Damage Observations and Issues Related to Building Performance

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- Damage Overview
- Findings from Surveys and Recommendations

Quick Report of Damage Investigation on Buildings and Houses due to October 8, 2005 Pakistan Earthquake

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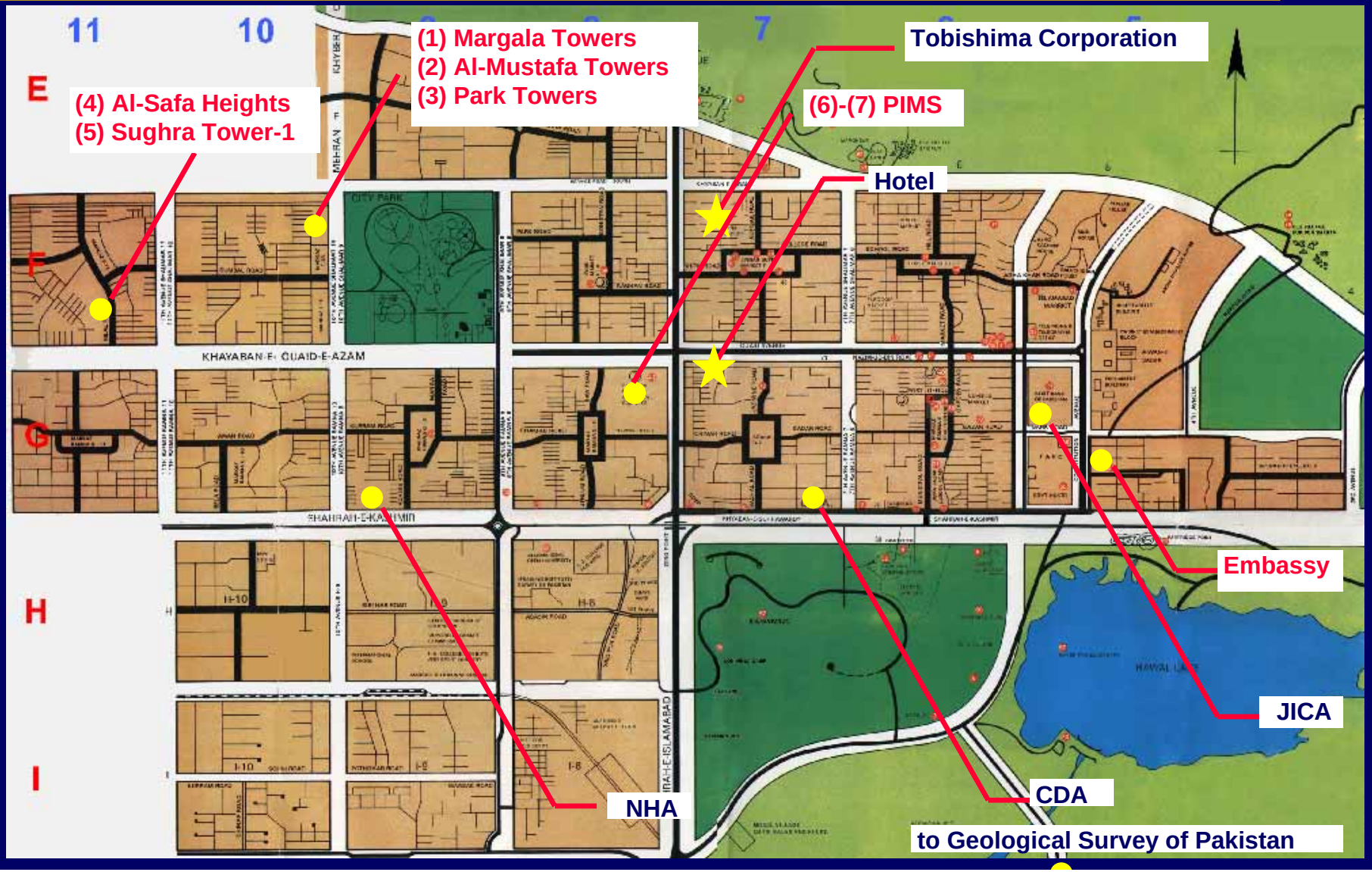
Surveyed Areas (1)



Surveyed Areas (2)

Islamabad Margala Towers

Islamabad Margala Towers

- Extensive Damage to URM Walls
- Damage to Expansion Joints
- However, No Major Damage to Structural Members

