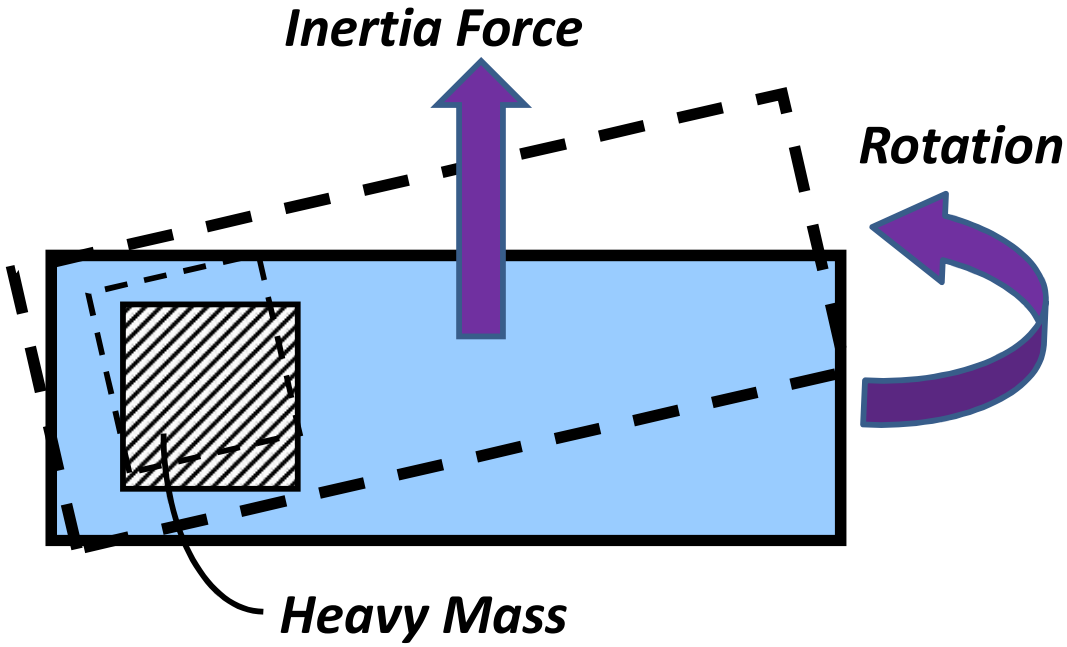


IRREGULAR FORM AND CONFIGURATION

PLAN IRREGULARITIES

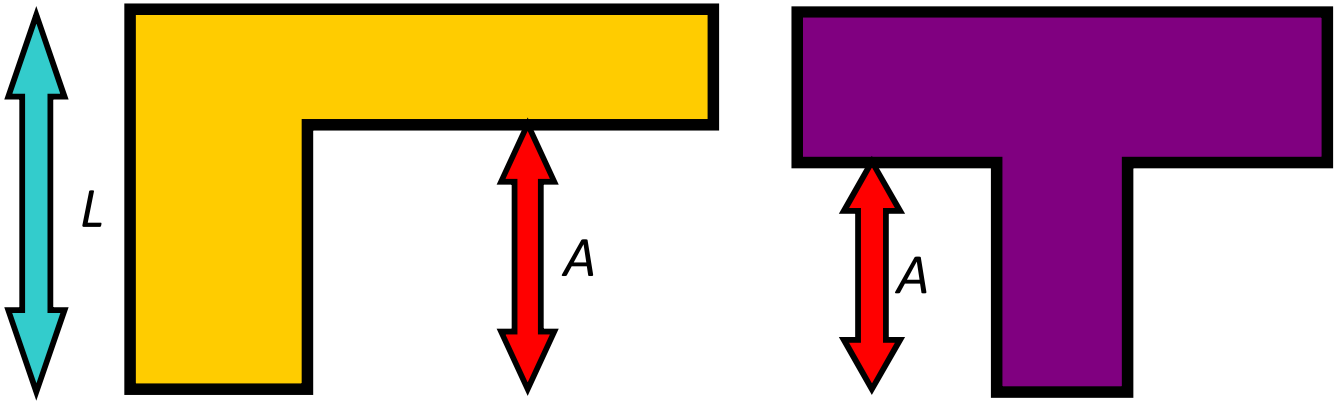
TORSION IRREGULARITY

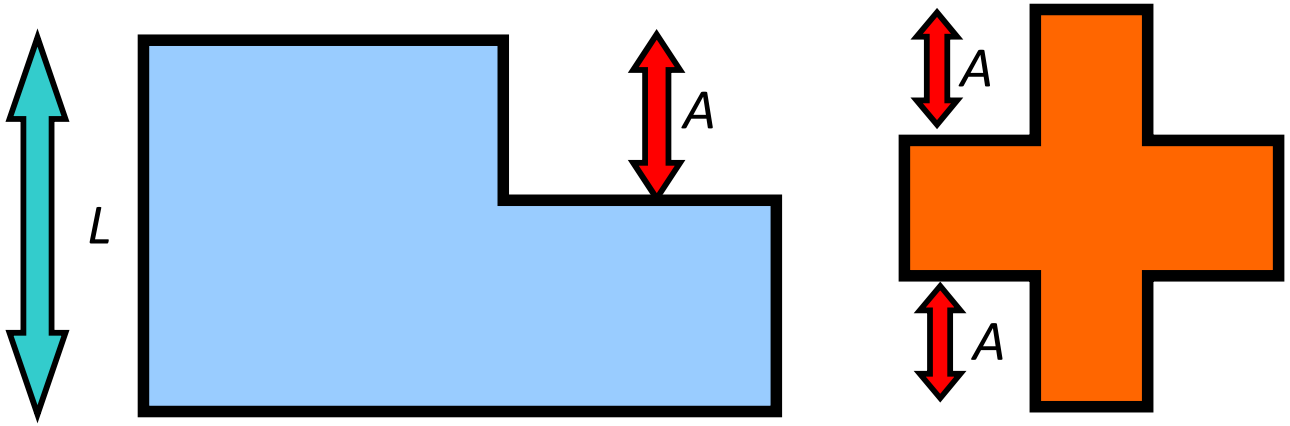
Eccentricity between centers of mass and stiffness increase effects of torsion



