SASPARM 2.0

EUCENTRE European Centre for Training and Research in Earthquake Engineering

IUSS Scuola Universitaria Superiore Pavia

Support Action for Strengthening PAlestine capabilities for seismic Risk Mitigation

SASPARM 2.0

2014 PROJECT FOR CIVIL PROTECTION FINANCIAL INSTRUMENT PREPAREDNESS AND PREVENTION SCHEME

RETROFIT MEASURES
BUILDING CONTRACTORS (deficiencies)

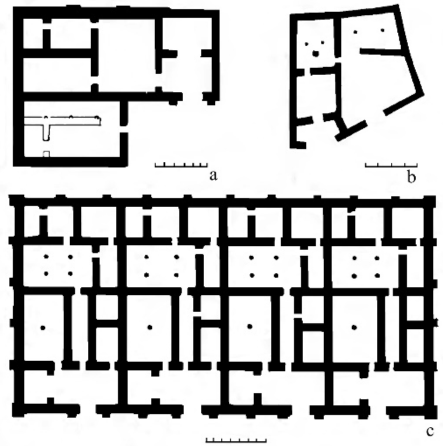
Pavia – Nablus
May 25, 2016

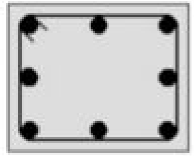
ECHO/SUB/2014/694399 - SASPARM 2.0 Support Action for strengthening PAlestine capabilities for seismic Risk Mitigation
Project co-funded by ECHO - Humanitarian Aid and Civil Protection

Presentation outline

1. General overview;
2. Classes of rehabilitation techniques;
3. RC: main deficiencies;
4. URM: main deficiencies;
5. Retrofit measures: common and advanced ones;
6. Implementation in Palestine.

Retrofitting of existing structures





1. Gather information about existing structure (plans)

2. Gather information about material conditions (non destructive testing methods)

3. Structural assessment of existing structure

4. Propose retrofitting measures and assess corresponding direct and indirect cost

5. Implementation of retrofitting measures

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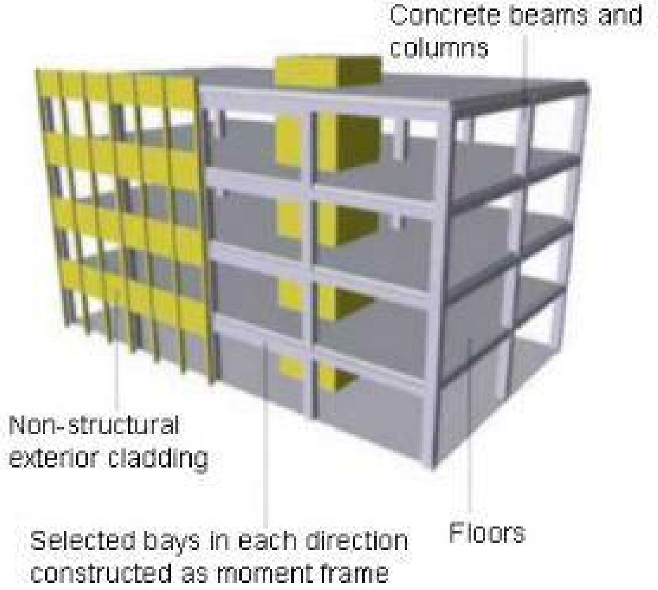
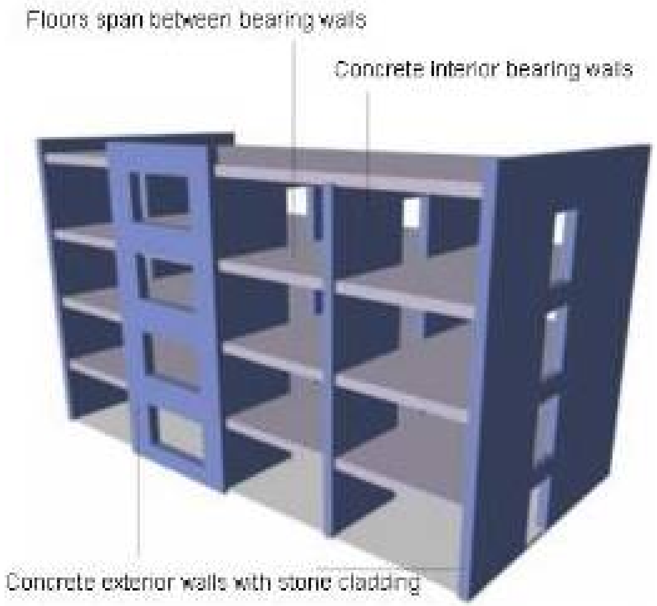
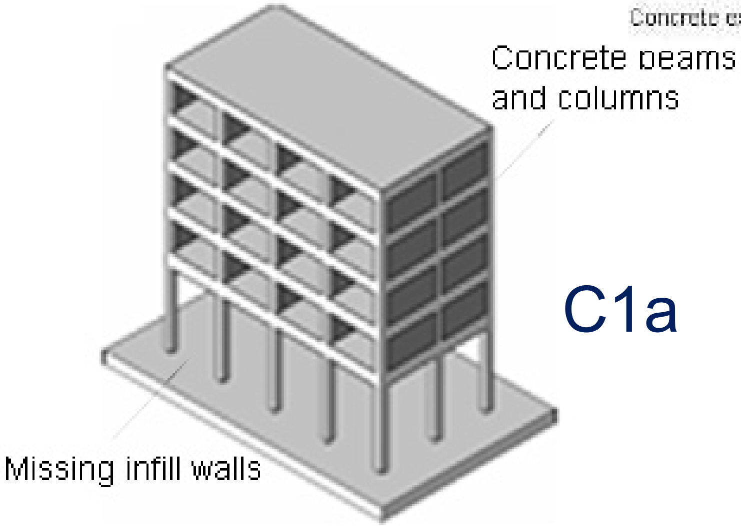
RC TYPOLOGIES



C1



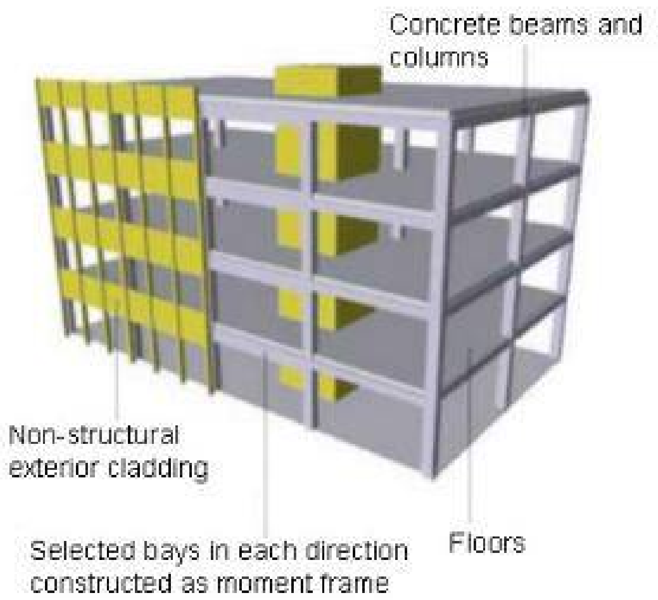
C2



C1a

Adapted from FEMA 547: Federal Emergency Management Agency, *Techniques for the seismic rehabilitation of existing buildings*, October 2006.

