RETROFITTING SIMPLE BUILDINGS DAMAGED BY EARTHQUAKES

TEDDY BOEN & ASSOCIATES

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WORLD SEISMIC SAFETY INITIATIVE
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PREFACE SECOND EDITION

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ORIGINALLY, THIS MANUAL "RETROFITTING SIMPLE BUILDINGS DAMAGED BY EARTHQUAKES" WAS A COMPILATION OF PUBLICATIONS AND LECTURES BY IR. TEDDY BOEN AS CAN BE SEEN IN THE REFERENCES.

THE FIRST EDITION WAS PUBLISHED IN NOVEMBER 2009 RIGHT AFTER THE SEPTEMBER 30, 2009 WEST SUMATRA EARTHQUAKE. DUE TO MANY SUGGESTIONS AND CORRECTIONS RECEIVED, THIS SECOND EDITION IS RE-EDITED BY A TEAM CONSISTING OF THE FOLLOWING:

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PREFACE

LATELY, MANY DESTRUCTIVE EARTHQUAKES OCCURRED IN VARIOUS COUNTRIES IN THE WORLD, INCLUDING INDONESIA. THOSE EARTHQUAKES CAUSED A LOT OF LOSS OF HUMAN LIFE AS WELL AS PROPERTY. THE DEGREE OF DAMAGE AND THE LOSSES CAUSED BY EARTHQUAKES TEND TO INCREASE IN THE FUTURE. THIS IS CAUSED BY THE FACT THAT THE WORLD POPULATIONS IS INCREASING AND MANY SETTLEMENTS ARE BUILT IN SEISMIC PRONE AREAS.

MANY BUILDINGS ARE BUILT WITHOUT FOLLOWING PRINCIPLES OF EARTHQUAKE RESISTANT DESIGN. MORE SO, IN MANY PLACES IN THE WORLD, THE MATERIALS QUALITY AND WORKMANSHIP ARE SO LOW THAT THE CHANCES OF THOSE BUILDINGS GET DAMAGED OR COLLAPSED IS VERY BIG, EVEN IF SHAKEN BY WEAK EARTHQUAKES.

ONE OF THE DISADVANTAGE IS THE FACT THAT MOST OF THE LOSS OCCURRED IN DEVELOPING COUNTRIES. THEREFORE, THE MAJORITY OF THE BUILDINGS THAT SUFFERED DAMAGE BELONGS TO THE CATEGORY OF “NON-ENGINEERED” CONSTRUCTION.

RIGHT AFTER AN EARTHQUAKE, IT IS COMMON THAT PEOPLE ARE IN DOUBT TO DETERMINE WHICH BUILDINGS SHOULD BE DEMOLISHED, WHICH ONES MUST BE REPAIRED, AND WHICH ONES MUST BE STRENGTHENED AND HOW TO DO IT.

THIS MANUAL IS WRITTEN TO TRY TO ANSWER THOSE QUESTIONS AND EXPLAIN WHAT CAN BE DONE EASILY, PRACTICALLY, SIMPLE, AND RELATIVELY AT LOW COST.

THE METHODS SUGGESTED AND THE DETAILS SHOWN IN THIS MANUAL ARE PARTICULARLY FOR NON-ENGINEERED UNCONFINED, CONFINED MASONRY BUILDINGS, AND SIMPLE REINFORCED CONCRETE BUILDINGS. THE DETAILS ARE BASIC PRINCIPLES AND ARE MINIMUM REQUIREMENTS TO OBTAIN EARTHQUAKE RESISTANCE.

ALTHOUGH THE SEISMICITY IN EACH AREA ARE NOT THE SAME, THOSE PRINCIPLES CAN STILL BE APPLIED WITH THE NECESSARY ADJUSTMENTS.

JAKARTA, DECEMBER 1992
TEDDY BOEN

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I. INTRODUCTION

1.1. BACKGROUND AND PROBLEM

MOST OF THE LOSS OF LIFE AND PROPERTY IN PAST EARTHQUAKES HAS OCCURRED DUE TO THE COLLAPSE OF NON-ENGINEERED BUILDINGS.

NON-ENGINEERED BUILDINGS ARE BUILDINGS WHICH ARE SPONTANEOUSLY AND INFORMALLY CONSTRUCTED IN VARIOUS COUNTRIES IN THE TRADITIONAL MANNER USING LOCAL AVAILABLE MATERIALS LIKE STONE, BRICK, ADOBE, AND WOOD, WITHOUT ANY OR LITTLE INTERVENTION BY QUALIFIED ARCHITECTS AND ENGINEERS IN THEIR DESIGN.

IN VIEW OF THE CONTINUED USE OF SUCH BUILDINGS, ONE OF THE EFFORTS TO REDUCE THE EARTHQUAKE RISK IN THE FUTURE IS TO INTRODUCE EARTHQUAKE RESISTANCE FEATURES IN THEIR CONSTRUCTION.

FOR EXISTING BUILDINGS, RETROFITTING (STRENGTHENING) METHODS MUST BE INTRODUCED.