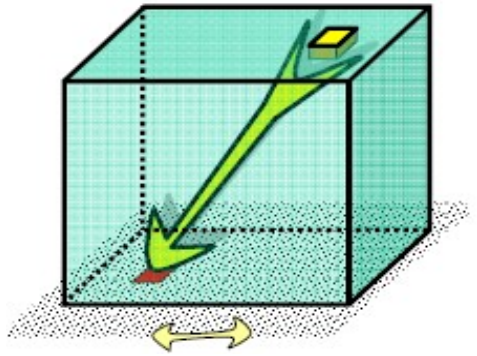
PLAN IRREGULARITIES

RE-ENTRANT CORNERS

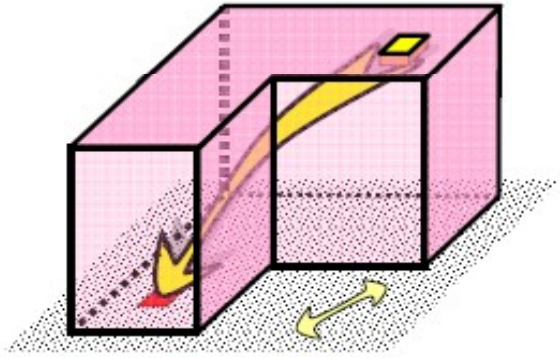




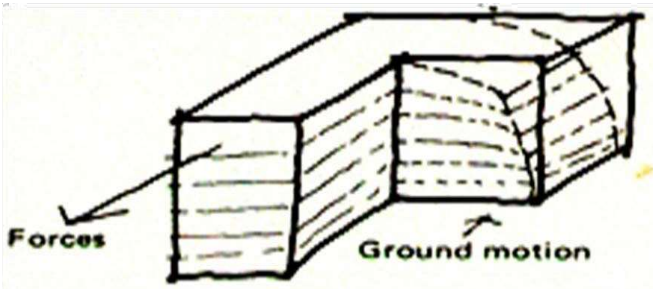
$$\frac{A}{L} > 0.15 - 0.20$$



straight load path

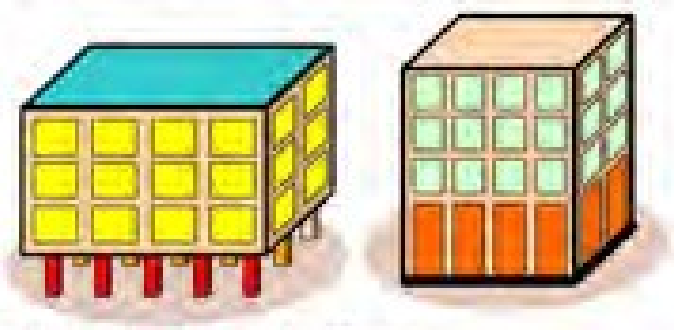


changed load path

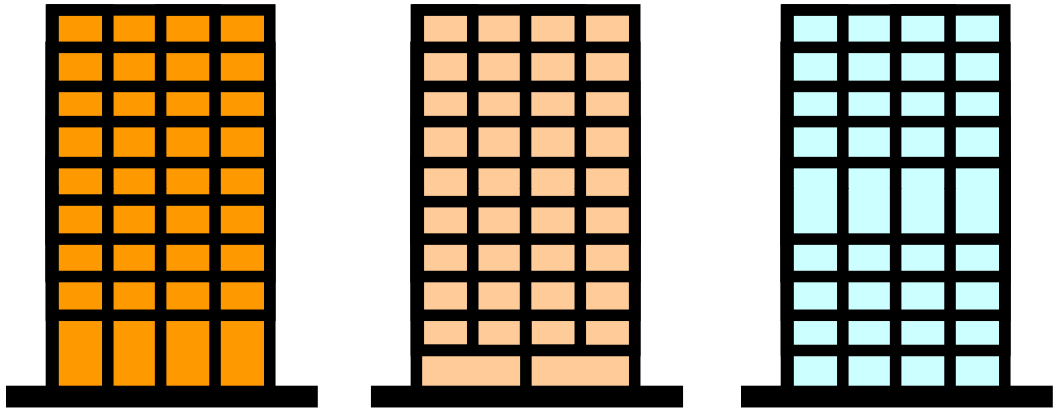


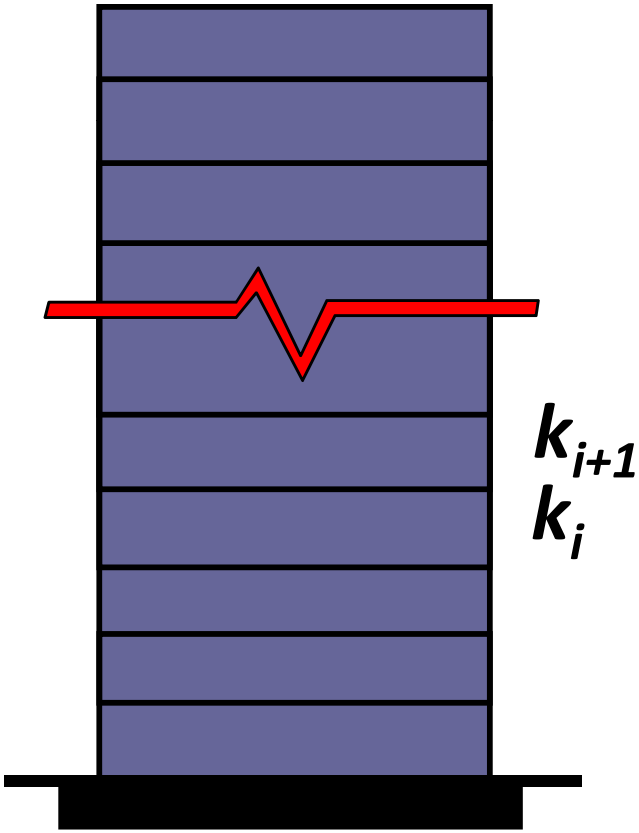
VERTICAL IRREGULARITIES

STIFFNESS IRREGULARITY



Soft Storey

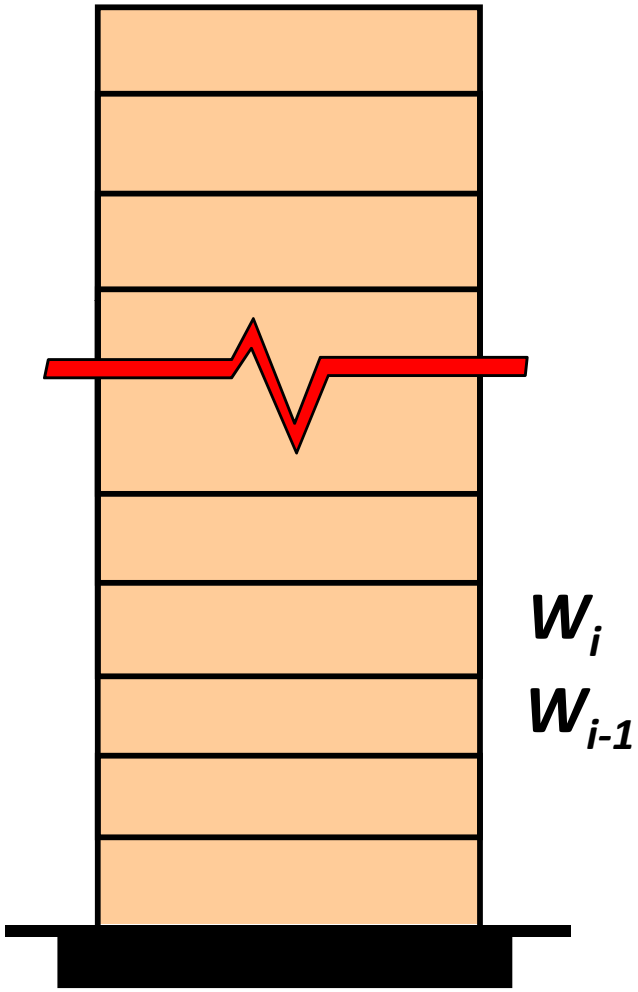


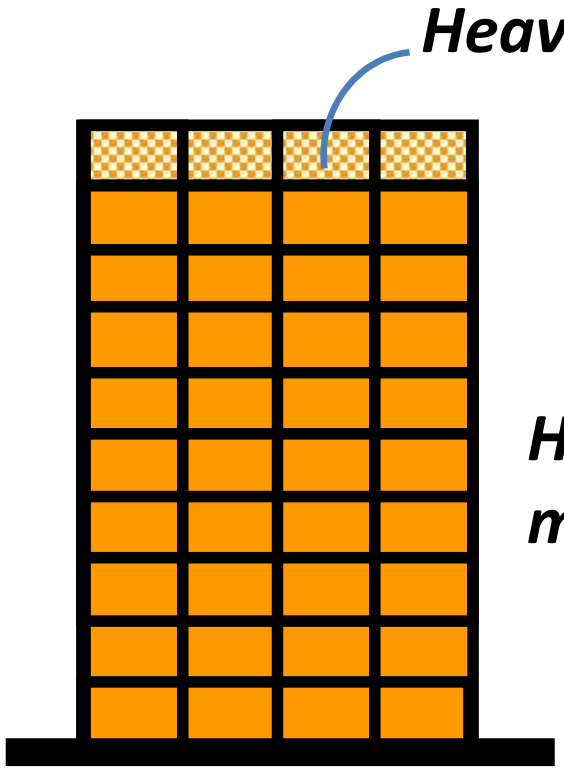


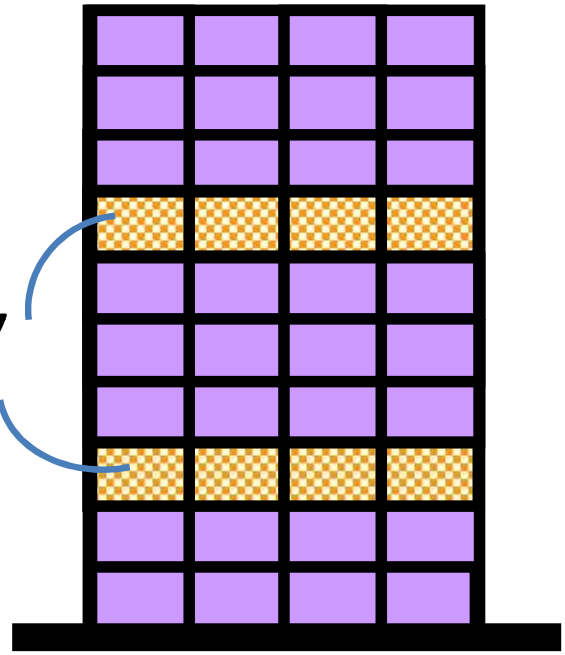
$$k_i < k_{i+1}$$

VERTICAL IRREGULARITIES

MASS IRREGULARITY



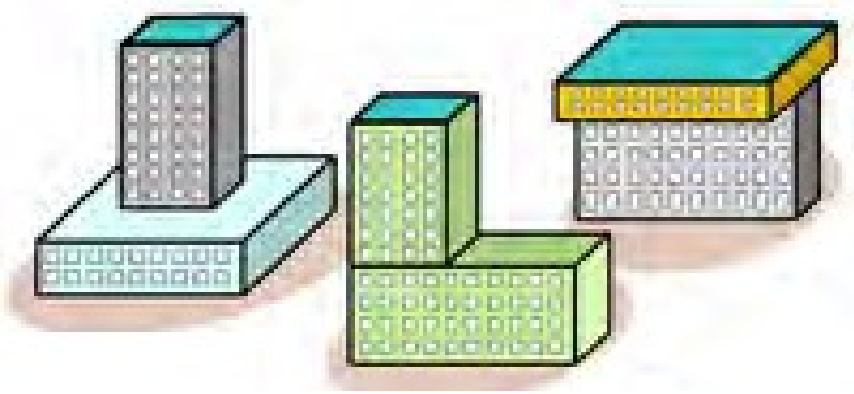


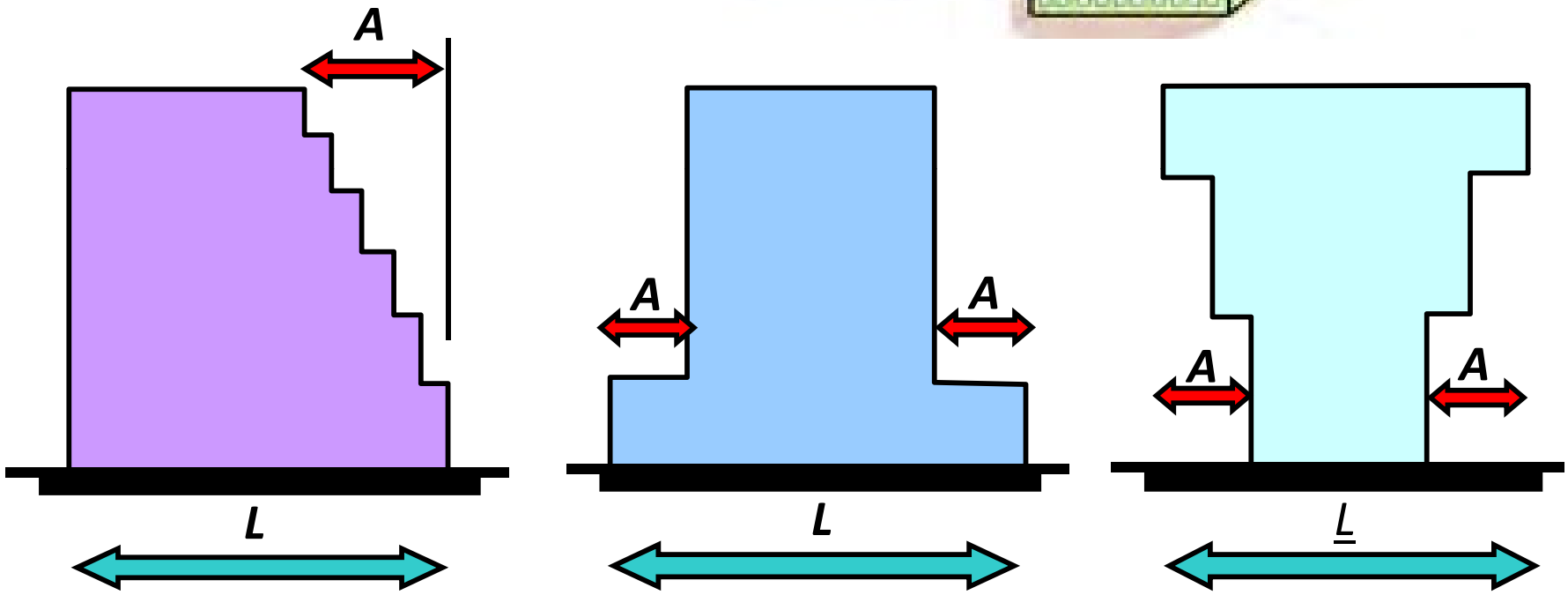


$$W_i > 1.5 W_{i-1}$$

VERTICAL IRREGULARITIES

VERTICAL GEOMETRIC IRREGULARITY





$A > 0.25L$

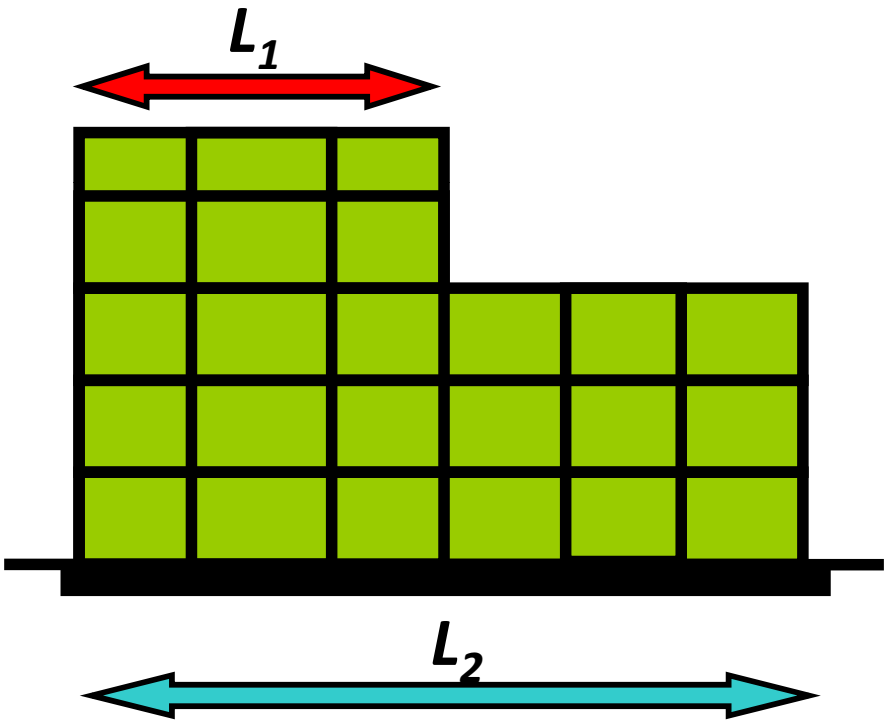
$A > 0.125L$

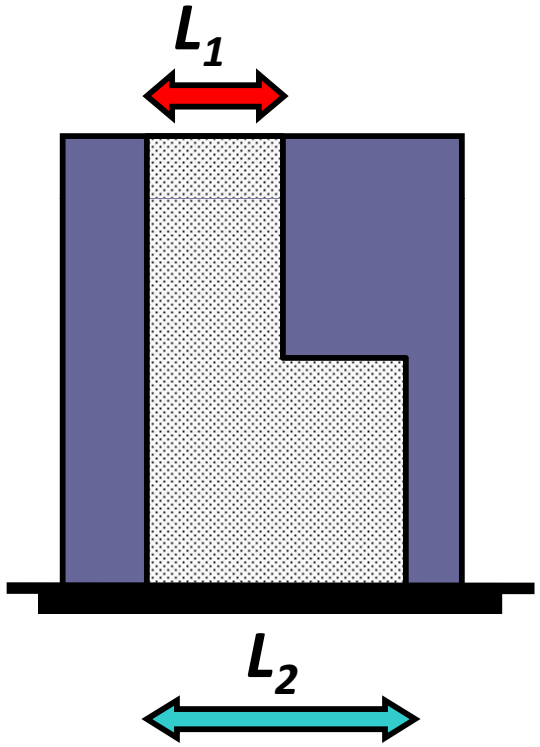
$A > 0.1L$

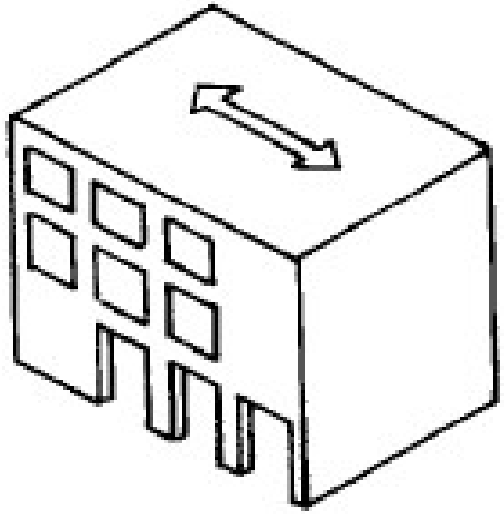
VERTICAL IRREGULARITIES