RC FRAME TYPOLOGY



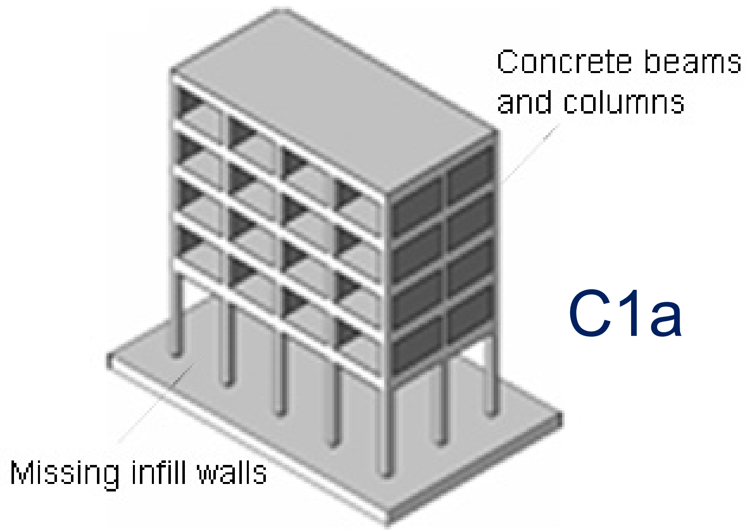
C1

Type C1 can be generically defined as a complete RC frame system of beams and columns supporting slabs.

Adapted from FEMA 547: Federal Emergency Management Agency, *Techniques for the seismic rehabilitation of existing buildings*, October 2006.

RC FRAME (soft storey) TYPOLOGY

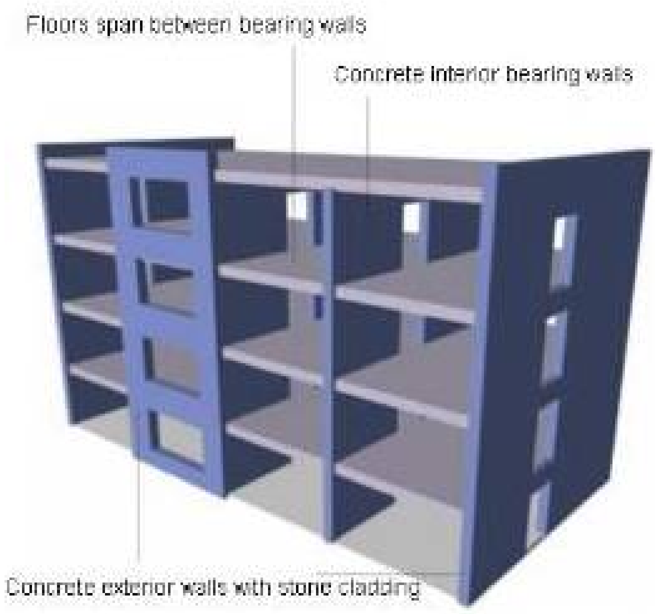
RC buildings with soft storey (C1a) have the same structural characteristics with type C1, but with the peculiarity of lacking significant infill walls in a floor or in a side of it.



C1a

DUAL SYSTEM TYPOLOGY

Building Type C2 is made of RC shear walls.
RC columns may be present for carrying gravity loads only.
It is the only typology that fulfills requirements of Seismic Code.

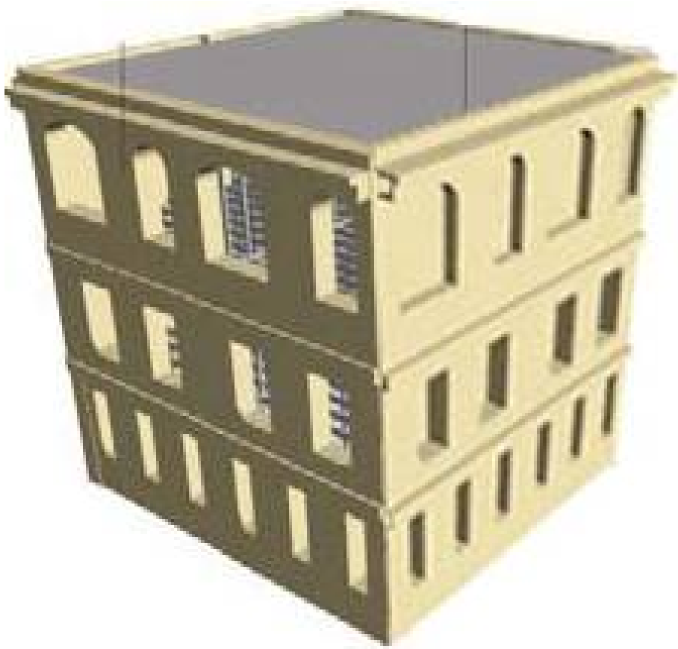


C2

Adapted from FEMA 547: Federal Emergency Management Agency, *Techniques for the seismic rehabilitation of existing buildings*, October 2006.

UNREINFORCED MASONRY TYPOLOGY

Building Type URM consists of unreinforced masonry bearing walls.
In general, all walls act as both bearing and shear walls
and the floors are concrete slabs cast-in-place.



URM

Adapted from FEMA 547: Federal Emergency Management Agency, *Techniques for the seismic rehabilitation of existing buildings*, October 2006.

Category of Seismic Deficiency vs Classes of Rehabilitation Techniques

- ✓ Global Strength / Stiffness;
- ✓ Configuration;
- ✓ Sectional Detailing;
- ✓ Diaphragms;
- ✓ Foundations.

- ✓ **Addition** of new elements (increasing strength/stiffness);
- ✓ **Enhancement** of existing elements (increasing strength or deformation capacity);
- ✓ **Reduction** of demand (providing acceptable performance for weak lateral system);
- ✓ **Removal** of selected components (enhancing deformation capacity).

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Global Strength/Stiffness and Configuration	Building Category		
	C1/C1a	C2	URM
Insufficient n° of frames	X		
Short – column mechanism	X		
Infill walls failing or causing torsion	X		
Insufficient in-plane wall strength			X
Re-entrant corner	X	X	X
Torsional layout (RC elevator core and staircases)	X	X	X
Discontinuous walls		X	
Soft-storey	X		

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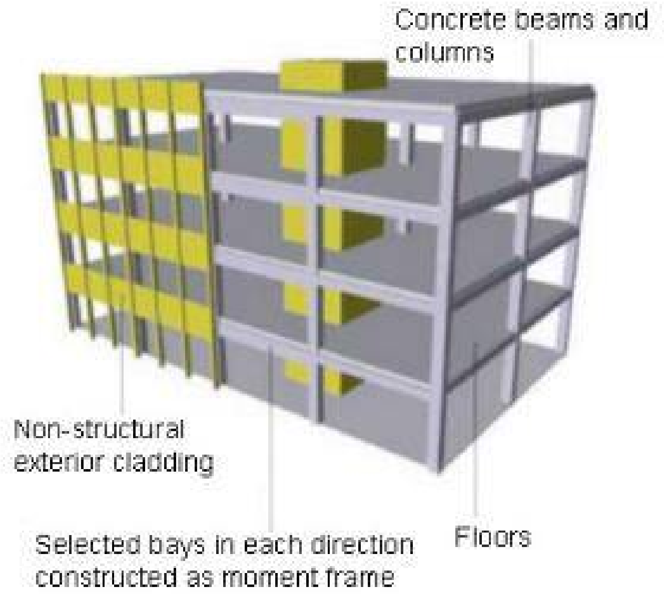
Structural Detailing	Building Category		
	C1/C1a	C2	URM
Weak column – strong beam	X		
Inadequate shear strength in column or beam	X	X	
Splices	X		
Insufficient in-plane wall shear strength (web or boundary element)		X	
Insufficient flexural capacity (chord rotation)	X	X	
Brittle failure of coupling beams		X	
Wall inadequate for out-of-plane bending			X
Unbraced parapet			X
Poorly anchored veneer or appendages			X

Diaphragms	Building Category		
	C1/C1a	C2	URM
Inadequate in-plane shear capacity	X	X	X
Punching shear failure of slab-column connection	X		
Excessive stresses at openings and irregularities	X	X	X
Inadequate chord capacity	X	X	X