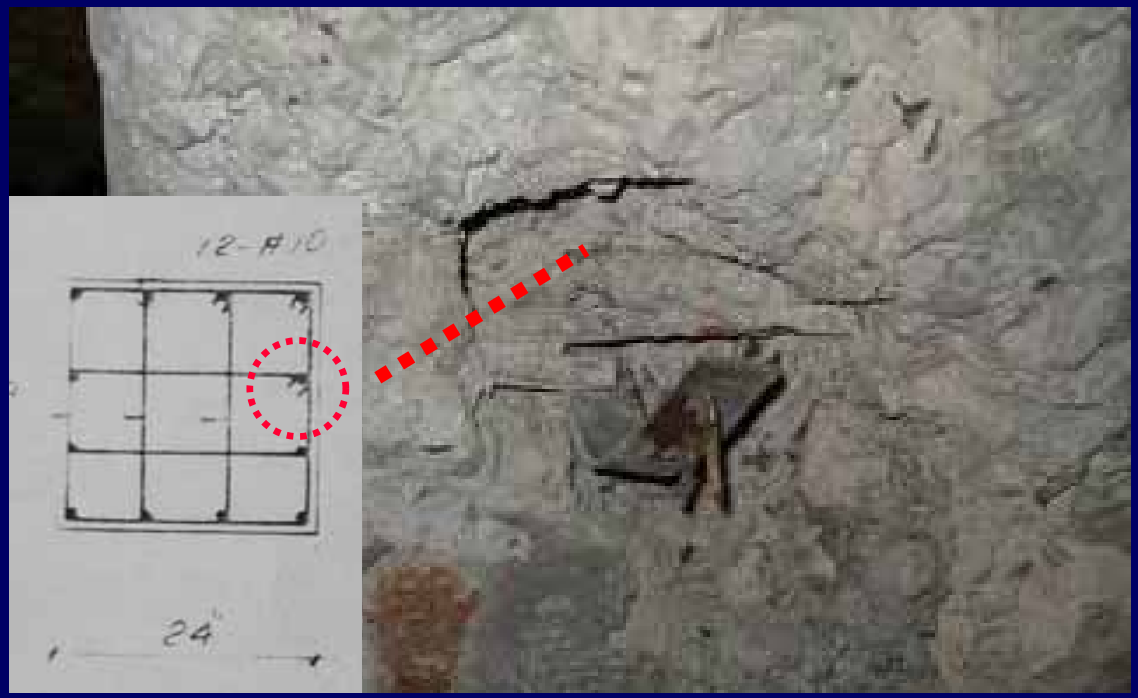
Islamabad Margala Towers

- Schmidt Hammer Tests in Building Nos. 2 - 4
  - Non-destructive test to estimate concrete strength from hardness of concrete surface.
  - It is often referred to estimate concrete strength especially when destructive tests are difficult to perform.
- Test results
  - 12 N/mm^2 (No. 2)
  - 17 N/mm^2 (No. 3)
  - 15 N/mm^2 (No. 4: collapsed)

  ➔Generally lower than requirements for Japanese high-rise buildings

Islamabad Margala Towers

- Reinforcement Detections
  - 90-degree hooks although
    135-degree specified in structural drawings



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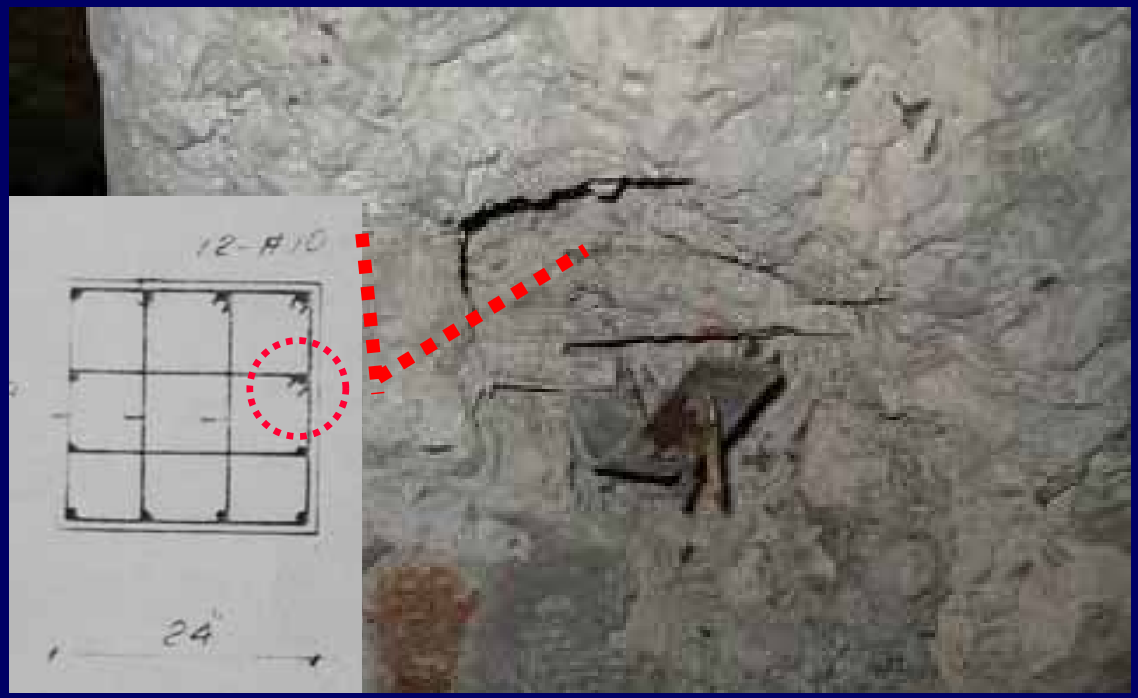

