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IUSS Scuola Universitaria Superiore Pavia

Support Action for Strengthening PAlestine capabilities for seismic Risk Mitigation

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2014 PROJECT FOR CIVIL PROTECTION FINANCIAL INSTRUMENT PREPAREDNESS AND PREVENTION SCHEME

RETROFIT MEASURES
BUILDING CONTRACTORS (common retrofitting measures)

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

Seismic Deficiencies and Potential Rehabilitation Techniques

The tables and the chapters referenced in this presentation can be found in Deliverable D.C.1.
The following three tables are adapted from FEMA 547: Federal Emergency Management Agency, *Techniques for the seismic rehabilitation of existing buildings*, October 2006.

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Seismic Deficiencies and Potential Rehabilitation Techniques (C1 / C1a)

Category	Deficiency	Add new elements	Enhance existing elements	Reduce demand (Advanced Techniques)	Remove selected components
Global Strength/ Stiffness	Insufficient n° of frames	Steel X-braces [9.1] RC shear walls [9.2] Strong masonry infill walls [9.3]	Columns and/or beams: FRP jacketing* [9.4] RC jacketing [9.5] Steel jacketing [9.5]	Seismic Isolation* Supplemental damping*	
	Short – column mechanism	Masonry infill wall [9.3]	RC jacketing [9.5]		
	Infill walls failing or causing torsion	RC shear walls [9.2]	Uncouple infill walls		Remove infill walls
Configuration	Soft story mechanism	Steel X-braces [9.1] RC shear walls [9.2] Strong masonry infill walls [9.3]			
	Re-entrant corner	RC shear walls [9.2] New seismic joint* [9.18]			
	Torsional layout (RC elevator core and staircases)	RC shear walls [9.2]			Remove RC shear walls
Sectional Detailing (ductility)	Weak column – strong beam		FRP jacketing* [9.4] RC jacketing [9.5] Steel jacketing [9.5]		
	Inadequate shear strength in column or beam		FRP jacketing* [9.4] RC/steel jacketing [9.5]		
	Insufficient flexural capacity (chord rotation)	RC shear wall [9.2] Steel X braces [9.1]	Column/Beams: RC jacketing [9.5] and FRP jacketing* [9.4] Shear walls: FRP jacketing* [9.4]	Seismic Isolation* Supplemental damping*	
	Splices		FRP jacketing* [9.4] RC/steel jacketing [9.5]		
Diaphragms	Inadequate in-plane shear capacity		RC topping slab overlay [9.15] FRP overlays* [9.16]		
	Punching shear failure of slab-column connection		RC/Steel jacketing [9.19]		
	Excessive stresses at openings and irregularities	Add steel braces [9.17]	RC topping slab overlay [9.15] FRP overlays* [9.16]		Fill openings [9.14]
Foundation	Annex 1				

Seismic Deficiencies and Potential Rehabilitation Techniques (C2)

		Rehabilitation Techniques			
Category	**Deficiency**	**Add new elements**	**Enhance existing elements**	**Reduce demand (Advanced Techniques)**	**Remove selected components**
Sectional Detailing	Insufficient in-plane wall shear strength (web or boundary element)	Steel X braces [9.1] RC shear wall [9.2]	FRP jacketing* [9.4] RC jacketing [9.5]	Seismic Isolation* Supplemental damping*	
	Insufficient flexural capacity (chord rotation)	Steel X braces [9.1] RC shear wall [9.2]	Column/Beams: FRP jacketing* [9.4] RC jacketing [9.5] Shear walls: FRP jacketing* [9.4]	Seismic Isolation* Supplemental damping*	
	Brittle failure of coupling beams	RC shear wall [9.2]	FRP jacketing* [9.4] RC jacketing [9.5] Steel jacketing [9.5]	Seismic Isolation* Supplemental damping*	
Configuration	Torsional layout (RC elevator core and staircases)	Concrete shear walls [9.2]			Remove RC shear walls
	Re-entrant corner	Concrete shear walls [9.2] New seismic joint* [9.18]			
	Discontinuous walls	Concrete shear wall [9.2] or adequate columns beneath	Concrete/steel jacket of supporting columns [9.5]		Remove wall
Diaphragms	Inadequate in-plane shear capacity		RC topping slab overlay [9.15] FRP overlays* [9.16]		
	Excessive stresses at openings and irregularities	Steel horizontal braces [9.17]	RC topping slab overlay [9.15] FRP overlays* [9.16]		Fill openings [9.14]
Foundation	Annex 1				

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Seismic Deficiencies and Potential Rehabilitation Techniques (URM)

		Rehabilitation Techniques			
Category	**Deficiency**	**Add new elements**	**Enhance existing elements**	**Reduce demand (Advanced Techniques)**	**Remove selected components**
Global Strength	Insufficient in-plane wall strength	Steel braced frame [9.1]	RC jacketing [9.9] FRP jacketing* [9.10] Grouting infill openings [9.11]	Seismic Isolation*	
Configuration	Excessive torsion	Braced frame [9.1] Concrete/masonry shear wall [9.2; 9.3]			
Structural Detailing	Wall inadequate for out-of-plane bending	Out-of-plane bracing [9.7] Diagonal/vertical bracings [9.13]	Reinforced cores [9.8] Concrete wall overlay [9.9] FRP overlay* [9.10]		
	Unbraced parapet		Brace parapet [9.6]		Remove parapet [9.6]
	Poorly anchored veneer or appendages		Add veneer ties [9.13]		Remove veneer or appendages
Diaphragms	Inadequate in-plane strength and stiffness	Add horizontal braced frame [9.17]			
	Inadequate chord capacity	Add steel strap or angle			
	Excessive stresses at openings and irregularities	Add wood or steel strap reinforcement			
Foundation	Annex 1				

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Rehabilitations Techniques made with RC

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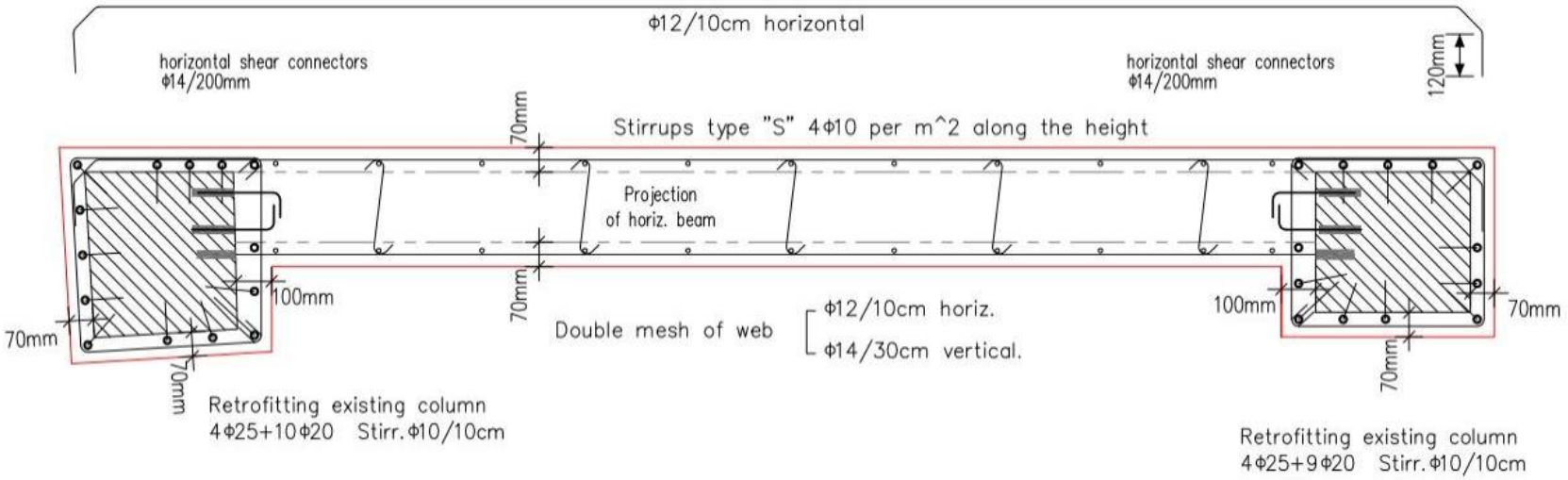
Rehabilitation Techniques made with RC