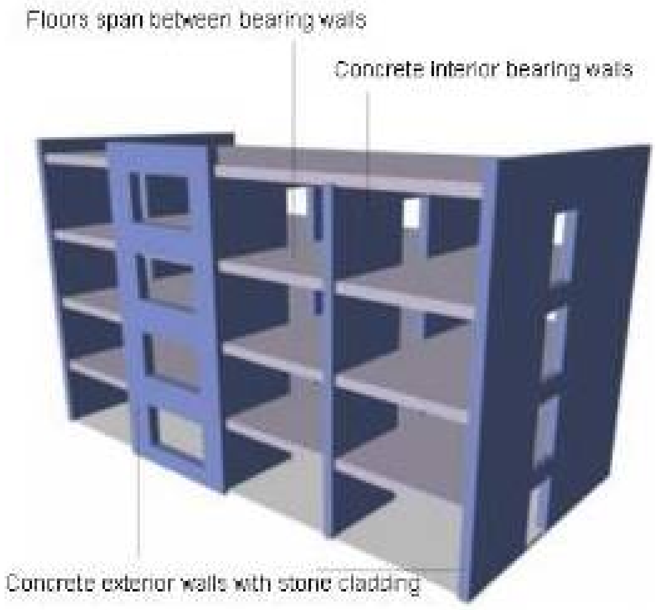
Foundations		Building Category		
		C1/C1a	C2	URM
New Foundations	Add shallow found next to existing shallow ones	X	X	X
	Add deep foundations next to existing shallow ones	X	X	X
Existing Shallow Foundations	Add Micropiles			
	Enlarge exisisting spread footing	X	X	X
Existing Deep Foundations	Add a Mat Foundation, Extended Pile Cap or Grade Beam	X	X	X
Ground Improvement	Compaction Grouting	X	X	X
	Permeation Grouting	X	X	X

RC MAIN DEFICIENCIES

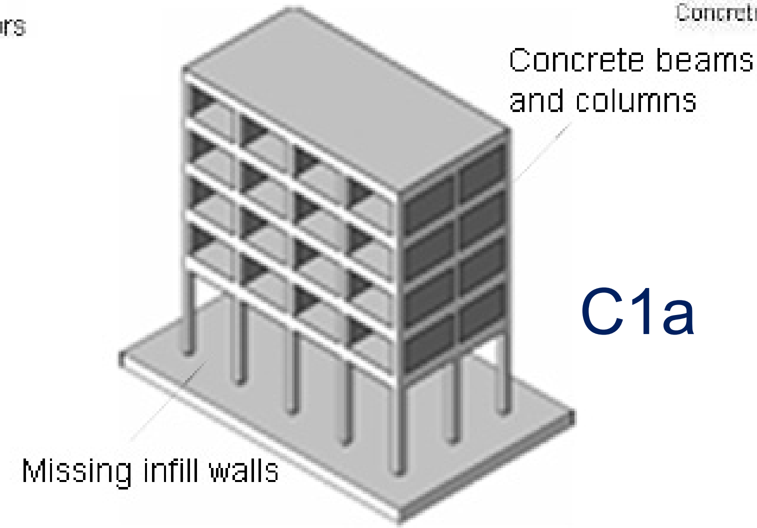
FRAME and DUAL SYSTEM TYPOLOGY



C1



C2



C1a

Adapted from FEMA 547: Federal Emergency Management Agency, *Techniques for the seismic rehabilitation of existing buildings*, October 2006.

RC Deficiencies – Global Strength /Stiffness

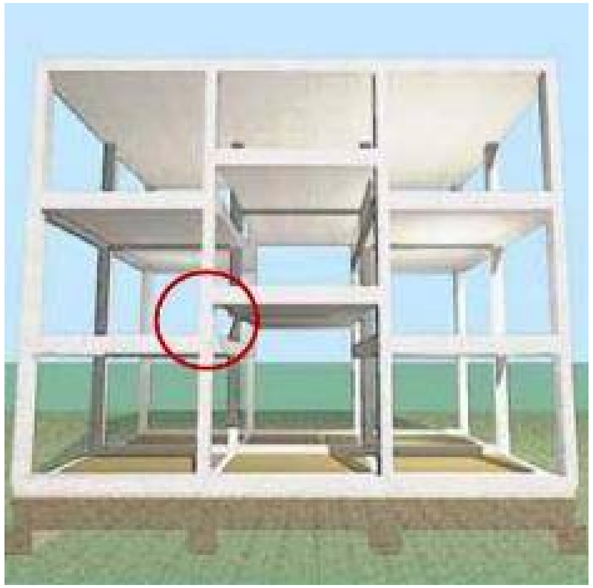
✓ Insufficient number of frames

- Frames in only one direction;
- Frame not related to each other in order to resist in both direction;
- Frame would present irregularities.

Italian Department of Civil Protection, *Manuale per la compilazione della scheda di 1° livello di rilevamento danno, pronto intervento e agibilità per edifici ordinari nell'emergenza post-sisma (AeDES)*, 2014.

RC Deficiencies – Global Strength /Stiffness

✓ Frames with inadequate stiffness


Italian Department of Civil Protection, *Manuale per la compilazione della scheda di 1° livello di rilevamento danno, pronto intervento e agibilità per edifici ordinari nell'emergenza post-sisma (AeDES)*, 2014.

- Tall column with instability problem;
- Short column with high concentration of shear stress.

RC Deficiencies – Global Strength /Stiffness

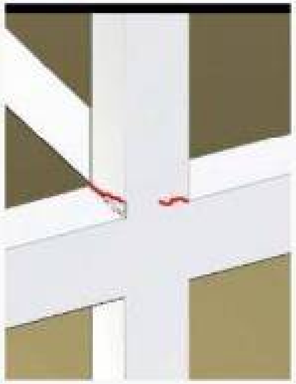
✓ Infill walls failing or causing torsion

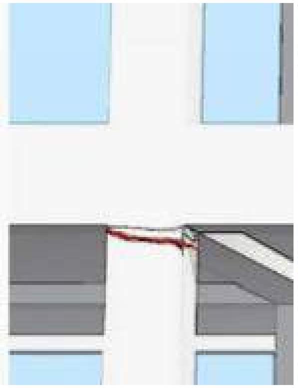
- Infill walls collapse out-of-plane due to inadequate fixing to the frame (causing only mass addition);
- Infill walls not appropriate arranged to the frame structure cause asymmetrical behavior.

Italian Department of Civil Protection, *Manuale per la compilazione della scheda di 1° livello di rilevamento danno, pronto intervento e agibilità per edifici ordinari nell'emergenza post-sisma (AeDES)*, 2014.

RC Deficiencies – Structural Detailing

✓ Weak column – strong beam (should be avoided)

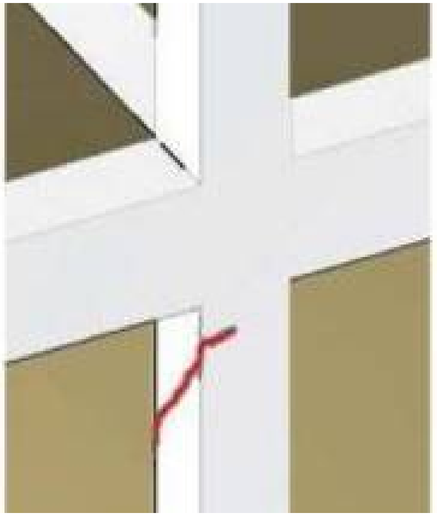


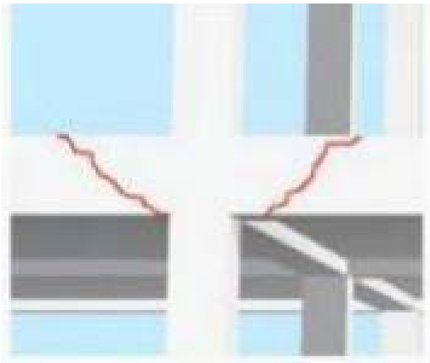

- Column sway plastic mechanism
- Plastic hinge at the top or the base of the column due to an element with higher stiffness

Italian Department of Civil Protection, *Manuale per la compilazione della scheda di 1° livello di rilevamento danno, pronto intervento e agibilità per edifici ordinari nell'emergenza post-sisma (AeDES)*, 2014.