IN-PLANE DISCONTINUITY OF VERTICAL ELEMENTS

Interruption of vertical members, Abrupt changes in stiffness ratio



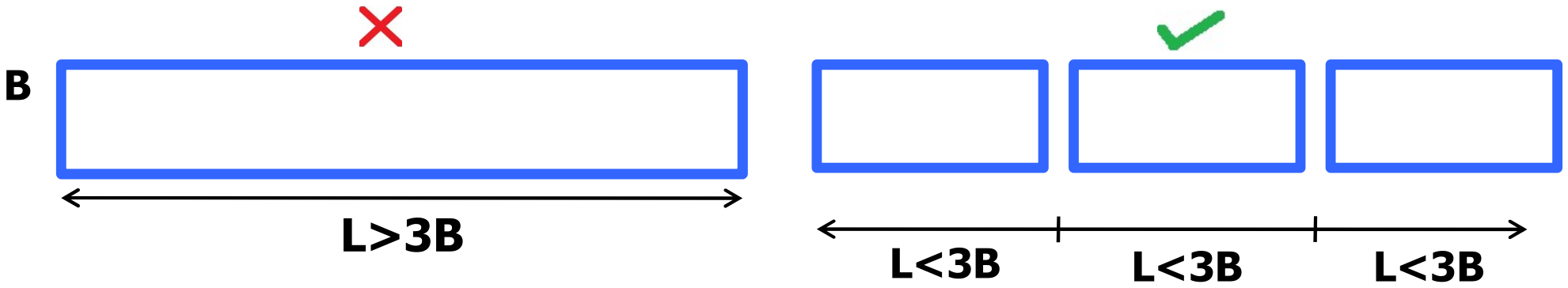




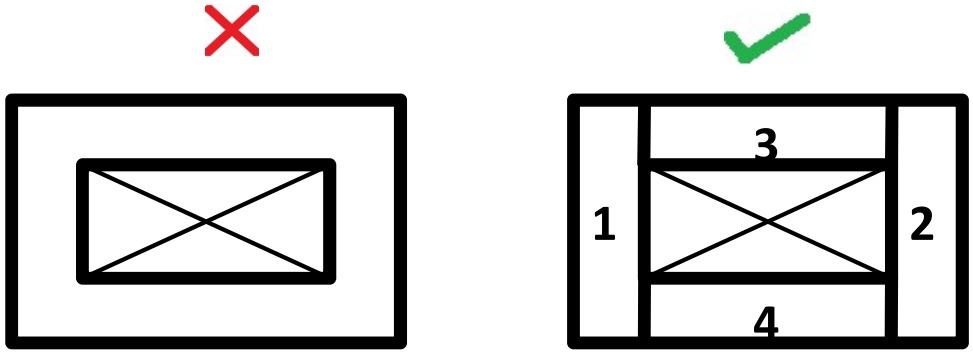
$$L_2 > 1.25\,L_1$$

SEISMIC SEPARATION JOINTS

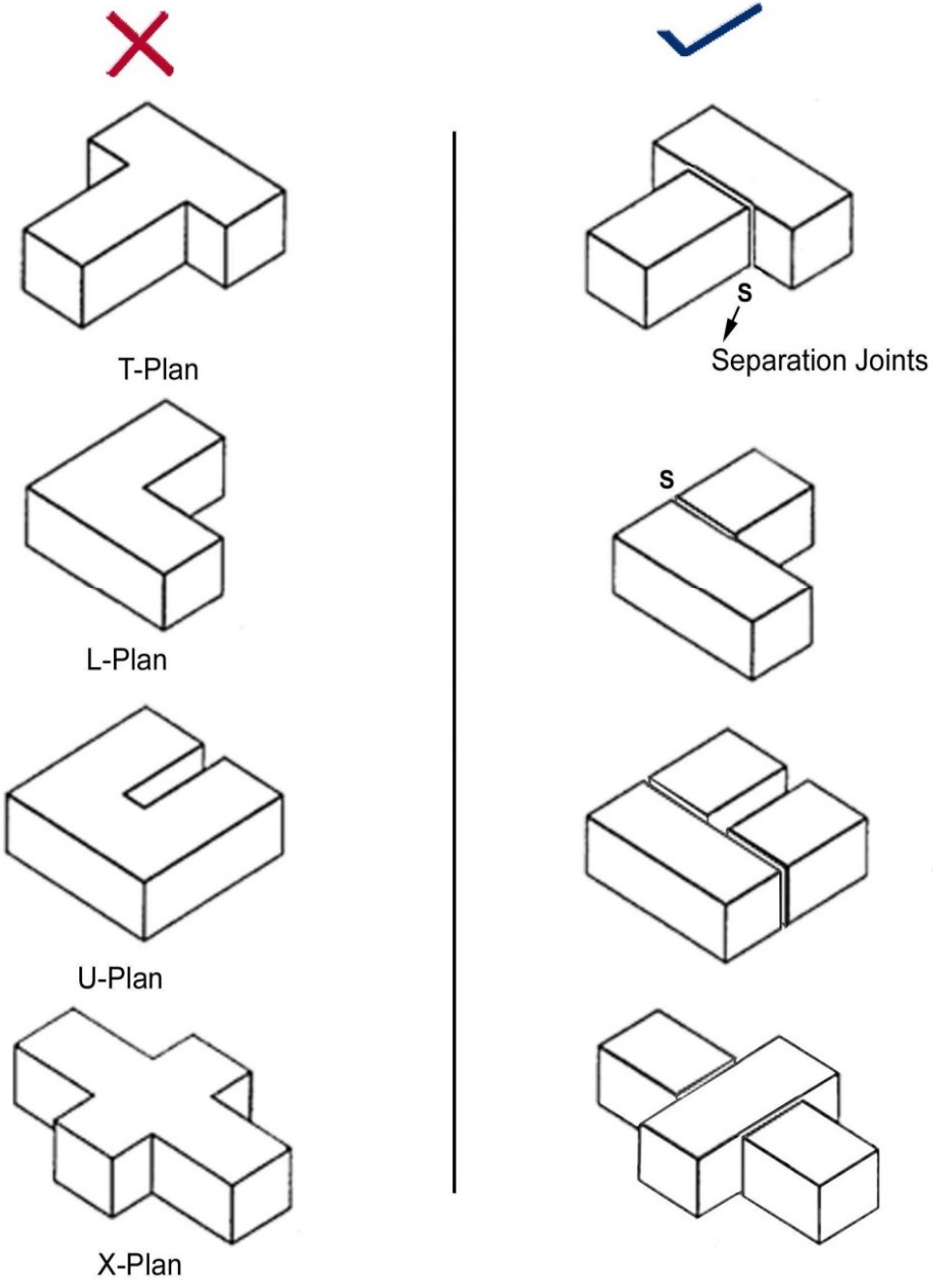
LONG RECTANGULAR BLOCKS



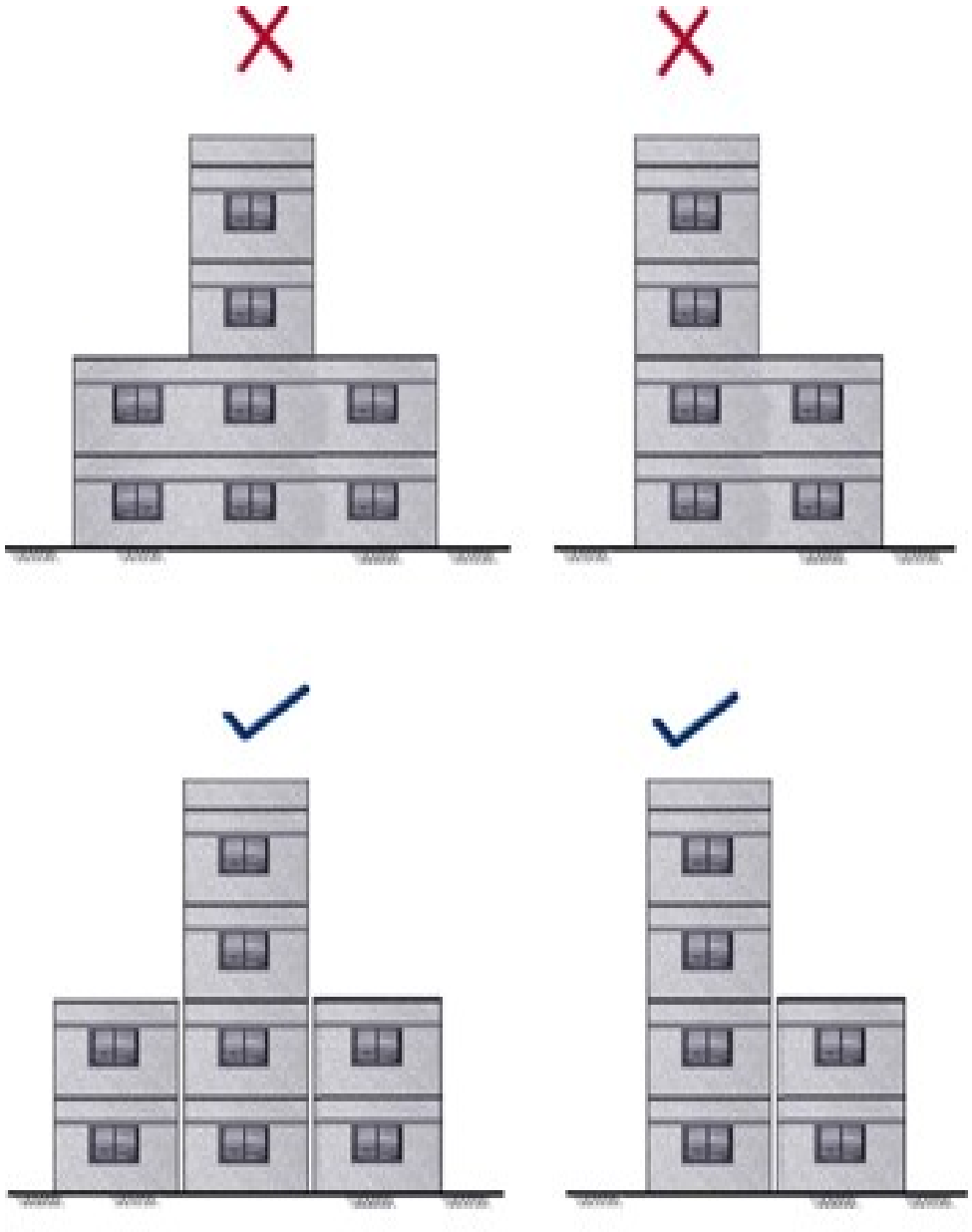
FLOOR WITH LARGE OPENING



CORNERS



VERICAL DISCONTINUITY



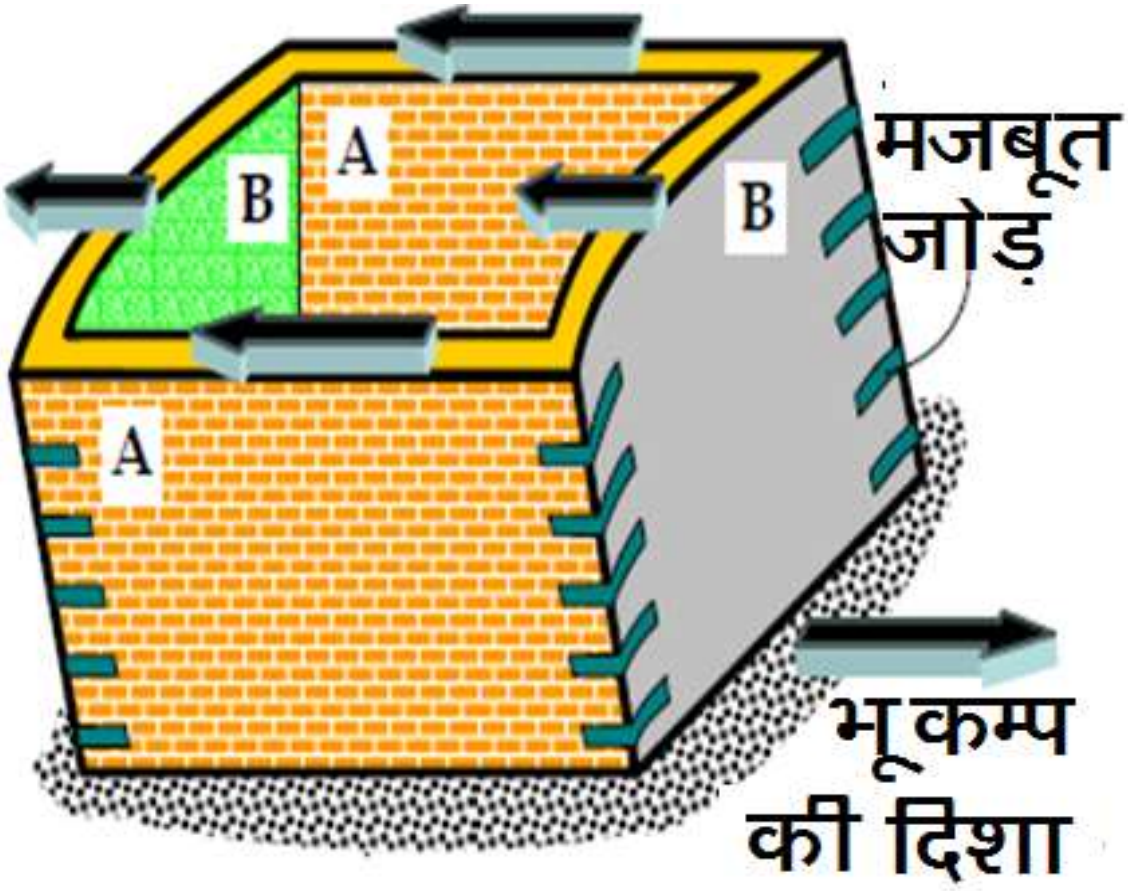
SEISMIC SAFETY OF MASONRY BUILDINGS (Load Bearing Walls)

SEISMIC SAFETY OF MASONRY BUILDINGS

BOX ACTION

ईंट जोड़ाई दीवारों पर आधारित मकान की भूकम्प से सुरक्षा हेतु सबसे महत्वपूर्ण यह है कि सभी दीवारें साथ–साथ काम करें और मकान एक पूर्ण बॉक्स की तरह काम करे।

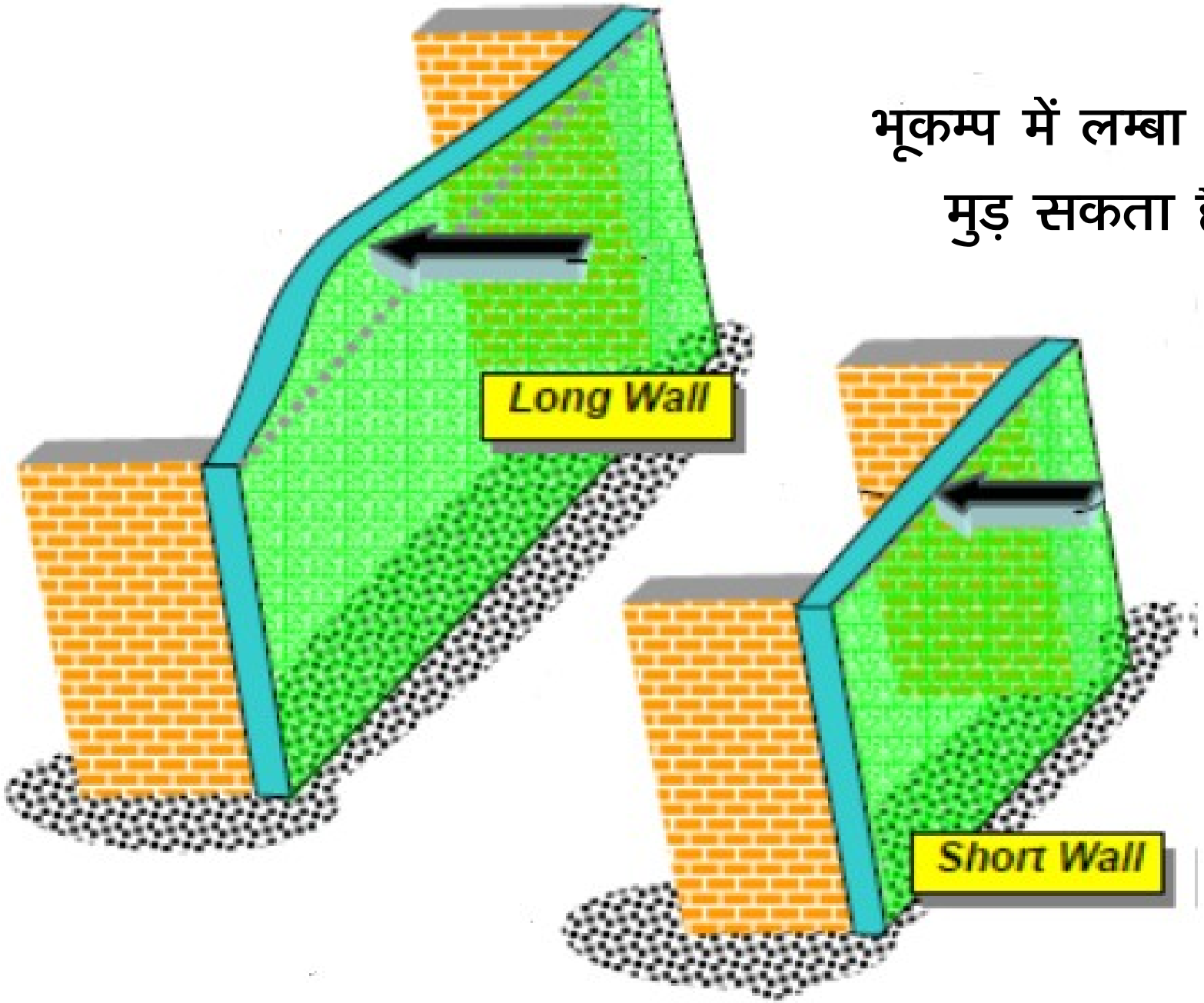
मजबूत दीवार तथा कमजोर दीवार का बंधन



- **A** दीवार मजबूत है। भूकम्प में कम डोलता है।
- **B** दीवार कमजोर है। भूकम्प में ज्यादा डोलता है।

अगर दीवारों के बीच मजबूत जोड़ बनाया जाय तो, **B** दीवार को भूकम्प में **A** दीवार सहारा दे सकता है।