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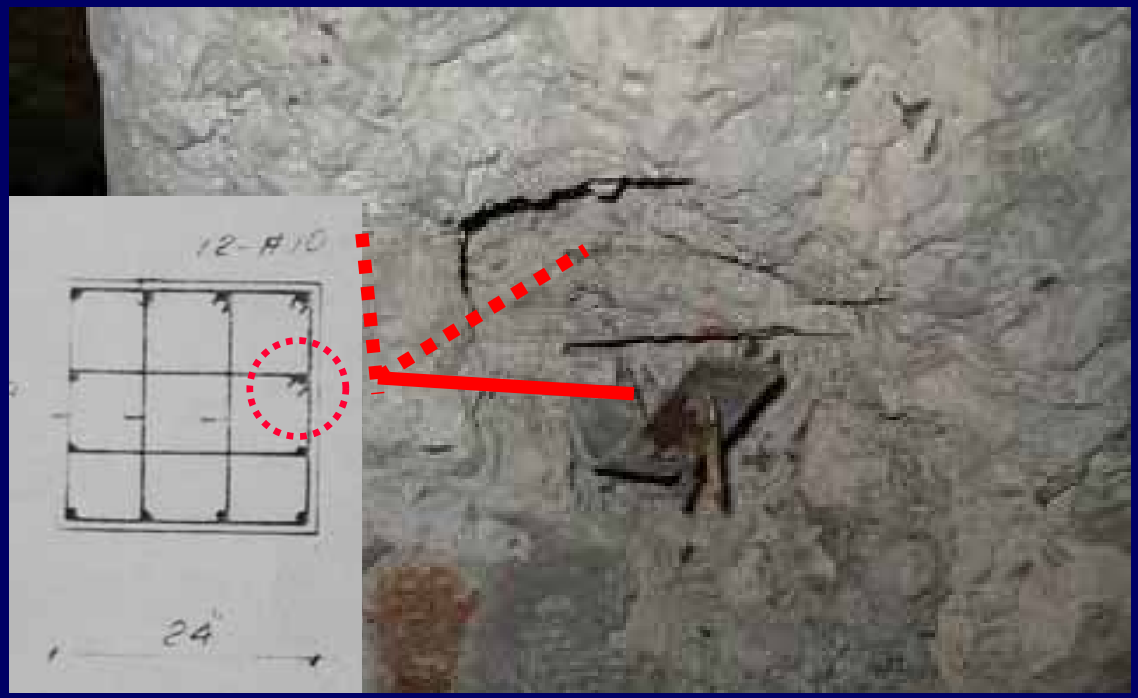


Islamabad Margala Towers

- Why the tower was collapsed?

➔ Various Possible Reasons

  - Low Quality of Concrete?
  - Poor Reinforcement Detailing?
  - Low Member Strength?
  - Larger Building Weight?
  - Soil Conditions?
  - Soil Amplification?
  - Long-period Ground Motions?
  - …..

Islamabad Margala Towers

- Why the tower was collapsed?

➔ Various Possible Reasons

	Possible Surveys
• Low Quality of Concrete?	← Concrete core tests
• Poor Reinforcement Detailing?	← Rebar exposure
• Low Member Strength?	← Seismic Capacity
• Larger Building Weight?	← Seismic Capacity
• Soil Conditions?	← Soil Profile
• Soil Amplification?	← Microtremor
• Long-period Ground Motions?	← Response Spectra
• …..	…..