RC Deficiencies – Structural Detailing

✓ Inadequate transverse reinforcement

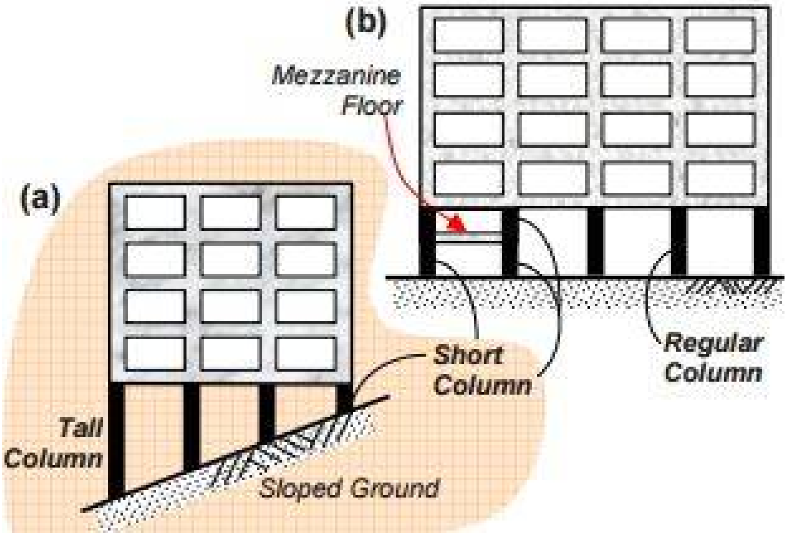


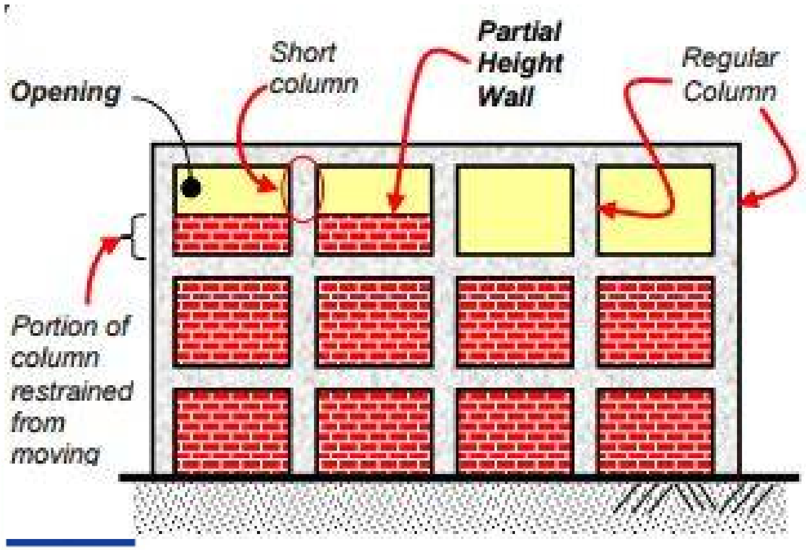



- Inadequate shear resistance in beam and/or columns;
- Poor restraints against buckling of longitudinal reinforcement.
- Low member ductility

Italian Department of Civil Protection, *Manuale per la compilazione della scheda di 1° livello di rilevamento danno, pronto intervento e agibilità per edifici ordinari nell'emergenza post-sisma (AeDES)*, 2014.

✓ Short column mechanism

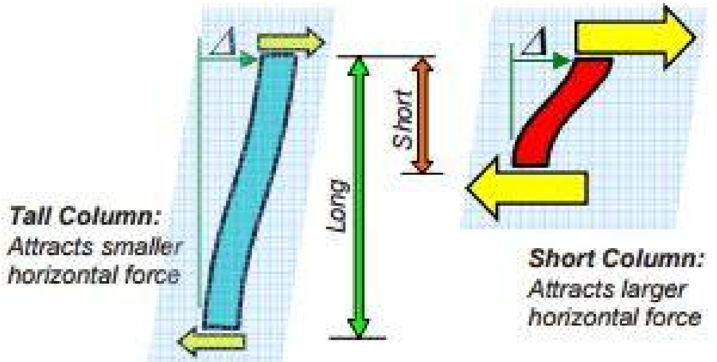


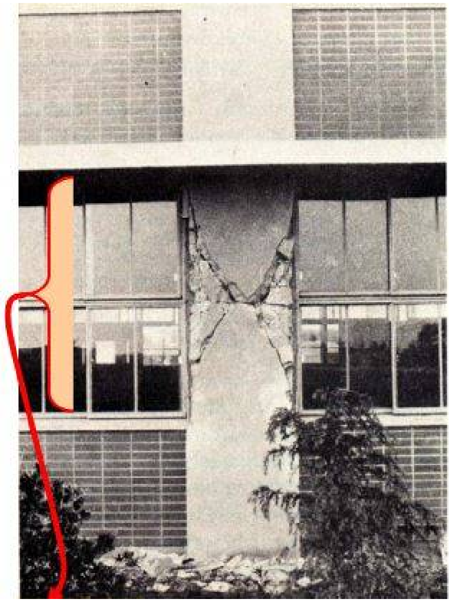


- Building is rested on sloped ground;
- In columns supporting mezzanine floors or loft slabs that are added in between two regular floors;
- Walls of partial height built, adjacent columns behave as short columns due to presence of these walls.

C.V.R. Murty, *Why are Short Columns More Damaged during Earthquakes?,* Indian Institute of Technology, Kanpur, 2004.

✓ Short column mechanism





Poor behavior of short columns because a tall column and a short column of same cross-section move horizontally by same amount Δ;

- Short column is stiffer than tall column and it attracts larger earthquake force;
- Larger is the stiffness, larger is the force required to deform it;
- If a short column not adequately designed for a large force, it can suffer significant damage;
- X-shaped cracking due to shear failure.

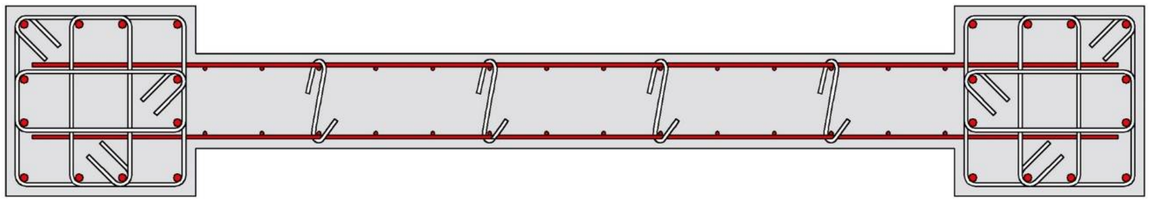
C.V.R. Murty, *Why are Short Columns More Damaged during Earthquakes?*, Indian Institute of Technology, Kanpur, 2004.

RC Deficiencies – Sectional Detailing

✓ Insufficient wall shear strength (shear wall typology)

- Inadequate transverse reinforcement in web (horiz. rebars);
- Inadequate boundary elements (stirrups);
- Early brittle failure of crucial elements.