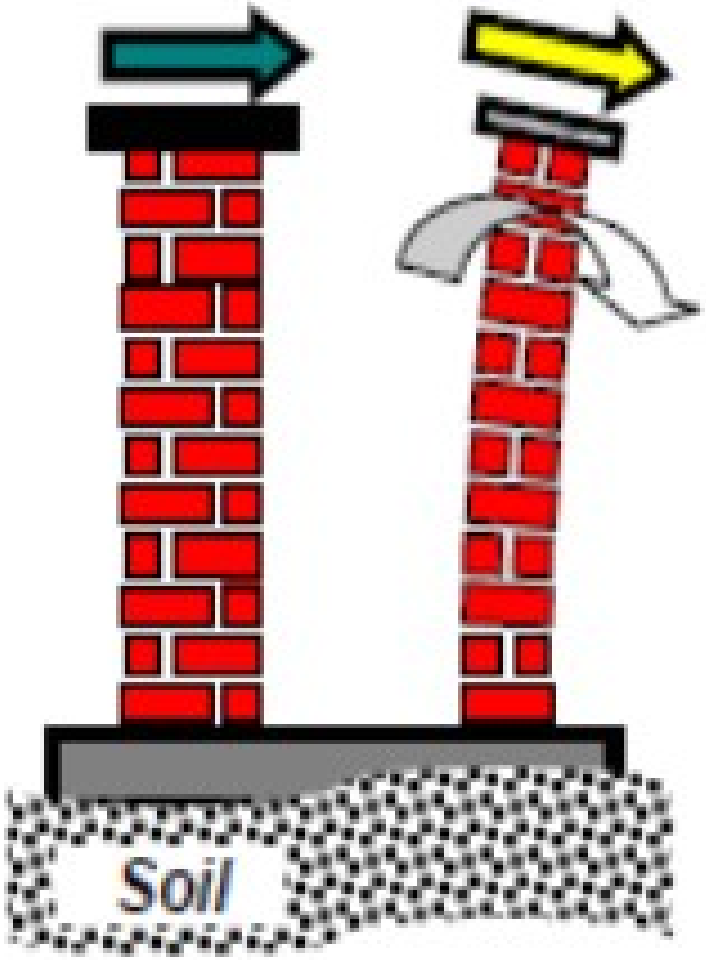
दीवारों की लम्बाई

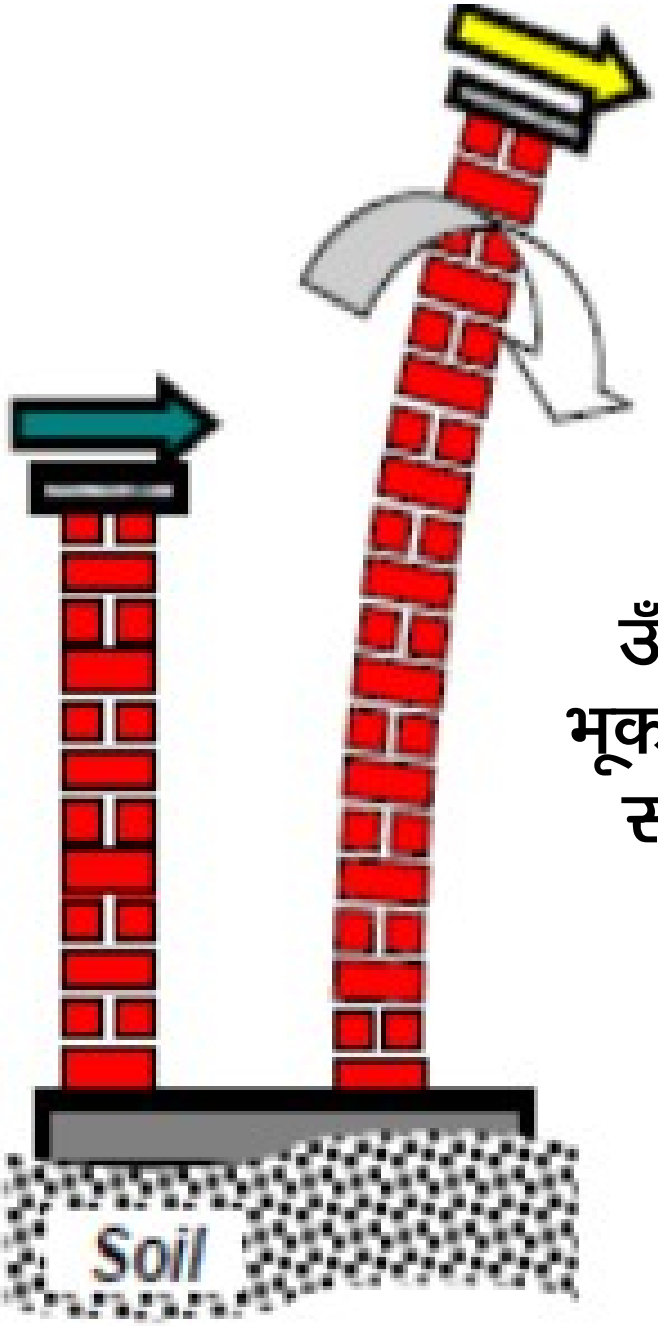


भूकम्प में लम्बा दीवार
मुड़ सकता है।

दीवारों की मोटाई एवं उँचाई

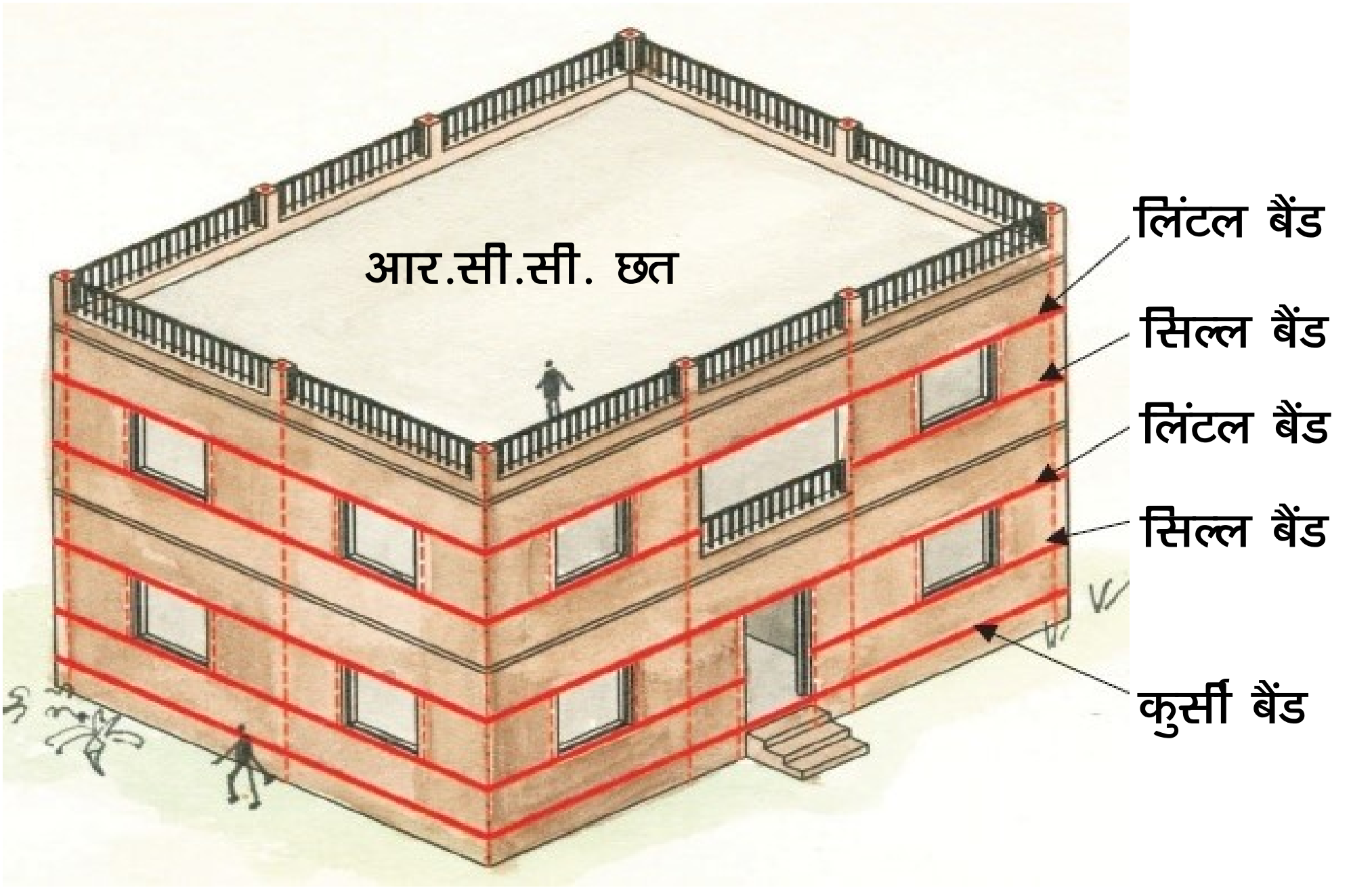
पतला दीवार भूकम्प में पलट सकता है।





उँचा दीवार भूकम्प में पलट सकता है।

HORIZONTAL BANDS IN FLAT ROOF BUILDINGS



HORIZONTAL BANDS IN SLOPED ROOF BUILDINGS

सभी दीवारों पर, एक ही लेवल पर आर.सी.सी. बैंड बनाएं।

छत बैंड :
सिर्फ ढलवाँ छत वाले मकान मे

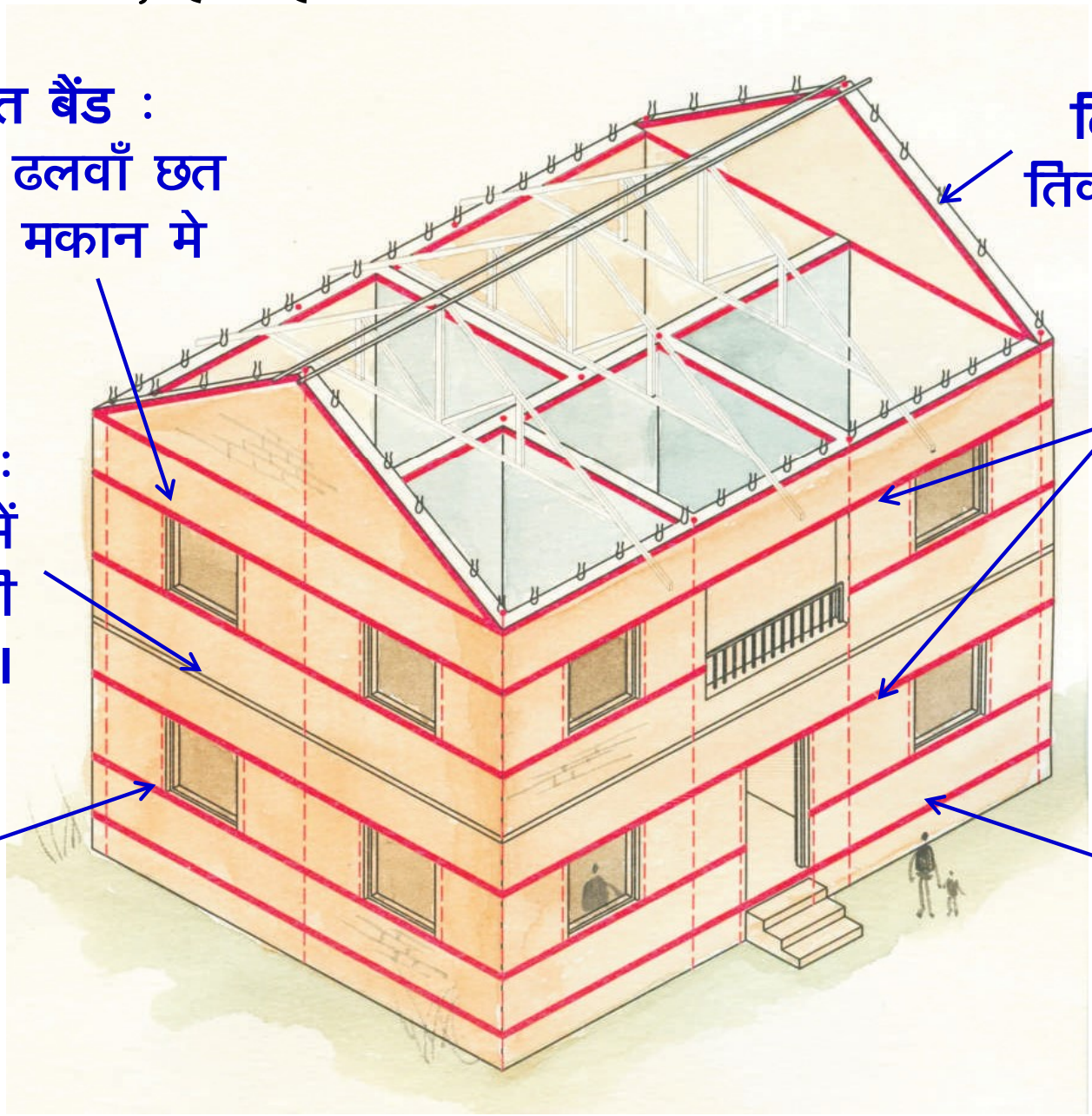
तिकोना बैंड :
तिकोनी दीवार पर

फर्श बैंड :
आर.सी.सी. छत में नहीं। शेष सभी प्रकार के फर्श में।

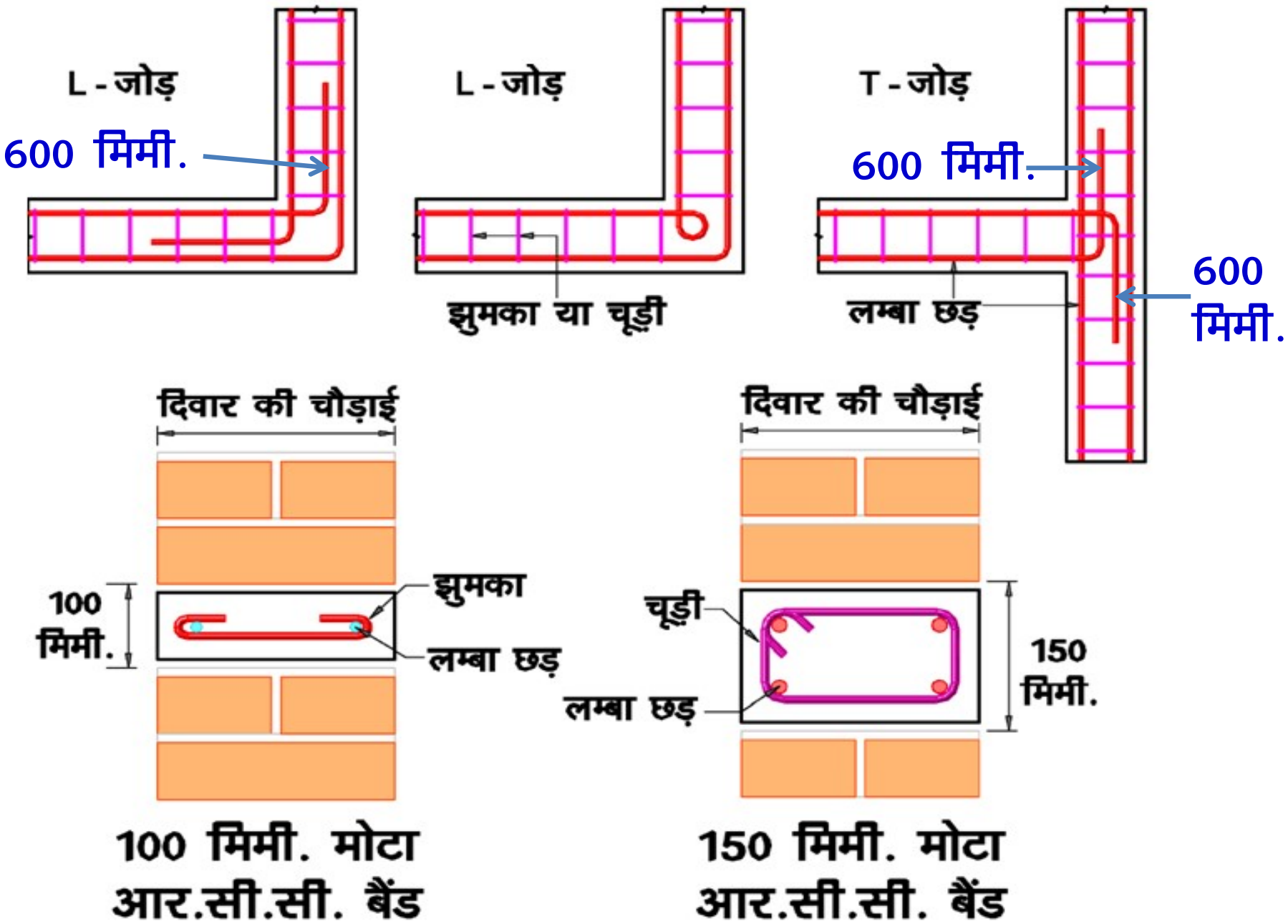
लिंटल बैंड :
सभी भवनों में

सिल्ल बैंड :
सिर्फ भूकंप जोन V में

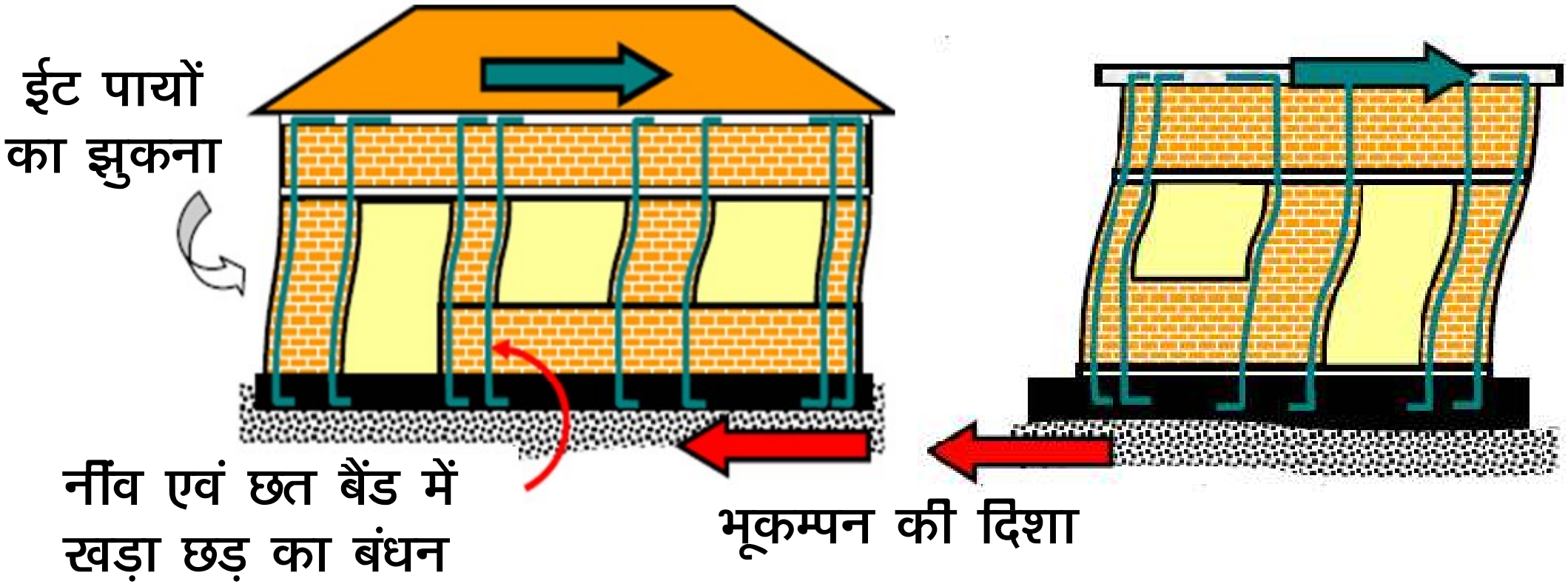
कुर्सी बैंड :
सभी भवनों में



REINFORCEMENT IN HORIZONTAL RC BANDS



VETICAL REINFORCEMENT IN WALLS



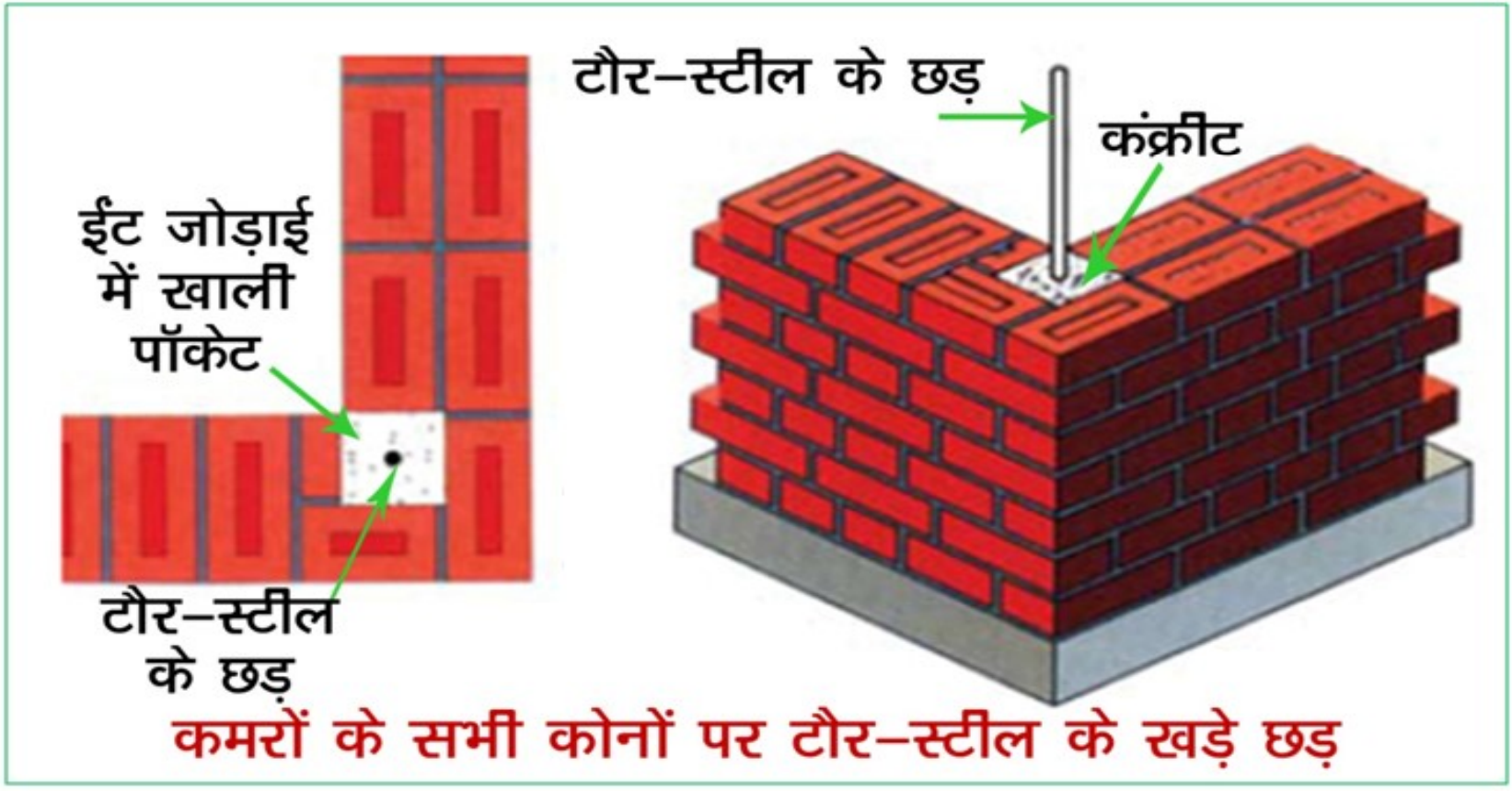
कमरों के सभी कोनों पर तथा दरवाजों / खिड़कियों के पाखों में, छड़ खड़ा करें। इससे भूकम्प के दौरान दीवारों में दरार पडने की सम्भवना कम हो जाती है।

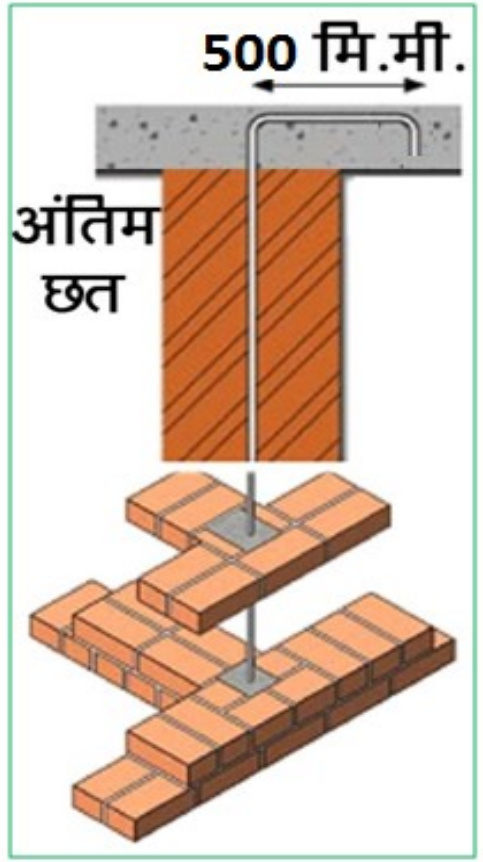
VETICAL REINFORCEMENT IN WALLS

दीवार के सभी कोनों पर ईंट जोड़ाई में खाली पॉकेट बनाएं।
पॉकेट में छड़ खड़ा करके कंक्रीट ढ़ालें।