Islamabad Al-Mustafa Towers

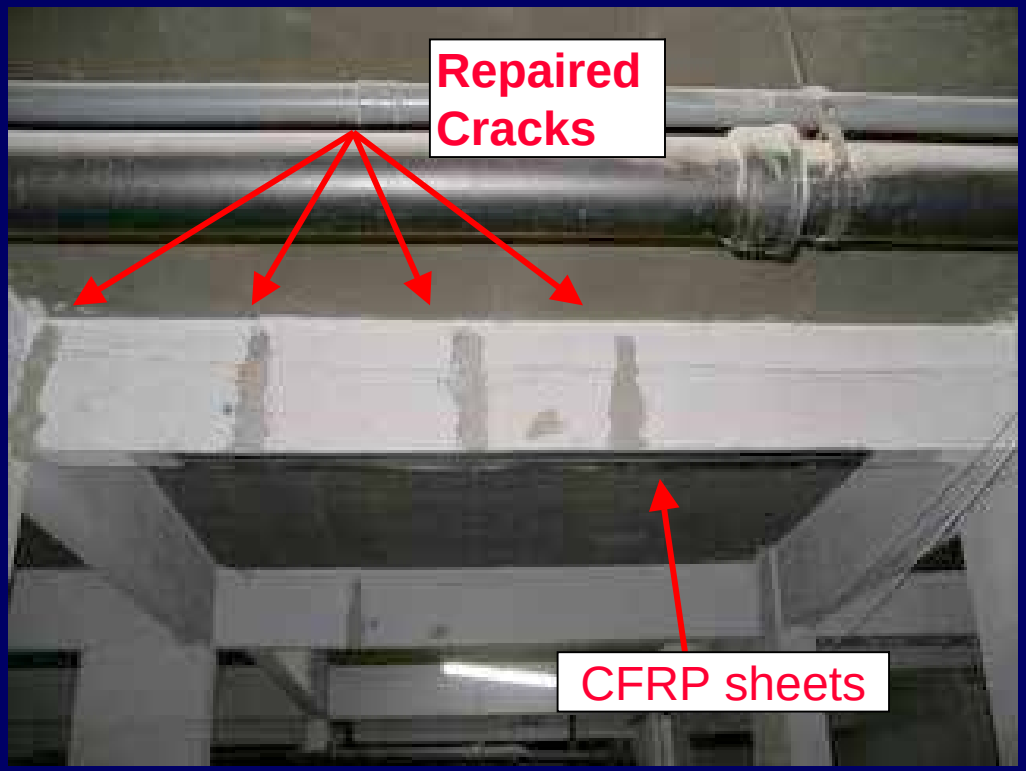
- Cracks in URM Walls
- No Visible Damage to Structure
- Schmidt Hammer
  - 28 N/mm^2

Islamabad Park Towers

- Cracks in Beams of:
  - Basement
  - Open corridor in upper stories

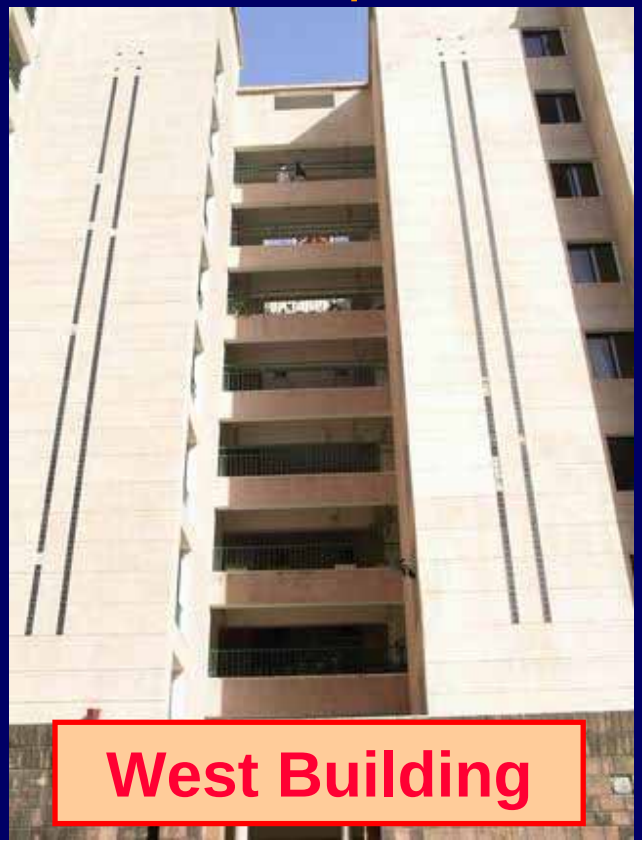
Islamabad Park Towers

- Cracks in Beams of:
  - Basement: Mid-span ➔ Vertical Loads ➔ Initiated before
  - Open corridor in upper stories EQ



Islamabad Park Towers

- Cracks in Beams of:
  - Basement: Mid-span
  - Open corridor in upper stories: Beam-ends ➔ Caused by EQ