1.2. SOCIO-ECONOMIC CONSIDERATIONS IN SEISMIC SAFETY OF BUILDINGS

1.2.1. REQUIREMENTS TO DETERMINE THE RETROFITTING METHOD

1. REVOLUTIONARY CHANGES TO THE PREVAILING CONSTRUCTION METHOD IS NOT SUITABLE AND NOT PRACTICAL.
2. THE CHANGES IN TECHNIQUES TO THE PREVAILING CONSTRUCTION METHOD SHOULD BE AS SIMPLE AS POSSIBLE, CAN BE UNDERSTOOD AND FOLLOWED BY THE LOCAL ARTISANS.
3. THE TECHNIQUES INTRODUCED SHOULD BE SUCH THAT CAN BE FOLLOWED EASILY BY THE LOCAL ARTISANS AND MOST OF THE WORKS CAN BE DONE WITHOUT EXCESSIVE SUPERVISION.
4. THE USE OF LOCAL MATERIALS IS PREFERRED, MATERIALS THAT ARE DIFFICULT TO OBTAIN SHOULD BE AVOIDED.
5. MATERIALS USED MUST BE AVAILABLE AT LOW COST, SAME AS WHEN CONSTRUCTING THE ORIGINAL HOUSE.
6. THE ADDITIONAL COST MUST BE NEGLIGIBLE.

1.2.2. SOCIO-ECONOMIC CONSTRAINTS FOR CHANGES

1. LACK OF CONCERN ABOUT SEISMIC SAFETY DUE TO INFREQUENT OCCURRENCE OF EARTHQUAKES.

2. LACK OF AWARENESS THAT BUILDINGS COULD BE MADE EARTHQUAKE RESISTANT AT SMALL ADDITIONAL COST ONLY, HENCE LACK OF MOTIVATION.
3. LACK OF FINANCIAL RESOURCES FOR ADDITIONAL INPUTS FOR MEETING EARTHQUAKE RESISTANCE REQUIREMENTS IN BUILDING CONSTRUCTION.
4. OTHER NORMAL PRIORITIES ON FINANCIAL INPUTS IN THE DAILY LIFE OF THE PEOPLE.
5. LACK OF SKILL IN ASESIMIC DESIGN AND CONSTRUCTION TECHNIQUES AND UNORGANIZED OF THE BUILDING SECTOR.

1.2.3. OBSTACLES TO TRANSFER OF TECHNOLOGY

1. DIFFERENT CLIMATE AND TOPOGRAPHY CONDITIONS
2. THE AREAS TO BE COVERED IS TREMENDOUS
3. THE NUMBER OF VILLAGES TO BE COVERED IS LARGE
4. LACK OF SKILL AND CONSTRUCTION TECHNIQUES
5. LACK OF ORGANIZED FINANCIAL RESOURCES AND ASSISTANCE

1.3. OBJECTIVE AND SCOPE

THE OBJECTIVE OF THIS MANUAL IS TO PROVIDE BASIC PRINCIPLES AND BASIC REQUIREMENTS REGARDING THE RETROFITTING OF NON-ENGINEERED CONSTRUCTION THAT ARE DAMAGED DURING EARTHQUAKES, SO THAT THE BUILDINGS ARE EARTHQUAKE RESISTANCE TAKING INTO CONSIDERATIONS MENTIONED IN 1.2.

NON-ENGINEERED BUILDINGS DISCUSSED IN THIS MANUAL INCLUDE:

- UNCONFINED MASONRY BUILDINGS
- CONFINED MASONRY BUILDINGS
- SIMPLE R.C. BUILDINGS

THE PRINCIPLES AND DETAILS OF RECONSTRUCTION OF TOTALLY DAMAGED AND/OR COLLAPSED BUILDINGS ARE NOT INCLUDED IN THIS MANUAL.

GUIDELINES FOR CONSTRUCTING NEW (NON-ENGINEERED) BUILDINGS IS EXPLAINED IN "DETAILER'S MANUAL FOR SMALL BUILDINGS IN SEISMIC AREAS" BY IR. TEDDY BOEN [46].

II. EARTHQUAKE EFFECTS TO STRUCTURES

2.1. GENERAL

EARTHQUAKES ARE NATURAL HAZARDS UNDER WHICH DISASTERS ARE MAINLY CAUSED BY THE DAMAGE TO OR COLLAPSE OF BUILDINGS AND OTHER MAN-MADE STRUCTURES.

UNTIL TODAY, THERE IS NOT MUCH THAT CAN BE DONE TO PREVENT THE OCCURRENCE OF EARTHQUAKES. HOWEVER, THE EARTHQUAKE-INDUCED DAMAGE CAN BE REDUCED WITH PLANNING AND CONSTRUCTING EARTHQUAKE RESISTANT BUILDINGS OR EVALUATING AND STRENGTHENING EXISTING BUILDINGS BEFORE AN EARTHQUAKE.