✓ 9.2 - Add Concrete Shear Wall

- Method of adding significant strength and/or stiffness;
- New walls: cast-in-place concrete, shotcrete or fully grouted concrete masonry unit construction;
- Attention to connection at the top of the new wall to the existing concrete diaphragm, to facilitate transfer of shear forces

Rehabilitation Techniques made with RC

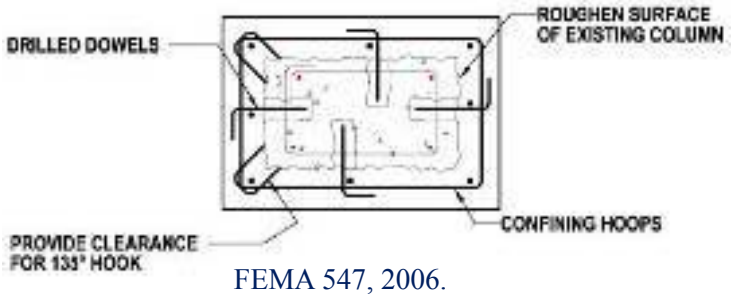
✓ 9.2 - Add Concrete Shear Wall



- Many shear connectors are needed to ensure rigid connections

Rehabilitation Techniques made with RC

✓ 9.5 – RC Jacketing for column



FEMA 547, 2006.

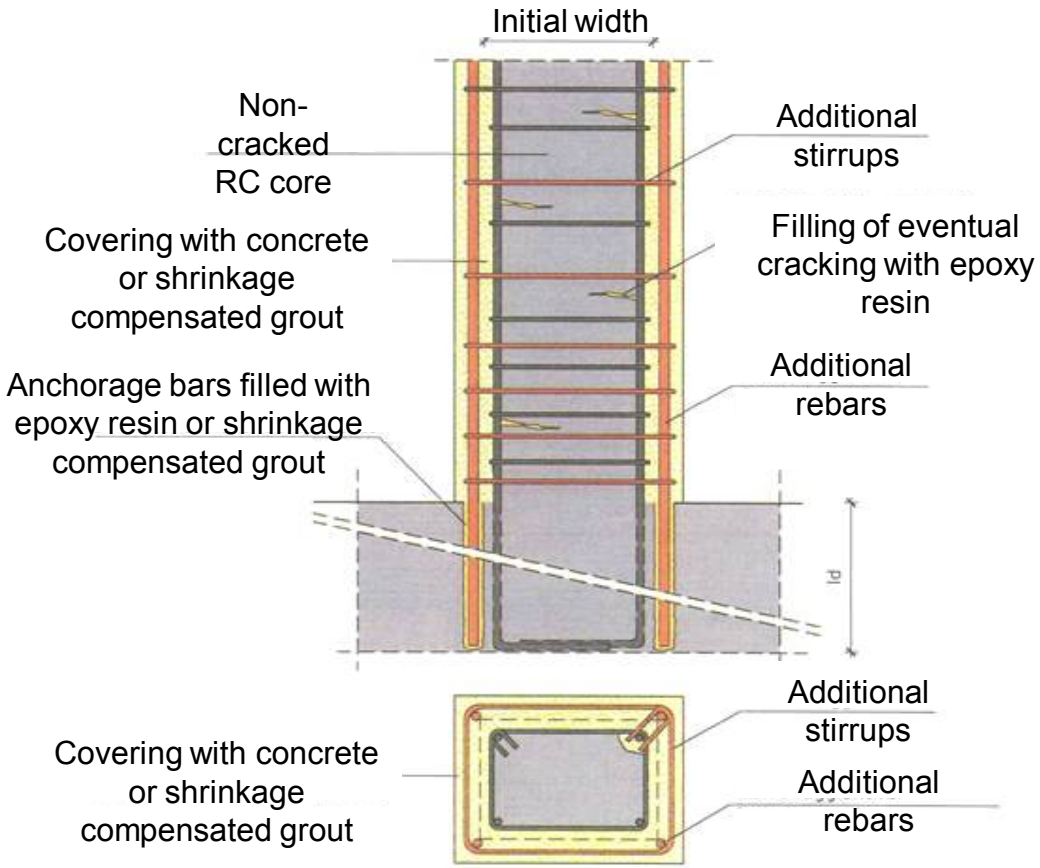
- Surface of the existing concrete must be roughened;
- 135° hooks are required for confining ties and may dictate the size of the overlay.

Rehabilitation Techniques made with RC

✓ 9.5 – RC Jacketing for column (play video)

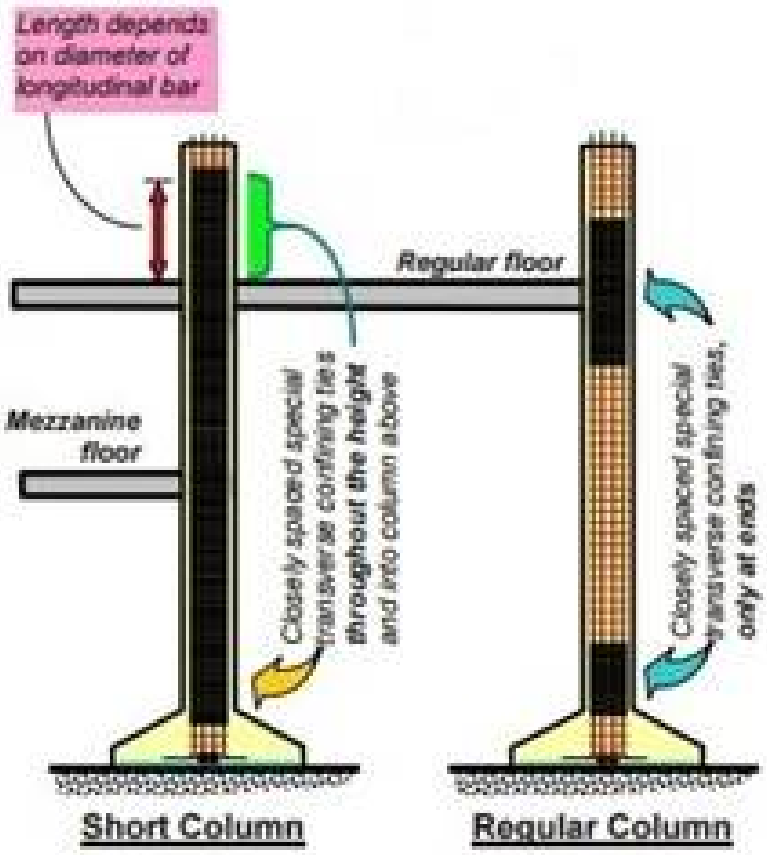
Rehabilitation Techniques made with RC

✓ 9.5 – RC Jacketing for column



Courtesy of
Prof. A. Masi, Dr M. Vona
(University of Basilicata)