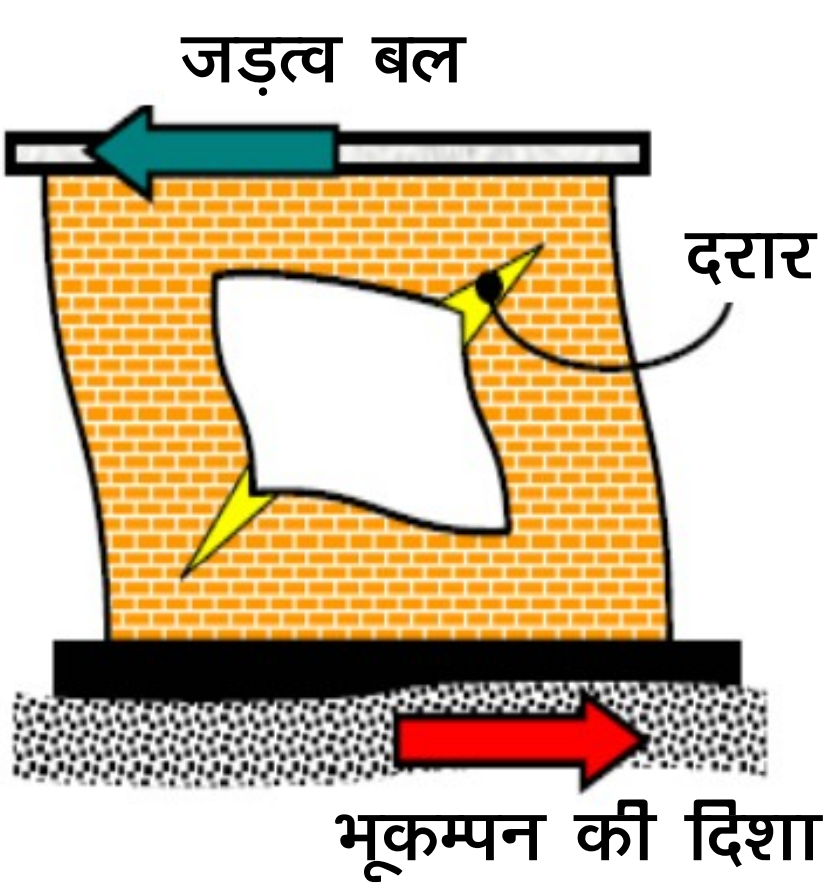
खड़ा छड़ को नींव से शुरू करना है।

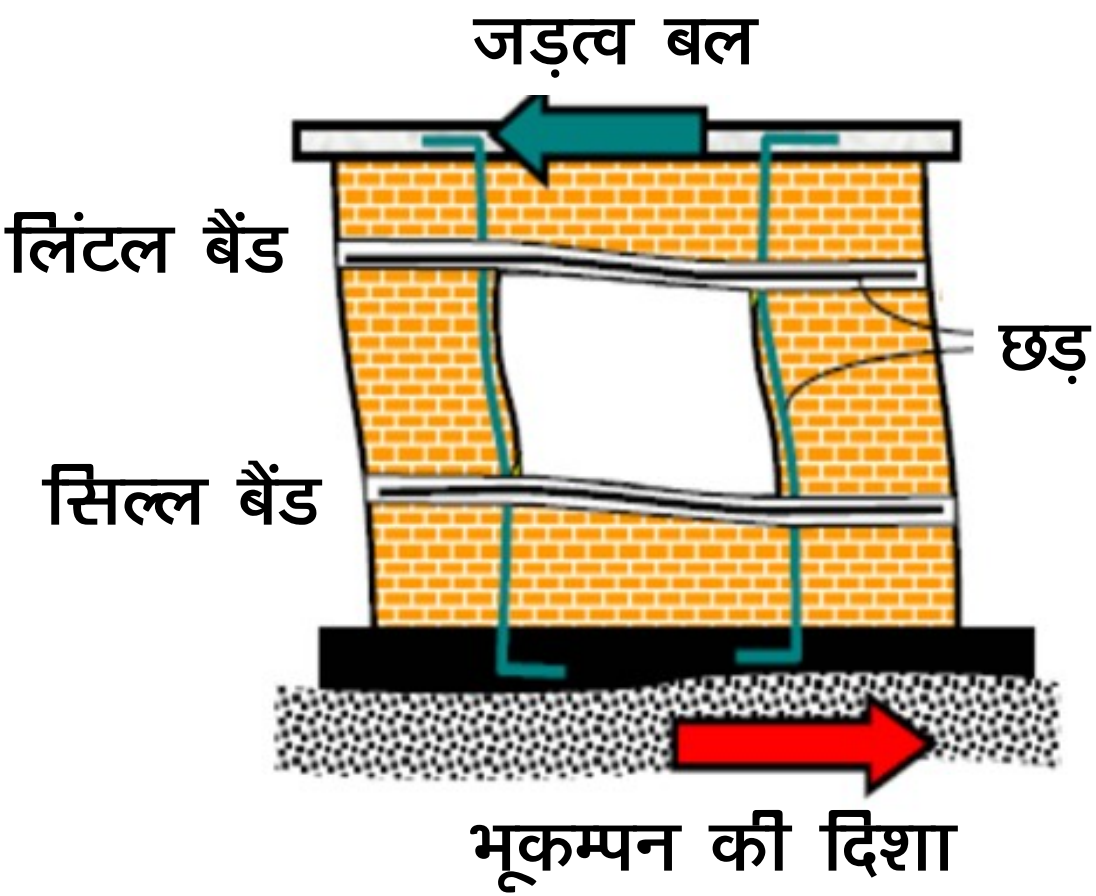
खड़ा छड़ को अंतिम छत की ढ़लाई के अंदर 500 मिलीमीटर मोड़ दें।





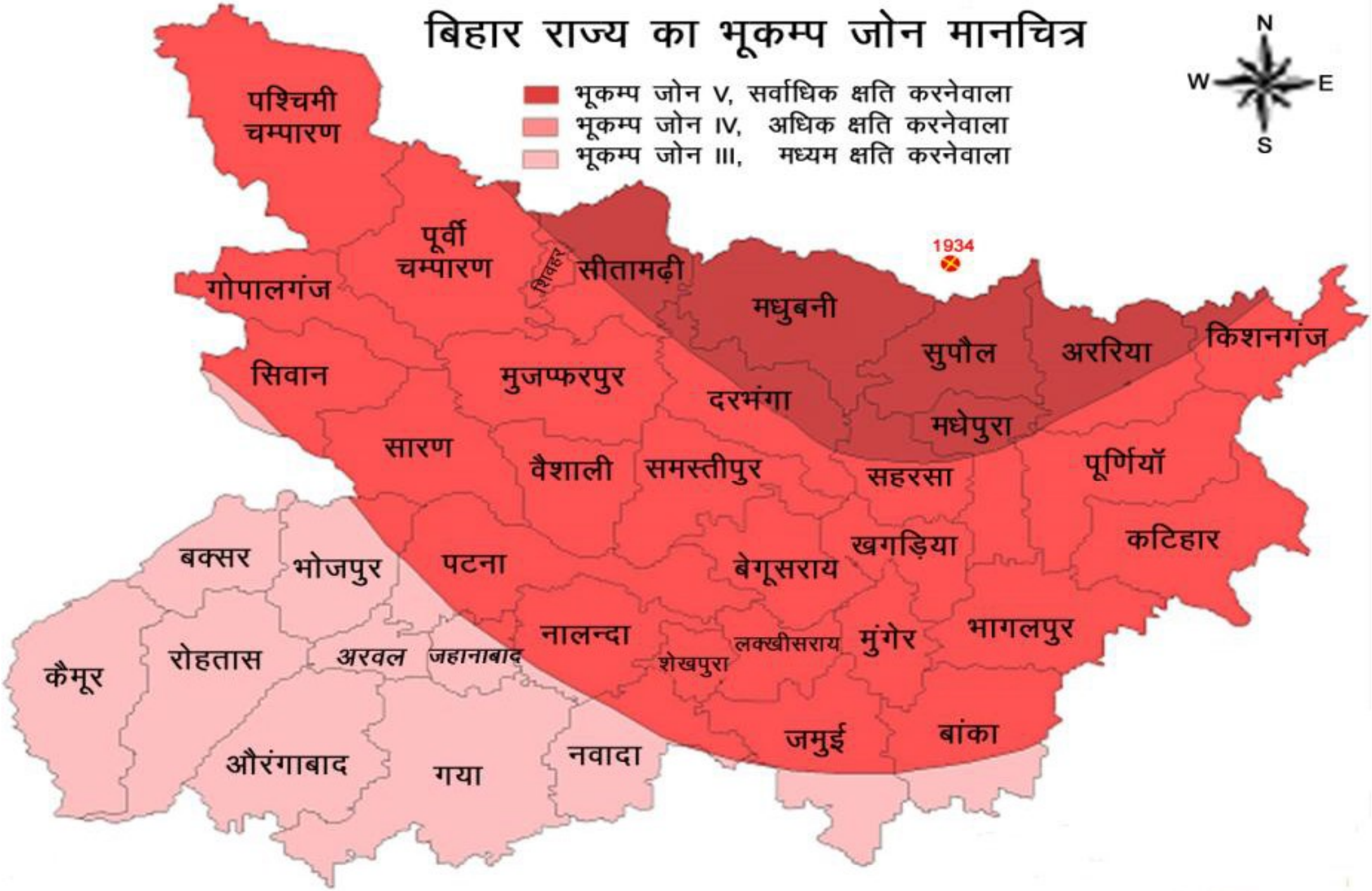
बड़ी खिड़कियों के कारण दरार एवं उससे सुरक्षा के उपाय





भूकम्प के दौरान खिड़की के कारण दीवार में दरारें पड़ती हैं। खिड़की बड़ी है तो दरार भी बड़ी होगी।

लिंटल बैंड, सिल्ल बैंड एवं खिड़कियों के पाखों में खड़ा छड़ दरार बनने से रोकता है।

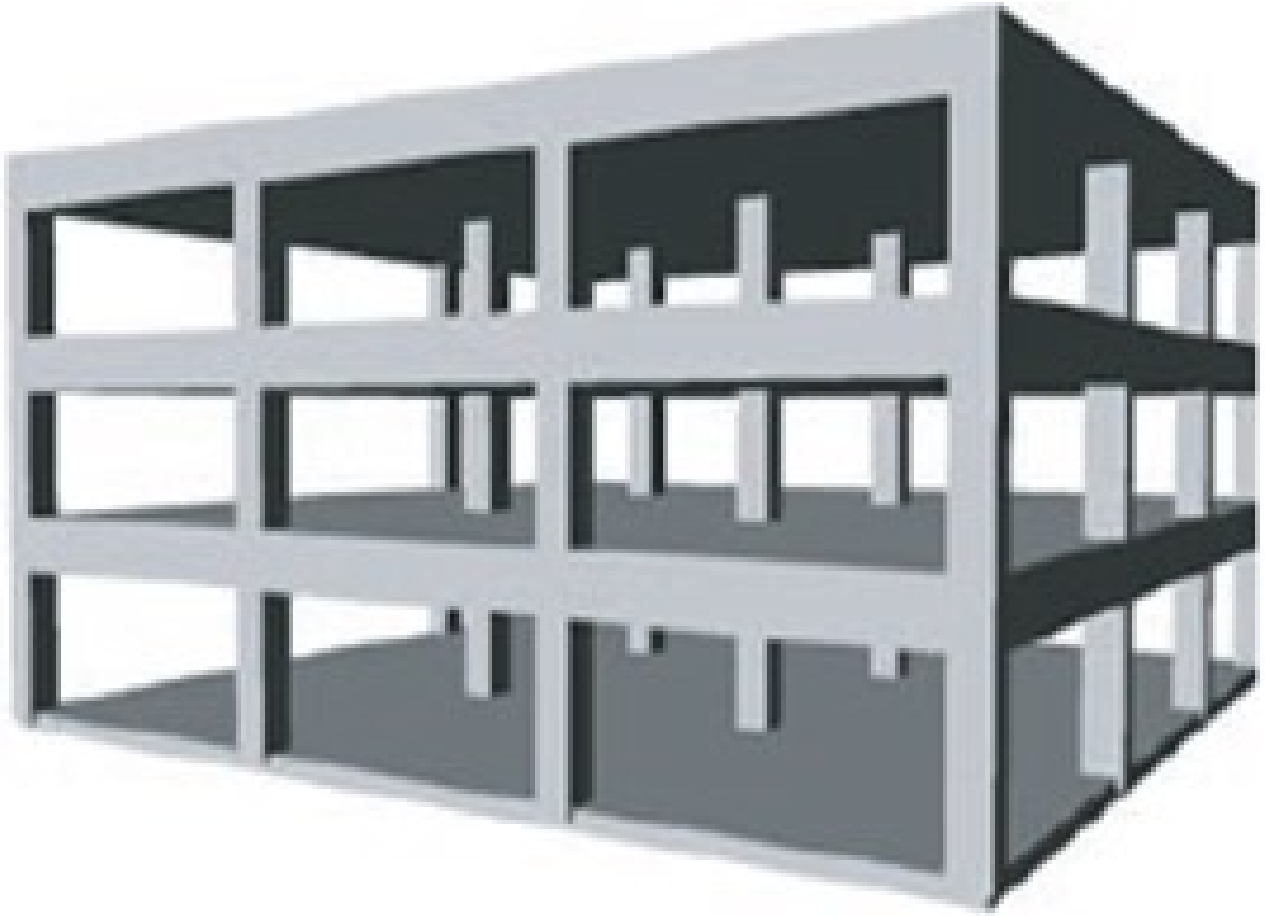

बिहार राज्य का भूकम्प जोन मानचित्र
भूकम्प जोन V, सर्वाधिक क्षति करनेवाला
भूकम्प जोन IV, अधिक क्षति करनेवाला
भूकम्प जोन III, मध्यम क्षति करनेवाला
N
W
E
S
1934
पश्चिमी चम्पारण
पूर्वी चम्पारण
शिवहर
सीतामढ़ी
गोपालगंज
मधुबनी
सुपौल
अररिया
किशनगंज
सिवान
मुजफ्फरपुर
दरभंगा
मधेपुरा
सारण
वैशाली
समस्तीपुर
सहरसा
पूर्णियॉ
बक्सर
भोजपुर
पटना
बेगूसराय
खगड़िया
कटिहार
नालन्दा
लक्खीसराय
मुंगेर
भागलपुर
रोहतास
अरवल
जहानाबाद
शेखपुरा
कैमूर
जमुई
बांका
औरंगाबाद
गया
नवादा

SEISMIC STRENGTHENING OF WALLS

भूकम्प जोन	मकान की अधिकतम उँचाई	ईंट जोड़ाई मसाला का अनुपात	क्षैतिज भूकम्परोधी आर.सी.सी. बैंड	दीवार के कोनों एवं किनारों पर खड़े स्टील के छड़
V	तीन मंजिल (12 मीटर से कम)	सिमेंट:बालू – 1:4	कुरसी बैंड लिंटेल बैंड सिल्ल बैंड छत बैंड	कमरों के सभी कोनों पर तथा एक मीटर से बड़े दरवाजों एवं खिड़कियों के दोनों तरफ
IV	चार मंजिल (15 मीटर से कम)	सिमेंट:बालू – 1:4	कुरसी बैंड लिंटेल बैंड छत बैंड	कमरों के सभी कोनों पर तथा 1.5 मीटर बड़े से द्वारों के दोनों तरफ
III	चार मंजिल (15 मीटर से कम)	सिमेंट:बालू – 1:6	कुरसी बैंड लिंटेल बैंड छत बैंड	दो मंजिल से उँचे मकान के कमरों के सभी कोनों पर