Desirable configuration



RC Deficiencies – Structural Detailing

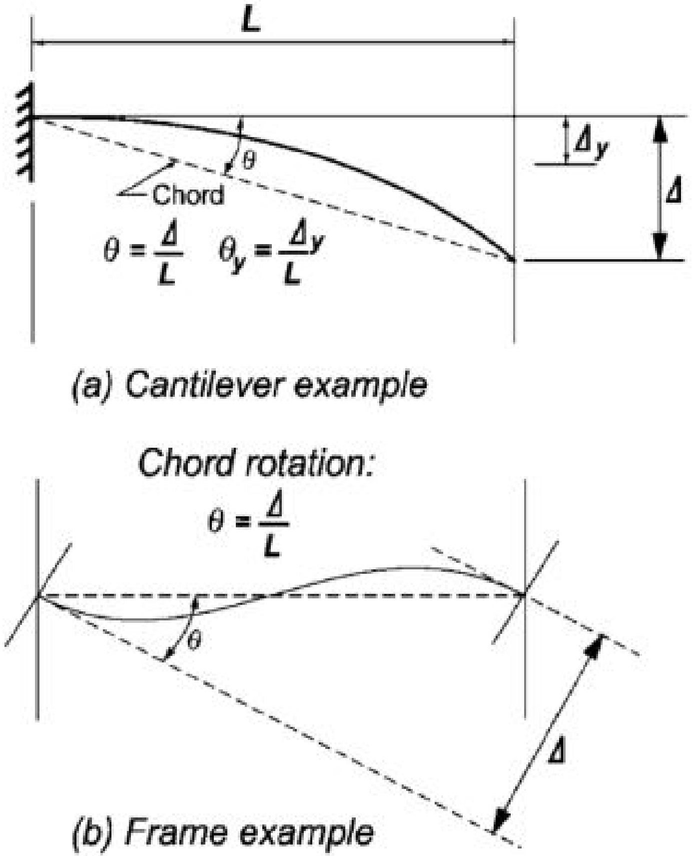
✓ Splices

- Beam-column joint with inadequate reinforcement;
- Beam-column joint with improper anchorage of longitudinal beam reinforcement.

Italian Department of Civil Protection, *Manuale per la compilazione della scheda di 1° livello di rilevamento danno, pronto intervento e agibilità per edifici ordinari nell'emergenza post-sisma (AeDES)*, 2014.

RC Deficiencies – Structural Detailing

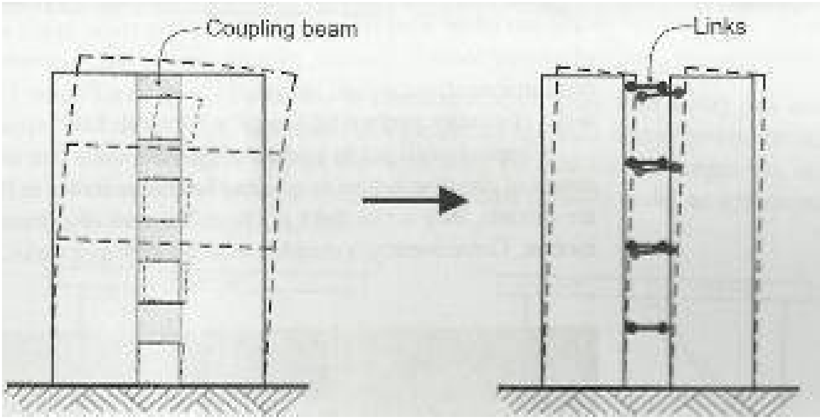
✓ Insufficient flexural capacity



- Inadequate confinement of beams/columns/walls in the critical regions;
- Early plastic hinge formation;
- Sections not reach large curvature values limiting the chord rotation capacity (ductility) and energy dissipation of the elements.

RC Deficiencies – Structural Detailing

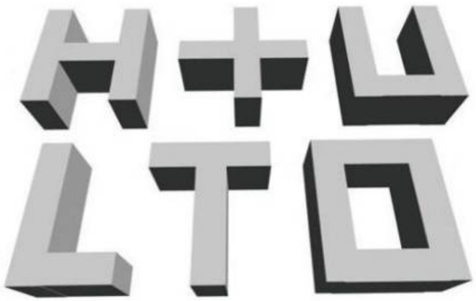
✓ Brittle failure of coupling beams

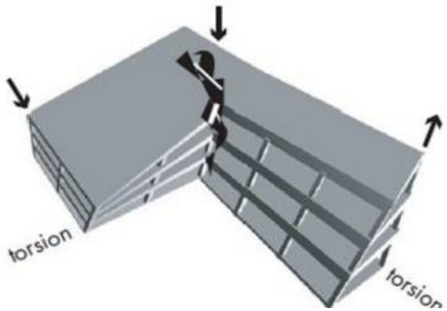


- The behavior of coupled shear walls is governed by coupling beams;
- Purpose of beams between coupled walls is transfer shear from one wall to the other;
- Many coupling beams are designed as conventional flexural members;
- Beams will inevitably fail in diagonal tension;
- Diagonal failure crack will divide a beam into two triangular parts.

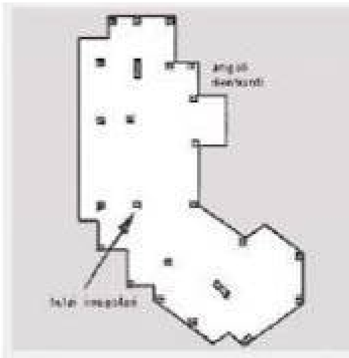
RC Deficiencies - Configuration

✓ Re-entrant corner

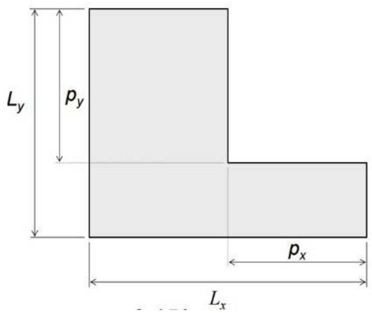




FEMA 451, *NEHRP Recommended Provisions: Design Examples*, August 2006.



- H, I, T, L, C, U shapes;
- Causes torsion due to center of mass ≠ center of rigidity
- Produces differential motion between different wings of the building leading to local stress concentration.

