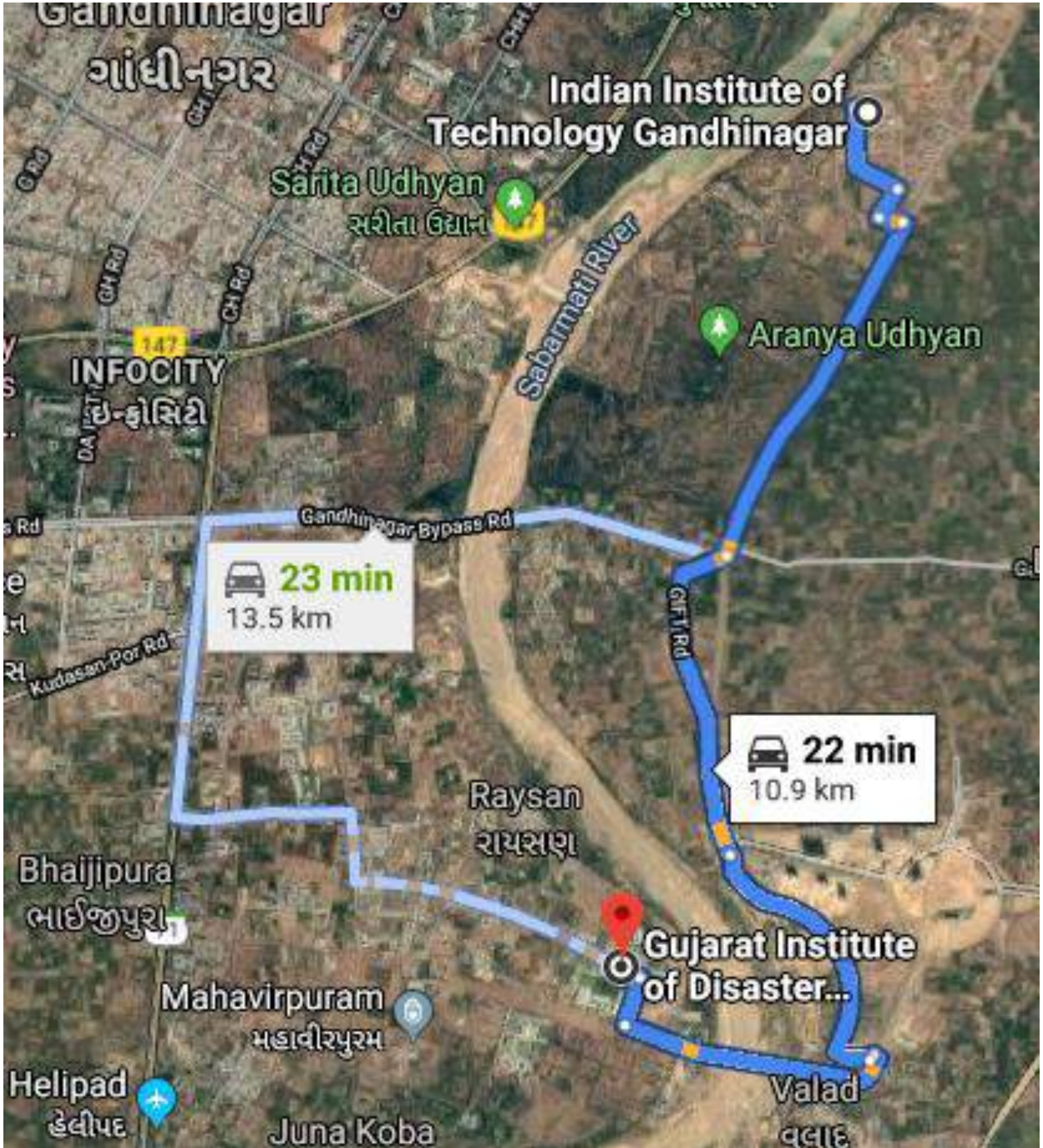
Structural Retrofit and Structural Risk Mitigation

Manish Kumar
Indian Institute of Technology Gandhinagar

Gujarat Institute of Disaster Management, Gandhinagar

January 22, 2020

Training Workshop on Structural & Non-structural Risk Assessment of School Buildings


ગાંધીનગર
Indian Institute of Technology Gandhinagar
Sarita Udhyan
સરીતા ઉદ્યાન
Sabarmati River
Aranya Udhyan
147
INFOCITY
ઇન્ફોસિટી
CH Rd
Gandhinagar Bypass Rd
23 min
13.5 km
Kudasan-Por Rd
GIFT Rd
22 min
10.9 km
Raysan
રાયસણ
Bhaijipura
ભાઈજીપુરા
Gujarat Institute of Disaster...
Mahavirpuram
મહાવીરપુરમ
Helipad
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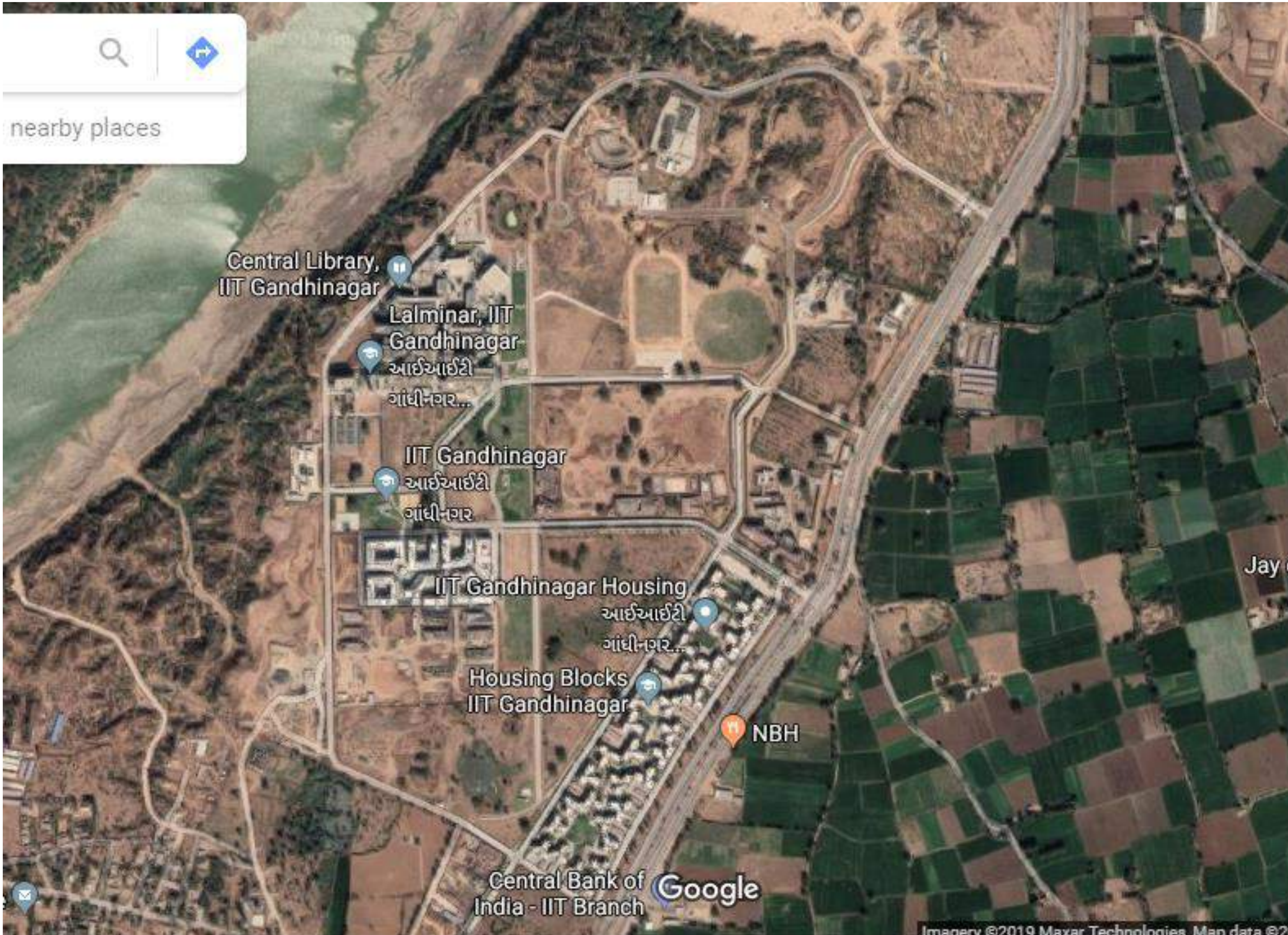
nearby places
Central Library, IIT Gandhinagar
Lalminar, IIT Gandhinagar
આઈઆઈટી ગાંધીનગર...
IIT Gandhinagar
આઈઆઈટી ગાંધીનગર
IIT Gandhinagar Housing
આઈઆઈટી ગાંધીનગર...
Housing Blocks IIT Gandhinagar
NBH
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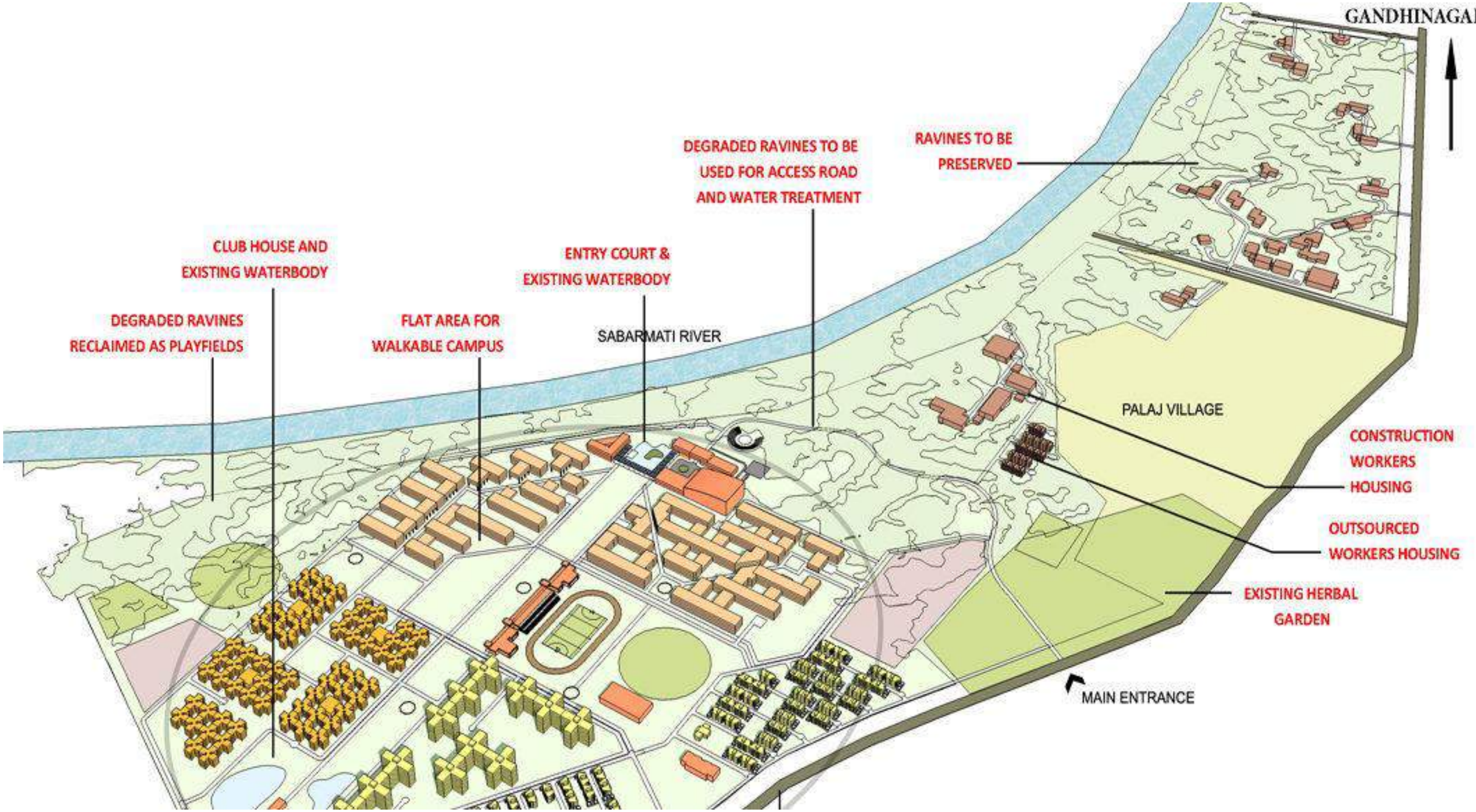

GANDHINAGAR
RAVINES TO BE
PRESERVED
DEGRADED RAVINES TO BE
USED FOR ACCESS ROAD
AND WATER TREATMENT
CLUB HOUSE AND
EXISTING WATERBODY
ENTRY COURT &
EXISTING WATERBODY
DEGRADED RAVINES
RECLAIMED AS PLAYFIELDS
FLAT AREA FOR
WALKABLE CAMPUS
SABARMATI RIVER
PALAJ VILLAGE
CONSTRUCTION
WORKERS
HOUSING
OUTSOURCED
WORKERS HOUSING
EXISTING HERBAL
GARDEN
MAIN ENTRANCE