West Building

East Building

Islamabad Park Towers

- Cracks in Beams of:
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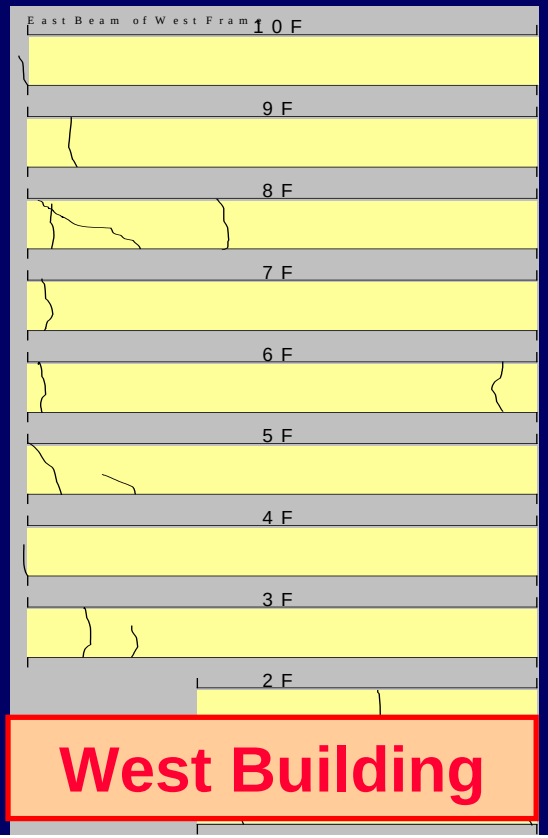
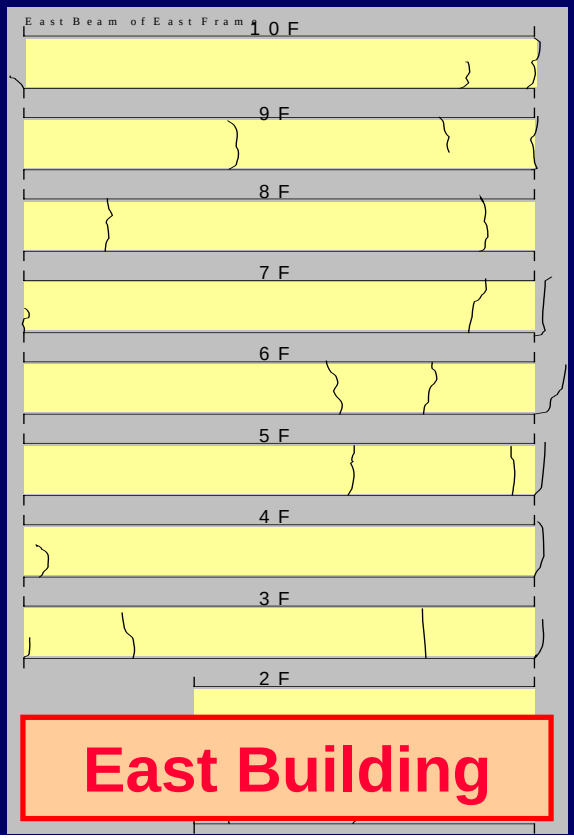
  - Open corridor in upper stories: Beam-ends ➔ Caused by EQ



West Building



East Building

No major difference in crack patterns between two buildings

➔ Two buildings behaved in the same manner

➔ Quantitative damage surveys are essential

Islamabad Park Towers

- Pounding at Expansion Joints
  - Wider gaps between adjacent buildings are recommended

Islamabad Other Issues

- Poor Detailing of Rebars
  - Beam rebars out of column reinforcement cage
  - 90-degree hooks of shear reinforcement

Battal Primary School

- 2-story School Designed to Japanese Building Code
  - Flexural cracks at the top of a column
  - Extensive shear cracks in an URM wall

Battal Primary School

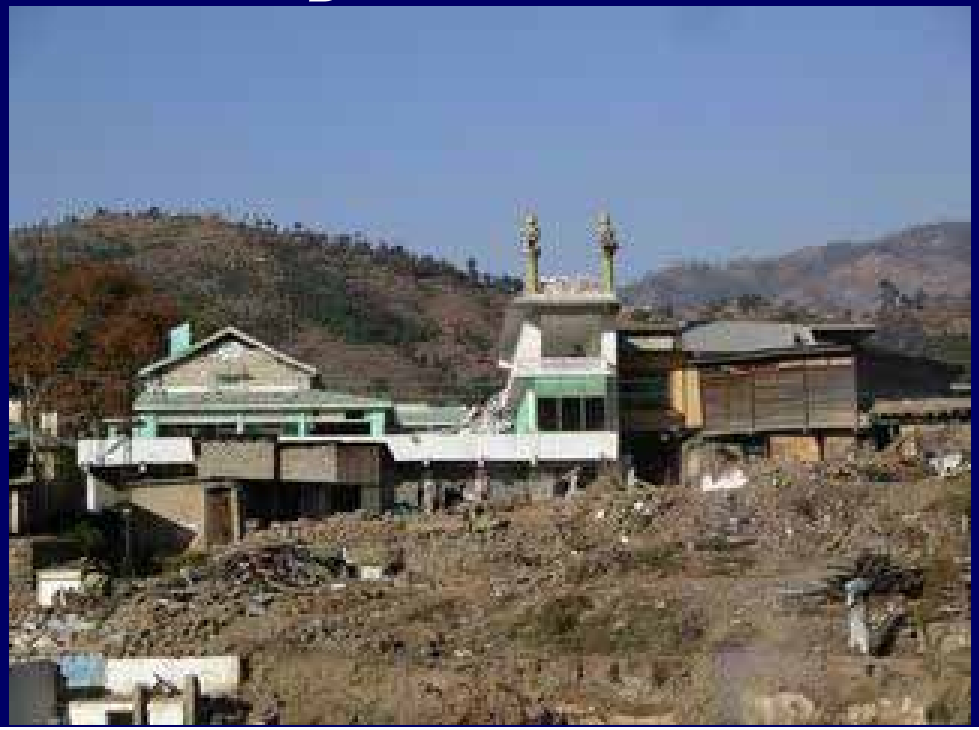
- Flexural Cracks Exposing Reinforcing Bars
  - Shear reinforcement: D10@10cm with 135-degree hooks
  - No buckling of main bars observed