✓ Dealing with short column mechanism

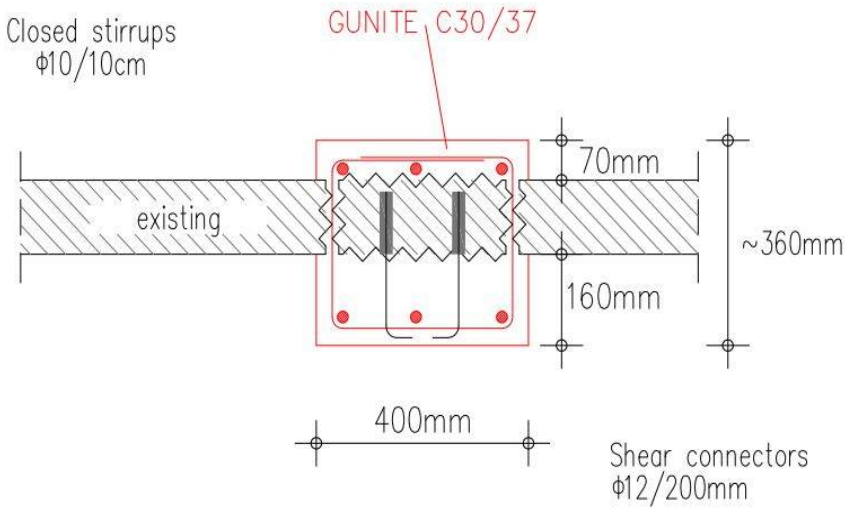


- Special confining reinforcement for the full height of columns to sustain short column effect;
- Closely spaced closed stirrups (Φ10/100 in mm) extended beyond the short column into the columns vertically above and below;
- Retrofit solutions: for walls of partial height, building a wall of full height;
- Retrofit solutions: strengthen short columns (RC or Steel or FRP jacketing).

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

Rehabilitation Techniques made with RC

✓ 9.5 – RC Jacketing for beam



- Surface of the existing concrete must be roughened;
- 135° hooks are required for confining ties and may dictate the size of the overlay.

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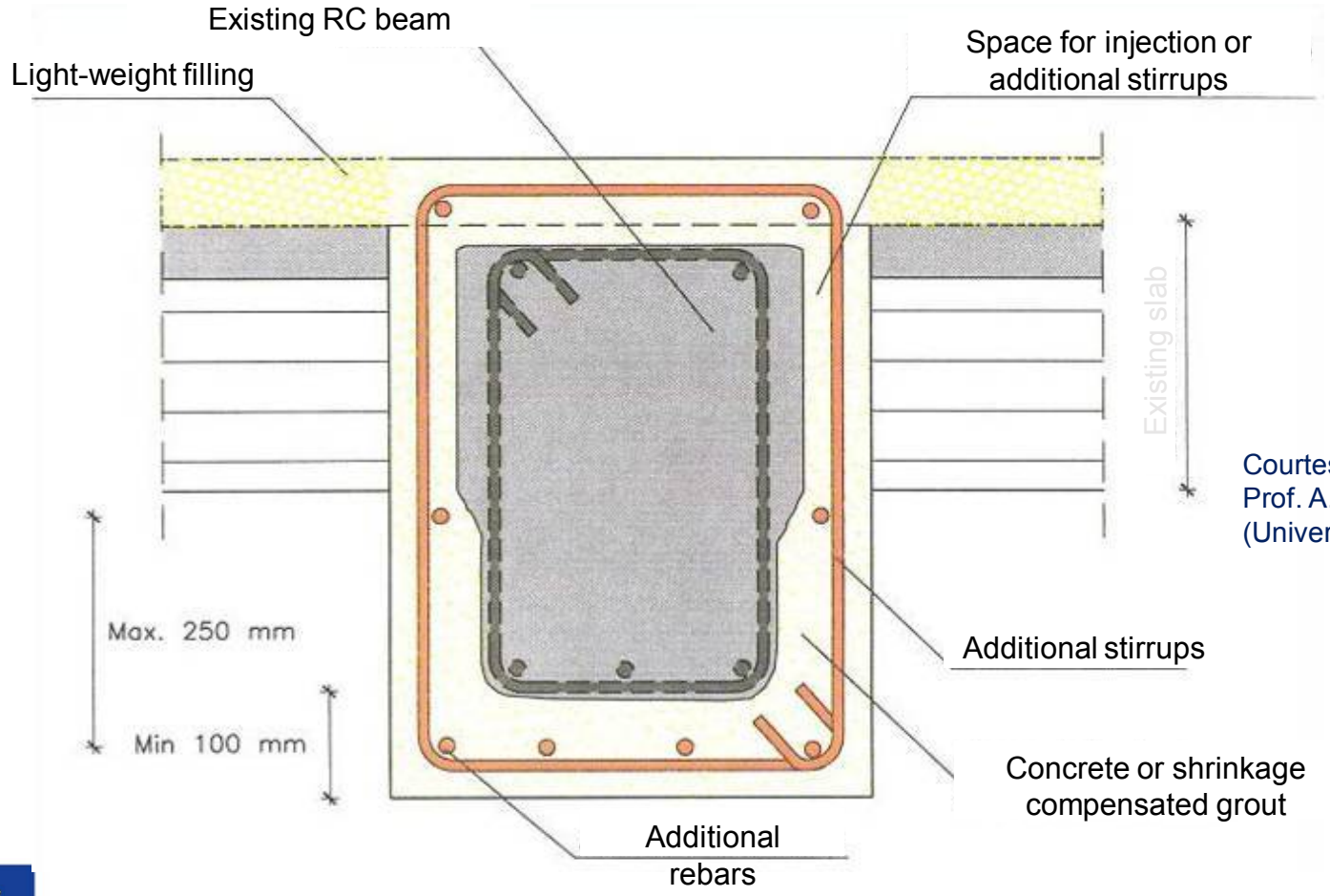
Rehabilitation Techniques made with RC

✓ 9.5 – RC Jacketing for beam



Courtesy of
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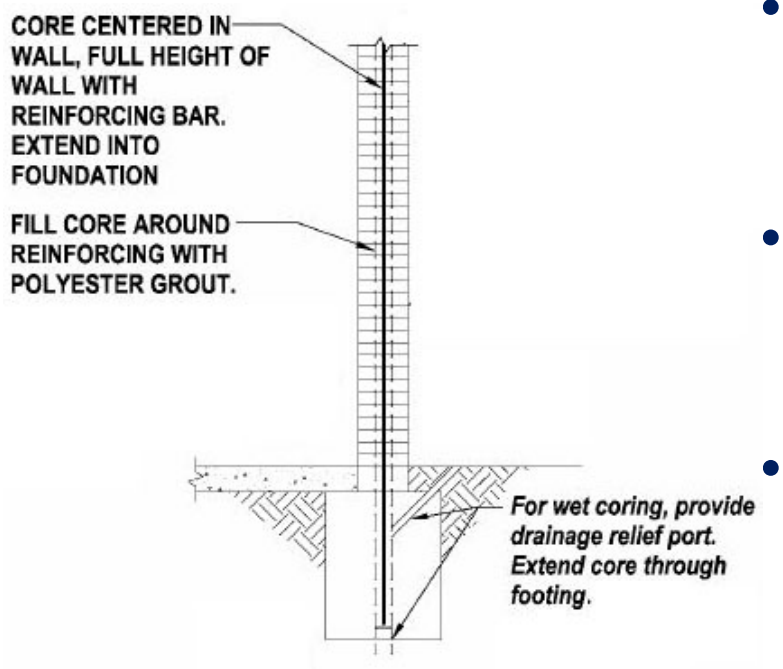
Rehabilitation Techniques made with RC

✓ 9.8 – RC cores to URM wall

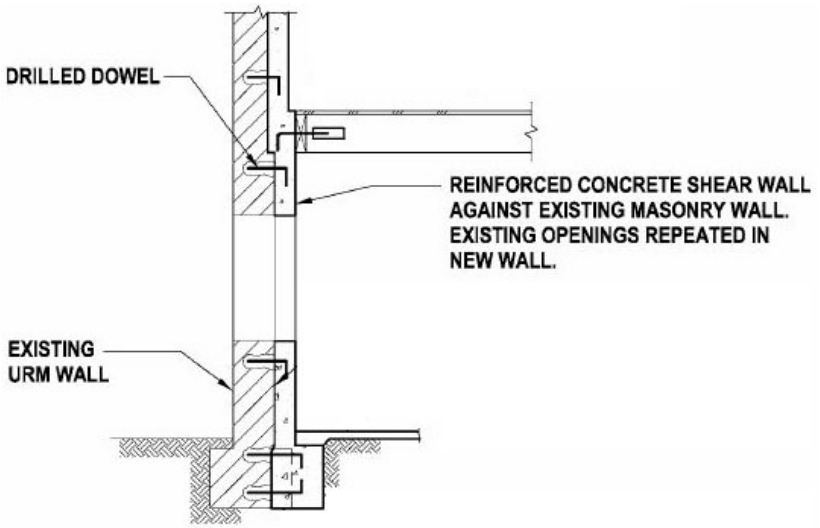


FEMA 547, 2006.