EARTHQUAKE DAMAGES DEPEND ON MANY PARAMETERS, SUCH AS:

1. EARTHQUAKE SHAKING CHARACTERISTICS:

   INTENSITY, DURATION, AND FREQUENCY CONTENT OF GROUND MOTION

2. SOIL CHARACTERISTICS:

   TOPOGRAPHY, GEOLOGIC, AND SOIL CONDITION

3. BUILDING CHARACTERISTICS:

   BUILDING'S STIFFNESS, STRENGTH, DUCTILITY, AND INTEGRITY

BESIDE THE PARAMETERS MENTIONED ABOVE, EARTHQUAKE CASUALTIES DEPEND ON IMPORTANT SOCIOLOGIC FACTORS, SUCH AS:

1. DENSITY OF POPULATION
2. TIME OF DAY OF THE EARTHQUAKE OCCURRENCE
3. COMMUNITY PREPAREDNESS

2.2. BASIC CAUSES OF EARTHQUAKE - INDUCED DAMAGE

1. GROUND SHAKING

   GROUND SHAKING IS THE MAIN CAUSE OF DAMAGE BY EARTHQUAKES.

2. GROUND FAILURE

   TYPES OF GROUND FAILURE:

   - LANDSLIDE,
   - SETTLEMENT, AND
   - LIQUEFACTION.

3. TSUNAMI

TSUNAMI IS A SEA CURRENT THAT IS TRIGGERED BY AN UNDERSEA EVENT SUCH AS EXPLOSION OF OCEANIC VOLCANO (KRAKATAU), UNDERSEA LANDSLIDE, ROCK SLIDES INTO THE OCEAN, TECTONIC FAULT, AND NUCLEAR EXPLOSION. THE CONDITIONS FOR A TSUNAMI TO OCCUR:

- UNDER-SEA EARTHQUAKE-REVERSE OR NORMAL FAULT
- SHALLOW EARTHQUAKE
- MAGNITUDE, M >6.5
- THE TSUNAMI DESTRUCTION IS BIGGER IF THE BEACH IS SLIGHTLY SLOPED.

4. FIRE

IT IS DIFFICULT TO EXTINGUISH THE FIRE BECAUSE OF THE LOSS OF WATER SUPPLY AND THE INFRASTRUCTURE IS BROKEN.

THE MAIN CAUSE OF DAMAGE IS GROUND SHAKING (NO. 1). OTHERS (GROUND FAILURE, TSUNAMI AND FIRE) ARE SECONDARY DISASTER. THEREFORE THE MAIN PRIORITY IS MAKING EARTHQUAKE RESISTANT STRUCTURES.


Aceh Eq, December 26, 2004


West-Sumatra Eq, September 30, 2009

EXAMPLE OF BUILDING FAILURE CAUSED BY GROUND SHAKING


West-Java Eq, September 2, 2009


West-Sumatra Eq, September 30, 2009

EXAMPLE OF GROUND FAILURE - LANDSLIDE

Kerinci Eq, October 7, 1995

Nias / Simeulue Eq, March 28, 2005

EXAMPLE OF GROUND FAILURE - LANDSLIDE

Flores Eq, December 12, 1992

West-Sumatra Eq, September 30, 2009

EXAMPLE OF GROUND FAILURE - LIQUEFACTION

Aceh Eq, December 26, 2004

Pangandaran Eq, July 17, 2006

EXAMPLE OF BUILDING DESTRUCTION CAUSED BY TSUNAMI

Nias / Simeulue Eq, March 28, 2005

West-Sumatra Eq, September 30, 2009

EXAMPLE OF BUILDING DESTRUCTION CAUSED BY FIRE

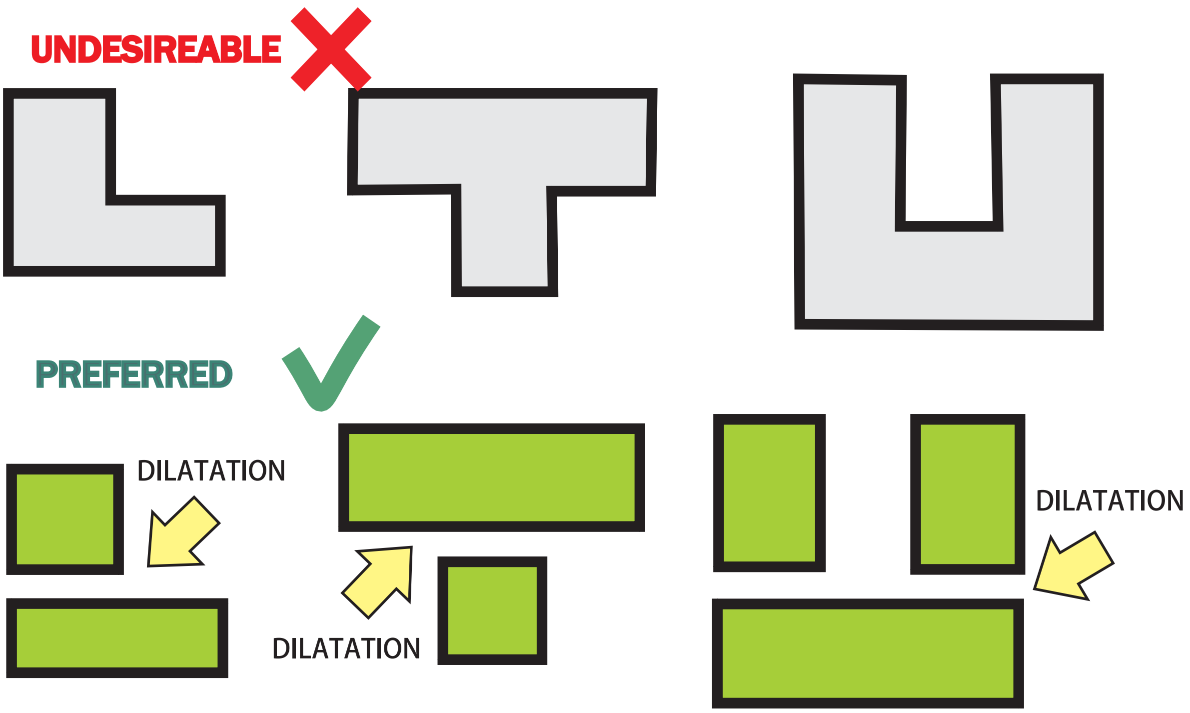
2.3. FACTORS AFFECTING STRUCTURAL DAMAGE