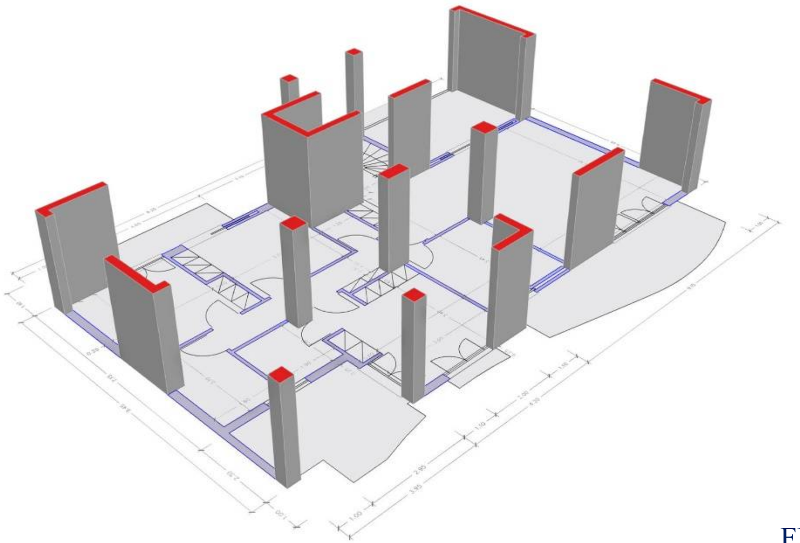


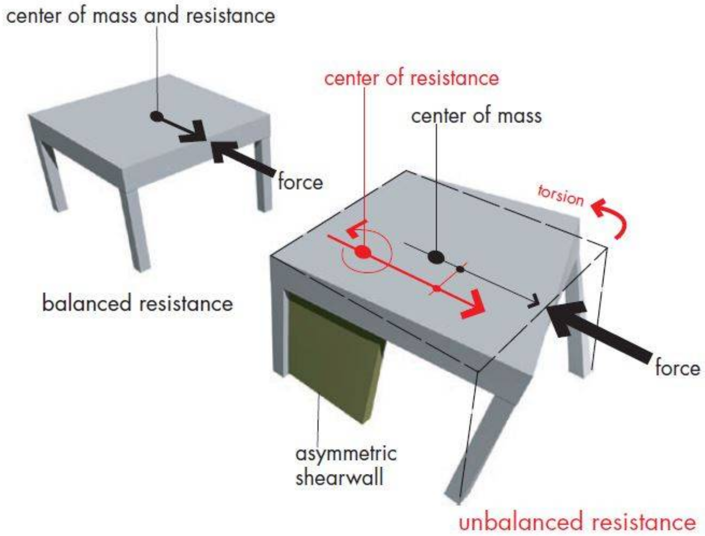
- Irregularity if $p_x > 0.15\ L_x$ and $p_y > 0.15\ L_y$

M. Divyashree, G. Sippada, *Seismic Behavior of RC Building with Re-entrant Corners and Strengthening*, IOSR Journal of Mechanical and Civil Engineering, e-ISSN: 2278-1684, pp. 69-69, 2013.

RC Deficiencies - Configuration

✓ Torsional Layout (RC elevator and staircase) frame typology



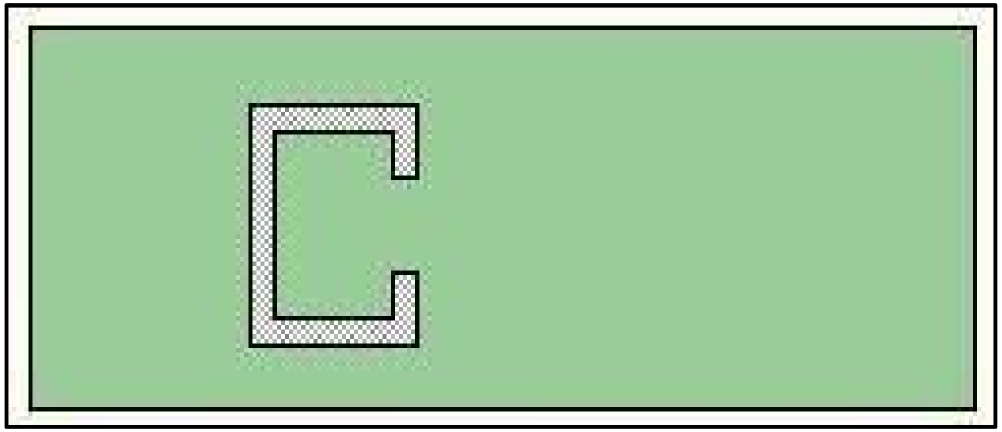


FEMA 451, *NEHRP Recommended Provisions: Design Examples*, August 2006.

- Lack of balance between the location of the resisting elements and the arrangement of the building mass;
- Eccentricity problem: center of mass ≠ center of resistance;
- Eccentricity during earthquake leads building rotating around its center of resistance, creating torsion in plan.

RC Deficiencies - Configuration

✓ Torsional Layout (RC elevator and staircase) shear wall typology



- Shear walls are concentrated around elevator shafts and staircases;
- Lack of good torsional response due to stiffness eccentricity.

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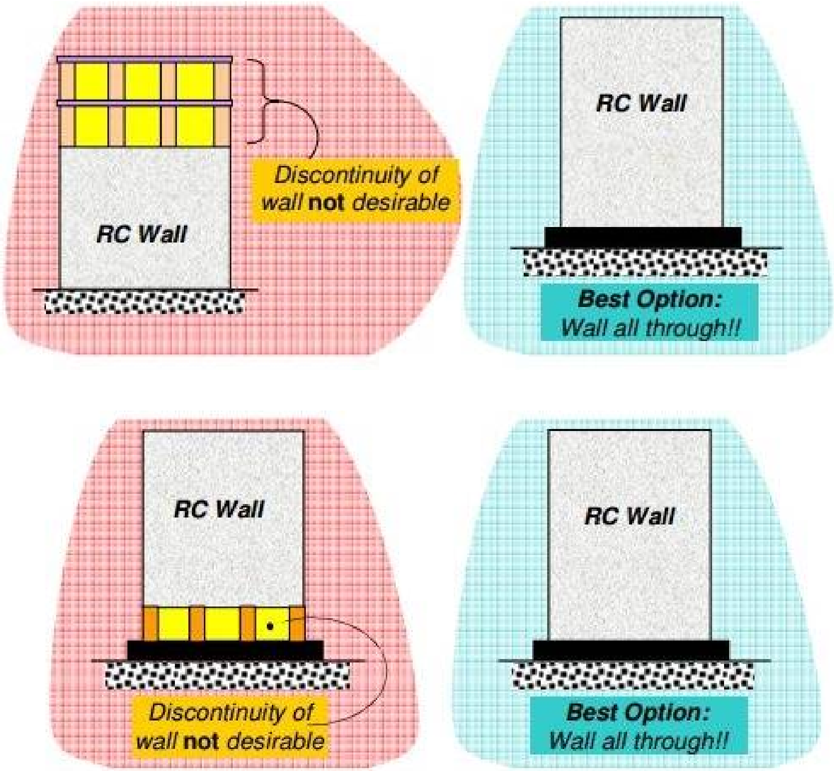
RC Deficiencies - Configuration

✓ Discontinuous walls (shear wall typology)

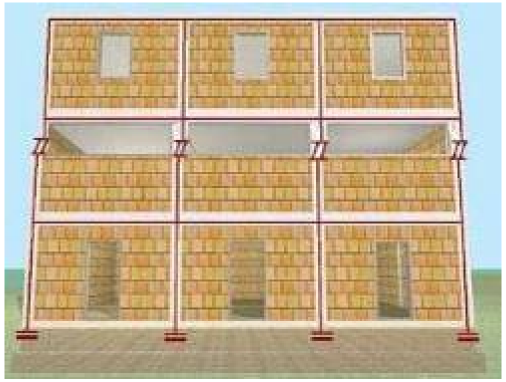


- Serious overstressing due to the non-continuity of the load path through the walls from the roof to foundation;
- Building unable to resist seismic forces regardless of the strength of the existing elements;
- Caution for gaps in the load path (e.g. discontinuity in height).