Outline

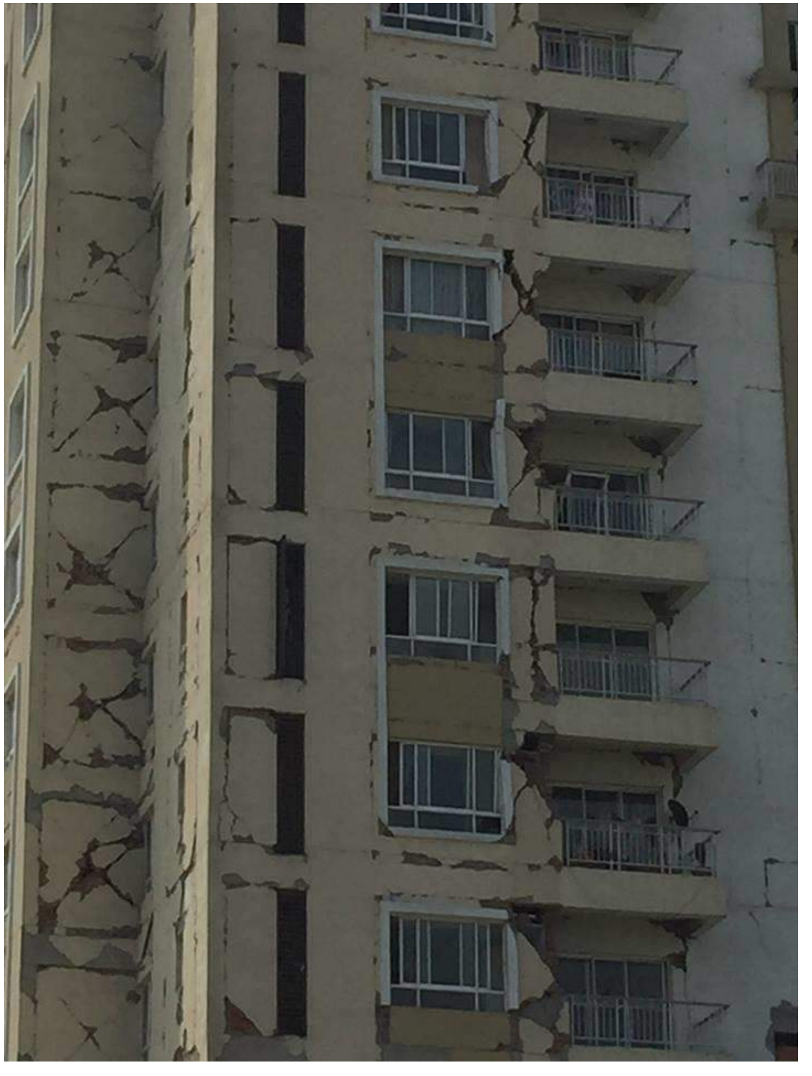
- Structural systems
- Example RVS
- Detailed evaluation and strengthening
- Examples of retrofit and strengthening
- Summary

Structural systems

Earthquake damage

2015 Nepal earthquake: photo by UB team

Earthquake damage



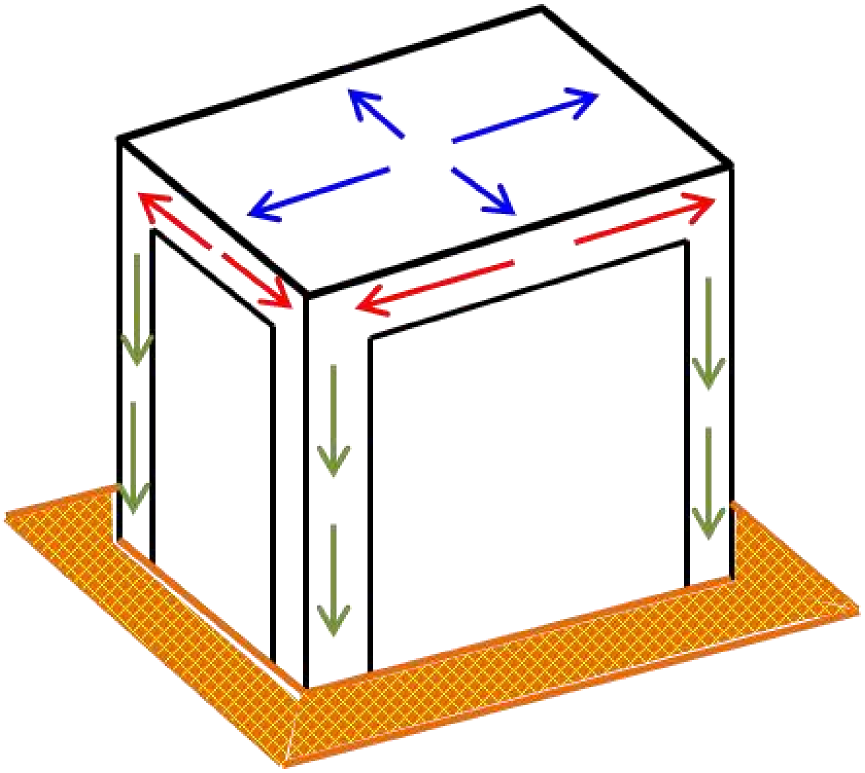
2015 Nepal earthquake: photo by UB team

Structural damage

2015 Nepal earthquake: photo by IITK team

Load path

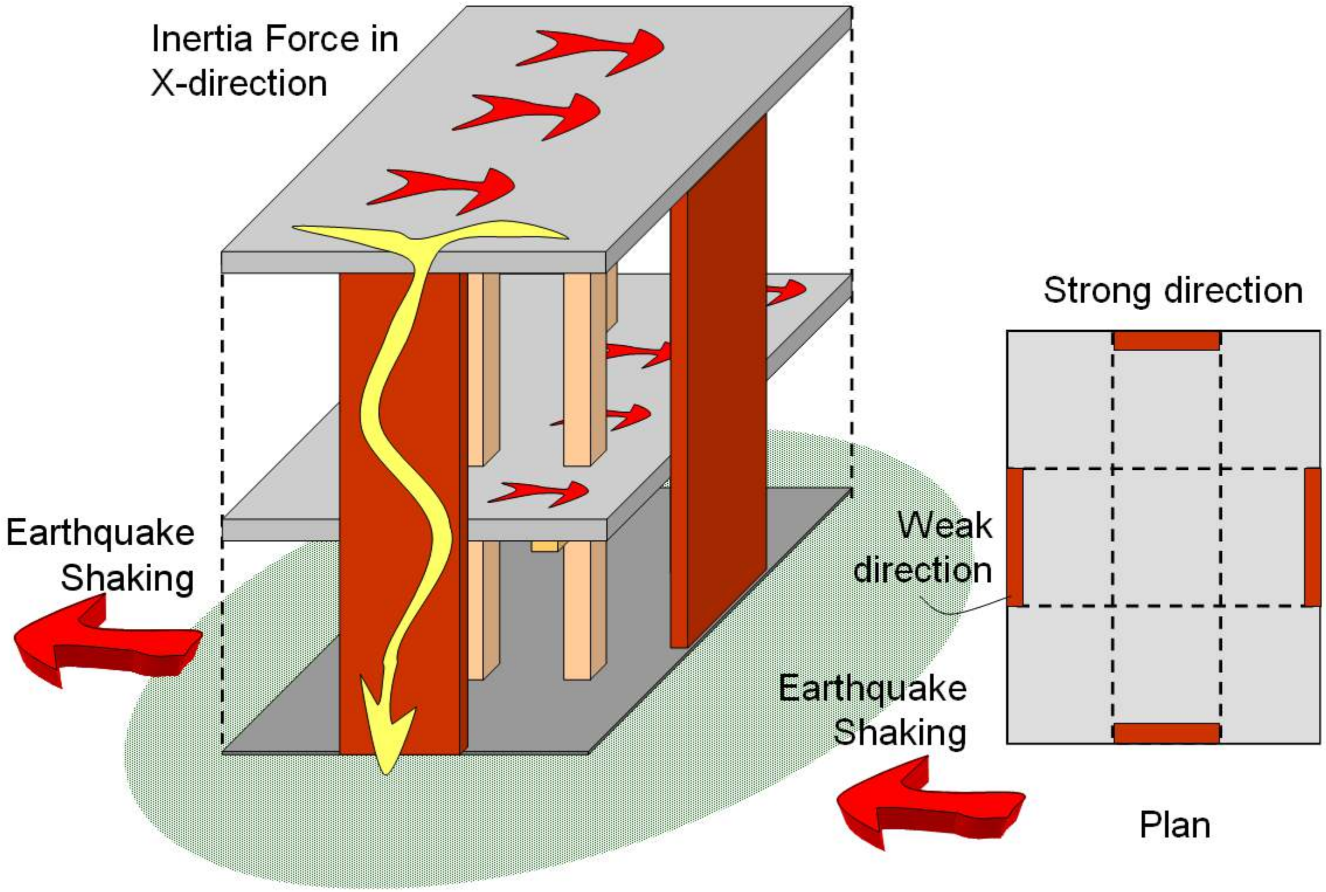
- Load transfer path
  - slab >>> beams >>> columns



Load path

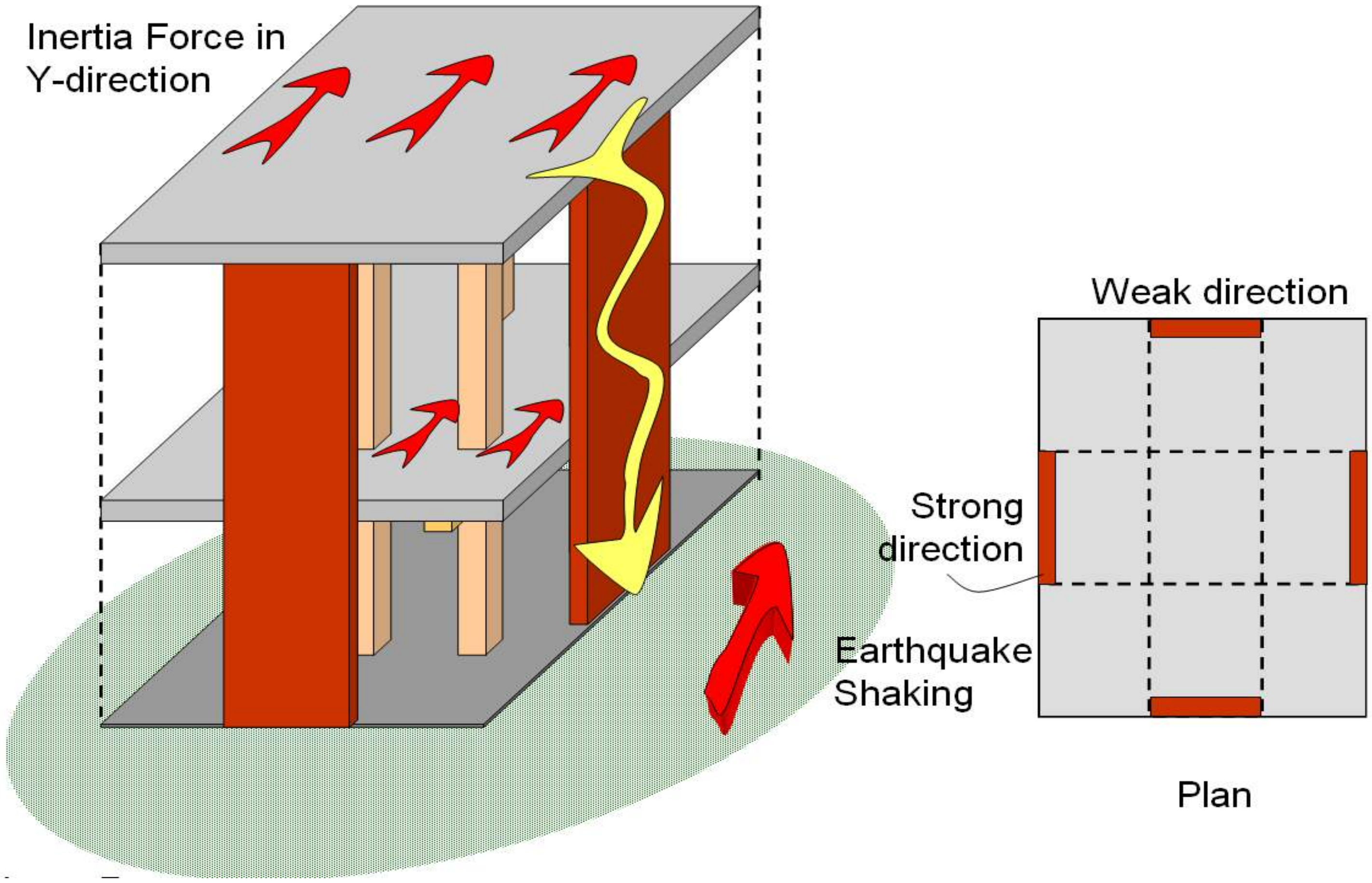
- Load path is function of
  - Structural system
  - Direction of loading
  - Support condition
  - …