2.3.1. SITE CONDITION

- SITE CONDITION SIGNIFICANTLY AFFECTS A BUILDING DAMAGE.
- EARTHQUAKE SHAKING CHARACTERISTICS IS DIRECTLY RELATED TO THE TYPE OF SOIL LAYERS SUPPORTING THE BUILDING.

2.3.2. SUGGESTED EARTHQUAKE RESISTANT BUILDING CONFIGURATION

- REGULARITY
- SYMMETRY IN THE OVERALL SHAPE OF A BUILDING



NOT SUGGESTED VERTICAL CONFIGURATION

2.3.3. DIMENSIONS OF OPENINGS

- OPENINGS IN WALLS OF A BUILDING TEND TO WEAKEN THE WALLS.
- GENERALLY, THE DAMAGE OF WALLS WITH LESS OPENINGS WILL ALSO BE REDUCED.

Flores Eq, December 12, 1992

West-Sumatra Eq, September 30, 2009

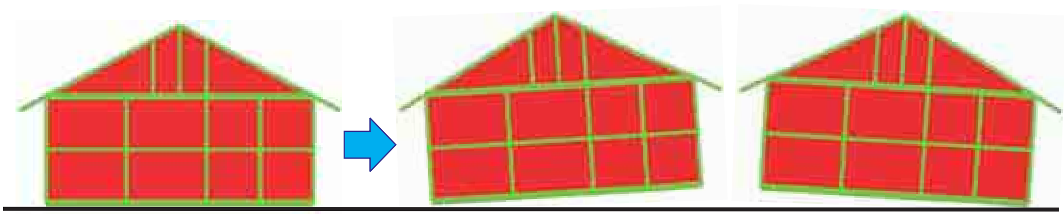
EXAMPLE OF EARTHQUAKE DAMAGE AT THE CORNERS OF OPENING

2.3.4. RIGIDITY DISTRIBUTION

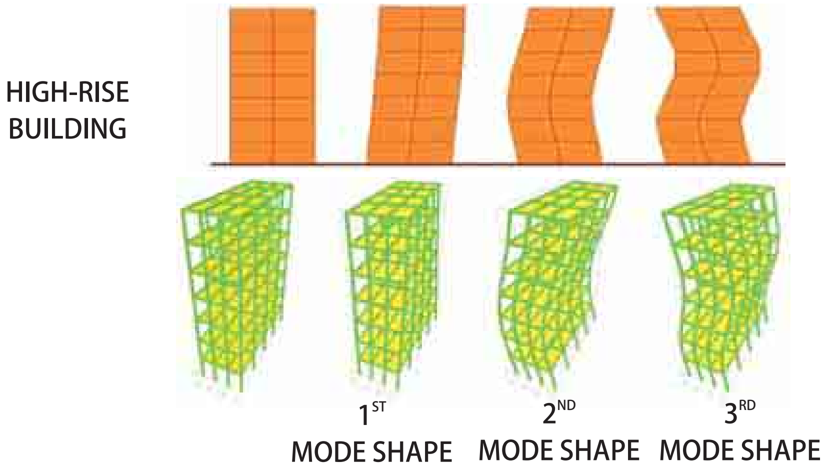
- THE RIGIDITY OF A BUILDING SHALL BE DISTRIBUTED AS UNIFORM AS POSSIBLE IN THE VERTICAL AS WELL AS HORIZONTAL DIRECTION.
- THE DIFFERENCE IN RIGIDITY FROM ONE FLOOR TO THE OTHER TEND TO DAMAGE THE BUILDINGS WHEN SHAKEN BY EARTHQUAKES.
- THE GREATER THE DISTANCE BETWEEN CENTER OF MASS AND CENTER OF RIGIDITY, THE GREATER THE TENDENCY OF DAMAGE WHEN SHAKEN BY EARTHQUAKES.