- Reinforced core involves drilling a core from the roof down the inside of an unreinforced masonry wall;
- Steel reinforcing bar + grout are placed inside the hole to increase the wall strength;
- Used to avoid the aesthetic impact of exposed bracing.

Rehabilitation Techniques made with RC

✓ 9.9 – Concrete overlay to URM wall



FEMA 547, 2006.

- To increase the shear capacity of the wall;
- New concrete is attached to the old wall with adhesive anchors;
- Cast-in-place concrete or shotcrete;
- Thickness varies with strength requirements: 10 to 30 cm.

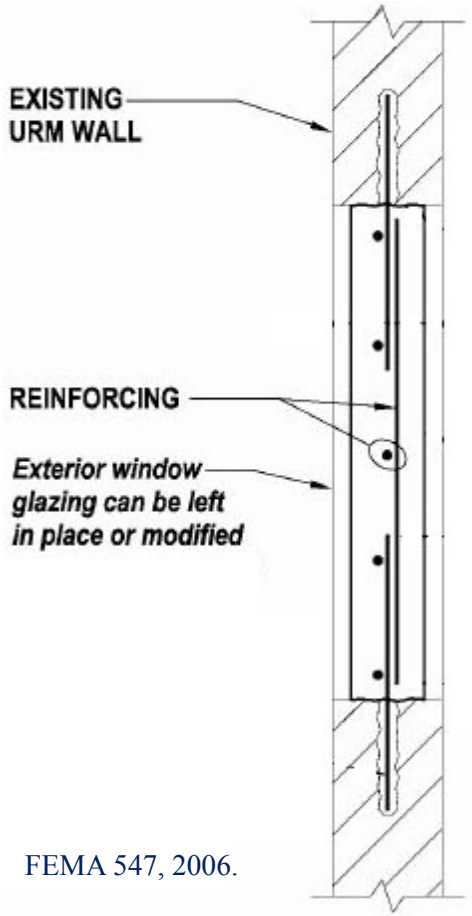
Rehabilitation Techniques made in RC

✓ 9.9 – Concrete overlay to URM wall (play video)

STATIS LLC, Greece

Rehabilitation Techniques made with RC

✓ 9.11 – RCM infills in URM wall



FEMA 547, 2006.

- To increase the shear capacity and reduce the shear stresses of the wall;
- Opening is filled with reinforced concrete masonry units;
- Interface can be toothed to provide shear transfer between the existing wall and the new infill;
- Typically, drilled dowels are used.

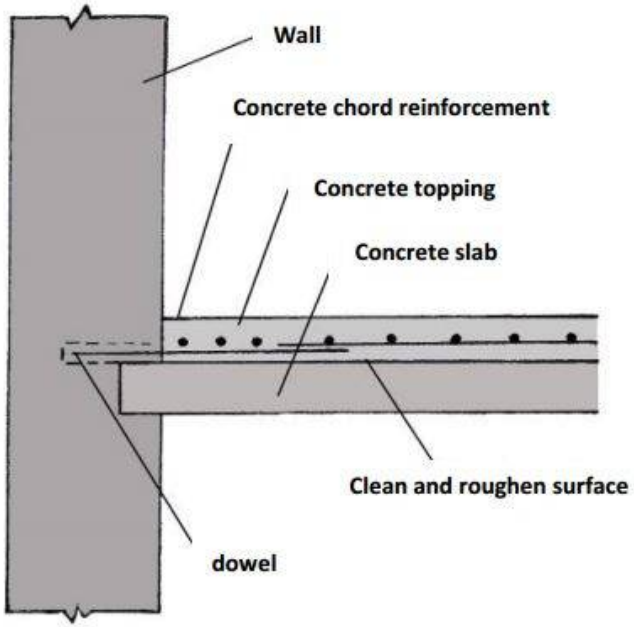
Rehabilitation Techniques made with RC

✓ 9.11 – RC infills in diaphragms

- Reduction of concentrated shear and chord force demand in the surrounding diaphragm;
- New infill: cast-in-place reinforced concrete or shotcrete;
- Dowels must be placed into the existing diaphragm slab on all sides of the opening to transfer the required shear demand to and from the infill section.

Rehabilitation Techniques made with RC

✓ 9.15 – RC overlay to concrete diaphragms



- For strengthening shear capacity: new reinforced concrete topping slab and provide supplemental vertical-resisting elements;
- For strengthening the flexural capacity: casting a new chord member integral with the slab and provide additional vertical-resisting elements.

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Rehabilitations Techniques made with Steel

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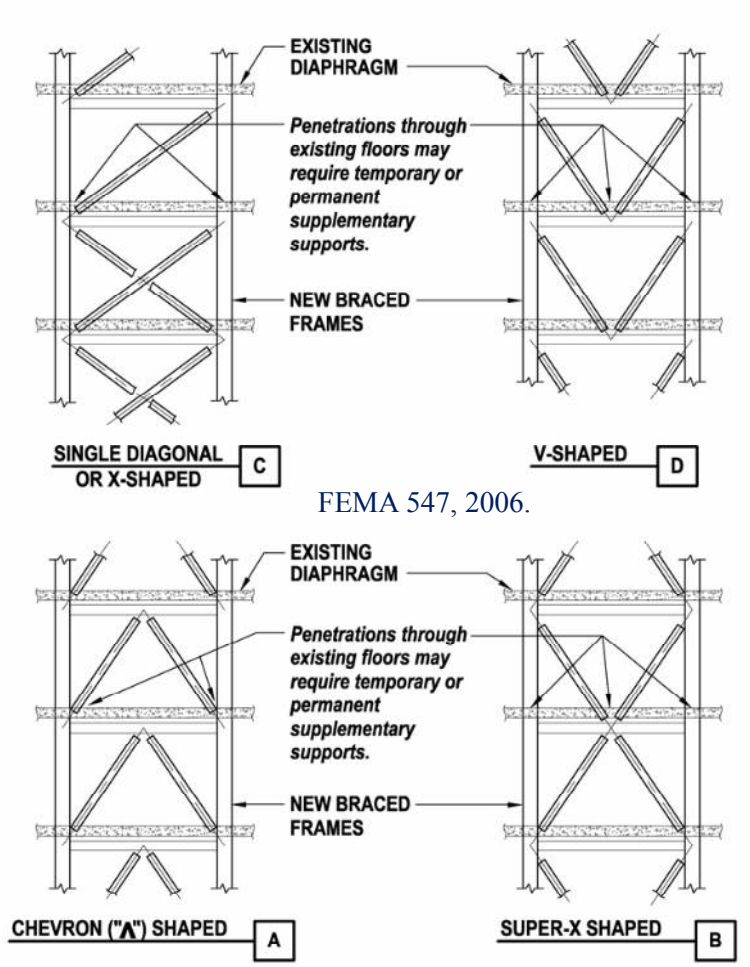
Rehabilitation Techniques made with Steel