RC Deficiencies - Configuration

✓ Soft storey (frame typology)



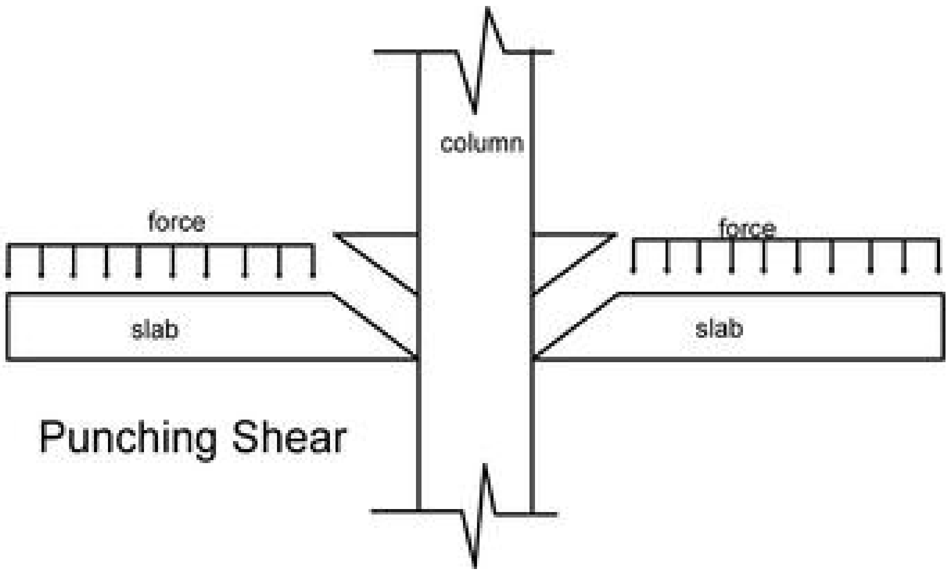



- Abrupt variation in storey stiffness along vertical direction;
- A storey has lower stiffness respect to upper storeys triggering soft storey mechanism failure;
- Plastic hinges form at column ends of one floor;
- Leads to column sway plastic mechanism and to low energy dissipation

Italian Department of Civil Protection, *Manuale per la compilazione della scheda di 1° livello di rilevamento danno, pronto intervento e agibilità per edifici ordinari nell'emergenza post-sisma (AeDES)*, 2014.

RC Deficiencies - Diaphragms

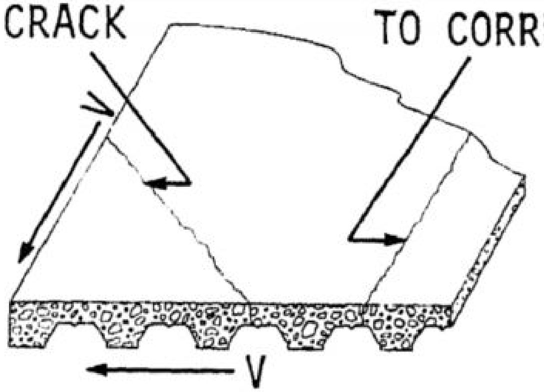
✓ Punching shear failure of slab-column connection (frame typology)



- Due to high localized forces in RC slabs;
- In flat slab structures this occurs at column support points;
- Catastrophic failure because no visible signs are shown prior to failure.

RC Deficiencies - Diaphragms

✓ Inadequate in-plane shear capacity



- When concrete stress reaches its tensile limit, diagonal cracks (at an angle of approximately 45°) occur across the slab;
- Direct shearing of the concrete along a line parallel to the deck corrugations.

RC Deficiencies - Diaphragms

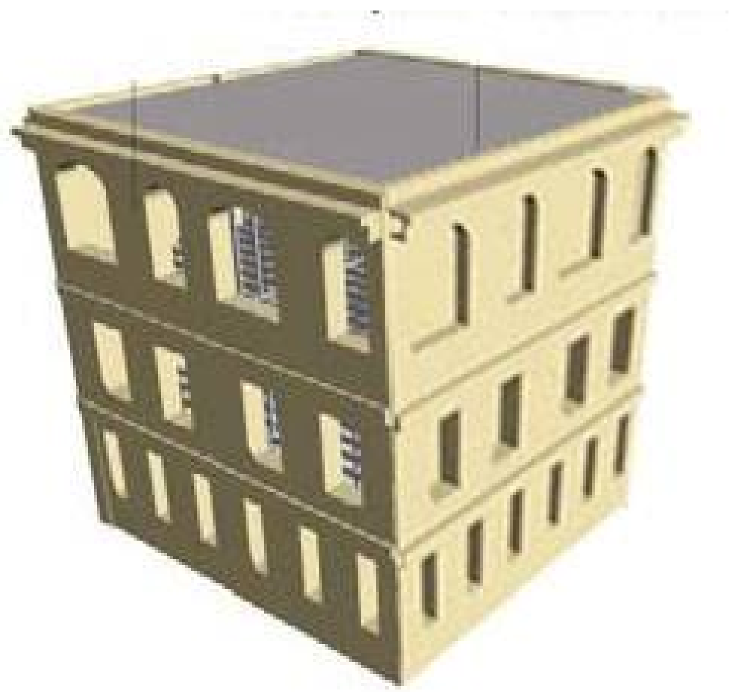
✓ Excessive stresses at openings and irregularities

M. Mota, M. Kamara, *Floor Openings in Two-Way Slab*, Concrete International, American Concrete Institute, Farmington Hills, USA, July 2006, pp. 33-36.

- Openings in existing slabs should be approached with caution and avoided if possible;
- Effect on the structural integrity of the slab must be analysed: especially for excess capacity and possible moment redistribution.

URM MAIN DEFICIENCIES

UNREINFORCED MASONRY TYPOLOGY

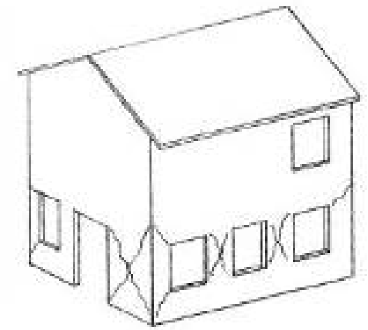


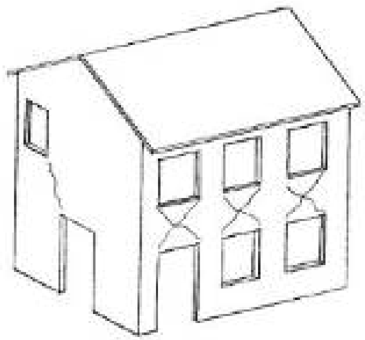
URM

Adapted from FEMA 547: Federal Emergency Management Agency, *Techniques for the seismic rehabilitation of existing buildings*, October 2006.

URM Deficiencies – Global Strength / Stiffness

✓ Insufficient in-plane wall strength



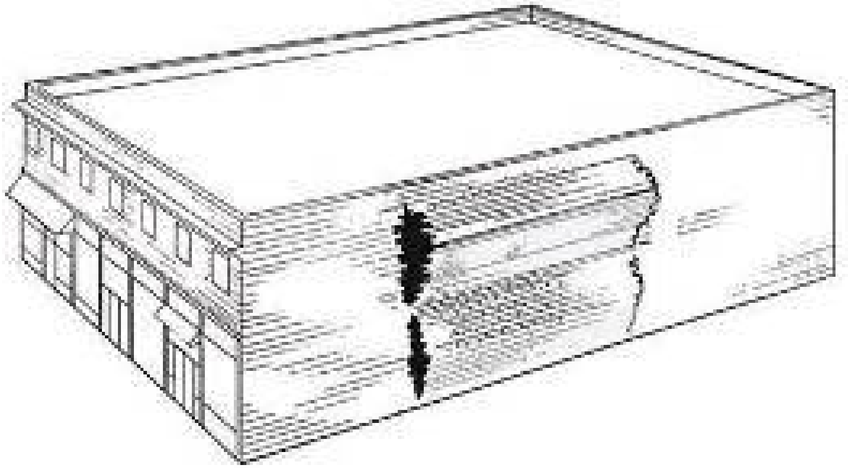


- Unreinforced walls incapable of withstanding severe repeated load reversals;
- Severe strength degradation characteristics are double-diagonal (X) shear cracking.

Italian Department of Civil Protection, *Manuale per la compilazione della scheda di 1° livello di rilevamento danno, pronto intervento e agibilità per edifici ordinari nell'emergenza post-sisma (AeDES)*, 2014.