2.3.5. STRENGTH OF BUILDINGS

- STRUCTURES OF BUILDINGS SHOULD HAVE ADEQUATE STRENGTH TO RESIST EARTHQUAKE SHAKING AND PARTICULARLY THE "ROCKING" EFFECT. GENERALLY "ROCKING"OCCURS IN RIGID COMMON-PEOPLE HOUSES.
- ALL BUILDING COMPONENTS, FOUNDATION, COLUMN, BEAM, WALLS, ROOF TRUSSES, ROOFING MUST BE TIED TO EACH OTHER, SO THAT WHEN SHAKEN BY EARTHQUAKES, THE BUILDINGS WILL ACT AS ONE INTEGRAL UNIT.

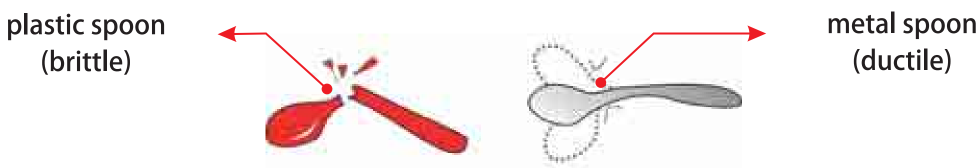


RIGID BUILDING "ROCKING" WHEN STRUCK BY EARTHQUAKE



2.3.6. DUCTILITY

- GENERALLY, DUCTILITY IS MEANT THE ABILITY OF THE BUILDING TO BEND, SWAY, DAN DEFORM BY LARGE AMOUNTS WITHOUT COLLAPSE. TECHNICALLY, DUCTILITY IS THE COMPARISON BETWEEN DEFLECTION BEFORE THE BUILDING COLLAPSE WITH THE DEFLECTION WHEN THE BUILDING START TO DAMAGE.
- A STRUCTURE IS EARTHQUAKE RESISTANCE IF THE OVERALL STRUCTURE HAS HIGH DUCTILITY. FOR THIS PURPOSE, HIGH DUCTILITY MATERIAL CAN BE COMBINED WITH LOW DUCTILITY MATERIAL WITH THE APPROPRIATE PROPORTION AND LOCATION SO THAT THE OVERALL STRUCTURE HAS HIGH DUCTILITY.
- DUCTILITY IS ESPECIALLY NEEDED IN THE BUILDING WHICH WILL HAVE LARGE DEFLECTION WHEN SHAKING BY EARTHQUAKE, GENERALLY IN THE HIGH-RISE BUILDING.
- FOR HIGH-RISE BUILDING, BESIDE STRENGTH, DUCTILITY IS NEEDED. HOWEVER FOR COMMON-PEOPLE HOUSE WHICH RELATIVELY RIGID, THE STRENGTH EFFECT IS MORE DOMINANT COMPARE TO DUCTILITY.



EXAMPLE OF DUCTILITY ILLUSTRATION

2.3.7. FOUNDATION

- BUILDINGS WHICH ARE STRUCTURALLY STRONG TO WITHSTAND EARTHQUAKES SOMETIMES FAIL DUE TO INADEQUATE FOUNDATION DESIGN.
- TILTING, CRACKING, AND FAILURE OF SUPERSTRUCTURES MAY RESULT FROM SOIL LIQUEFACTION, AND DIFFERENTIAL SETTLEMENT OF FOOTINGS.

2.3.8. CONSTRUCTION QUALITY

GENERALLY, THE FAILURE OF BUILDINGS IN AN EARTHQUAKE IS CAUSED BY:

- **POOR QUALITY OF MATERIALS**
- **POOR WORKMANSHIP**


Reconstruction of Houses after the December 26, 2004 Aceh Earthquake & Tsunami

EXAMPLE OF POOR QUALITY OF MATERIALS




Reconstruction of Houses after the December 26, 2004 Aceh Earthquake & Tsunami


Reconstruction of School Buildings after the May 27, 2006 Yogyakarta Earthquake

EXAMPLE OF POOR WORKMANSHIP

2.4. SUITABILITY EARTHQUAKE RESISTANT STRUCTURAL SYSTEM OF NON-ENGINEERED BUILDINGS

	STRUCTURAL SYSTEM	CHARACTERISTICS
VERY SUITABLE	• RIGID STEEL FRAMING • RIGID R.C. FRAMING • TIMBER FRAMING WITH BRACING	• MINIMUM WEIGHT • HIGH RESISTANCE FOR HORIZONTAL LOAD
SUITABLE	• CONFINED BRICK MASONRY WALL (CONFINEMENT WITH R.C. OR TIMBER) • CONFINED CONCRETE BLOCKS MASONRY WALL (CONFINEMENT WITH R.C. OR TIMBER)	• MODERATE WEIGHT • CAN RESIST HORIZONTAL LOAD • MODERATE DUCTILITY
LESS SUITABLE	• UNCONFINED BRICK MASONRY WALL, USING HORIZONTAL FLAT/CURVED ARC ABOVE WINDOR/DOOR OPENING • UNCONFINED CONCRETE BLOCK MASONRY WALL, USING HORIZONTAL FLAT/CURVED ARC ABOVE WINDOR/DOOR OPENING • UNCONFINED RUBBLE MASONRY WALL, USING HORIZONTAL FLAT/CURVED ARC ABOVE WINDOR/DOOR OPENING	• VERY HEAVY • LESS RESISTANCE FOR HORIZONTAL LOAD • LESS DUCTILITY
NOT SUITABLE	• UNCONFINED BRICK MASONRY WALL • UNCONFINED CONCRETE BLOCK MASONRY WALL • UNCONFINED RUBBLE MASONRY WALL • ADOBE/LODGE FROM MUD	• VERY HEAVY, ALMOST NO RESISTANCE FOR HORIZONTAL LOAD • ALMOST NO DUCTILITY