Battal Primary School

- Evidence of Strong Shaking but Survived the EQ
- Schmidt Hammer Tests: 21 N/mm^2
- Seismic Capacity Evaluation: C_B=0.48
  (C_B= Strength / Building Weight : Base Shear Coef.)

Battal Jamia Mosque

- Columns Seriously Damaged
- URM Walls Had Extensive Shear Cracks
- Seismic Capacity Evaluation: C_B=0.14
  (C_B= Strength / Building Weight : Base Shear Coef.)

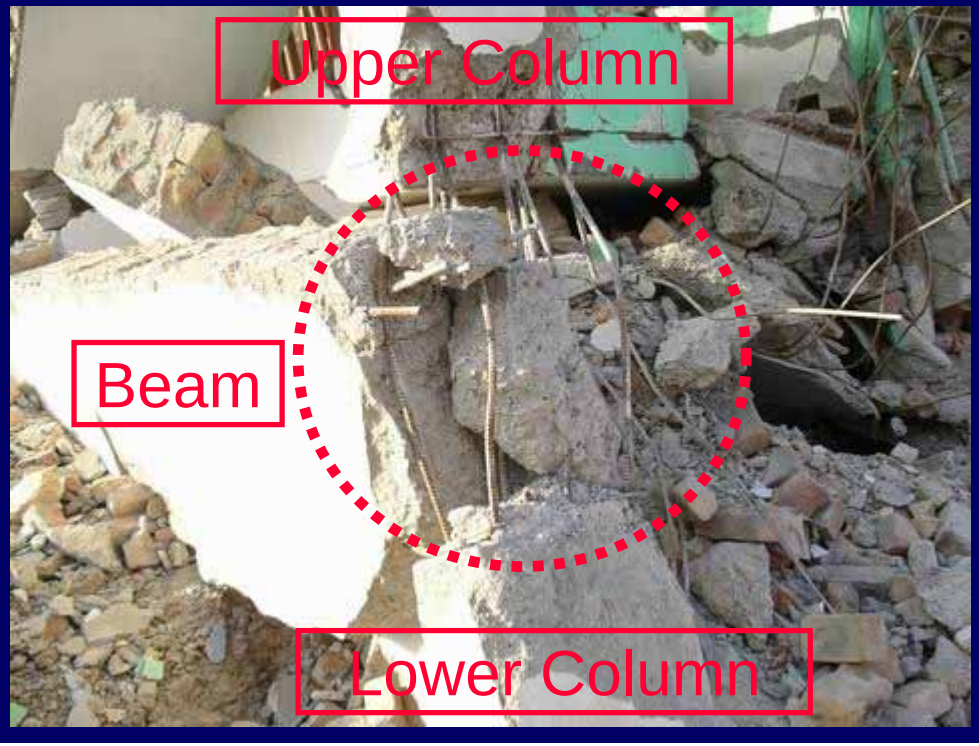


Abottabad

- Poor Shear Reinforcement in Members
- Poor Reinforcement Detailing in Beams

Abottabad

- Poor Shear Reinforcement in Members
  - Small diameter (6mm to 8mm) and wide space (30cm)
  - 90-degree hooks
  - No shear reinforcement in beam-column joints