URM Deficiencies – Structural Detailing

✓ Wall inadequacy for out-of-plane bending

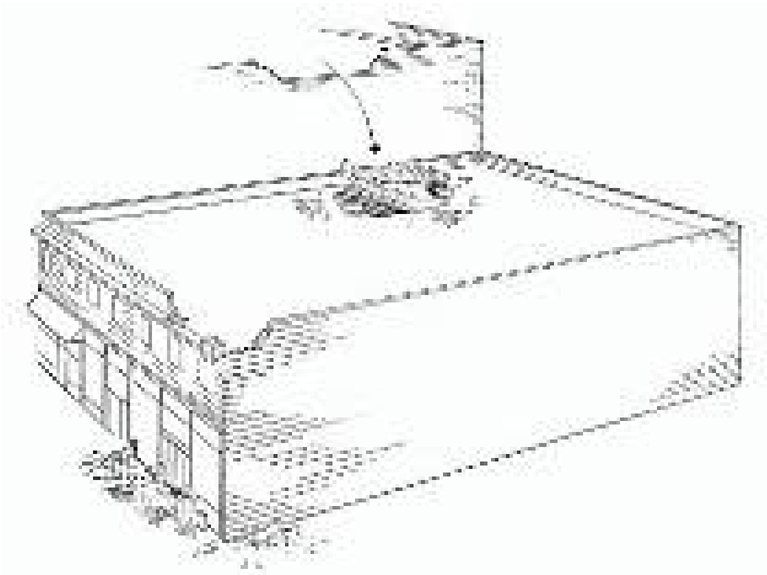


FEMA 774: Federal Emergency Management Agency, *Unreinforced Masonry Buildings and Earthquake*, October 2009.

- The unbraced length of brittle walls causes them to buckle out-of-plane during lateral loading.

URM Deficiencies – Structural Detailing

✓ Unbraced parapet

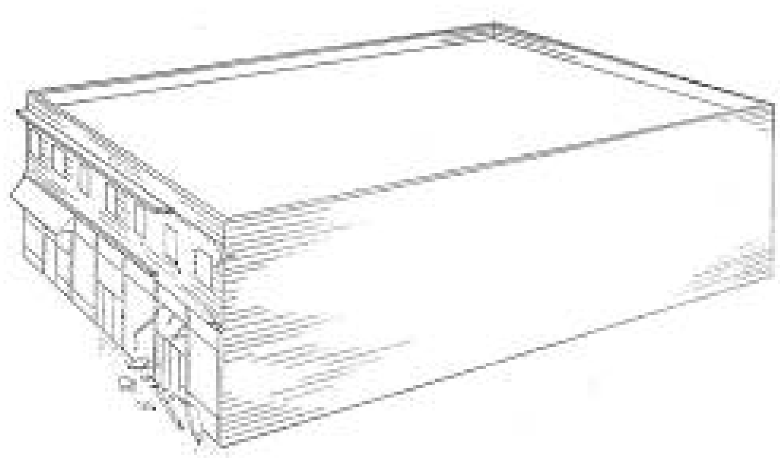


FEMA 774: Federal Emergency Management Agency, *Unreinforced Masonry Buildings and Earthquake*, October 2009.

- Parapet failures cause damages not only to the building itself, but to nearby buildings.

URM Deficiencies – Structural Detailing

✓ Poorly anchored veneer or appendages

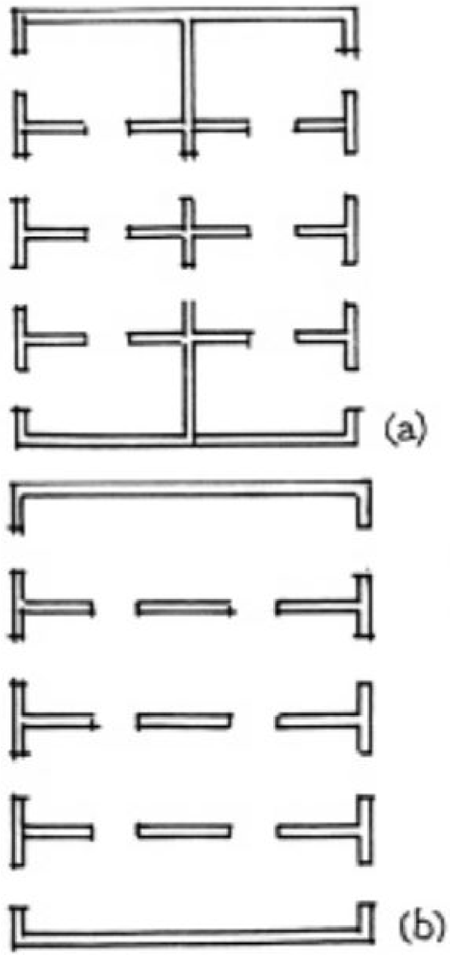


FEMA 774: Federal Emergency Management Agency, *Unreinforced Masonry Buildings and Earthquake*, October 2009.

- Non-structural elements can cause damages also in surroundings area.

URM Deficiencies – Configuration

✓ Insufficient in-plane wall strength



- Symmetrical buildings of simple form perform better than complex shapes where walls are asymmetrically distributed on plan.

M. Tomazevic, *Earthquake-Resistant Design of Masonry Building*, Imperial College Press, 2006.

URM Deficiencies – Diaphragms

✓ Inadequate in-plane strength and stiffness

2005 Pakistan Earthquake

- When concrete stress reaches its tensile limit, diagonal cracks (at an angle of approximately 45°) occur across the slab;
- Direct shearing of the concrete along a line parallel to the deck corrugations.

URM Deficiencies – Diaphragms

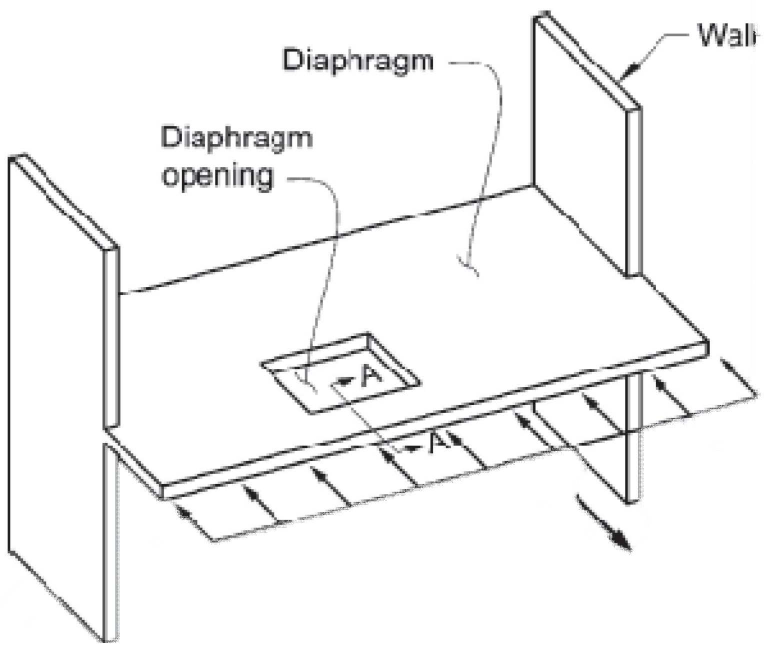
✓ Inadequate chord capacity

- Walls must be tied to the horizontal diaphragms (roof and floors) to increase their resiliency to out-of-plane loading.

Italian Department of Civil Protection, *Manuale per la compilazione della scheda di 1° livello di rilevamento danno, pronto intervento e agibilità per edifici ordinari nell'emergenza post-sisma (AeDES)*, 2014.

URM Deficiencies – Diaphragms

✓ Excessive stresses at openings and irregularities



- Large openings limit strength of diaphragm to transfer lateral forces;
- Creation of a vulnerable structural condition related to irregular construction (irregular stiffness);
- Opening/absence of a complete floor diaphragm at one or more levels results in inability to transfer lateral forces from walls at one level to walls and floors at adjacent levels.

The retrofitting measures follow …