2.5. PERFORMANCE LEVEL OF EARTHQUAKE RESISTANT BUILDING DESIGN

PLANNING A BUILDING TO RESIST THE MAXIMUM STRONG EARTHQUAKE THAT MIGHT OCCUR IN AN AREA WITHOUT ANY DAMAGE IS NOT ECONOMIC BECAUSE SUCH STRONG EARTHQUAKE DOES NOT OCCUR FREQUENTLY.

THE MAIN PRIORITY OF PLANNING AN EARTHQUAKE RESISTANT NON-ENGINEERED BUILDING IS TO PREVENT LOSS OF HUMAN LIFE. THE SECOND PRIORITY IS TO PREVENT PROPERTY LOSS.

THE MINIMUM PERFORMANCE LEVEL FOR EARTHQUAKE RESISTANT NON-ENGINEERED BUILDINGS ARE AS FOLLOWS:

1. STRONG ENOUGH TO BEAR GRAVITY LOAD (DEAD LOAD AND LIVE LOAD) AND WIND LOAD WITHOUT CAUSING DAMAGE TO STRUCTURAL COMPONENTS AS WELL AS NON-STRUCTURAL COMPONENTS (OPERATIONAL AND FUNCTIONAL COMPONENTS / OFC).
2. RESIST MINOR EARTHQUAKE (WITH RETURN PERIOD 43 YEARS), WITHOUT ANY DAMAGE.
3. RESIST MODERATE EARTHQUAKE (WITH RETURN PERIOD 72 YEARS) WITHOUT STRUCTURAL DAMAGE, BUT WITH SOME OFC (NON-STRUCTURAL) DAMAGE.
4. RESIST MAJOR EARTHQUAKE (WITH RETURN PERIOD 500 YEARS):
   - BUILDINGS SHOULD NOT SUFFER PARTIAL OR TOTAL COLLAPSE.
   - BUILDINGS SHOULD NOT SUFFER DAMAGE THAT CAN NOT BE RETROFITTED. IN OTHER WORDS, THE BUILDING SHOULD NOT SUFFER HEAVY DAMAGE THAT IT MUST BE DEMOLISHED AND RECONSTRUCTED.
   - BUILDINGS MAY SUFFER STRUCTURAL AS WELL AS NON-STRUCTURAL DAMAGE, BUT THE DAMAGE CAN BE RETROFITTED QUICKLY SO THAT IT CAN RE-FUNCTION AND THE COST OF RETROFITTING IS NOT GREATER THEN BUILD A NEW BUILDING.
   - IMPORTANT BUILDINGS, SUCH AS HOSPITALS, SCHOOLS, FOOD-STORAGES, WATER RESERVOIR, ELECTRIC GENERATING PLANTS, COMMUNICATIONS BUILDINGS, ETC. SHALL NOT SUFFER HEAVY DAMAGE SO THAT THEY CAN NOT FUNCTION.