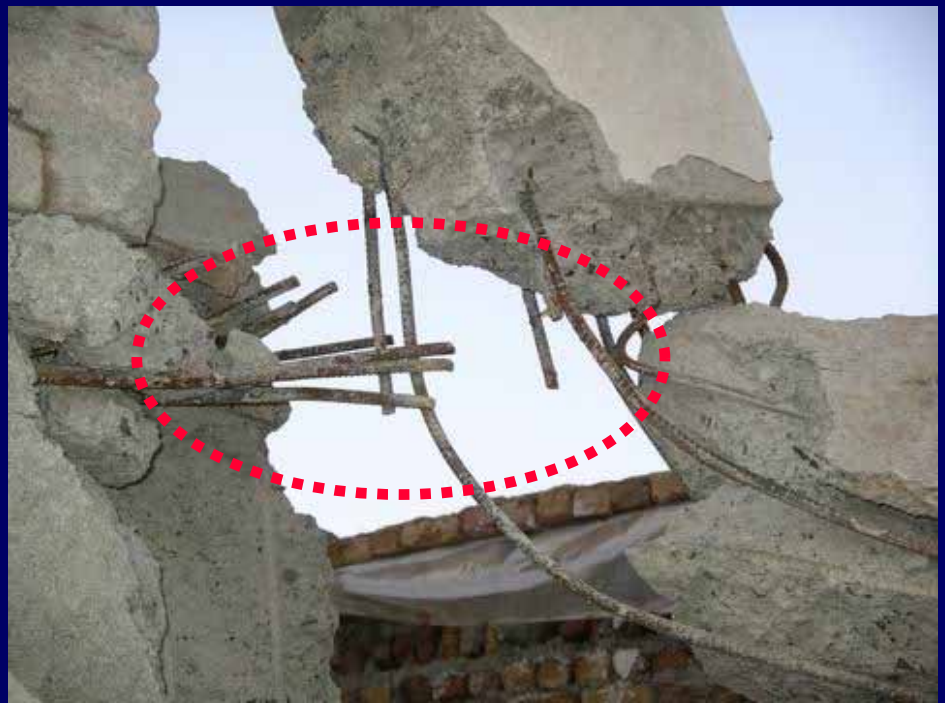


Abottabad

- Poor Reinforcement Detailing in Beams
  - Anchored straightly into beam-column joints
  - No bent into core concrete

  ➔ Beam-column connection failure

  ➔ Pin-connected frames rather than moment resisting frames



Abottabad

- Poorly Repaired Damaged Buildings

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Abottabad

- Poorly Repaired Damaged Buildings
  - ➔ Technical guidelines for post-earthquake rehabilitation are most needed

Abottabad

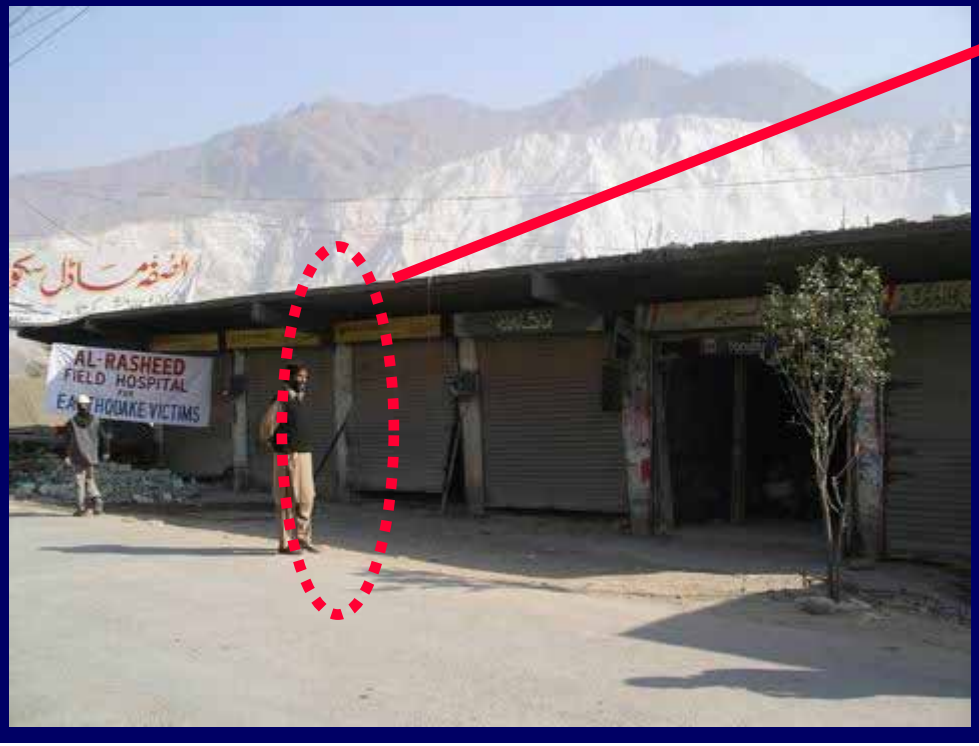
- Quality of Reinforcing Bars
  - Brittle failure without necking at fractured section
  - Also observed in other areas