✓ 9.1 – Steel X bracing



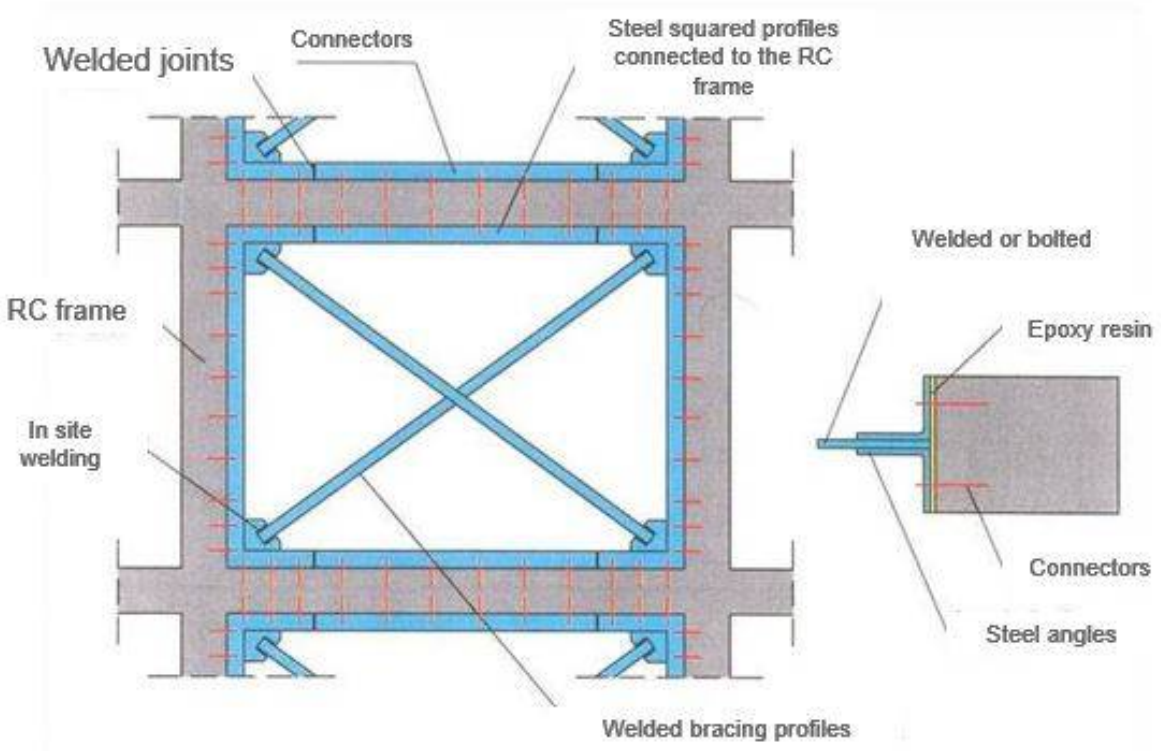
FEMA 547, 2006.

- Adding stiffness;
- Can solve soft storey deficiencies;
- Steel elements work mainly in tension;
- Buckling of steel in compression;
- Impacts the architectural character of the building.

Rehabilitation Techniques made with Steel

✓ 9.1 – Steel X bracing

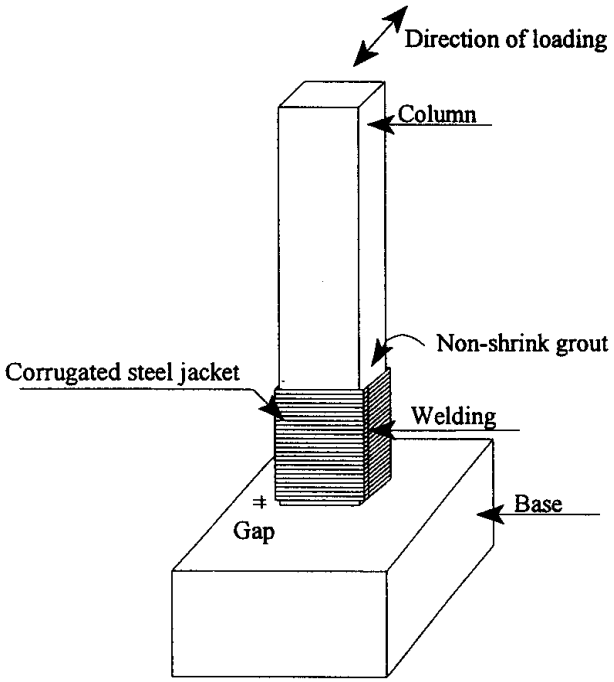
- Attention to connection of the beam at the top of the story to the existing concrete diaphragm;
- Connection made with concrete anchors;



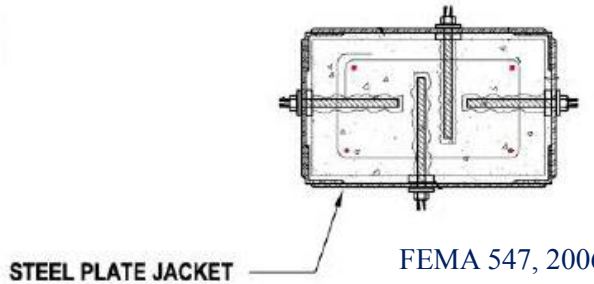
Courtesy of Prof. A. Masi, Dr M. Vona (University of Basilicata)

Rehabilitation Techniques made with Steel

✓ 9.5 – Steel Jacketing



- Steel jackets require at least two pieces to get around the existing column;
- If aspect ratio of a rectangular column gets too large, the jacket becomes less effective.