2.6. GENERAL PLANNING OF EARTHQUAKE RESISTANT DESIGN

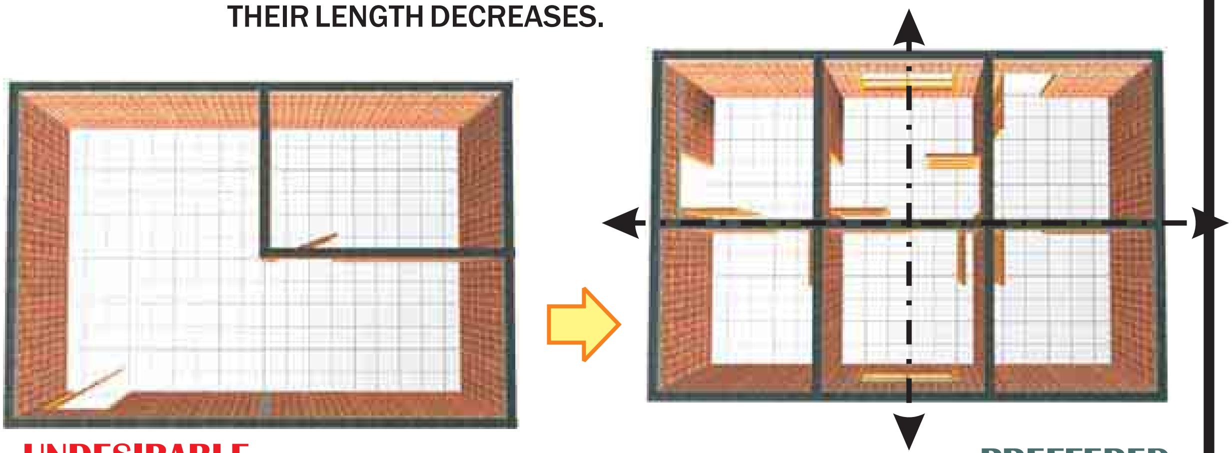
2.6.1. PLAN OF BUILDING

- SYMMETRY
  - THE BUILDING AS A WHOLE OR ITS VARIOUS BLOCKS SHOULD BE KEPT SYMMETRICAL TOWARDS BOTH THE AXES.
  - ASYMMETRY LEADS TO TORSION DURING EARTHQUAKES AND COULD CAUSE DAMAGE.
- REGULARITY
  - SIMPLE RECTANGULAR SHAPES BEHAVE BETTER IN AN EARTHQUAKE THAN SHAPES WITH MANY PROJECTIONS.
  - LONG NARROW RECTANGULAR BLOCKS SHOULD BE AVOIDED BECAUSE IT WILL CAUSE TORSIONAL EFFECTS.
- SEPARATION OF BLOCKS
  - SEPARATION OF A LARGE BUILDING INTO SEVERAL BLOCKS MAY BE REQUIRED SO AS TO OBTAIN SYMMETRY AND REGULARITY OF EACH BLOCK.

- SIMPLICITY
  - ORNAMENTATION INVOLVING LARGE CORNICES, VERTICAL OR HORIZONTAL CANTILEVER PROJECTIONS, ARE DANGEROUS AND UNDESIRABLE. IT SHOULD BE AVOIDED.

THE PLAN OF BUILDING SHOULD BE SIMPLE AND SYMMETRIC

- ENCLOSED AREA
  - A SMALL ENCLOSURE WITH PROPERLY INTERCONNECTED WALLS ACTS LIKE A RIGID BOX SINCE THE EARTHQUAKE STRENGTH WHICH LONG WALLS DERIVE FROM TRANSVERSE WALLS INCREASES AS THEIR LENGTH DECREASES.



UNDESIRABLE PREFFERED

PLACEMENT OF PARTITION WALLS AND DOOR/WINDOW OPENINGS MUST BE AS SYMMETRIC AS POSSIBLE TOWARD THE MAIN AXIS.

NOTE: WITH THE CURRENT SOFTWARES AVAILABLE IN THE MARKET, IT IS POSSIBLE TO ANALYZE AND DESIGN UNSYMMETRICAL AND COMPLEX BUILDINGS. HOWEVER, IT IS ADVISABLE TO DESIGN AND CONSTRUCT NON-ENGINEERED BUILDINGS BASED ON THE ABOVE PRINCIPLES.

2.6.2. CHOICE OF SITE

- SOIL TYPES: VERY FINE SANDS AND SENSITIVE CLAY SATURATED WITH WATER SHALL BE AVOIDED BECAUSE OF LIQUEFACTION POTENTIAL AND MAY LOSE ITS STRENGTH AND CAUSE DAMAGE TO BUILDINGS WHEN SHAKEN BY EARTHQUAKE.
- BUILDING ON UNSTABLE SLOPES MUST BE AVOIDED BECAUSE SUCH SLOPES MIGHT SLIDE WHEN SHAKEN BY EARTHQUAKE.

2.6.3. STRUCTURAL DESIGN

- STRENGTH
  - STRENGTH IS THE ABILITY OF STRUCTURE TO BEAR EARTHQUAKE SHAKING AND "ROCKING" EFFECT.
  - ALL BUILDING COMPONENTS MUST BE TIED TO EACH OTHER, SO THAT WHEN SHAKEN BY EARTHQUAKES, THE BUILDINGS WILL ACT AS ONE INTEGRAL UNIT.
- STIFFNESS
  - STIFFNESS IS THE RESISTANCE OF A STRUCTURE TO DEFORMATION BY AN APPLIED FORCES.
  - STIFFNESS IS APPLICABLE ONLY TO THE STRUCTURE.
- DUCTILITY
  - DUCTILITY IS THE RATIO OF THE DISPLACEMENT JUST PRIOR TO ULTIMATE DISPLACEMENT OR COLLAPSE TO THE DISPLACEMENT AT FIRST DAMAGE OR YIELD.
  - MATERIAL AS WELL AS STRUCTURAL DUCTILITY SHOULD BE CONSIDERED.

2.6.4. FIRE RESISTANCE

FIRE HAZARD SOMETIMES COULD EVEN BE MORE SERIOUS THAN THE EARTHQUAKE DAMAGE. THE CAUSES OF FIRE COULD BE SHORT-CIRCUITING OF ELECTRIC WIRES, KITCHEN FIRES OR OVERTURNING OF KEROSENE STOVES.

2.7. STRUCTURAL SYSTEMS OF NON-ENGINEERED BUILDINGS

GENERALLY, IN NON-ENGINEERED BUILDINGS THERE ARE TWO TYPES OF STRUCTURAL SYSTEMS:

1. WALL-BEARING CONSTRUCTION:

   TO BEAR VERTICAL AND LATERAL LOADS (UNCONFINED MASONRY)

2. MASONRY WALLS WITH FRAMING CONSTRUCTION:

   - WALLS WITH SIMPLE R.C. / TIMBER / STEEL CONFINEMENT TO BEAR VERTICAL AND LATERAL LOADS (CONFINED MASONRY).
   - RIGID FRAME CONSISTS OF BEAMS AND COLUMN TO BEAR VERTICAL AND LATERAL LOADS AND AN IN-FILL WALL IS PLACED WITHIN THE FRAME.