SEISMIC SAFETY OF RCC FRAMED BUILDINGS

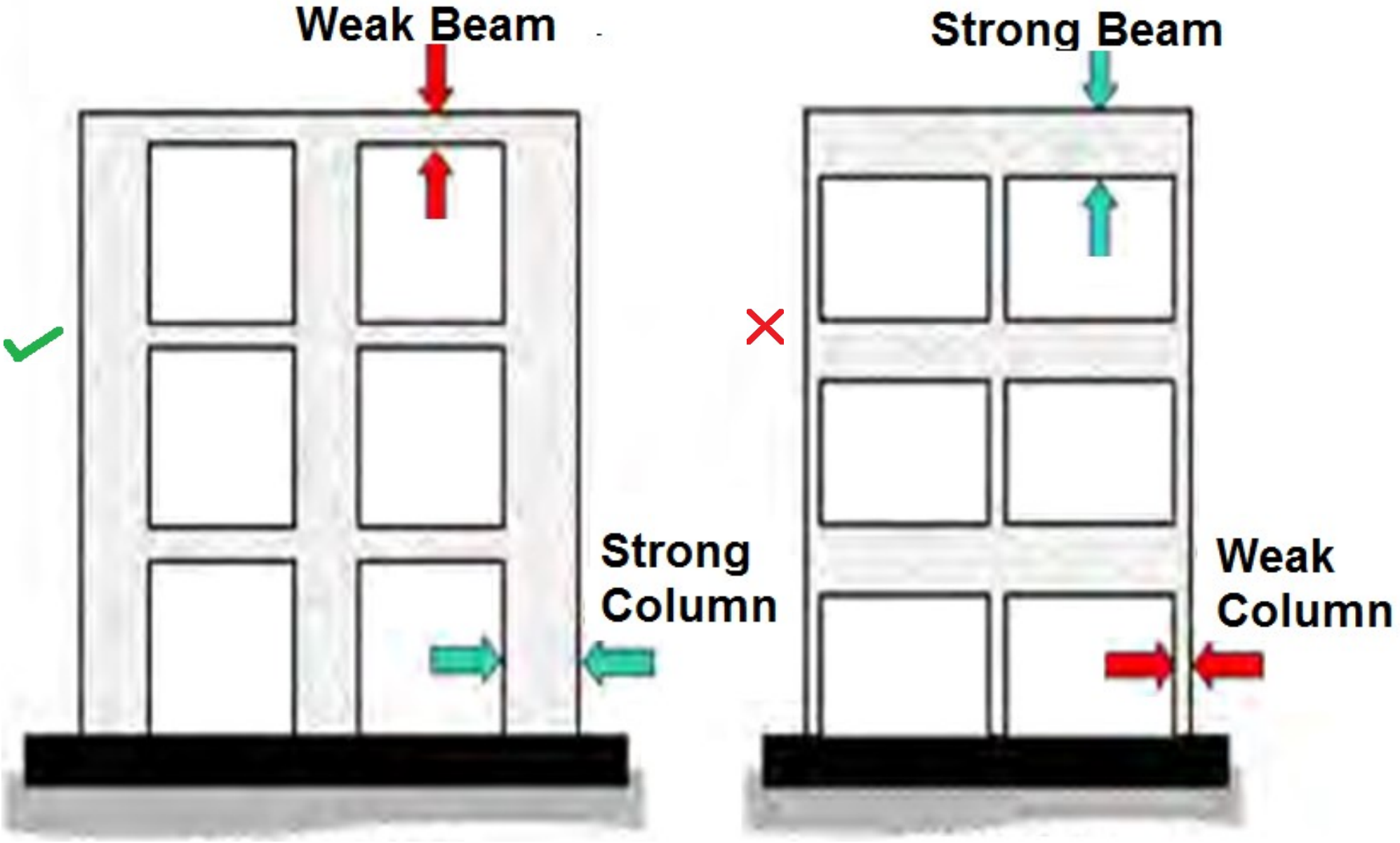
GOOD STRUCTURAL FRAMING



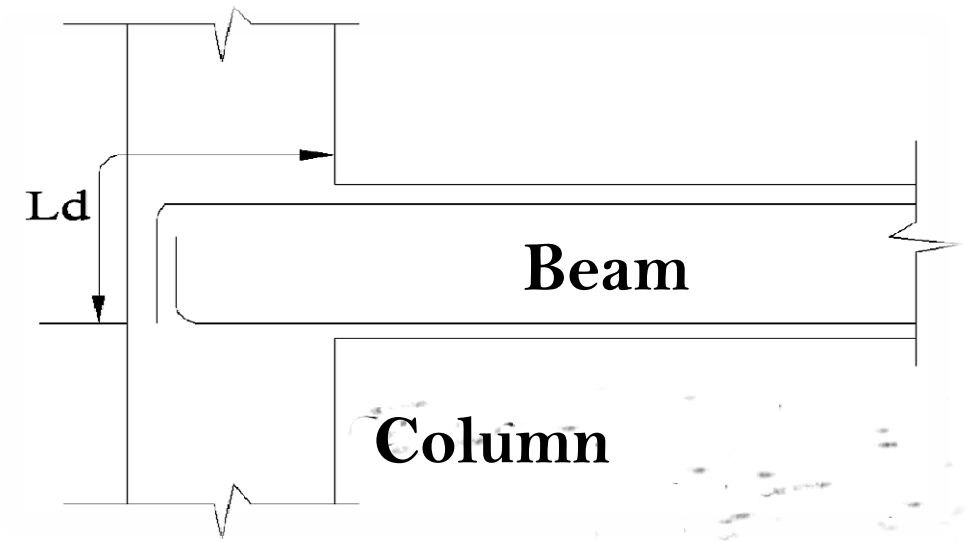
- Square Grids with Square columns
- Beams Concentric to columns
- No Abrupt Changes in Columns sizes

RELATIVE STRENGTH OF BEAM & COLUMN

$$\Sigma M_c \geq 1.4\ \Sigma M_b$$



ADEQUATE BEAM - COLUMN SIZES



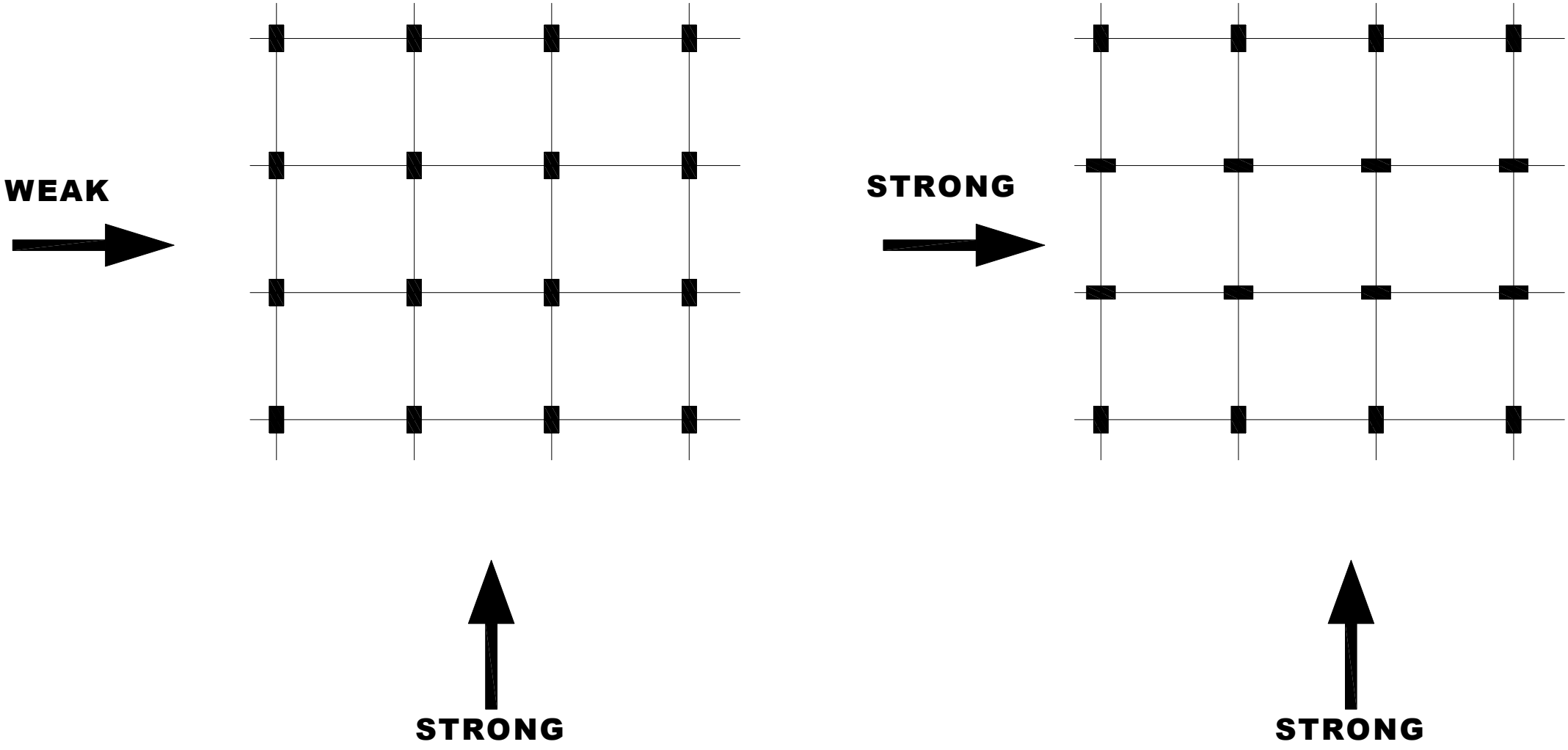
Structural member sizes usually depend on

- **Moments / Shear considerations**
- **Deflection (Stiffness consideration)**

But, the sizes important for

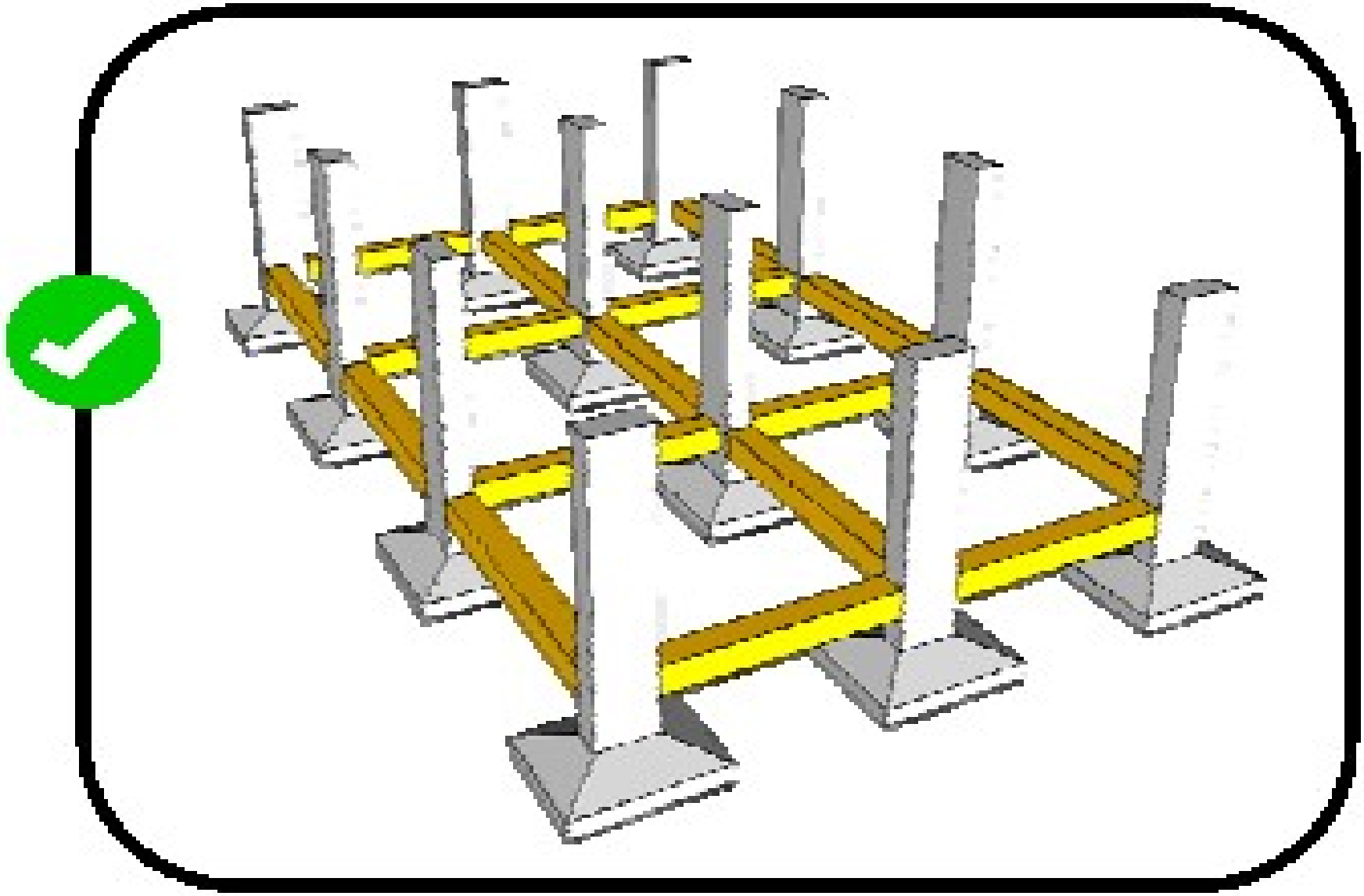
- **Beam - column joint design**
- **Reinforcement anchorage**
- **Confinement of joints**
- **Reduce reinforcement congestion**

COLUMN ORIENTATION IN BOTH DIRECTION



Minimum column size 300 mm

TIE BEAMS TO CONNECT FOUNDATIONS



HEAVY WATER TANKS ON THE ROOF

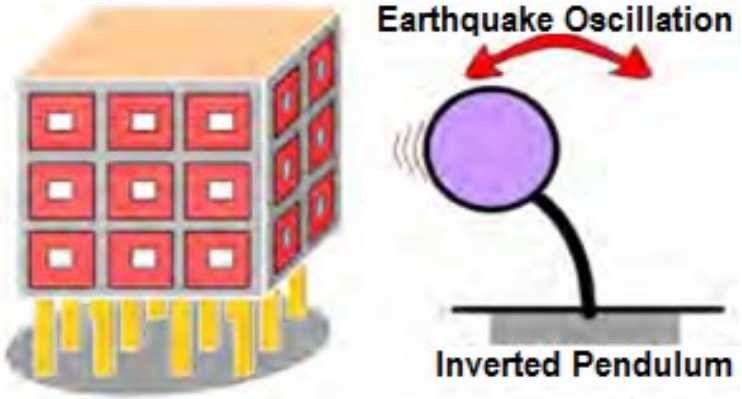
SOFT GROUND STOREY

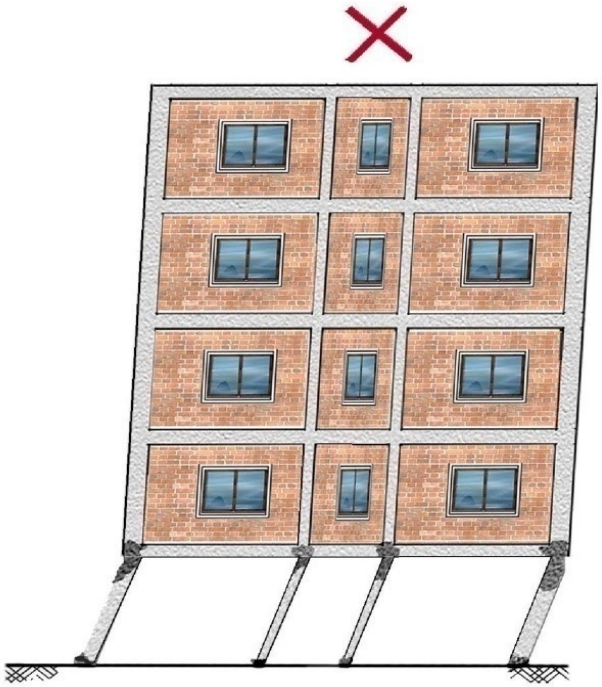
VERTICAL SPLIT BETWEEN TWO BLOCKS (BHUJ 2001)

SOFT GROUND STOREY

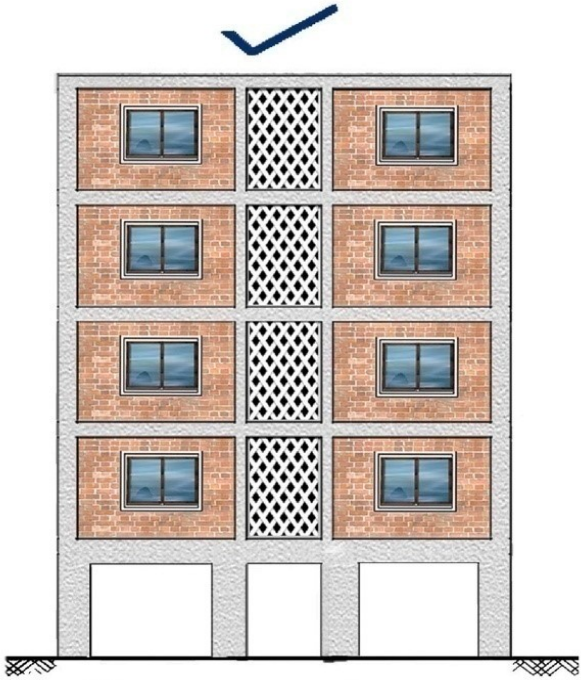
भू–मंजिल पर खुला पार्किंग वाले भवन

उपरी मंजिलों पर भरे गये दीवारों के कारण, उपरी मंजिलों की अपेक्षा, भूमंजिल पर **stiffness** में भारी कमी रहती है। इसके चलते, भूकम्प के दौरान उपरी मंजिलें एक साथ दोलन करते हैं, और भूमंजिल के पीलर में अत्यधिक विचलन होता है, इससे भवन के धराशायी होने की प्रबल सम्भावना बनी रहती है।