EQ load path: direction of loading



Source: NPEEE Material

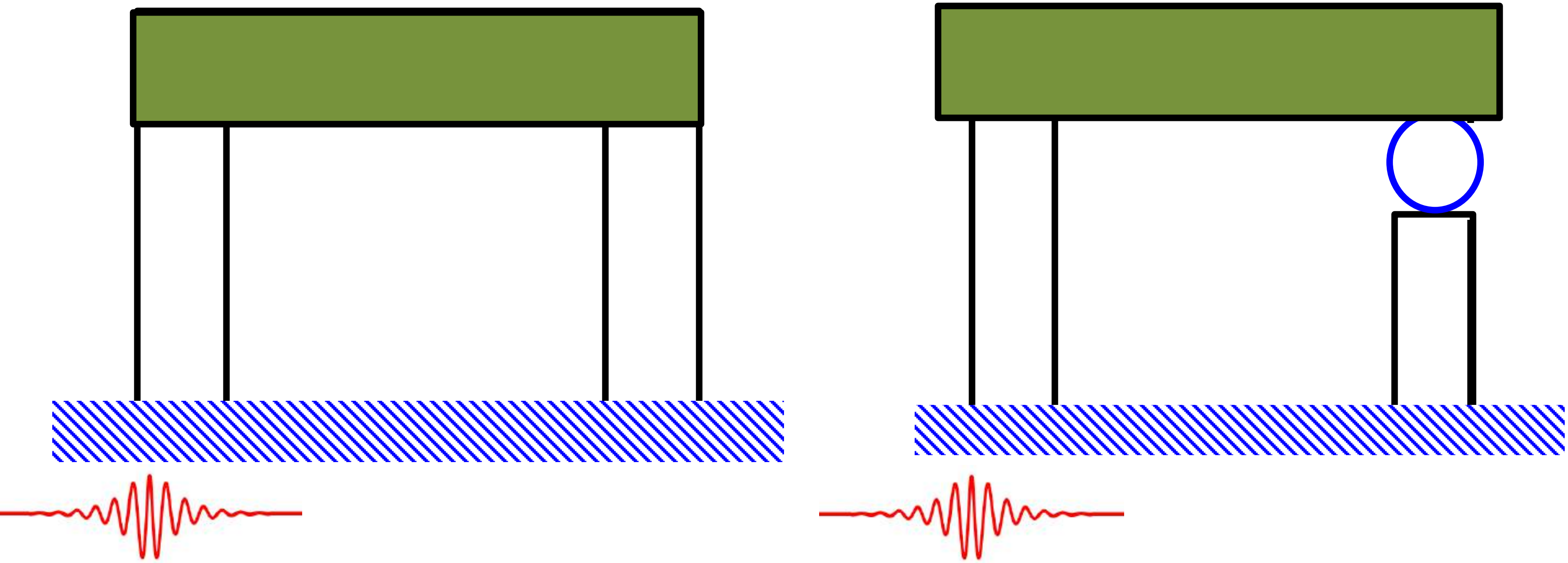
EQ load path: direction of loading



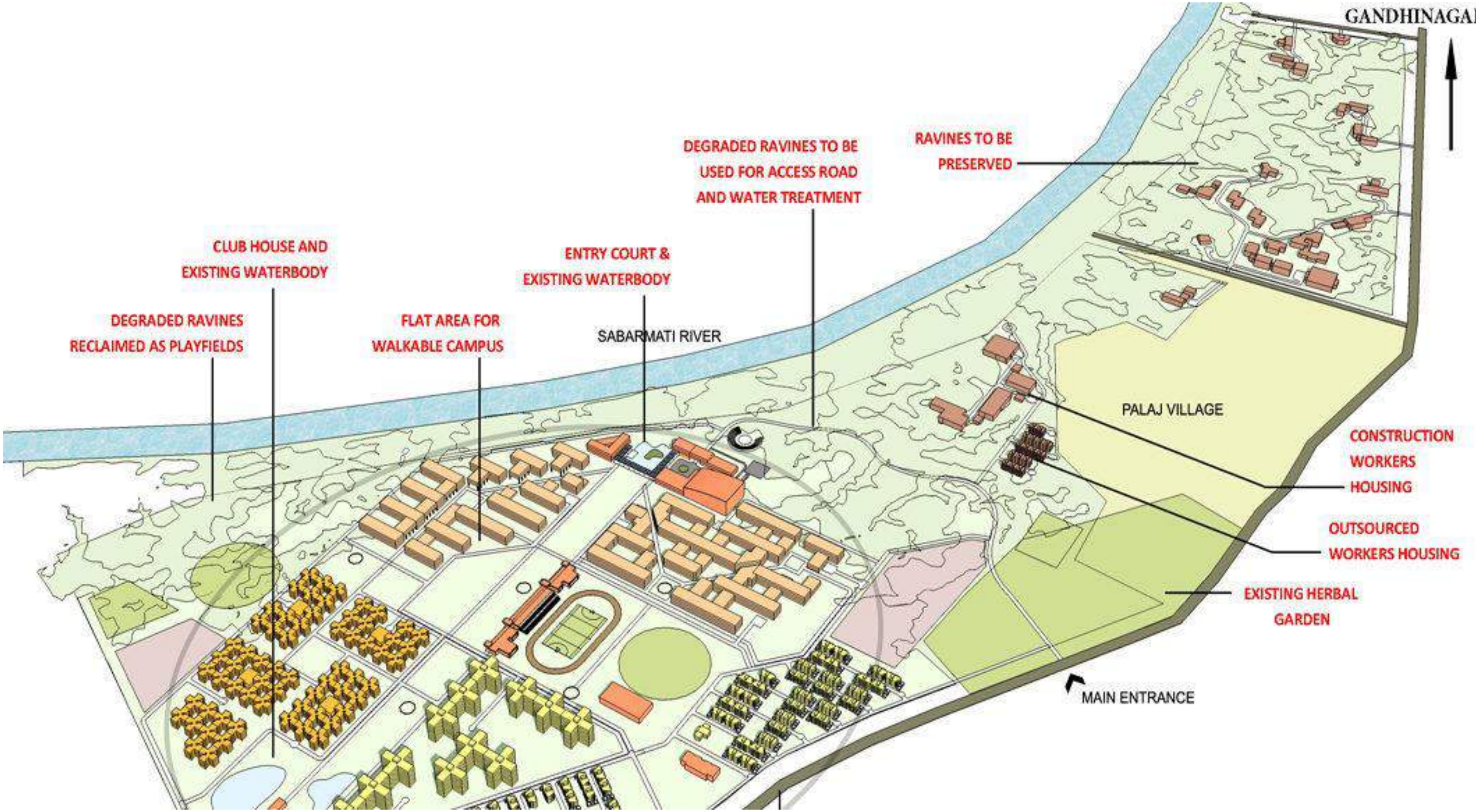
Source: NPEEE Material

EQ load path: support condition

- Member forces affected by support conditions



How many structural systems are there?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GARDEN
MAIN ENTRANCE

Faculty apartments: confined masonry

Courtesy: SK Jain

Student hostel: confined masonry

Courtesy: SK Jain

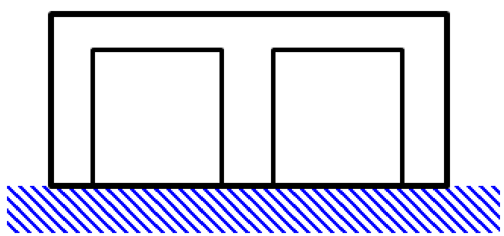
Academic area: infilled RC frame

Source: campus.iitgn.ac.in

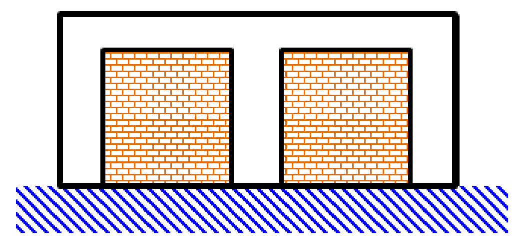
Infilled RC frame vs. confined masonry

Infilled RC frame

Step 1: Construction of RC frame

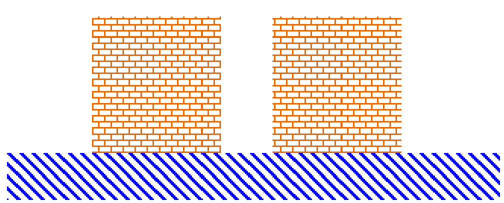


Step 2: Placement of infill

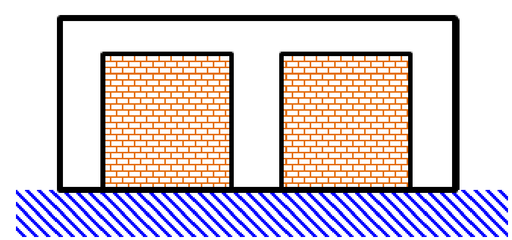


Confined masonry

Step 1: Masonry construction



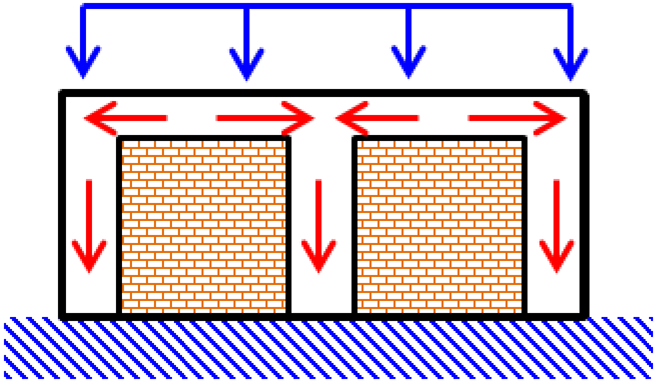
Step 2: Casting of frame



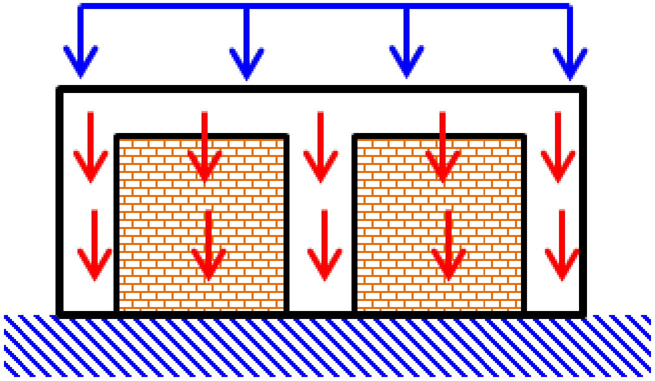
Infilled RC frame vs. confined masonry building

- Difference in load path
  - Infilled RC frame: beams >> columns
  - Confined masonry: walls

Infilled RC frame



Confined masonry



How many structural systems?

- Wide range
  - Function of space and time

Concrete moment-resisting frame

Source: FEMA 154

Concrete frame with masonry

Source: FEMA 154

Steel frame with masonry

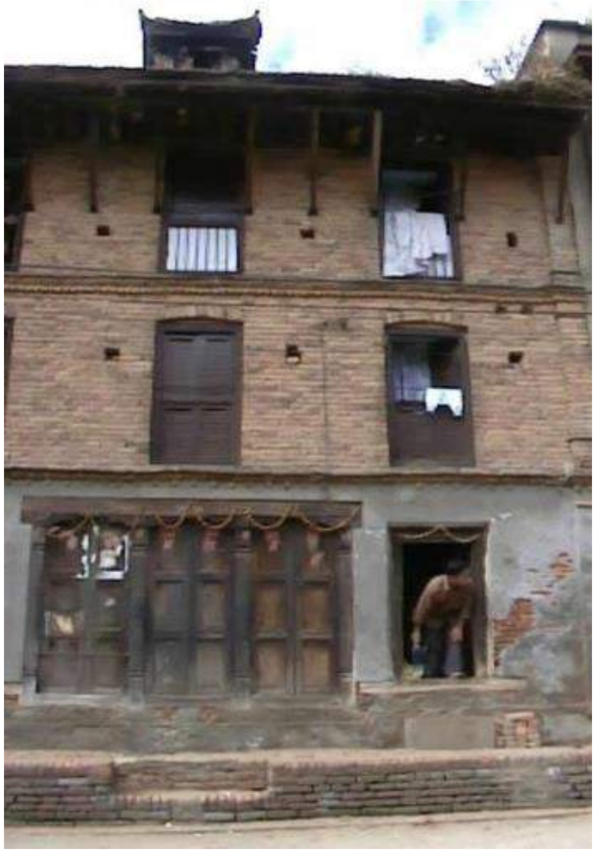
Source: FEMA 154

Steel frame with concrete wall

Source: FEMA 154

Nawari house

- Kathmandu, Nepal



Source: World Housing Encyclopaedia

Thathara house

- Himachal Pradesh, India

Source: World Housing Encyclopaedia

Dry stone construction

- Himachal Pradesh, India

Source: World Housing Encyclopaedia

Bhonga house

- Kutch, India

Source: World Housing Encyclopaedia

Dhajji dewari house

- Kashmir, India

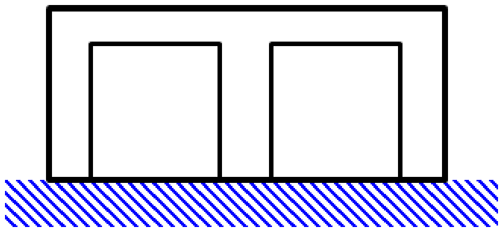
Source: World Housing Encyclopaedia

Example RVS: RC frame building with masonry infill

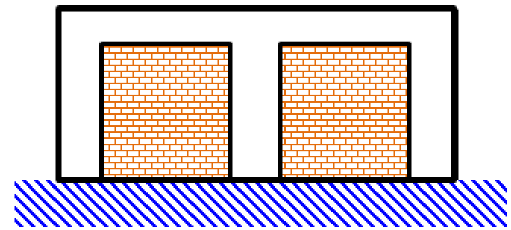
General

Infilled RC frame

Step 1: Construction of RC frame



Step 2: Placement of infill



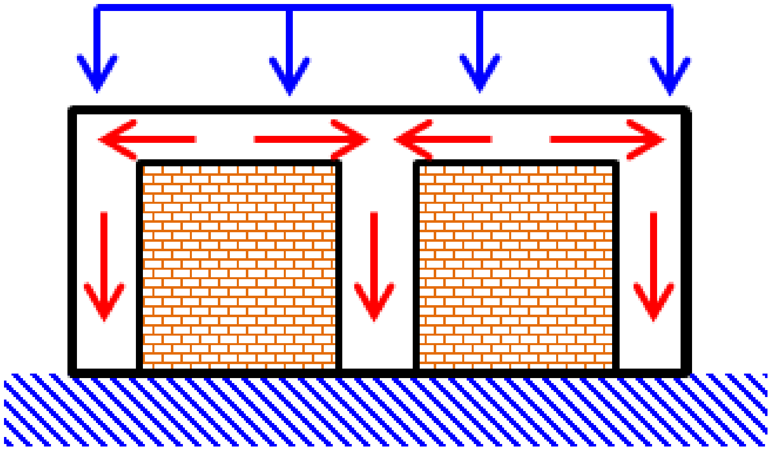


Photo: SK Jain

An RVS methodology

- Damage data from 2001 Bhuj earthquake
  - Approximately 300 RC frame buildings surveyed immediately after earthquake
    - Damage grade assigned
  - Additional survey conducted few years later
    - Number of stories
    - Status of maintenance
    - Presence of soft storey
    - Presence of heavy overhang
    - …

A Proposed Rapid Visual Screening Procedure for Seismic Evaluation of RC-Frame Buildings in India

Sudhir K. Jain,[a)] M.EERI, **Keya Mitra,**[b)] **Manish Kumar,**[c)] M.EERI, **and Mehul Shah**[d)]

Poor performance of reinforced concrete (RC) frame buildings in India during past earthquakes has been a matter of serious concern. Hence, it becomes important to identify and strengthen the deficient buildings. When dealing with a large building stock, one needs evaluation methods for quick assessment of the seismic safety of existing buildings so that corrective retrofitting measures may be undertaken on the deficient buildings. This paper presents a review of some of the available methods for rapid visual screening (RVS) of RC-frame buildings and proposes a RVS method for RC-frame buildings in India based on systematic studies on damage data of the 2001

Vulnerability scores

- Base score
  - Function of
    - Seismic zone: − 15 for a unit increase in seismic zone
    - Soil type: + 15 for better soil conditions
      - Soft, Medium, Rock
  - Ranges between 40 and 115
  - Ahmedabad
    - Seismic zone III
    - Medium soil
    - Base score: 85

Vulnerability scores

- Scores for different parameters
  - Basement present: + 10
  - Number of storeys > 5: + 10
  - Good maintenance: 20
  - Re-entrant corners present: – 10
  - Presence of open storey: – 10
  - Presence of short column: – 10
  - Non-residential usage: + 5