Muzaffarabad

Muzaffarabad

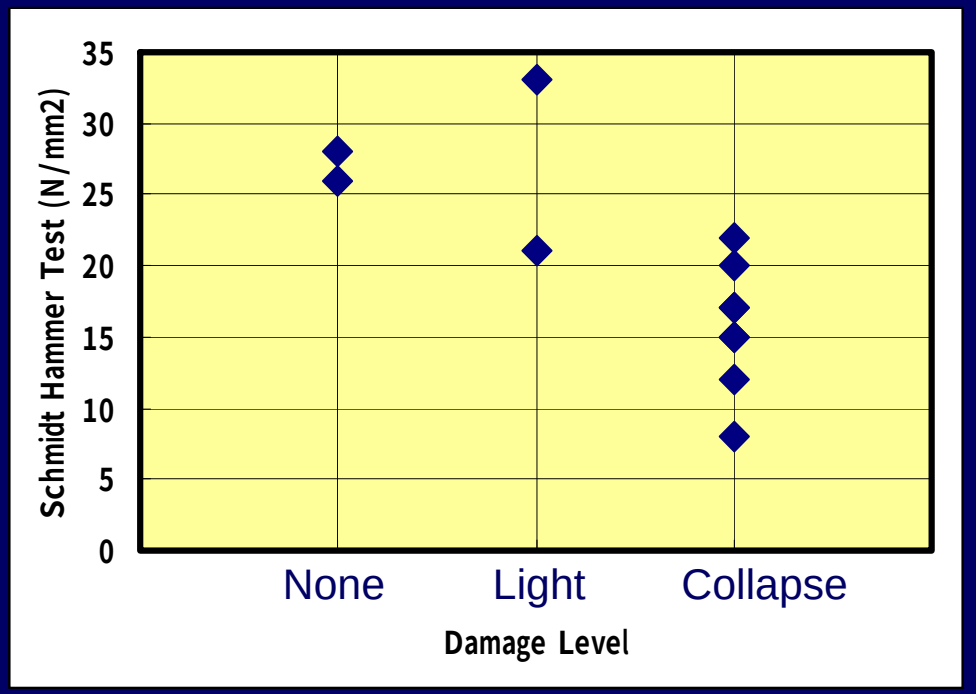
- Vulnerable Buildings in Use

➔ Quick inspection of damaged buildings needed



Summary of Investigations (1/5)

- Concrete Quality
  - No ready-mixed concrete
  - Honeycombs
  - Coarse/fine aggregate
  - Damage vs. strength
- Reinforcement Quality
  - Brittle failure



Summary of Investigations (2/5)

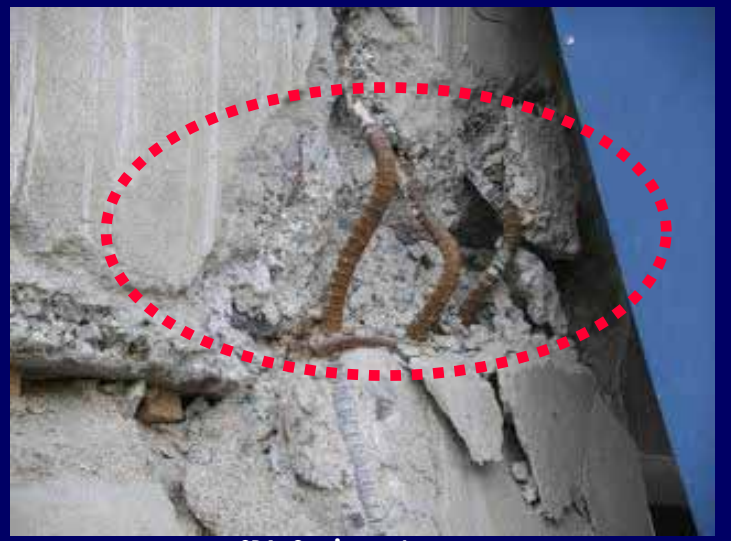
- Properly anchored beam rebars in joints to avoid
  - Easy pulled-out failure
  - Pin-connected frames (➔ moment resisting frames)
- Shear Reinforcement and Concrete Confinement
  - Too small and widely spaced shear reinforcement
  - 90-degree hooks (➔ 135-degree hooks)

  for poor ductility and axial load carrying capacity

Summary of Investigations (3/5)

- Nonstructural Damage to URM (Unreinforced Masonry) Walls
  - Falling debris: hazardous to occupants
  - Lateral resistance and stiffness from RC and/or RM Walls

- Beam-Column Joints
  - No shear reinforcement in practice
  - Joint failure with buckling of rebars



Summary of Investigations (4/5)

- Pounding
  - Gaps large enough to avoid pounding
- Site Effects
  - Site effects and resulting amplified ground motions
  - Microtremor measurements
- Strong Motion Observations
  - Observed damage vs. input ground motions
  - Design EQ loads determination

Summary of Investigations (5/5)

- Quantitative Post-Earthquake Inspection
  - Safety evaluation of damaged buildings to aftershocks
  - Quick inspection system, procedures, and inspectors

- Rehabilitation Strategies and Techniques
  - Damaged sections not fully recovered to the original
  - Buckled rebars still in use
  - Tilted buildings (obviously hazardous) not re-centered

  ➔ Technical guides to properly repair/strengthen damaged buildings