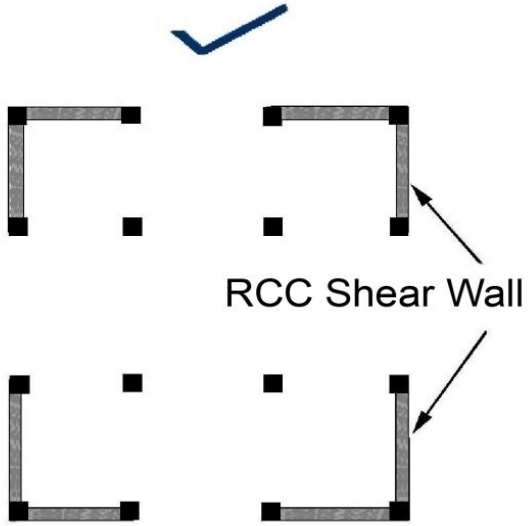




भूमंजिल पर खुला पार्किंग वाले भवन में क्षति



भूमंजिल पर बड़े आकार के पीलर एवं बीम



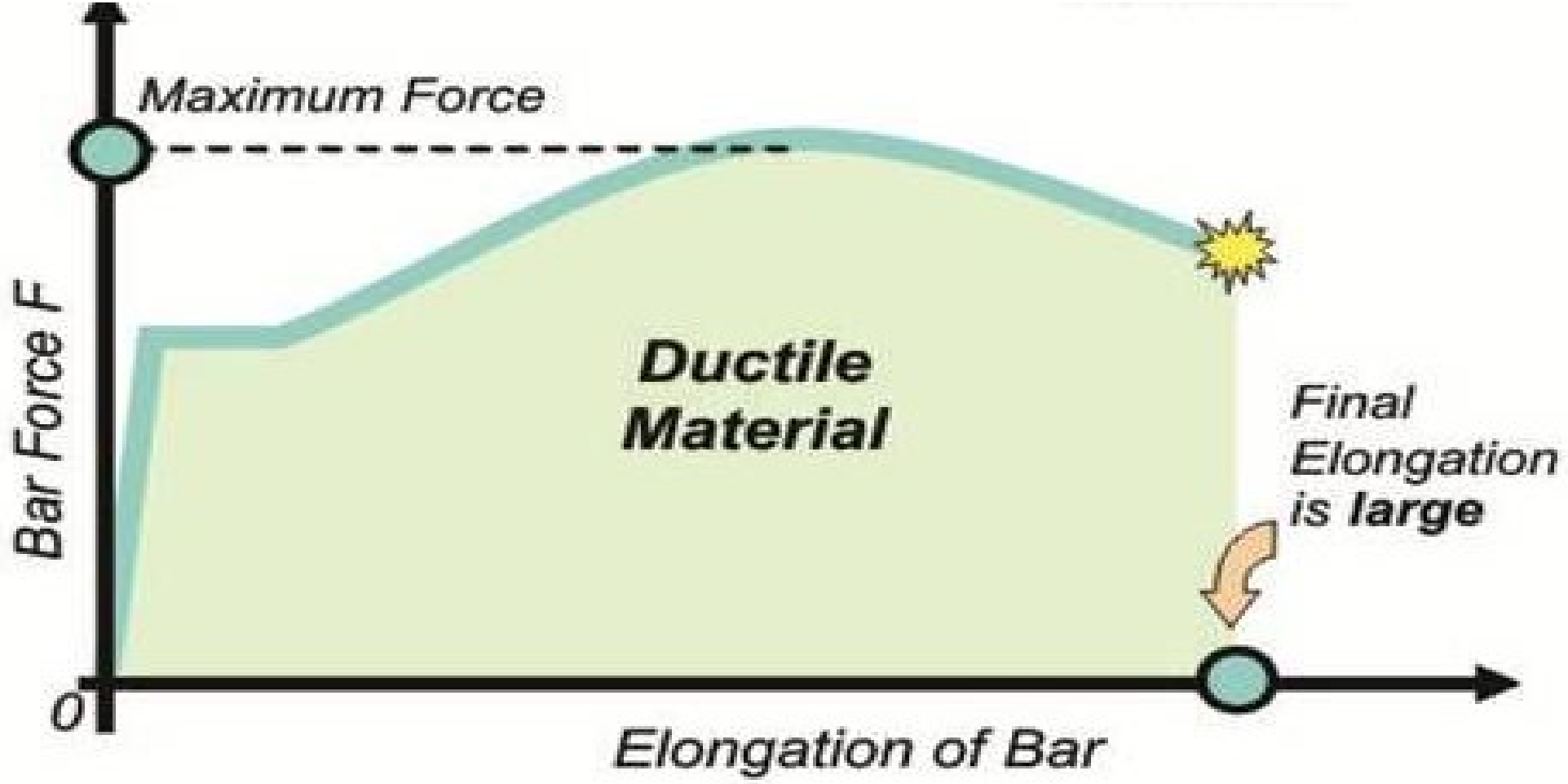
भूमंजिल पर पीलरों के बीच दीवार

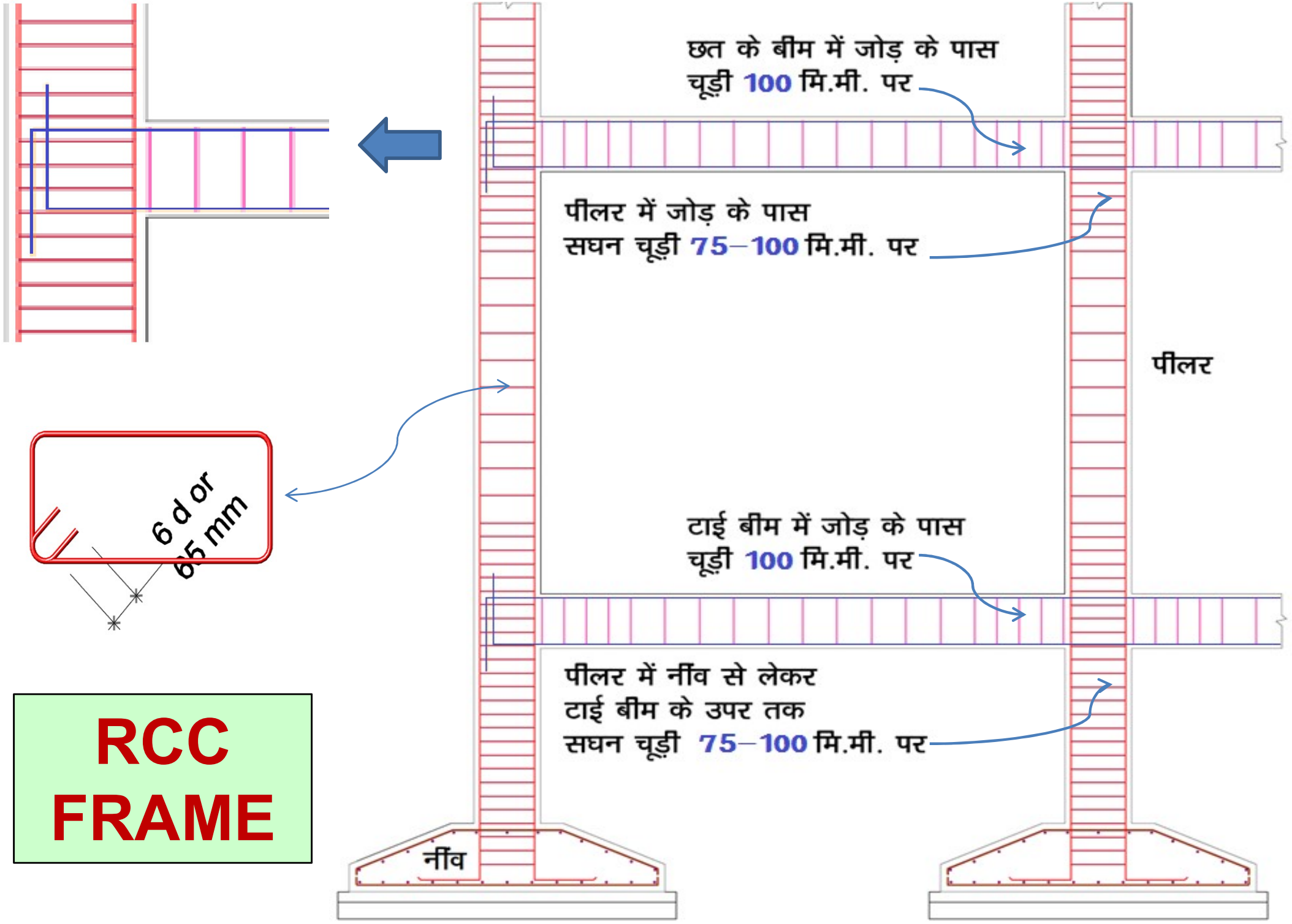
DUCTILITY of a structure, or its members

is the capacity to undergo large inelastic deformations

without significant loss of strength or stiffness

(often withstanding many cycles without fracture / collapse).

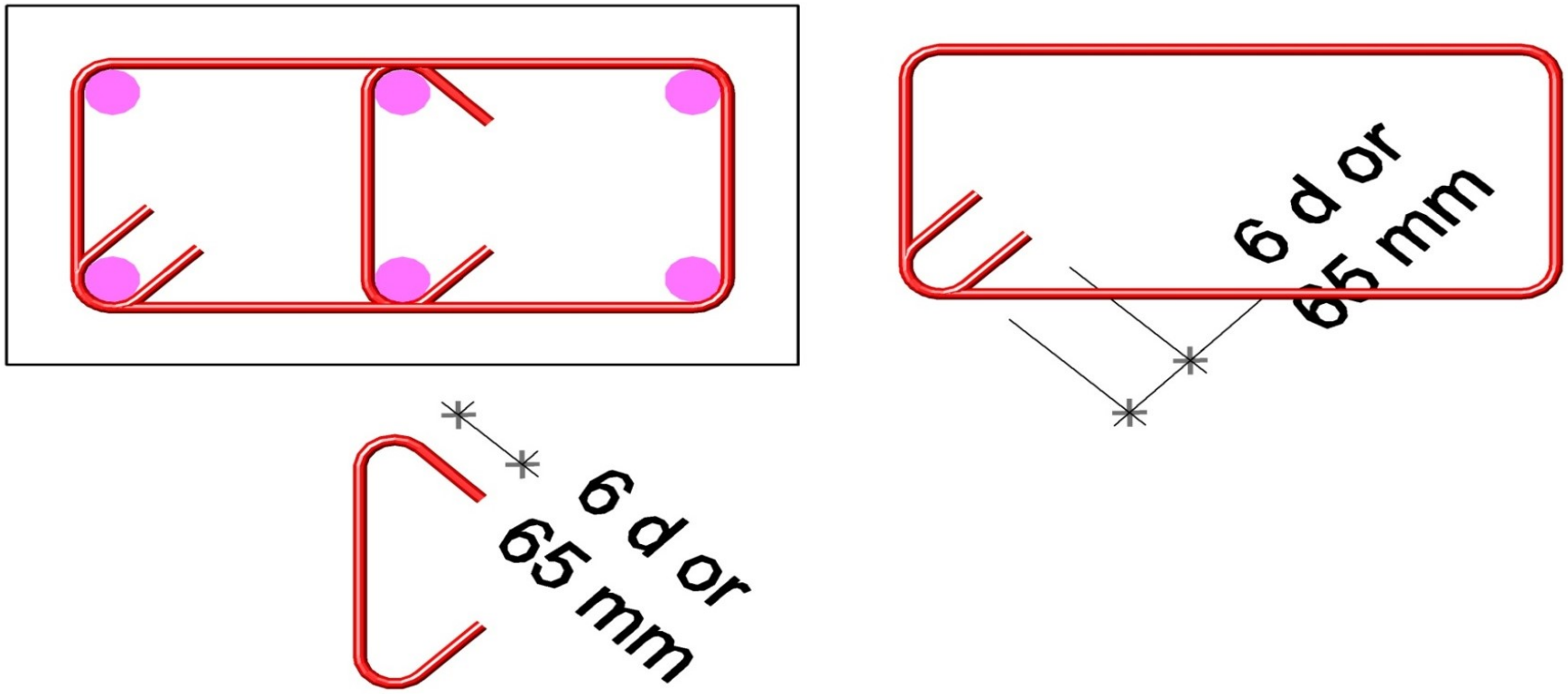



छत के बीम में जोड़ के पास
चूड़ी 100 मि.मी. पर
पीलर में जोड़ के पास
सघन चूड़ी 75–100 मि.मी. पर
पीलर
टाई बीम में जोड़ के पास
चूड़ी 100 मि.मी. पर
पीलर में नींव से लेकर
टाई बीम के उपर तक
सघन चूड़ी 75–100 मि.मी. पर
नींव
6 d or
65 mm
RCC
FRAME