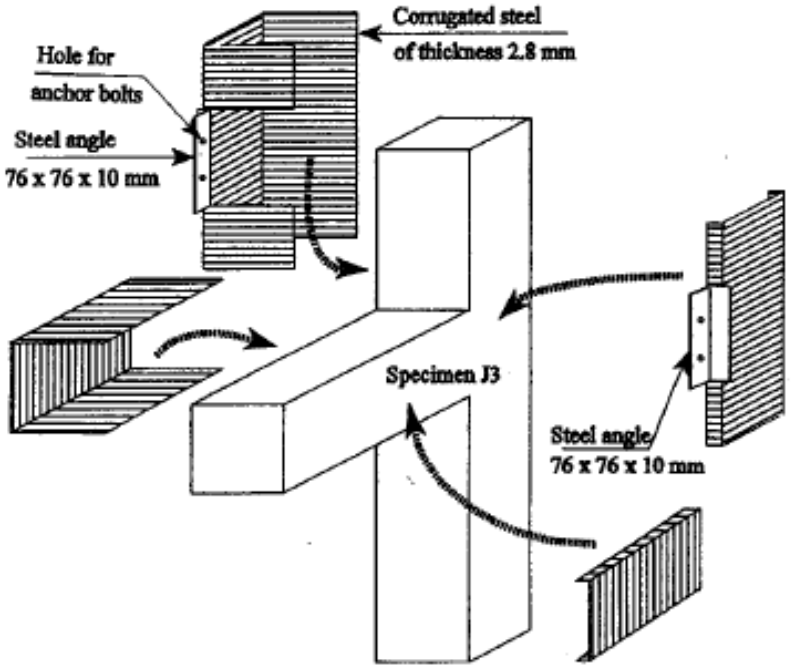


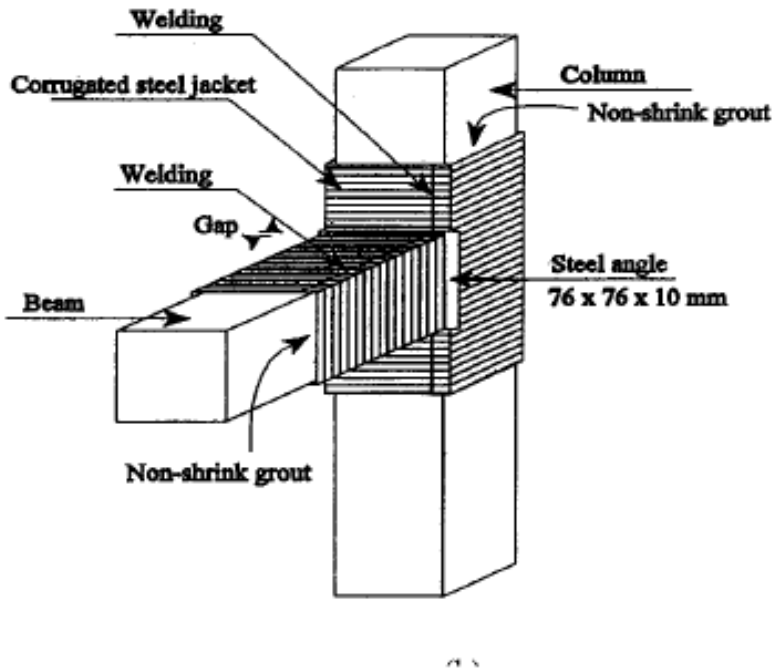
FEMA 547, 2006.

Rehabilitation Techniques made with Steel

✓ 9.5 – Steel Jacketing

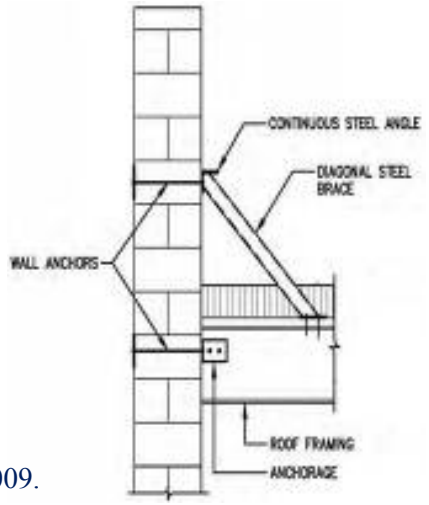
Field welding is involved.





Rehabilitation Techniques made with Steel

✓ 9.6 – Steel Bracing of URM Parapet



FEMA 774, 2009.

- Steel braces are used;
- Anchorage near the top of the parapet and to the roof;
- If the top of the parapet is removed, the vertical compressive stress on roof-to-wall anchors is reduced;
- Removing the parapet is often combined with adding a concrete cap or bond beam as part of the roof-to-wall anchorage.

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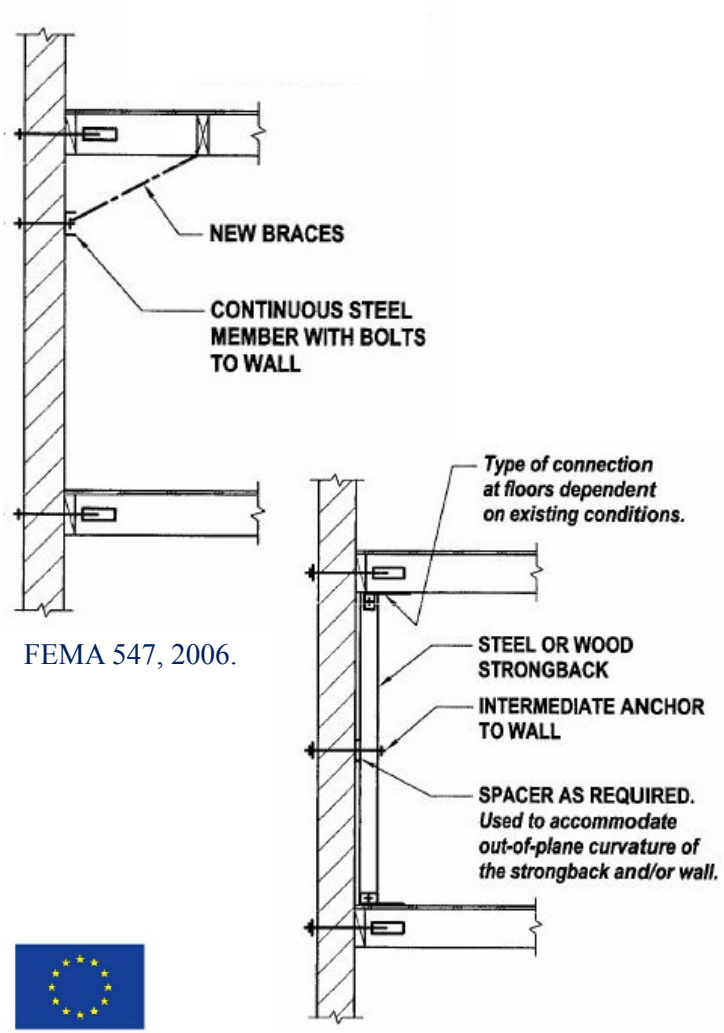
Rehabilitation Techniques made with Steel

✓ 9.7 – Out-of-plane bracing of URM Walls

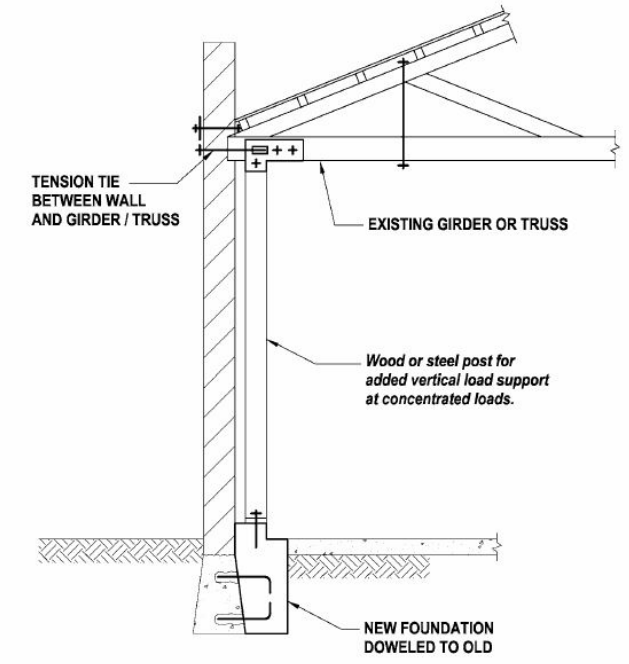


FEMA 547, 2006.

- Two types of bracing;
- Diagonal braces: reduce the effective height of the masonry wall;
- Vertical braces or strongbacks: span the full height of the inside face of the wall

Rehabilitation Techniques made with Steel

✓ 9.12 – Supplemental vertical support for truss or girder

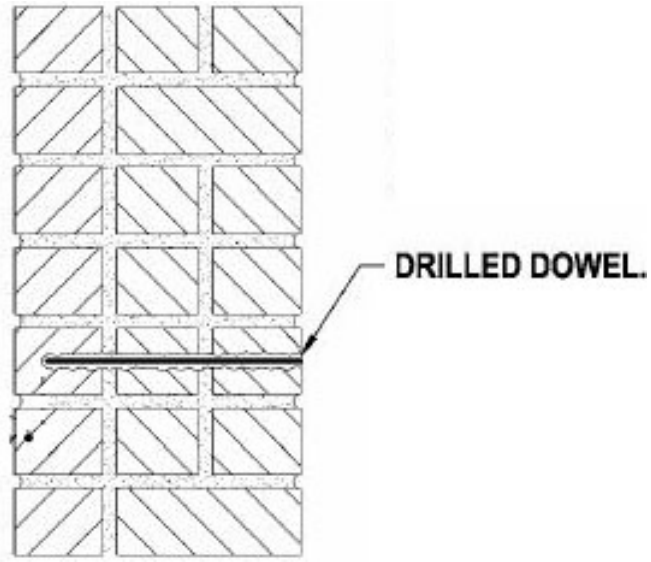


FEMA 547, 2006.