Maintenance

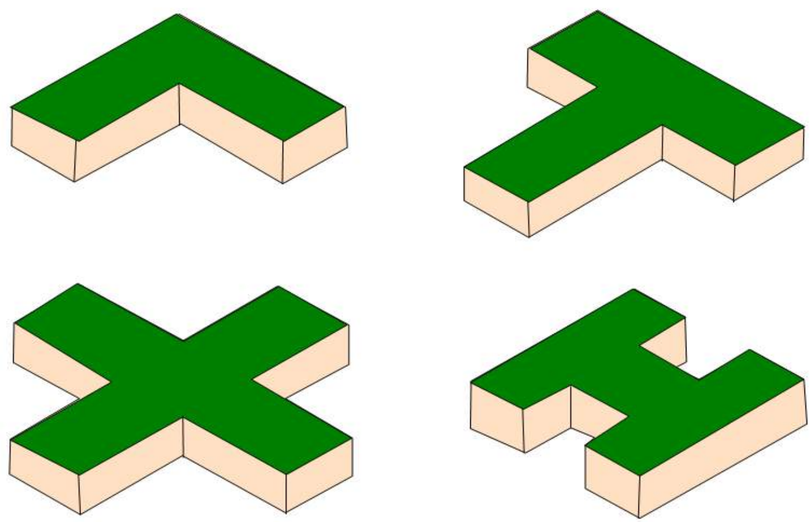
2015 Nepal earthquake: photo by UB team

Maintenance

- Effect of poor maintenance
  - Leakage/seepage affects the strength of building materials
    - Corrosion leads to further cracks
  - Poor maintenance affects the building performance score twice as much as soft story, re-entrant corners or short columns
- Owners may be encouraged to maintain the building better

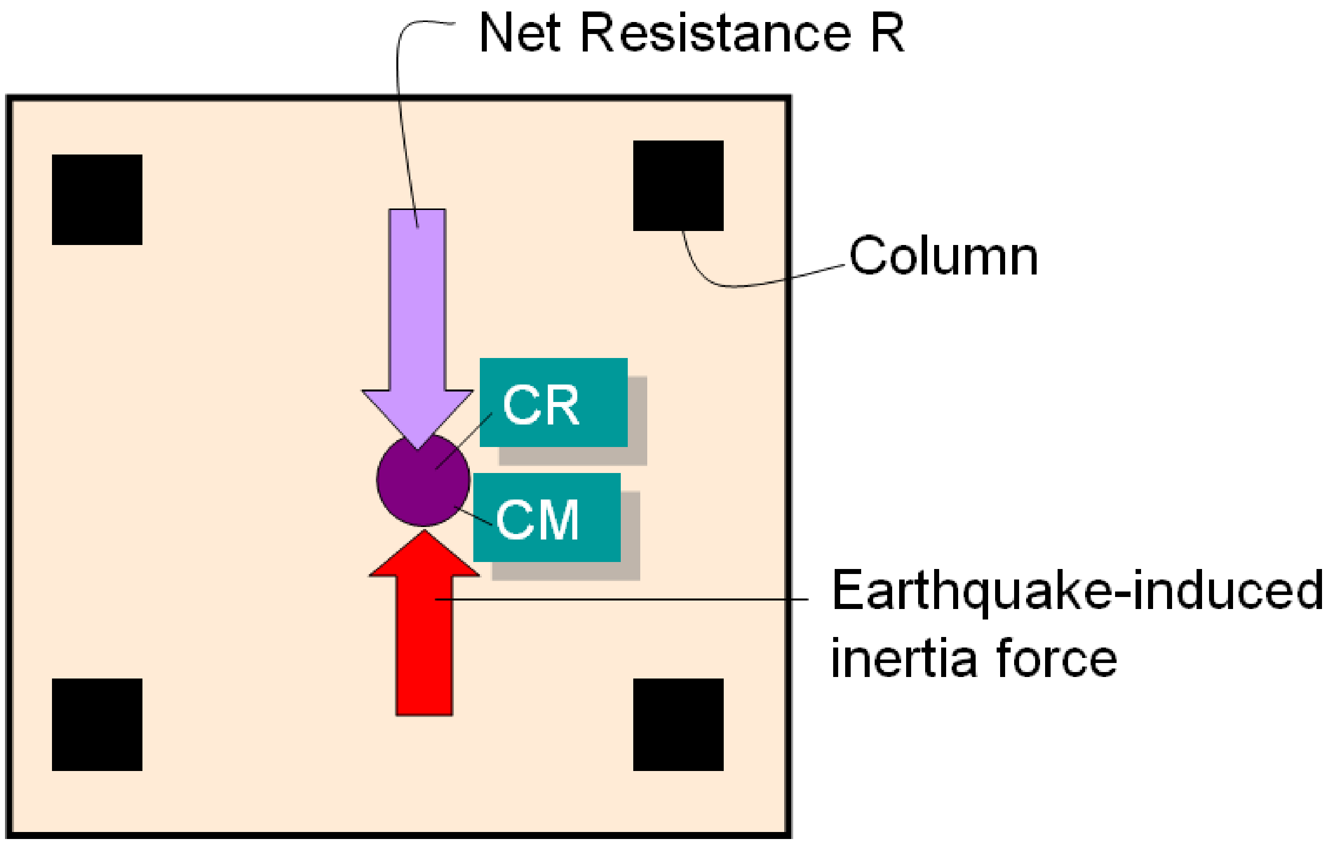
Re-entrant corners: issues

- Issues
  - Unsymmetrical plan may lead to torsion
  - Stress concentration at the re-entrant corners



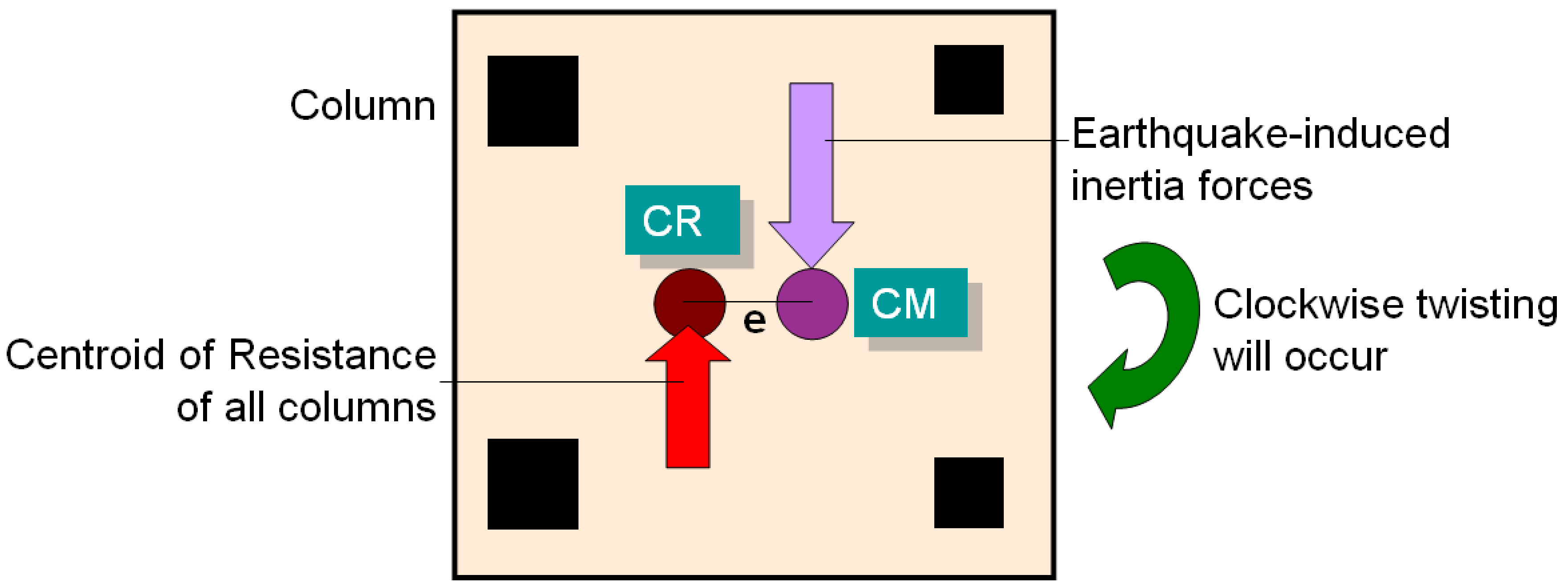
Source: NPEEE material

Re-entrant corners: issues

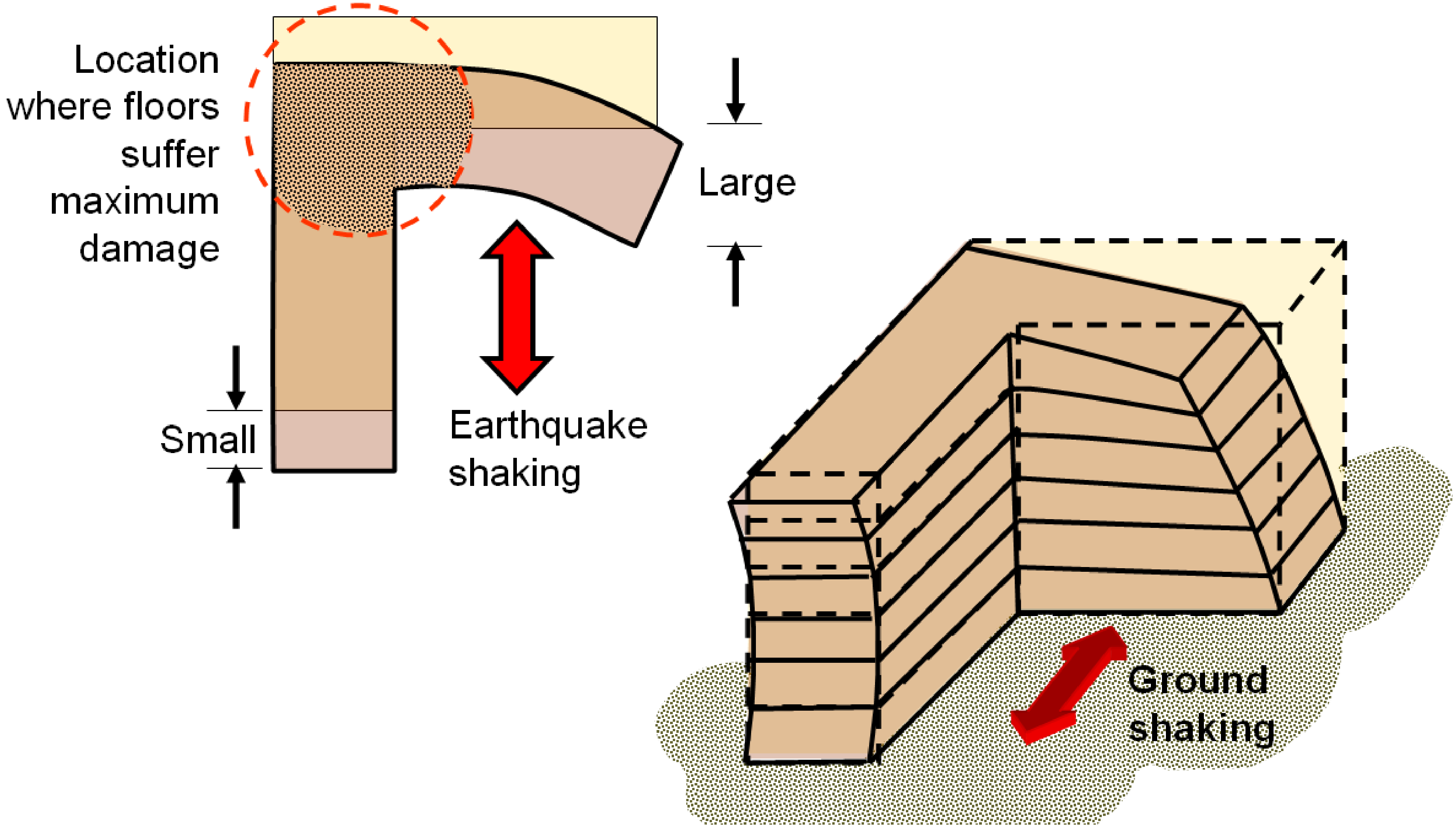


Source: NPEEE material

Re-entrant corners: issues



Source: NPEEE material



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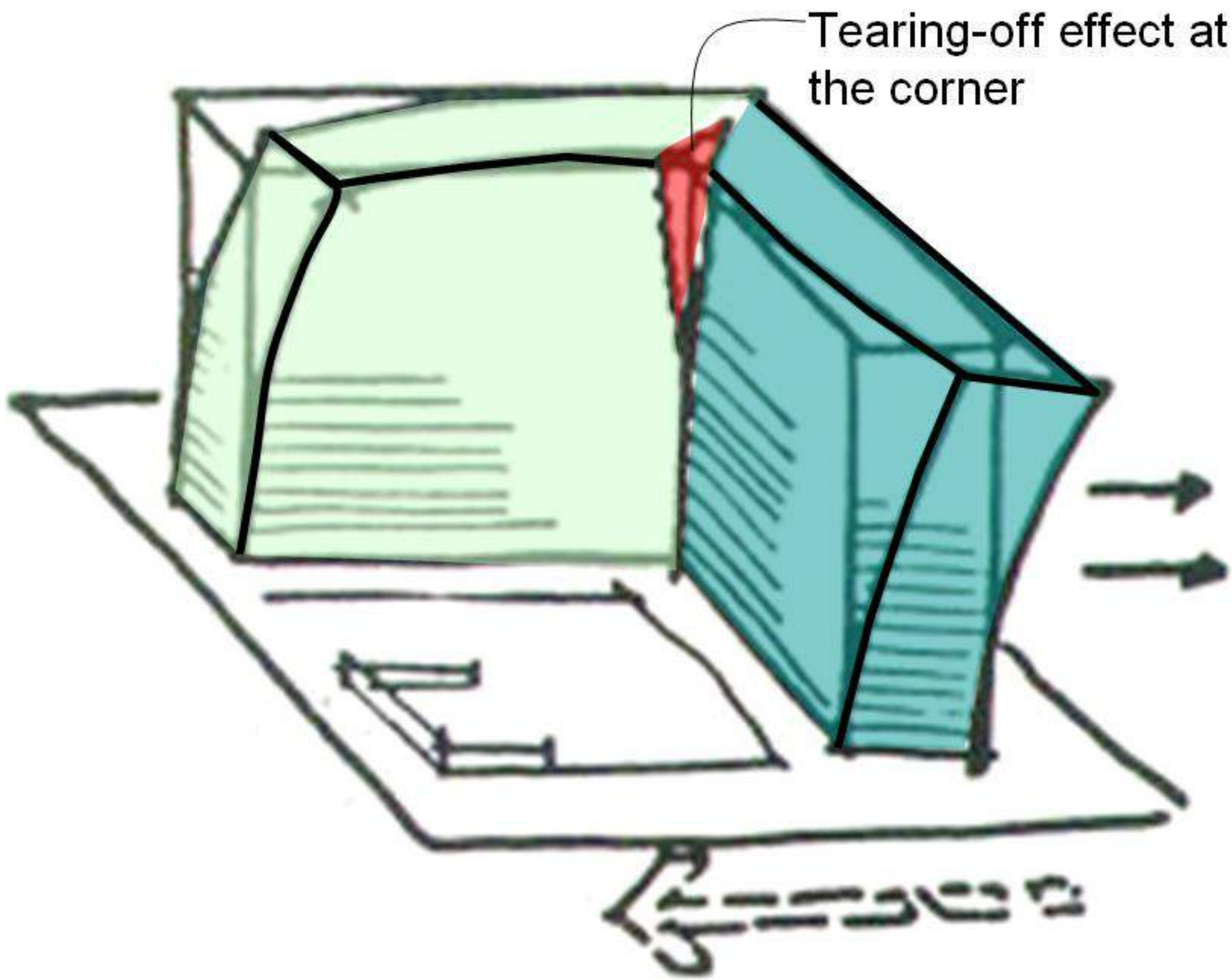
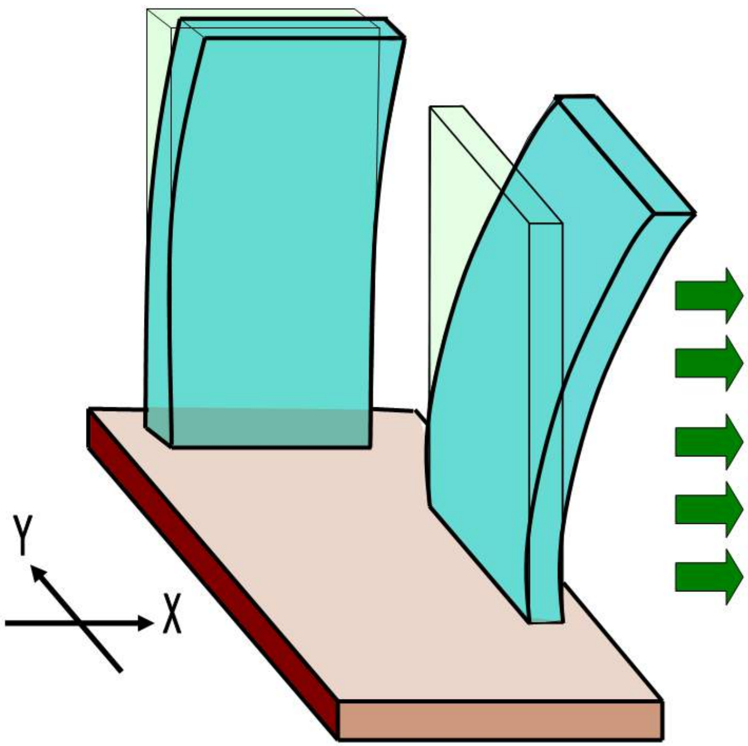