DIMENSION OF HOOK FOR LATERAL TIES

IS 13920 -1993 Cl. 6.3.1

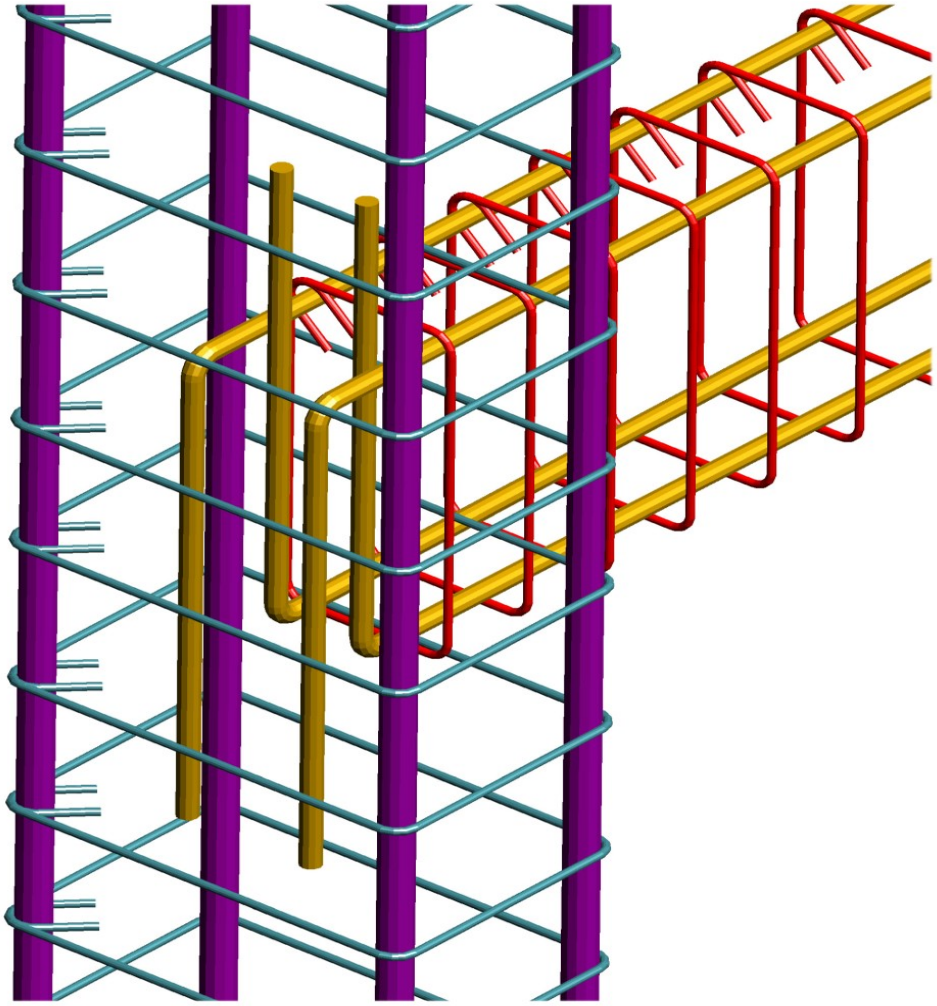
Straight Length of HOOK = 6d



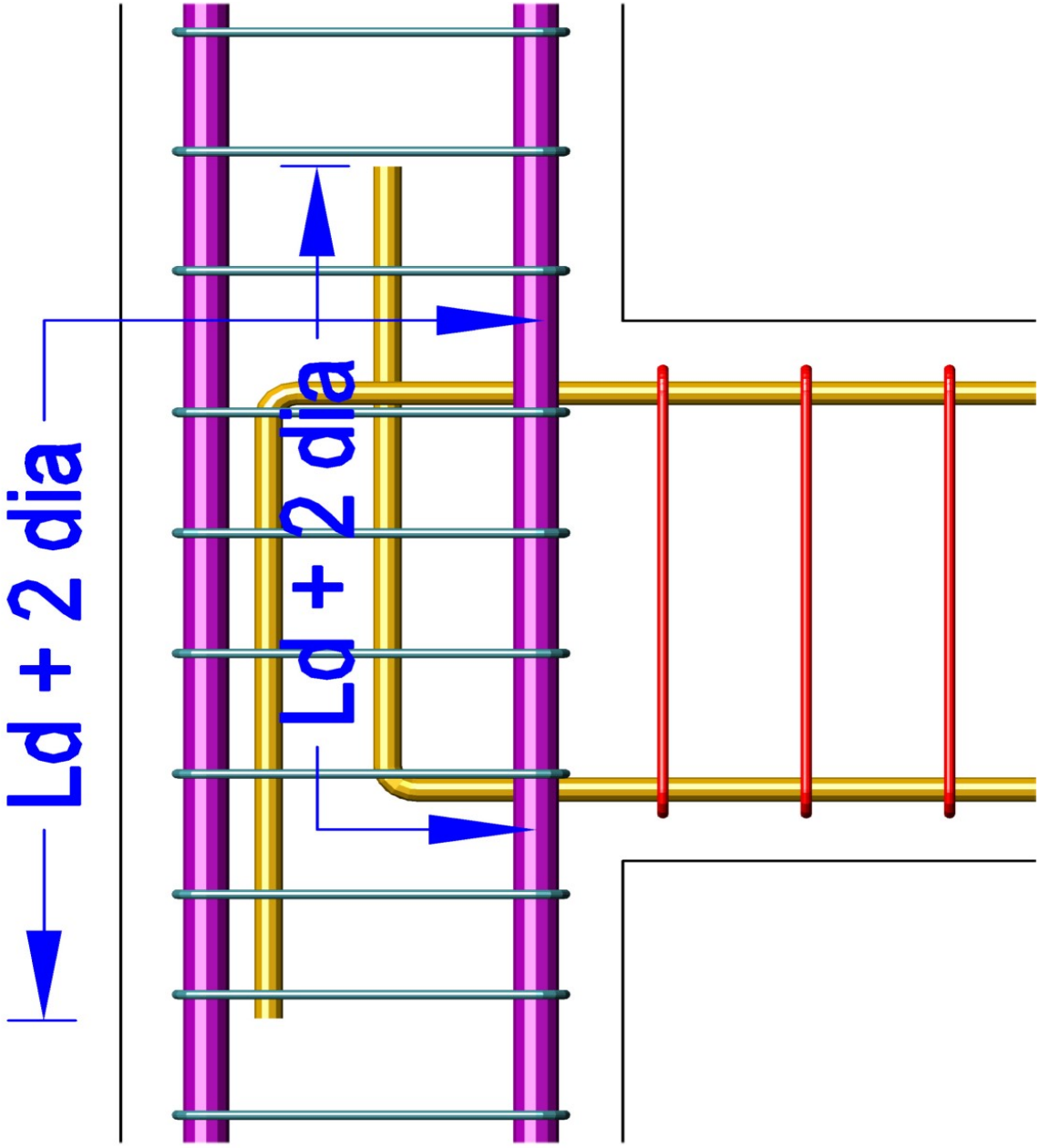
PLAN : COLUMN

TRANSVERSE REINFORCEMENT

ANCHORAGE OF BEAM BARS INTO EXTERIOR COLUMN

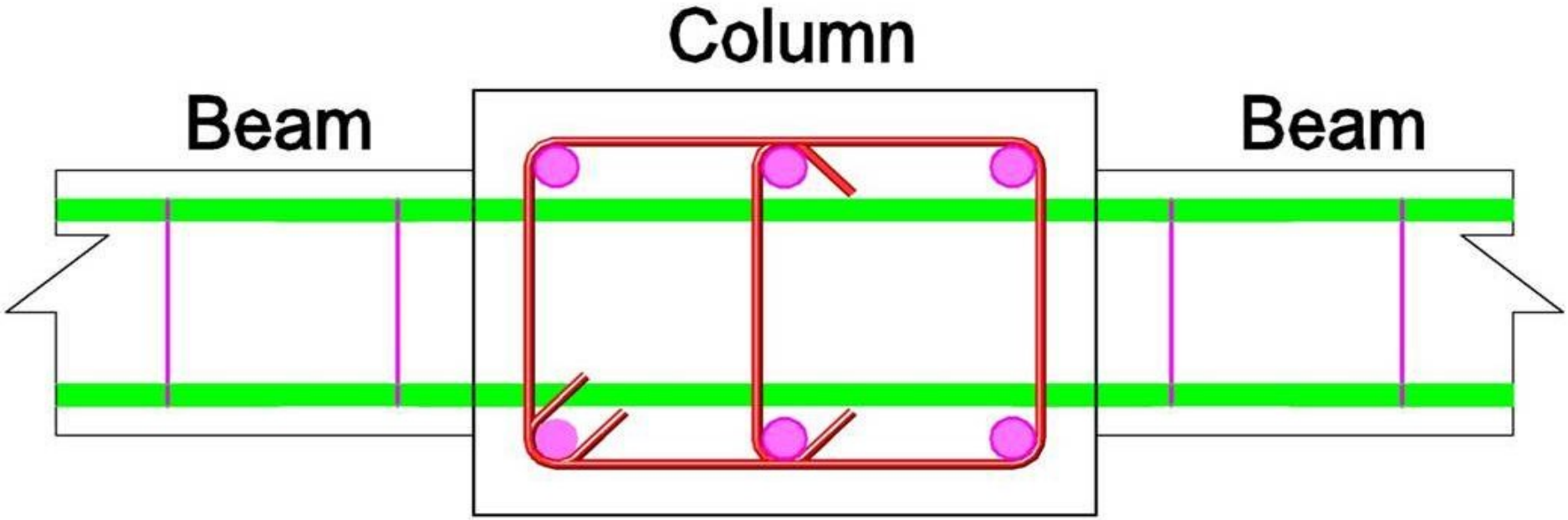


Ld ≈ 50 d



BEAM BARS THROUGH COLUMN

IS 13920-1993 Cl. 6.2.5



PLAN : BEAM COLUMN JOINT

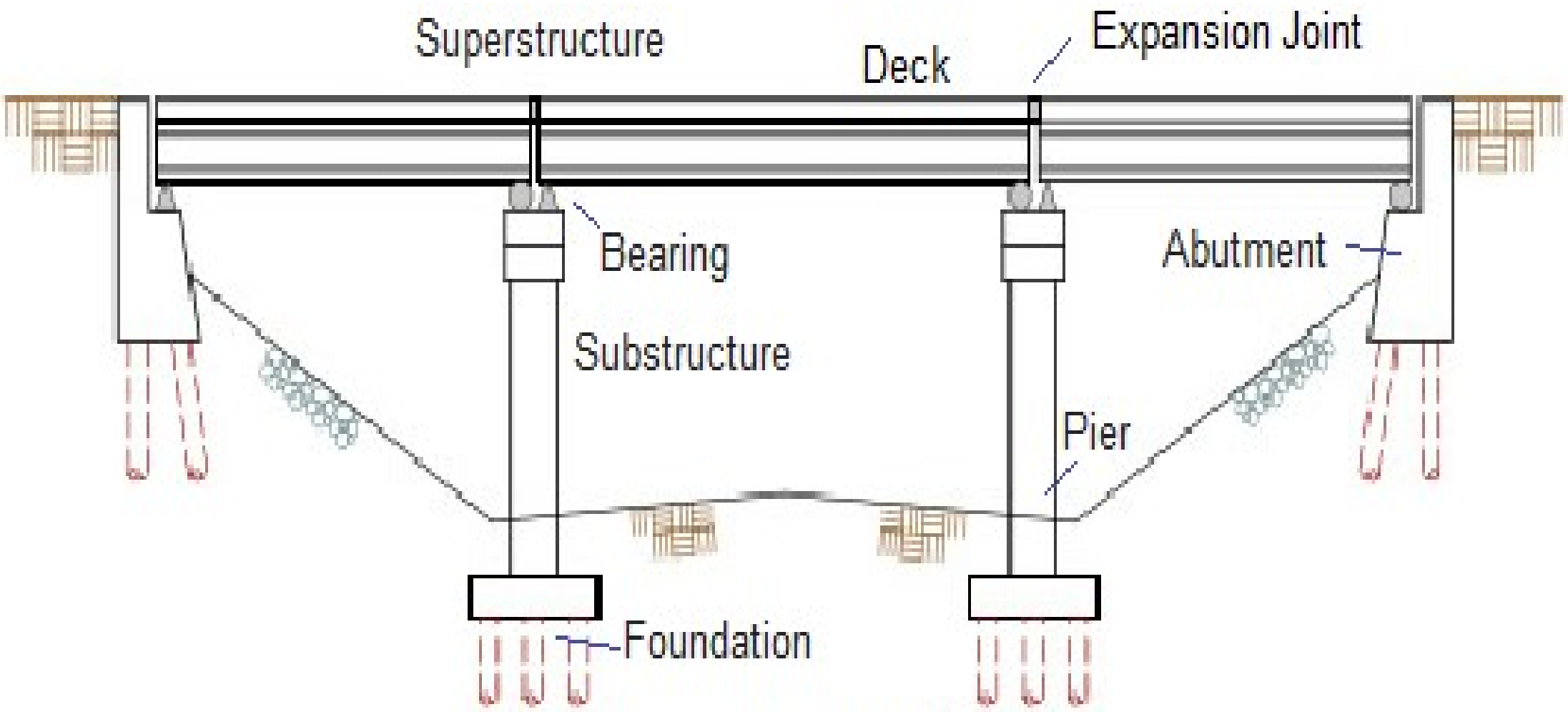
In the internal joint, both face bars of the beam shall be taken continuously through the column.

GOOD QUALITY OF RCC CONSTRUCTION

- Good quality water, sand and aggregates
- Designed quantity of cement in the mix
- Proper mixing of all the ingredients
- Control on water cement ratio
- Appropriate sampling and testing of materials
- Well maintained Results of tests for inspection
- Proper placement of steel
- Control on the cover to steel
- Adequate compaction of concrete by vibrators
- Supervision of all RCC operations
- Adequate curing
- Inspection while striking of the form work.

SEISMIC SAFETY OF BRIDGES

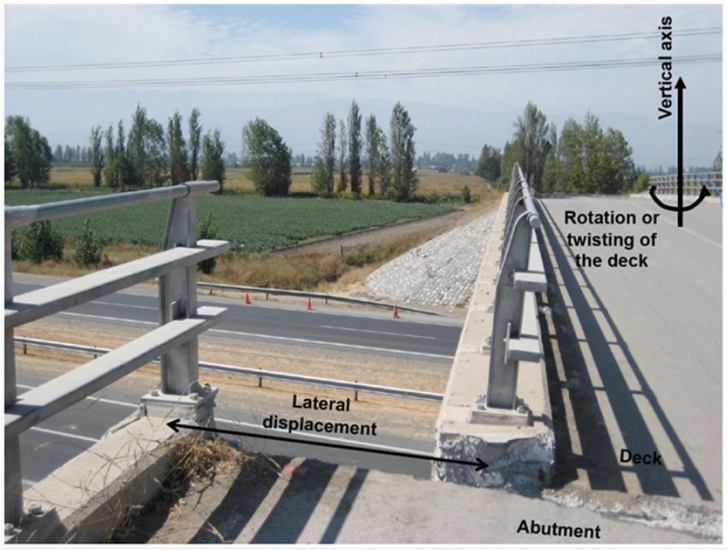
SEISMIC EFFECTS ON BRIDGES



Elevation of a Bridge

SEISMIC EFFECTS ON BRIDGES

Deck displacement



Rotation of skewed superstructure

Movement or Pounding of Deck

Expansion Joint failure

SEISMIC EFFECTS ON BRIDGES

Bearing failure

Shear failure of of substructure

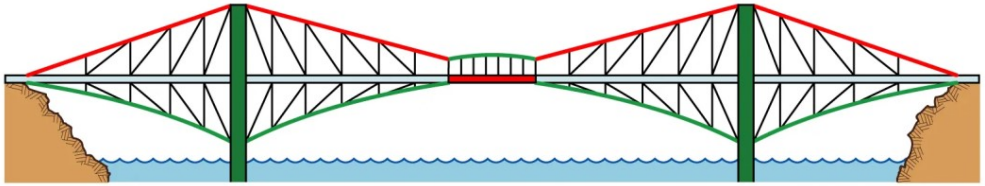
Abutment slumping

Foundation Failure

SEISMIC EFFECTS ON BRIDGES

Soil liquefaction

AVOID



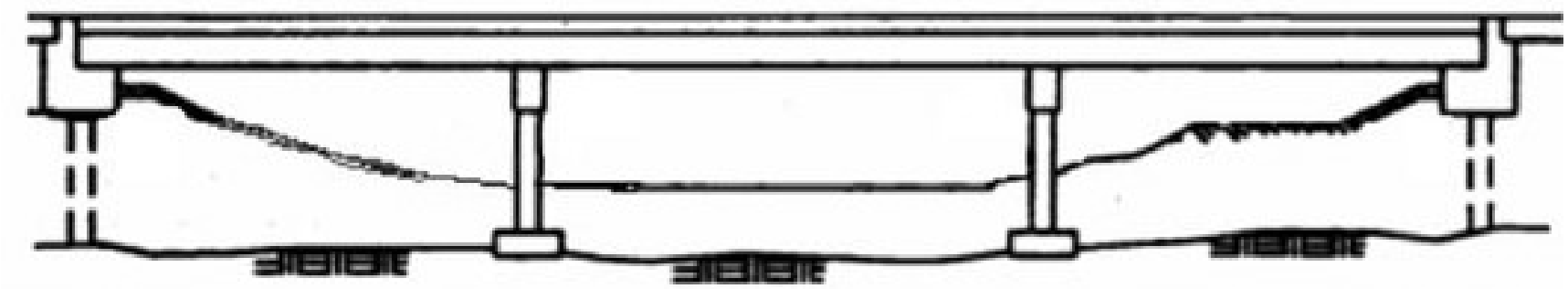
Cantilever spans

PCC and Masonry Piers
in Seismic zone IV and V

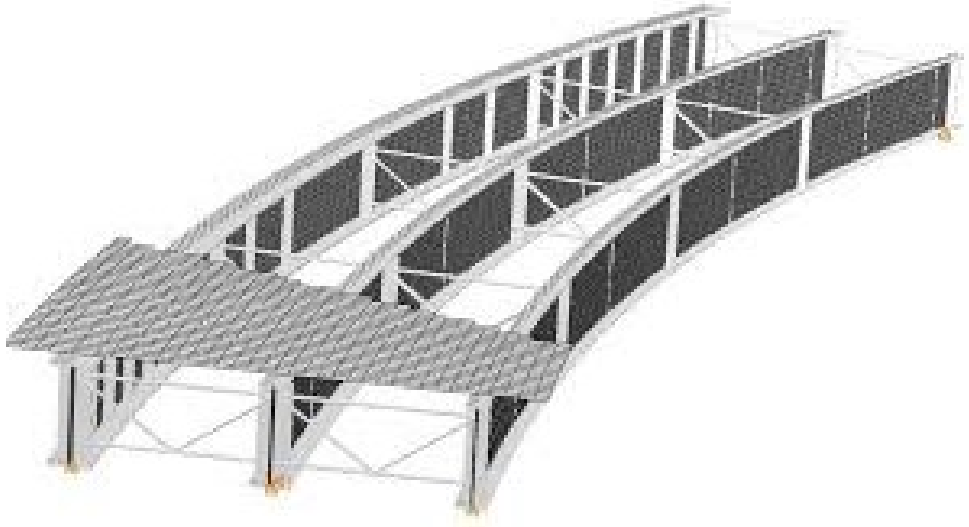
Plate Type Piers

Metallic Rocker-Roller bearings
in Seismic zone IV and V

ADOPT



Integral continuous superstructure



Small skews and curvature in superstructure

Lighter superstructure

ADOPT

Multiple column substructure

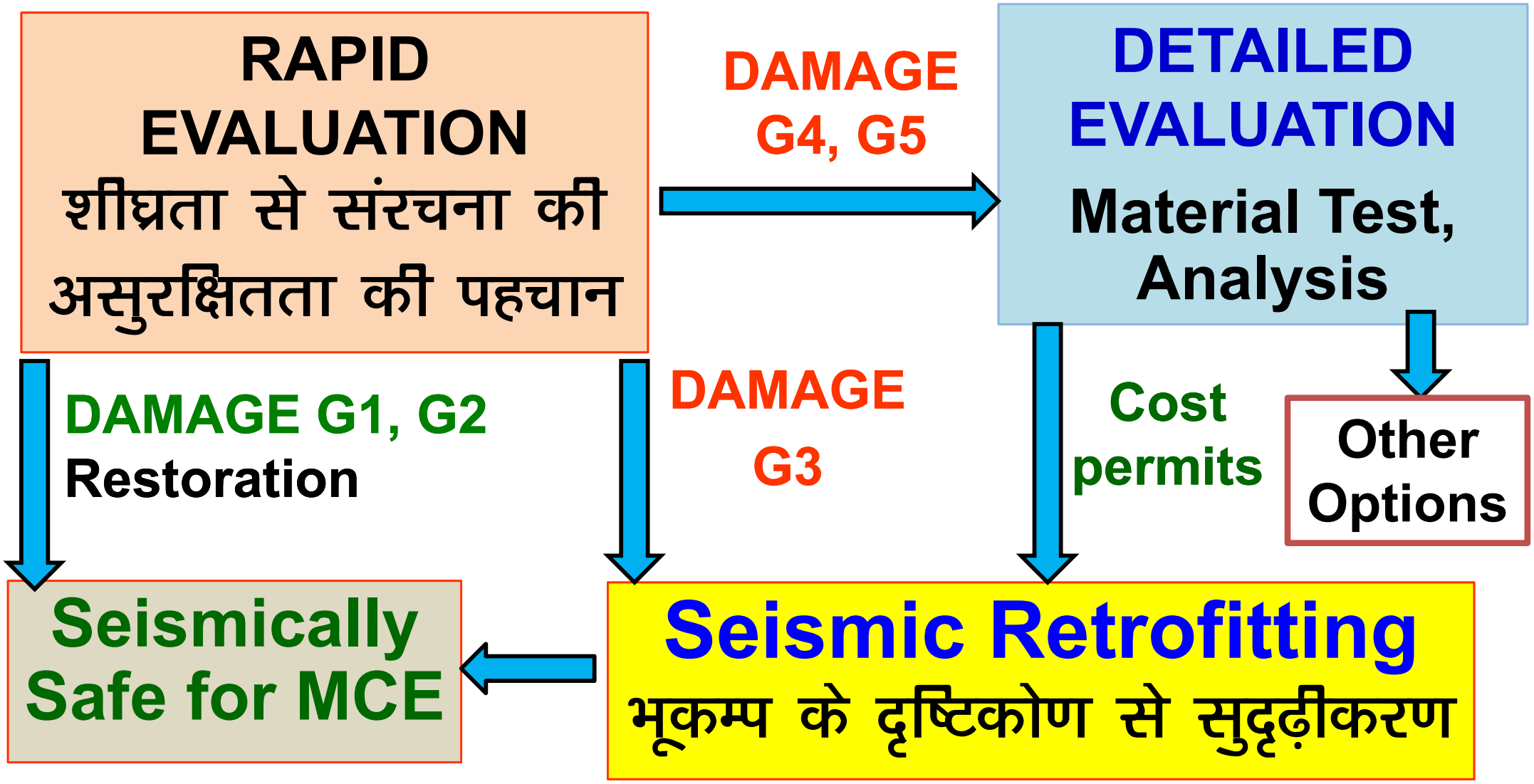
Bearings with high damping characteristics

Expansion gaps to cater for seismic movement

Foundation to add to flexibility to the system

SEISMIC RETROFITTING

VULNERABILITY ASSESSMENT and SEISMIC RETROFITTING



CODES FOR SEISMIC SAFETY

Buildings and Bridges

IS: 456 - 2000	PCC & RCC
IS : 1893 (P1)	EQ resistant design of structures
IS : 1893 (P3)	Bridges and Retaining Walls
IS : 4326	EQ resistant Masonry buildings
IS : 13920	Ductile detailing of RCC structures
IS : 13935	RVS & Retrofitting of Masonry buildings
IS : 15988	Evaluation & Retrofitting of RC buildings

IRC 6	Bridge Loadings
IRC SP 114	Seismic Design of Road Bridges

THANK YOU