- A steel post is added under existing trusses and girders.

Rehabilitation Techniques made with Steel

✓ 9.13 – Veneer Ties in URM walls



FEMA 547, 2006.

- Drilled dowels are used to connect the withes from the interior in a typical brick wall;
- Drilled dowel is located in the center of the brick;
- Dowel can be also placed in the bed joist or bed and head joint intersection to minimize the aesthetic impact.

Rehabilitation Techniques made with Steel

✓ 9.17 – Horizontal braced frame as diaphragm

- Method used if the existing floor cannot be disturbed for functional reasons or the cost of replacing the existing diaphragm is more expensive;
- Alternative method when concrete overlays add too much mass;
- New horizontal bracing added under the existing diaphragm;
- The diaphragm shears are shared with the existing diaphragm in proportion to the relative rigidity of the two systems.

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Rehabilitations Techniques made with Masonry

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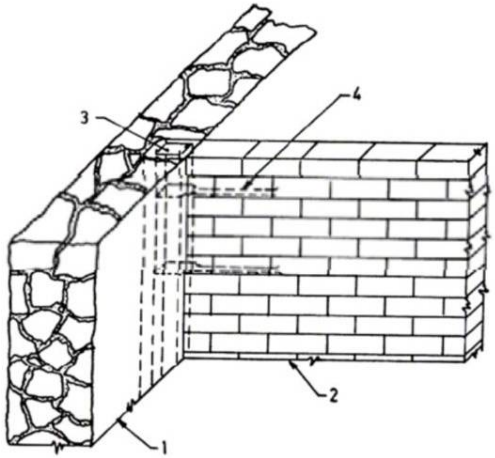
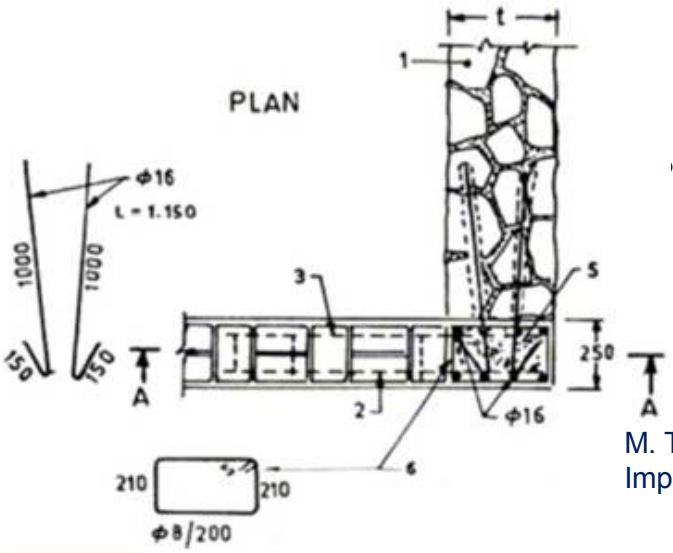
Rehabilitation Techniques made with Masonry

✓ 9.3 - Add Masonry Wall





- Method of adding significant strength and/or stiffness;
- Insertion of cross wall will be necessary for providing transverse supports to longitudinal walls;
- Connection between new and old walls is performed in two ways: T-junction or Corner junction.
- Can be used also for RC frames to add global stiffness

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

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Rehabilitations Techniques for Foundations

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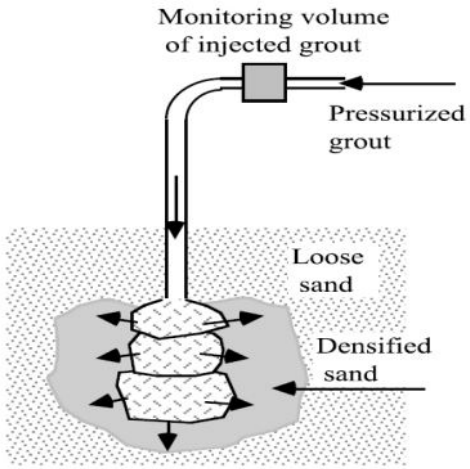
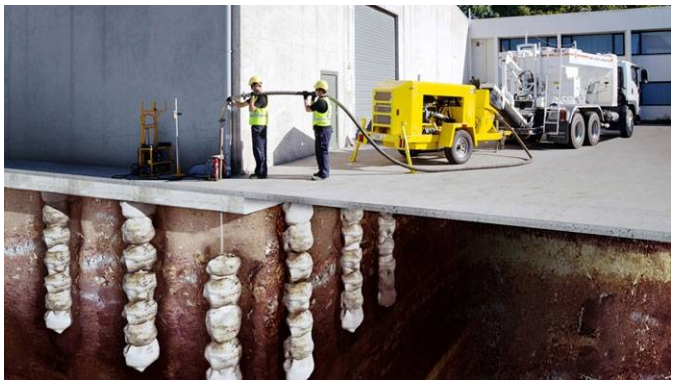
Rehabilitation Techniques – Ground Improvement

✓ 11.4.1 Compaction grouting





- To increase resistance to liquefaction and bearing capacity;
- Injection of a very stiff grout at a high pressure into a layer of soil to force the individual soil particles into a tighter packing;
- Grout (sand, cement, and water) injected through grout holes and injected in stages.

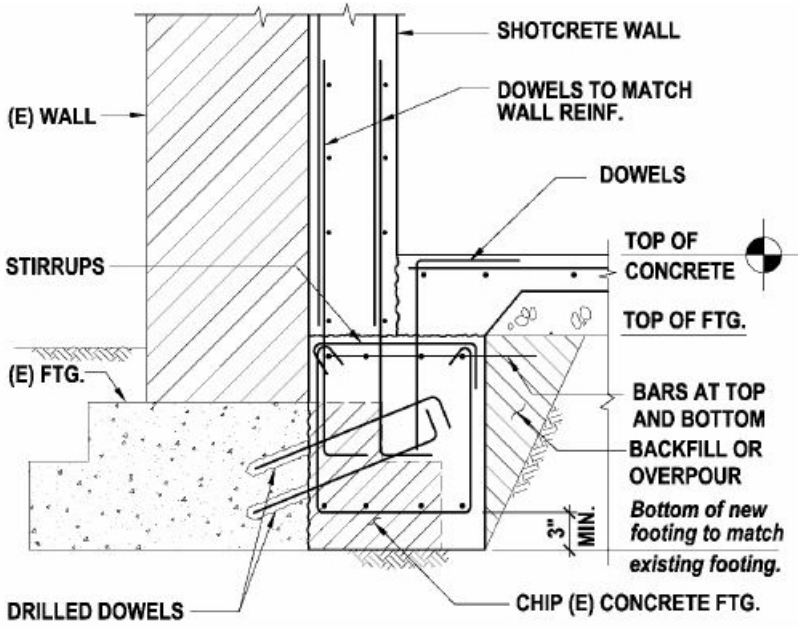
Rehabilitation Techniques – Existing Shallow Foundations

✓ 11.2.2 Enlarge existing spread footing

- To increase compression capacity or the dead load for resisting tension;
- Placing new drilled dowels at a higher elevation, with a resulting lower moment capacity;

Rehabilitation Techniques – New Foundations

✓ 11.1.1 Add shallow foundation next to existing shallow foundation



FEMA 547, 2006.