Tearing-off effect at the corner

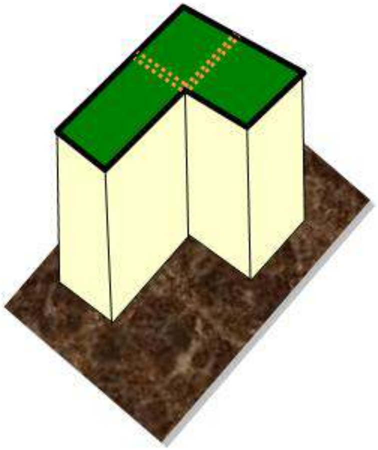
Source: NPEEE material

Re-entrant corners: solutions

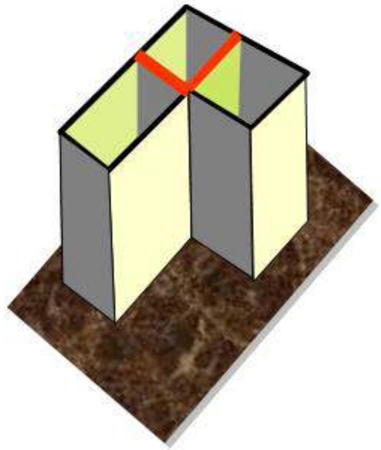
- Separation of segments



Source: NPEEE material

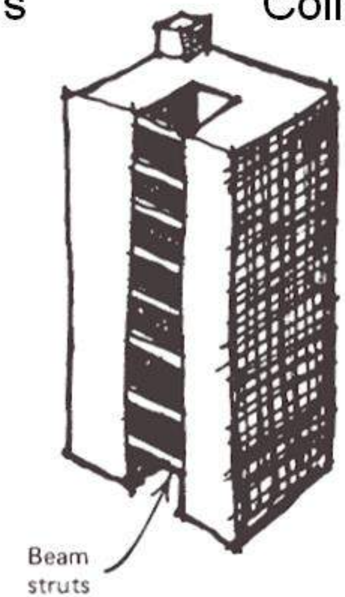


Collectors



Collector Walls

Tie the building together more strongly.



Place stiffening elements at the location

Source: NPEEE material

Open story: Issues

- Soft story
  - Parking lot, garage, shops

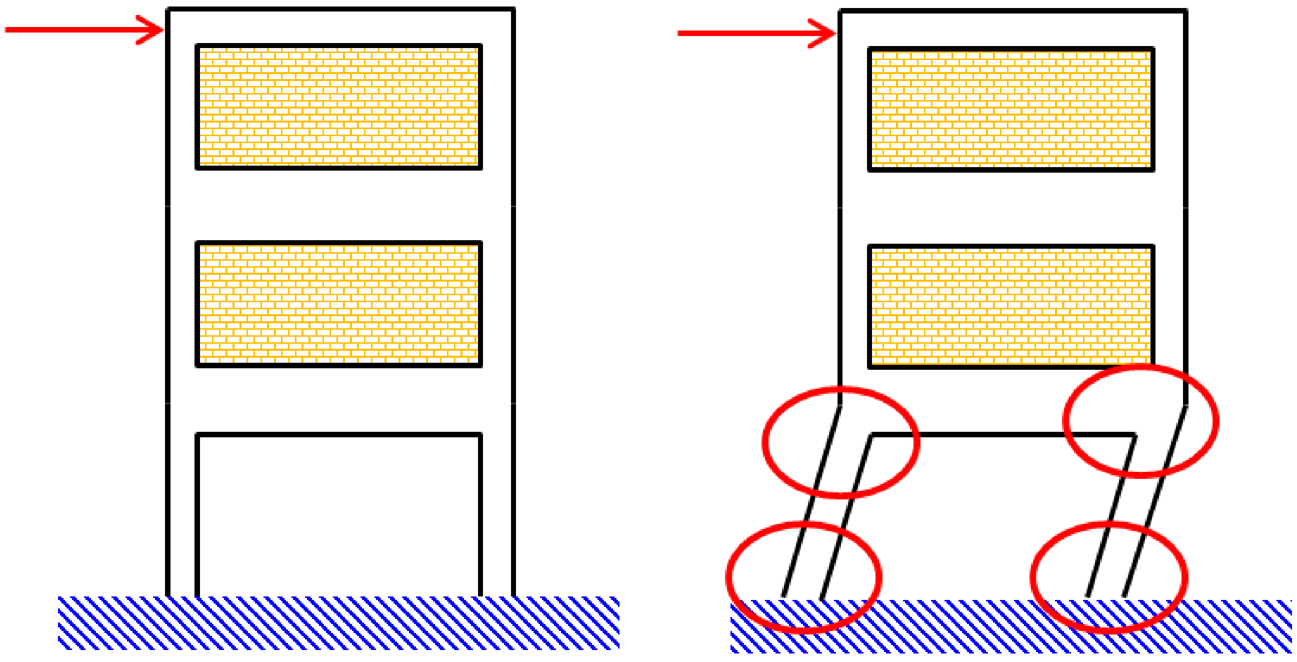
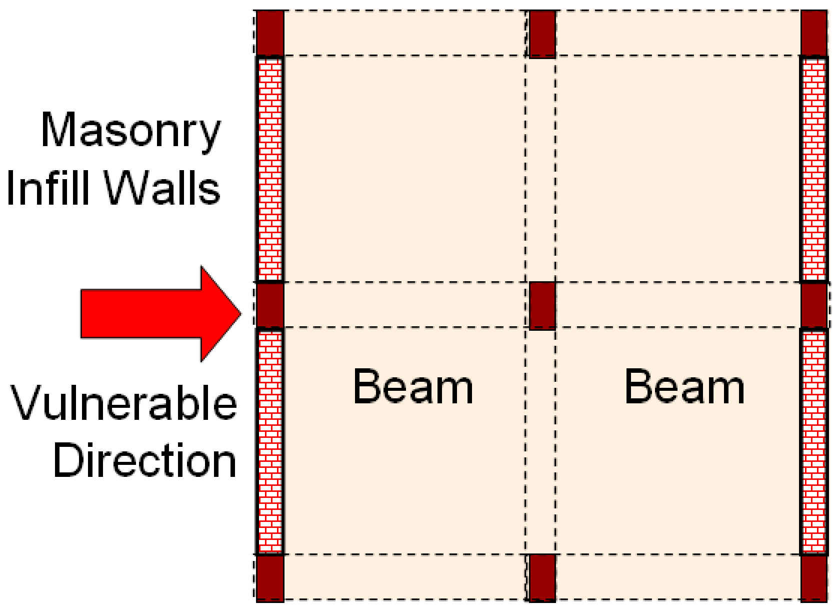