- If concrete overlay used for existing wall;
- Connection with drilled dowels to transfer forces;
- If unreinforced masonry or poorly RC beam as footings: bottom drilled dowels has to be extended deep into the existing footing to serve as positive reinforcing;
- New footing not deeper than existing one to avoid settlement.

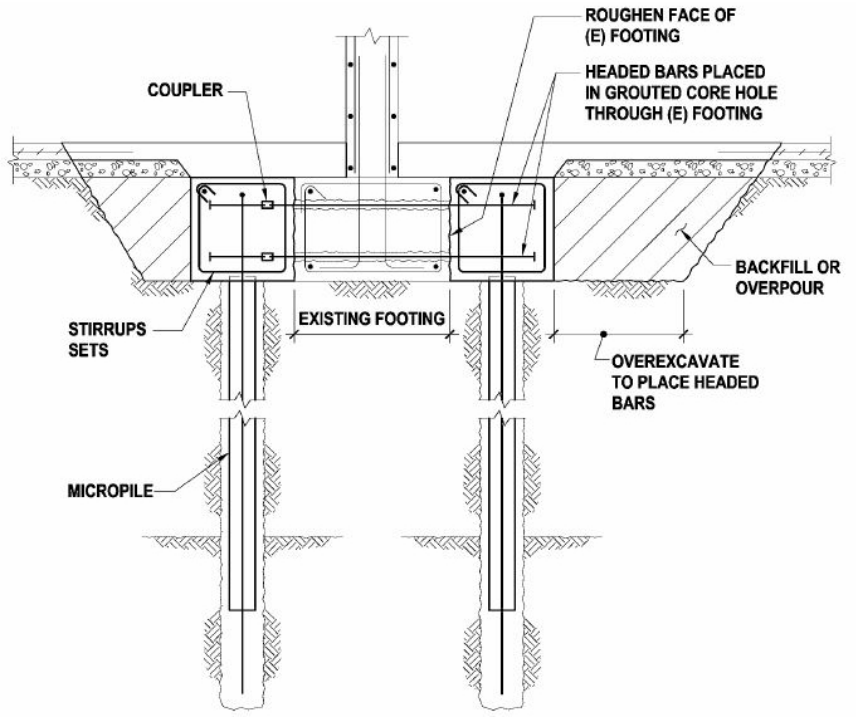
Rehabilitation Techniques – New Foundations

✓ 11.1.2 Add deep foundation next to existing shallow foundation

- Occasionally done;
- Drilling limitations can be significant (access requirements, height restrictions for the drill rig, vibration during drilling…)
- Drilled piers are spaced at a sufficient distance that the existing footing and walls can span around or over the open hole.

Rehabilitation Techniques – Existing Shallow Foundations

✓ 11.2.1 Add micropiles

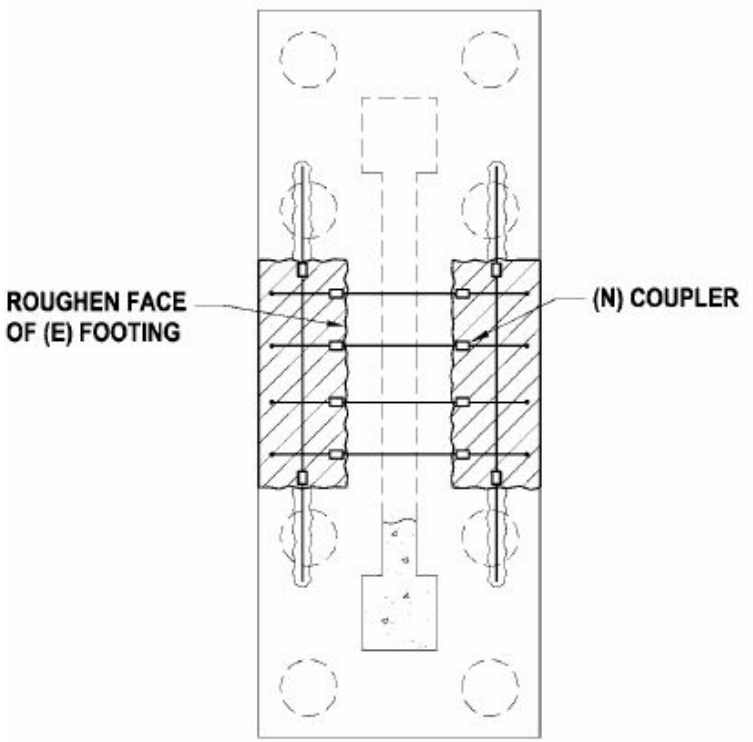


FEMA 547, 2006.

- Footing is widened and micropiles are added for enhancing compression and/or tension capacity of the existing footing;
- Connection to new footing with bars drilled through the existing footing.

Rehabilitation Techniques – Existing Deep Foundations

✓ 11.3.1 Add a Mat Foundation, Extended Pile Cap or Grade Beam

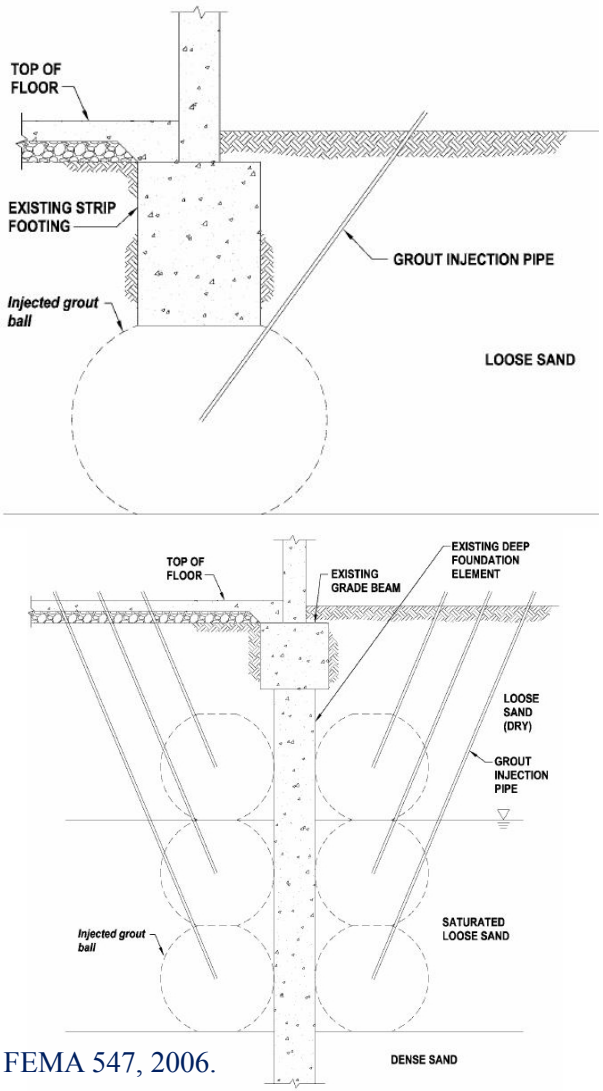


FEMA 547, 2006.

- To increase inadequate compression capacity;
- Install new micropiles or piers connected by grade beam to the existing adjacent piles or piers.

Rehabilitation Techniques – Ground Improvement

✓ 11.4.2 Permeation grouting



FEMA 547, 2006.

- Increase shear strength of soil, its resistance to liquefaction and bearing capacity;
- Injection of chemical or cement grout into pore spaces;
- Performed in sands and sandy soils with minor amounts of fine particles;
- Injected through grout holes and with strict primary-secondary pattern;
- For shallow foundation: creation of solidified mass of sandy soil below the footprint of footing;
- For deep foundation: creation of solidified sand around it.

An example of rehabilitation techniques…