Photo: SK Jain

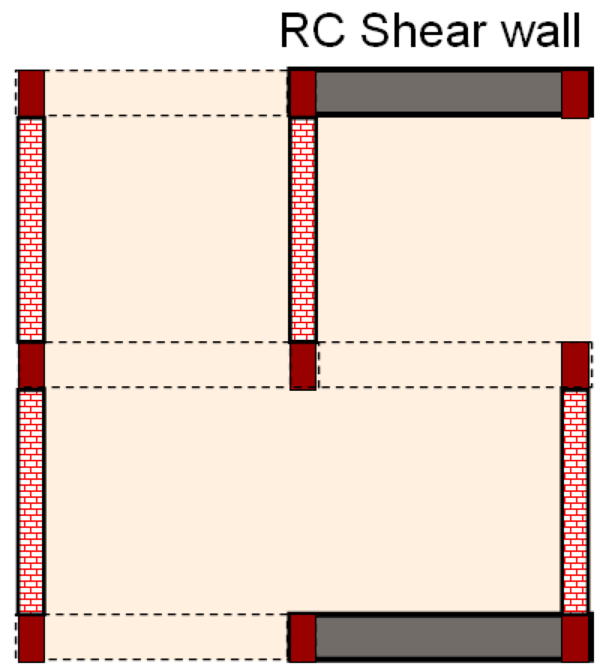
Open story: issues

2015 Nepal earthquake: photo by UB team

Open story: solutions

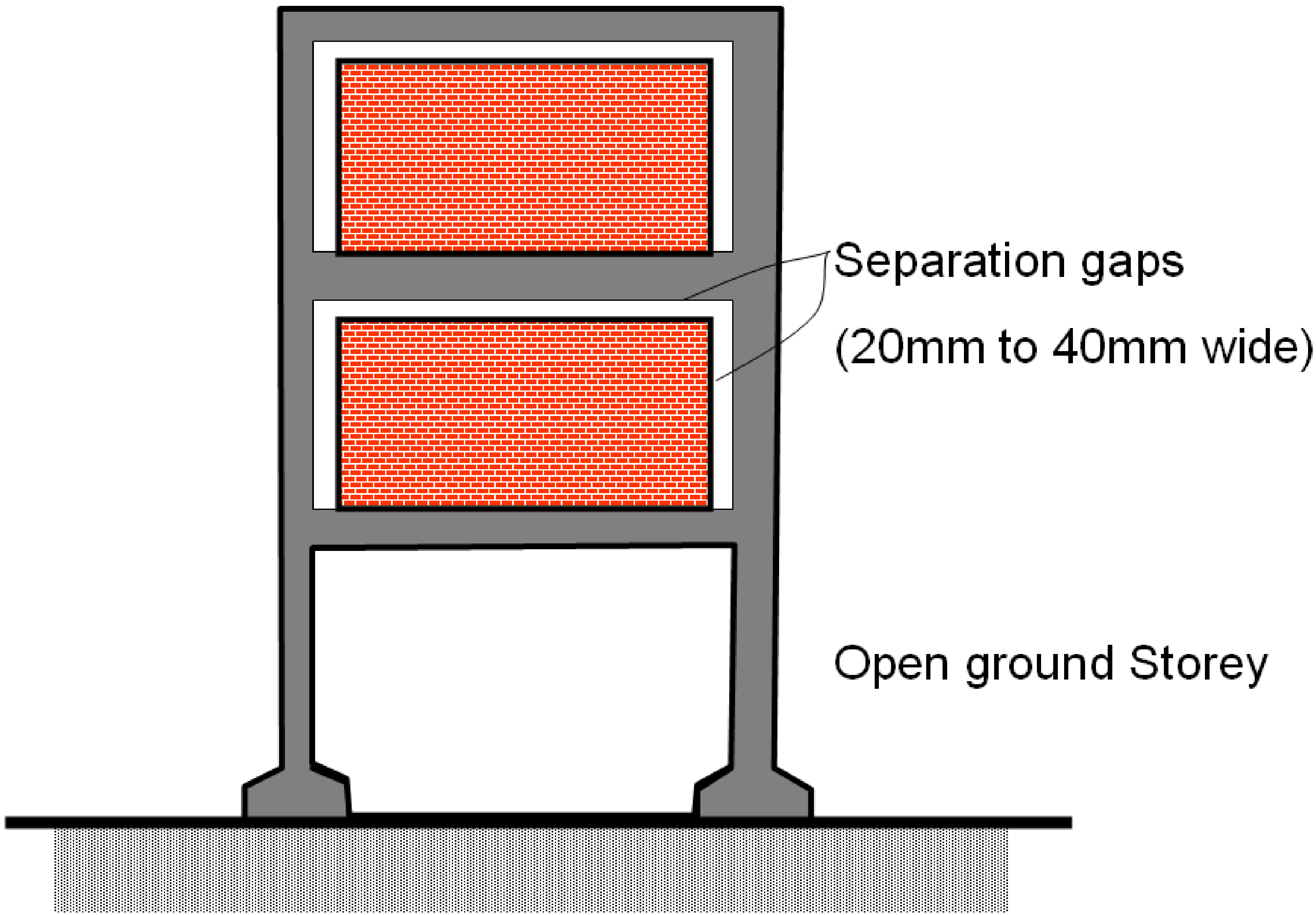


(a) Open Ground Storey



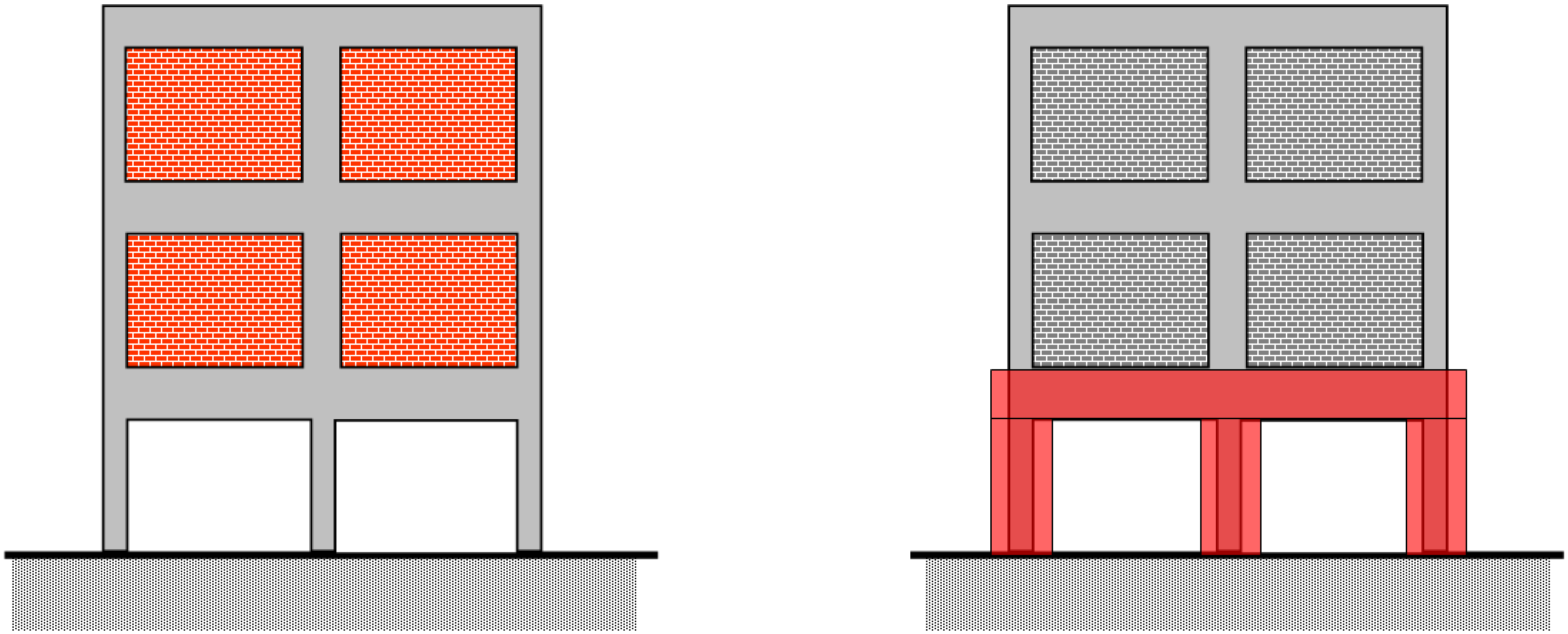
(b) Detrimental effects of Open Ground Storey avoided by using a RC shear walls

Source: NPEEE material



Source: NPEEE material

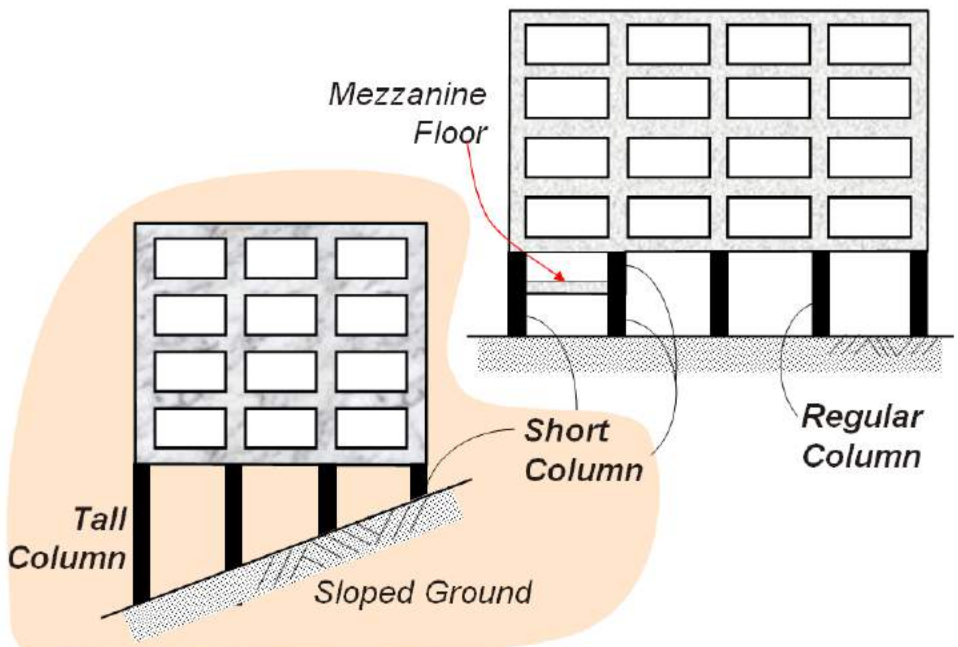
Soft story: solutions



Source: NPEEE material

Short column: issues

- Causes
  - Most deformation concentrated in a short length of the column



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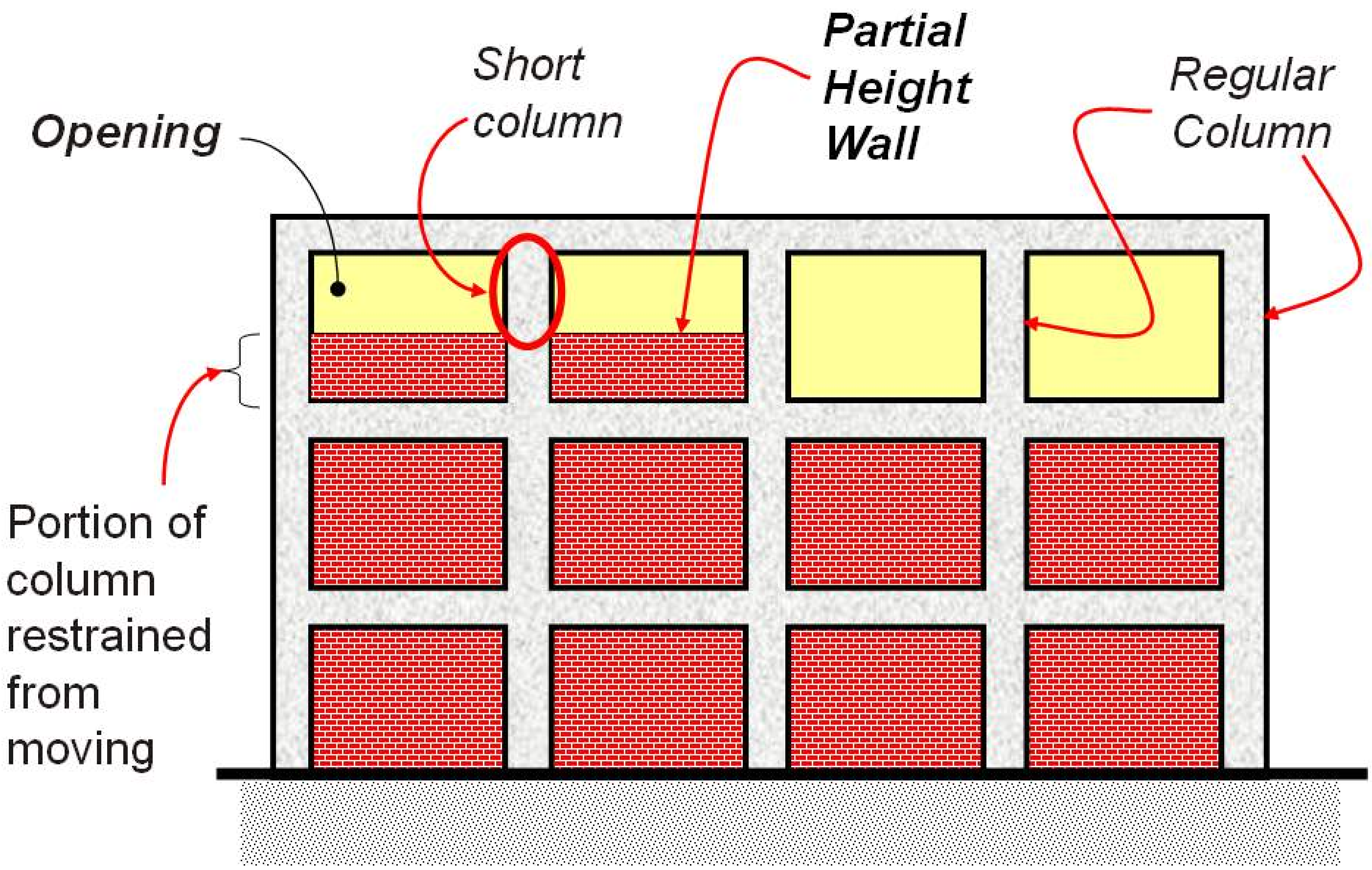

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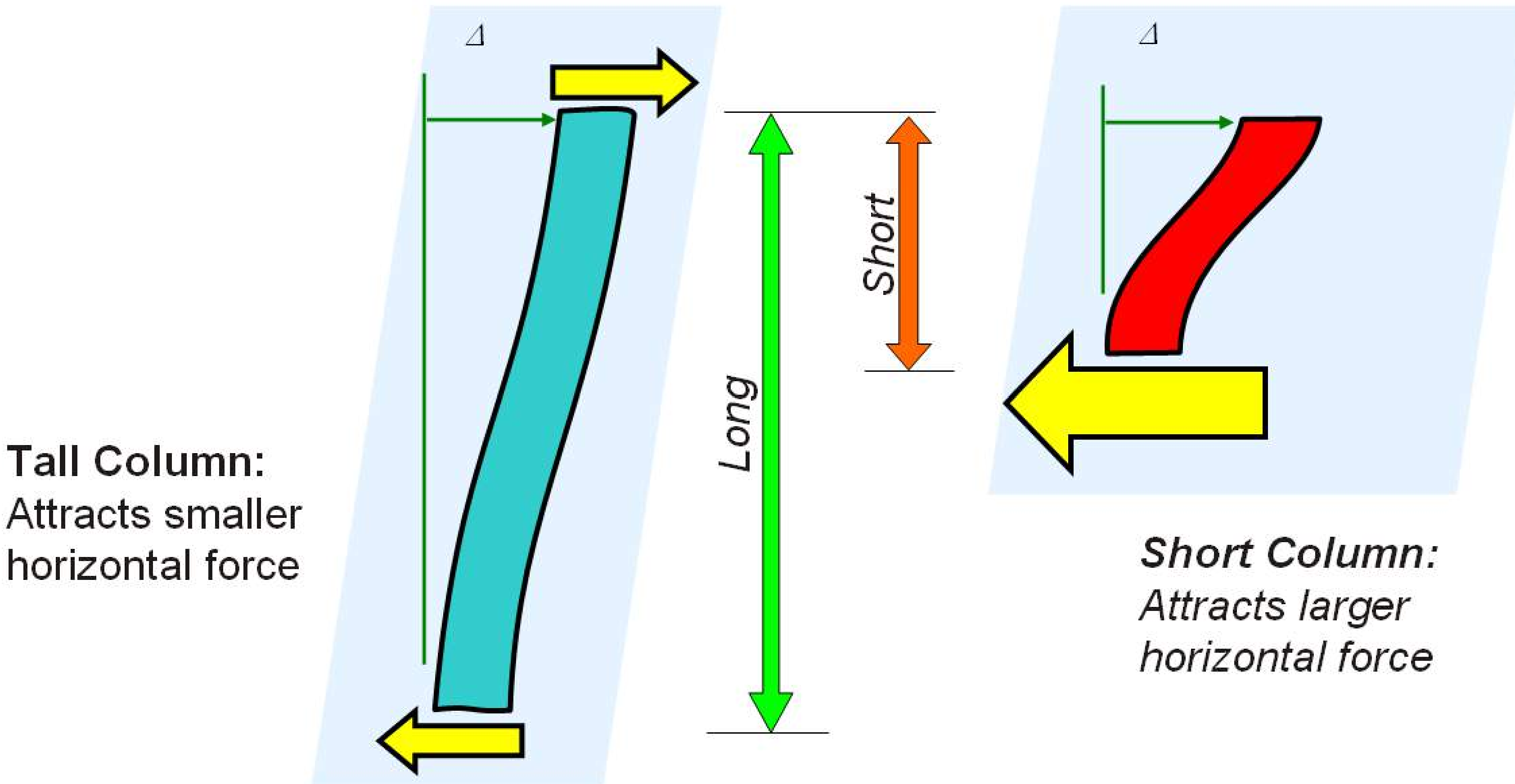

Source: NPEEE material

Source: Guevara-Perez and Garcia (2005)

Short column

- Separation between column and wall

Source: NPEEE material

After calculating vulnerability score

- Assign damage category
  - G1 for score > 77.5
    - Slight non-structural damage
  - G2 for scores between 60 and 77.5
    - Slight structural damage
  - G3 for scores between 37.5 and 60
    - Moderate structural damage
  - G4 for scores < 37.5
    - Severe structural damage
- Prioritize buildings
  - Detailed evaluation
  - Rehabilitation, if necessary

Detailed evaluation and strengthening

Relevant documents

- ASCE Standard 41: 2019
  - American Society of Civil Engineers, USA
  - Seismic evaluation and retrofit of existing buildings
- FEMA 310: 1998
  - Federal Emergency Management Agency, USA
  - Handbook for seismic evaluation of buildings
- FEMA 547: 2006
  - Federal Emergency Management Agency, USA
  - Techniques for seismic rehabilitation of existing buildings

Relevant documents

- FEMA 356: 2000
  - Federal Emergency Management Agency, USA
  - Prestandard and commentary for the seismic rehabilitation of the building
- IITK-GSDMA-EQ6: 2005
  - IIT Kanpur, Gujarat State Disaster Management Authority, India
  - IITK-GSDMA guidelines for seismic rehabilitation and retrofitting of buildings

Relevant documents

- FMEA P58: 2018
  - Federal Emergency Management Agency, USA
  - Seismic performance assessment of buildings
- IS 15988: 2013
  - Bureau of Indian Standards, India
  - Seismic evaluation and strengthening of existing reinforced concrete buildings – guidelines

IS 15988 : 2013

भारतीय मानक

प्रबलित कंक्रीट के बने भवनों के भूकम्पीय मूल्यांकन और सुद ढ़ीकरण — दिशा निर्देश

Indian Standard

SEISMIC EVALUATION AND STRENGTHENING OF EXISTING REINFORCED CONCRETE BUILDINGS — GUIDELINES

ICS 91.120.25

Outline of IS 15988

- Evaluation criteria
- Preliminary evaluation
- Detailed evaluation
- Seismic strengthening

Evaluation criteria

- Design forces
  - Indian earthquake standard
    - IS 1893, Part 1
- Consideration for age
  - Design lateral force may be reduced
    - Reduction should be less than 30%
- Consideration for availability of documents
  - A smaller material strength can be considered
    - Up to 50%

Preliminary evaluation

- Data collection
  - Soil type
  - Architectural and structural drawings
  - …
- Checks
  - Configuration-related
    - Load path
    - Redundancy
    - Soft story
    - Weak story
    - Short column
    - Torsion

Preliminary evaluation

- Checks
  - Configuration-related
    - Adjacent buildings
    - Mezzanine floors
    - …
  - Strength-related
    - Simplified expressions to calculate
      - Stresses in structural members
      - Limiting stress

Preliminary evaluation

- Acceptability criteria
  – Building considered acceptable if it meets all configuration- and strength-related checks
    - No further checks needed

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Detailed evaluation

- Necessary if acceptability criteria for preliminary evaluation NOT satisfied
- Steps
  - Develop detailed mathematical model
    - Probable capacity
      - Consideration for knowledge of material properties
    - Strength demands in members
      - Consideration for age

Detailed evaluation

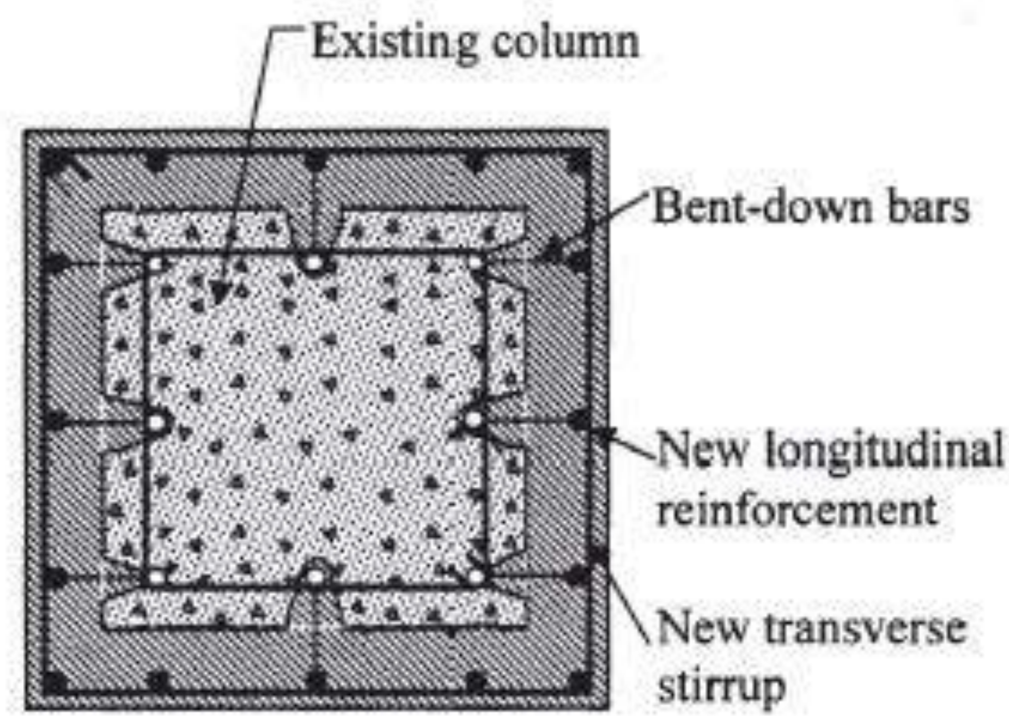
- Acceptability
  - Drift
    - Within limits set by IS 1893
  - Strength
    - Greater than demand for all members, or
    - Greater than demand for most critical members and stability of the system ensured through suitable non-linear analysis
- In addition to strength and drift checks, ductility checks should be performed

Detailed evaluation

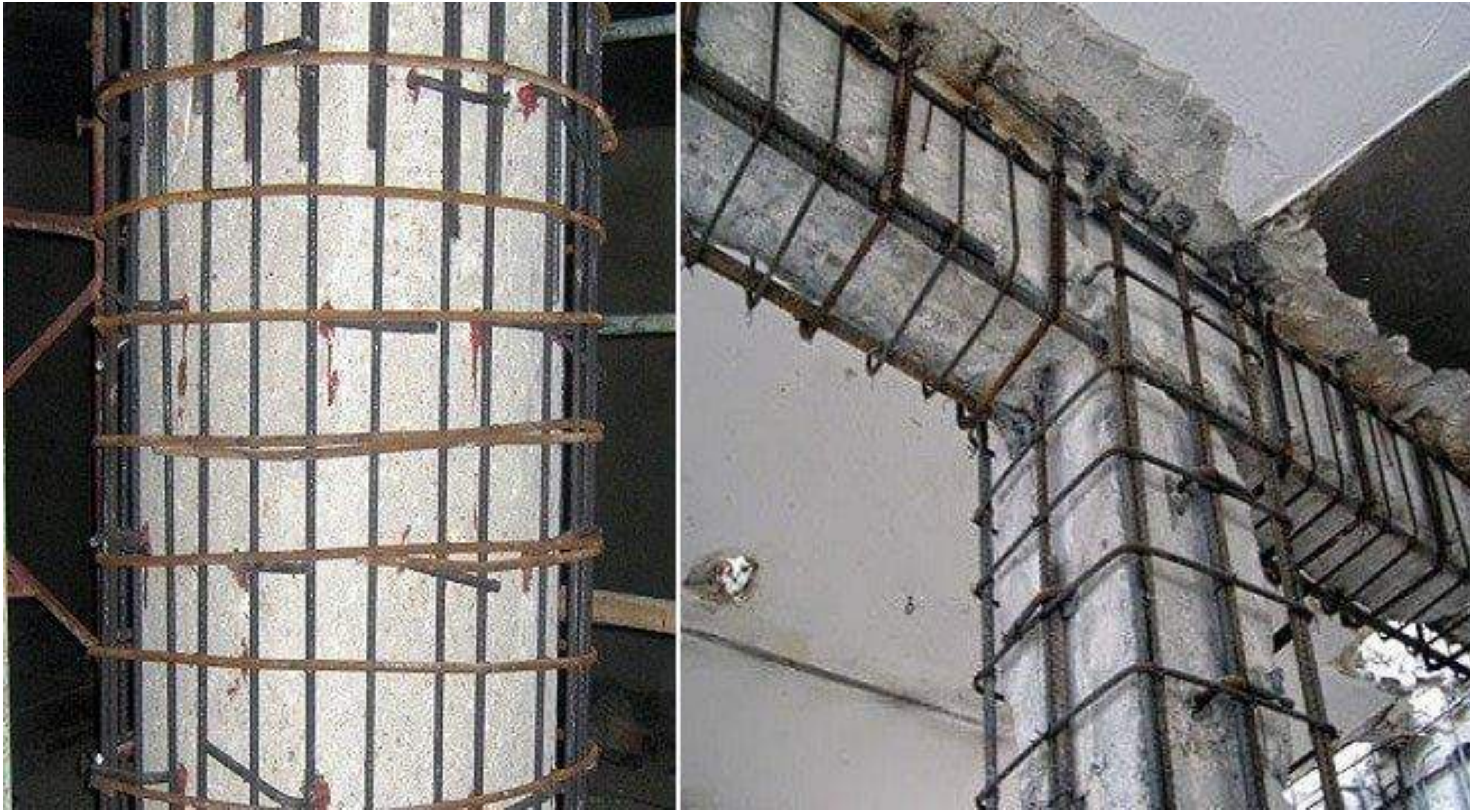
- Ductility provisions (RC frames)
  - Beams and column should fail in flexure before shear
  - At a beam-column joint
    - Sum of column capacities should be sufficiently greater than sum of beam capacities
  - Provisions on spacing of shear hoops near joints
  - Check on capacity of joints
- Provisions for
  - Shear wall buildings
  - RC frame buildings with masonry infill

Seismic strengthening

- Strengthening individual members
  - Jacketing



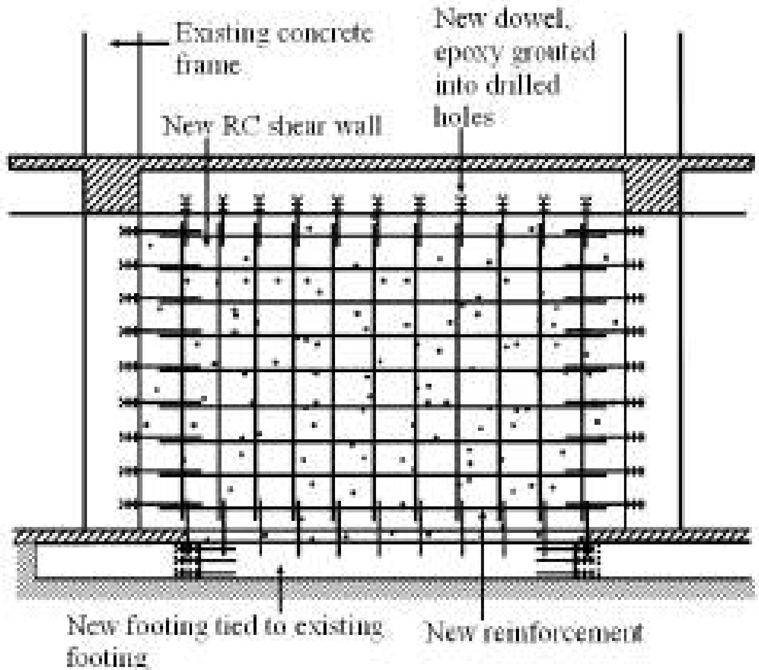
Source: IS 15988



Source: theconstructor.org

Seismic strengthening

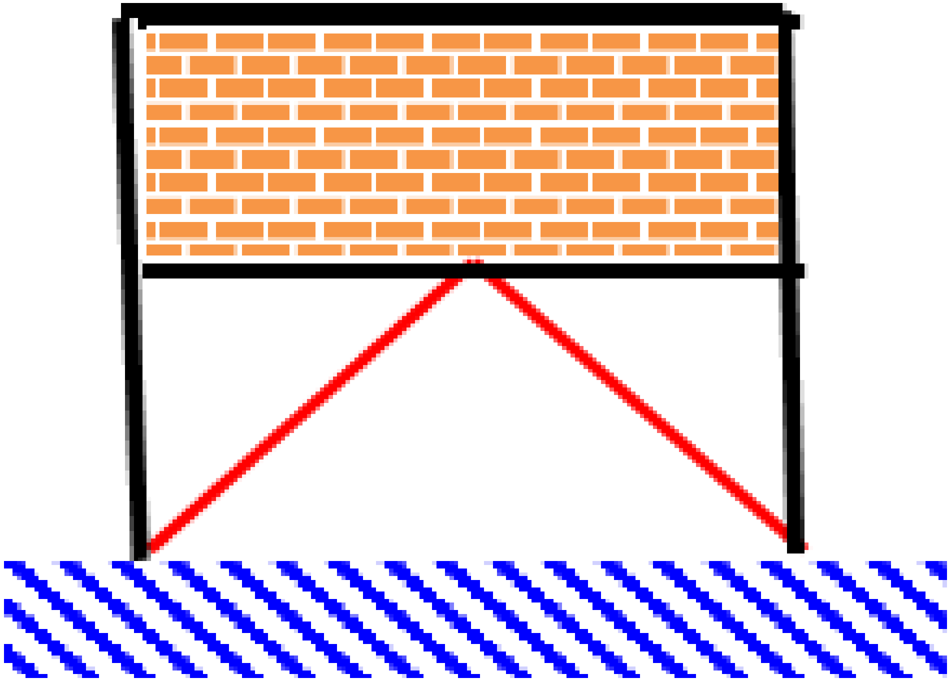
- Eliminating or reducing irregularity
  - Example: soft story can be mitigated through new shear walls



Source: IS 15988

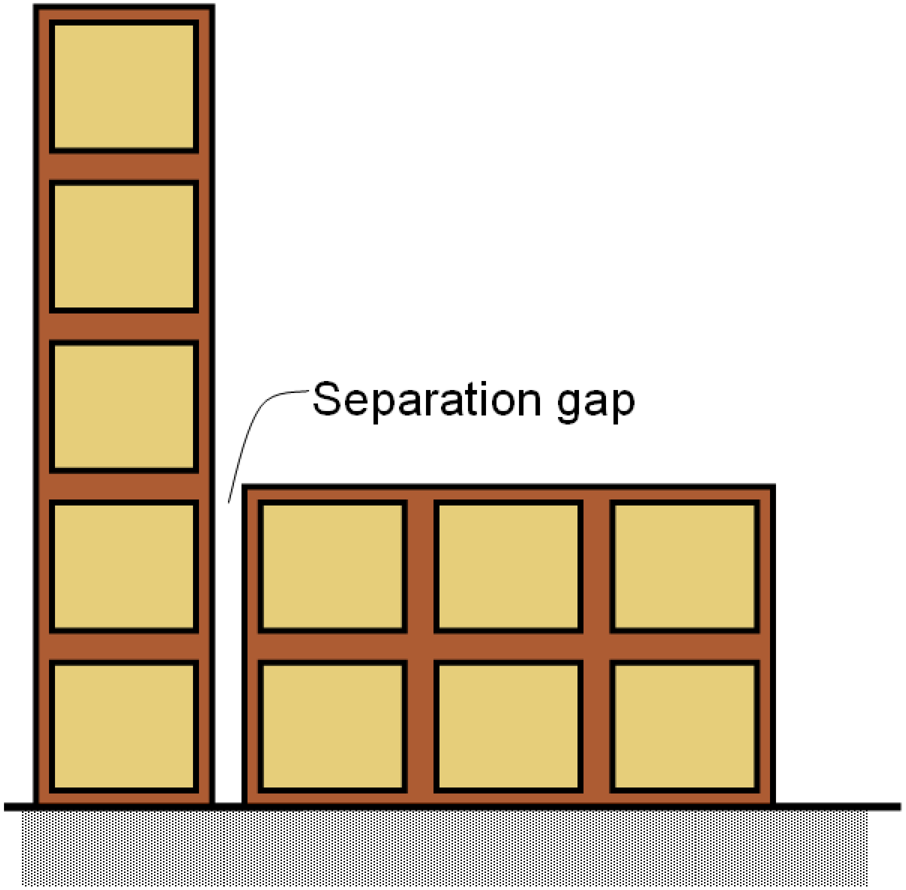
Seismic strengthening

- Eliminating or reducing irregularity
  - Example: soft story mitigation through braces



Seismic strengthening

- Eliminating or reducing irregularity
  - Providing a seismic gap at the joints



Source: NPEEE material

Seismic strengthening

- Eliminating or reducing irregularity
  - Providing a gap to avoid short column effect

Source: NPEEE material

Seismic strengthening

- Strengthening at structural level

Source: openquake.org

Seismic strengthening

- Damping devices

Source: taylordevices.in

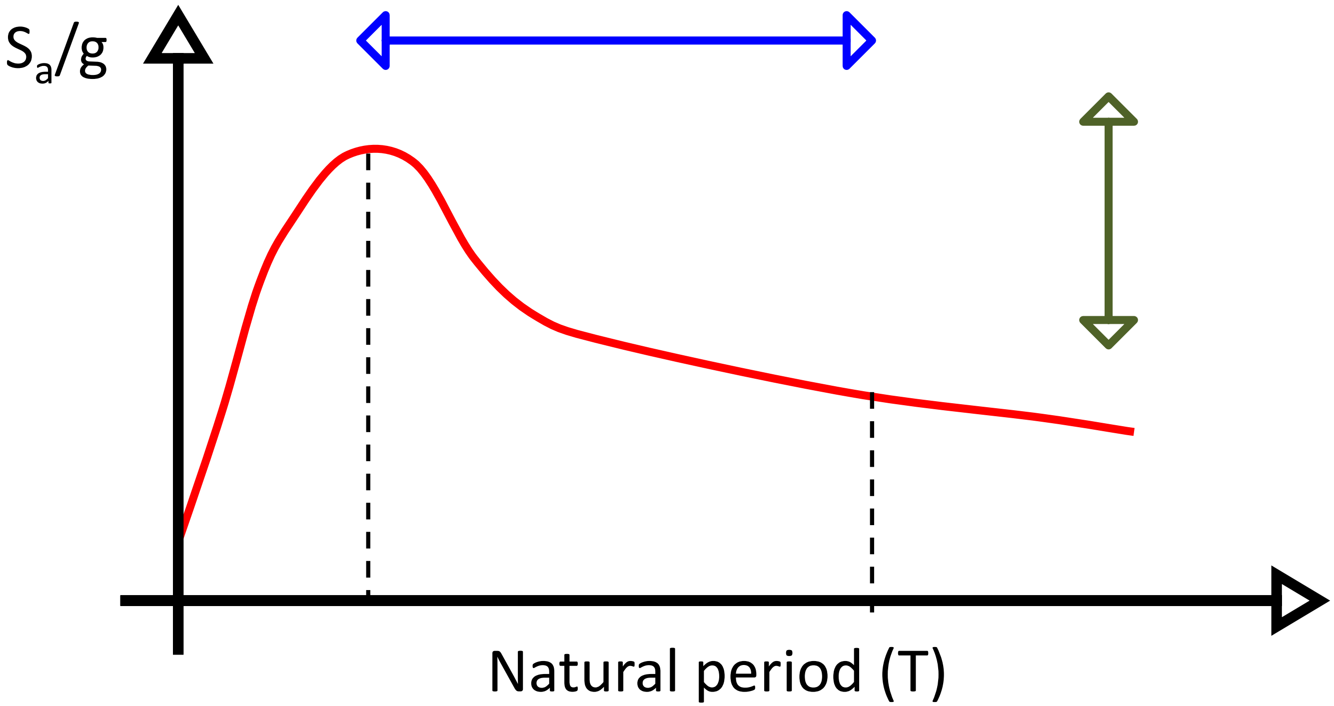
Seismic strengthening

- Seismic isolation
  - San Francisco City Hall

Source: Wikipedia

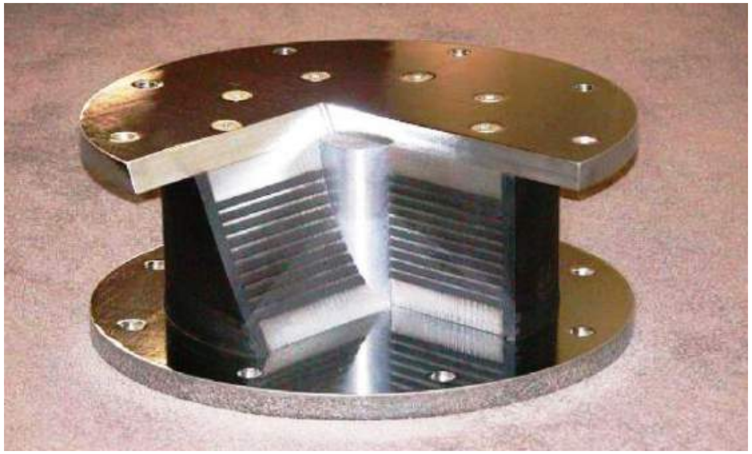
Seismic strengthening

- Seismic isolation increases natural period, which reduces input energy



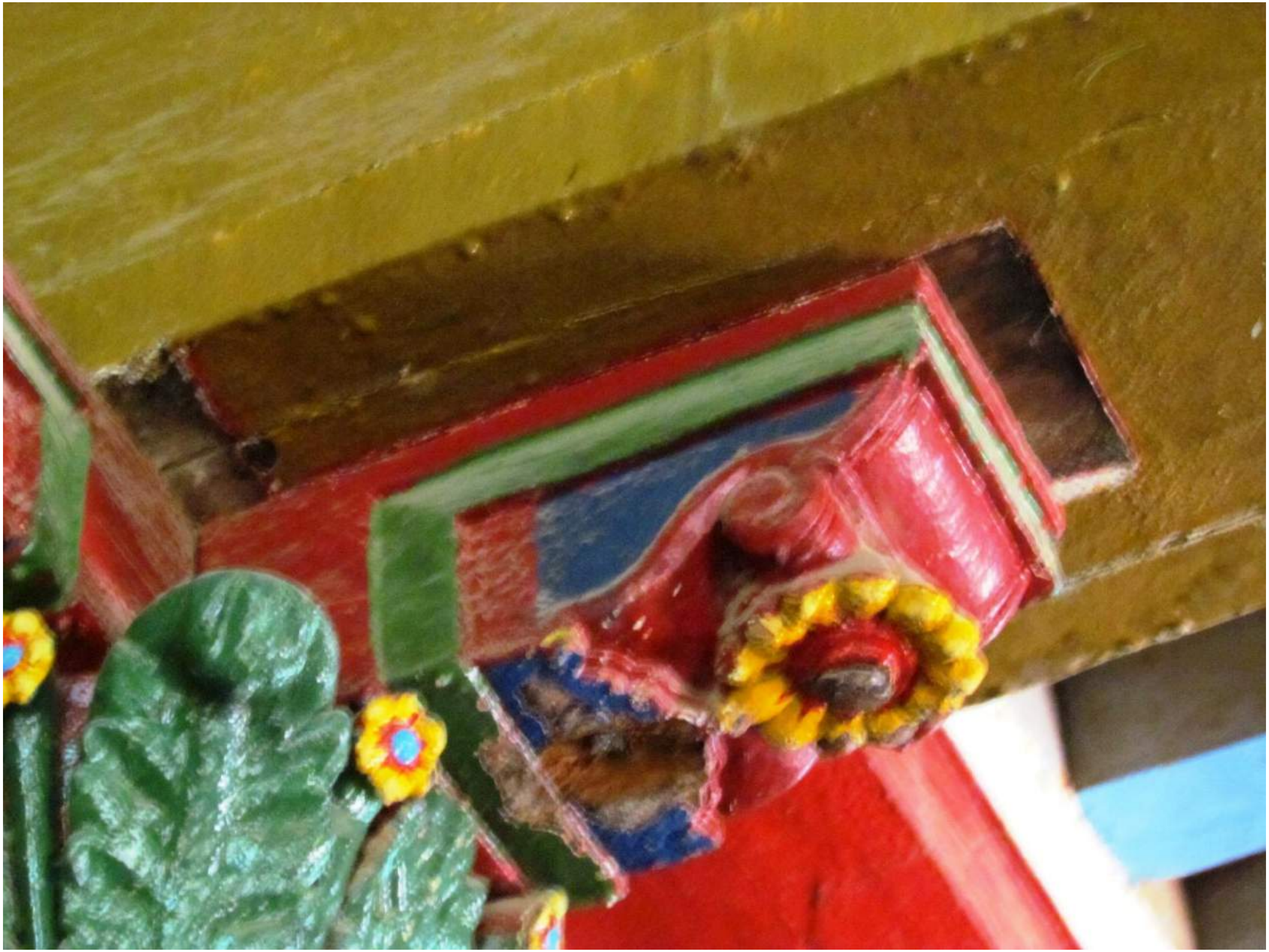
Seismic strengthening

Source: EPS



Source: Constantinou et al. (2007)

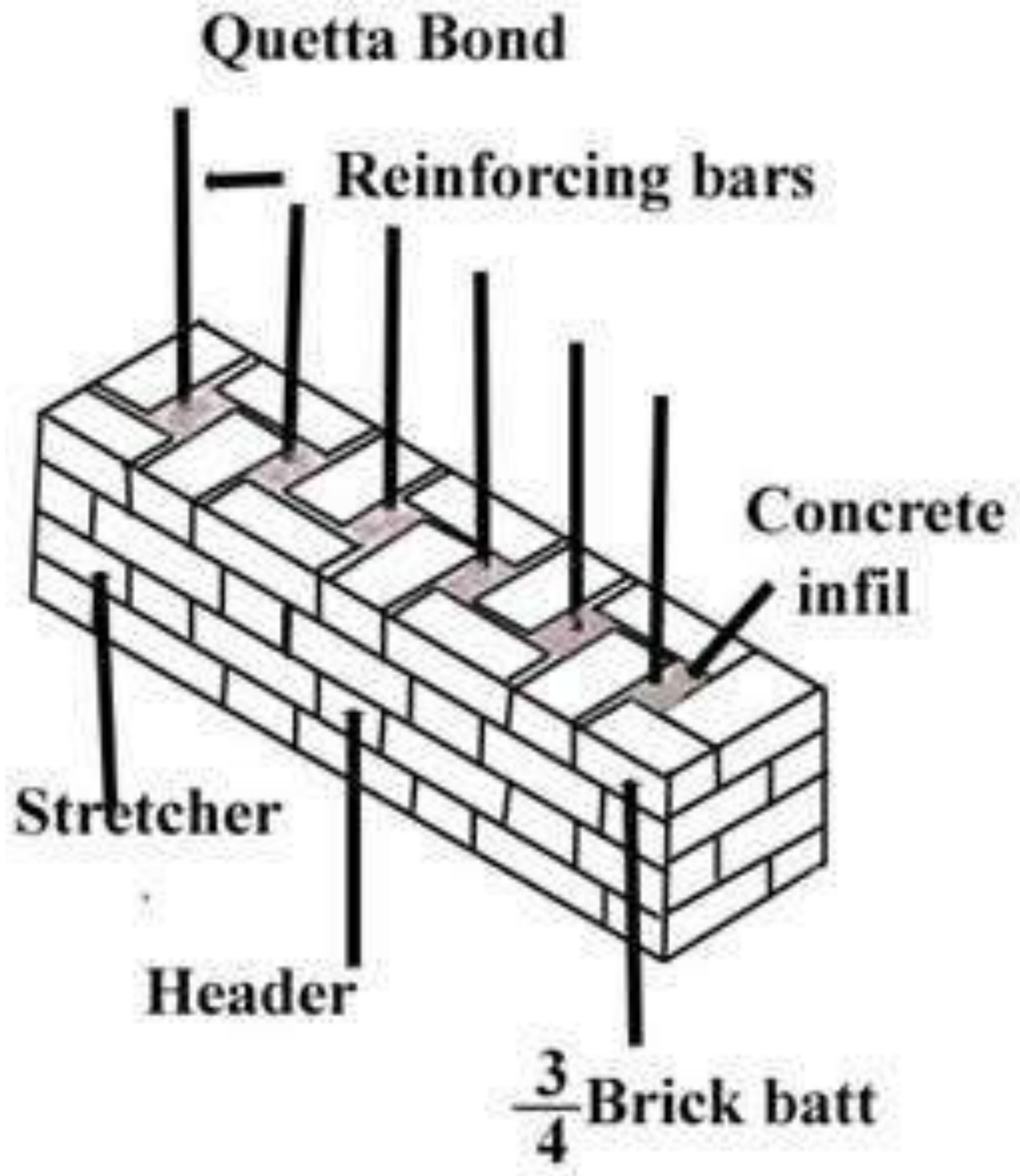
Examples of retrofitting and strengthening




(5th)પાંચમાં
અધિક સિની સીવીલ જજ
અને અધિક ચીફ જયુડી. મેજી.
ભુજ–કચ્છ
R.H.PRAJAPATI

Quetta bond

- 1931 Quetta earthquake, Baluchistan
  - Sardari Lal Kumar
    - Young engineer with Railways
    - Designed new earthquake-resistant staff quarters
    - Published a paper in 1933
      - First seismic zone map
      - Design coefficients
- 1935 Quetta earthquake
  - ~ 30,000 deaths
  - Houses designed by Kumar survived



Source: diydoctor.org.uk

Summary

- A regular structural system is best bet against earthquake
- RVS can be used to prioritize buildings for further evaluation
- Tools available for analysis of buildings identified during RVS
- Suitable retrofit mechanisms may be adopted

Do earthquakes always bring bad news?

Dianthe born in Christchurch earthquake

By Jarrod Booker

5:30 AM Saturday Sep 11, 2010

Australasia | Canterbury | Christchurch | ...

SHARE:

Have you been affected by the earthquake?
Send us your photos and video.

Sleeping peacefully in her mother's arms, little Dianthe Rose Barnard has no idea she was born in a natural disaster.

And at the time of her birth, when the 7.1 magnitude earthquake was hitting Christchurch last Saturday morning, her mother was not sure what was going on either.

Evert and Maruschke Barnard with their daughter Dianthe, who was born during the earthquake. Photo / Alan Gibson

Maruschke Barnard had her mind fully occupied at Christchurch

Do earthquakes always bring bad news?

"Lying in bed Swaminathan realized with a shudder that it was Monday morning. It looked as though only a moment ago it had been the last period on Friday; but Monday was already here. He hoped that an earthquake would reduce the school building to dust…"

– Malgudi Schooldays by R. K. Narayan

Acknowledgements

- SAARC Disaster Management Centre
- Gujarat Institute of Disaster Management
- GeoHazards Society
- IIT Gandhinagar

Thank you!