III. TYPICAL DAMAGE OF NON-ENGINEERED CONSTRUCTIONS

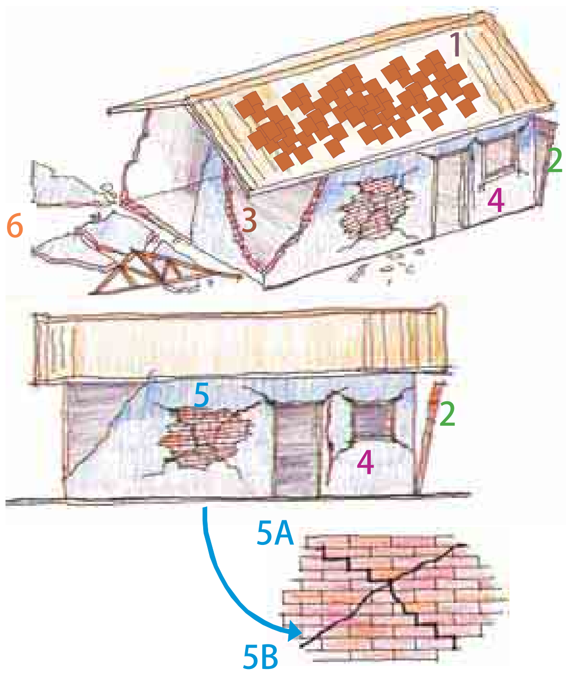
SO FAR, FIELD INSPECTION OF EARTHQUAKE DAMAGED CONSTRUCTION IS ONE OF THE MOST EFFECTIVE MEANS FOR OBTAINING INFORMATION.

EARTHQUAKE DAMAGE IS AN ACTUAL SIMULATION -> ACTUAL BEHAVIOR UNDER ACTUAL LOADS.

THE DAMAGE OR COLLAPSE OF THE HOUSES ARE CAUSED BY OUT-OF-PLANE LOADING OR IN-PLANE LOADING OF WALLS. HOWEVER, THE MAIN CAUSE IS OUT-OF-PLANE LOADING.

TYPICAL DAMAGE OF NON-ENGINEERED BUILDINGS IN INDONESIA BASED ON 35 YEARS OF OBSERVATIONS ARE AS FOLLOWS:

1. ROOF TILES DISLODGE
2. WALLS TEAR APART
3. FAILURE AT CORNERS OF WALLS
4. FAILURE AT CORNERS OF OPENINGS
5. DIAGONAL CRACKS IN WALLS
6. WALLS COLLAPSE
7. FAILURE OF CONNECTIONS
8. TOTAL DAMAGE



1 ROOF TILES DISLODGE

2 WALLS TEAR APART

3 FAILURE AT CORNERS OF WALLS

4 FAILURE AT CORNERS OF OPENINGS

5 DIAGONAL CRACKS IN WALLS

5A DIAGONAL CRACKS IN WALLS THROUGH THE MORTAR

5B DIAGONAL CRACKS IN WALLS THROUGH THE BRICKS

6 WALLS COLLAPSE

KARANGASEM EQ, JANUARY 1, 2004

YOGYAKARTA EQ, MAY 27, 2006

EXAMPLE OF TYPICAL DAMAGE - ROOF TILES DISLODGE

PADANG PANJANG EQ, FEBRUARY16, 2004

WEST SUMATRA EQ, SEPTEMBER 30, 2009

EXAMPLE OF TYPICAL DAMAGE - WALLS TEAR APART

HALMAHERA EQ, JANUARY 21, 1994

BENGKULU EQ, SEPTEMBER 12, 2007

EXAMPLE OF TYPICAL DAMAGE - FAILURE AT CORNERS OF WALLS

SUKABUMI EQ, 1982

WEST SUMATRA EQ, SEPTEMBER 30, 2009

EXAMPLE OF TYPICAL DAMAGE - FAILURE AT CORNERS OF OPENINGS

LIWA EQ, FEBRUARY 16, 1994

WEST-JAVA EQ, SEPTEMBER 2, 2009

EXAMPLE OF TYPICAL DAMAGE - DIAGONAL CRACKS IN WALLS

BALI EQ, JULY 1976

SUMBAWA, NOVEMBER 25, 2007

EXAMPLE OF TYPICAL DAMAGE - WALLS COLLAPSE

NIAS EQ, MARCH 28, 2005

SIMEULUE EQ, FEBRUARY 20, 2008

EXAMPLE OF TYPICAL DAMAGE - FAILURE OF CONNECTIONS

MANOKWARI EQ, JANUARY 4, 2009

WEST SUMATRA EQ, SEPTEMBER 30, 2009

EXAMPLE OF TYPICAL DAMAGE - TOTAL DAMAGE

IV. DAMAGE OF NON-ENGINEERED CONSTRUCTIONS

GENERALLY, THE DAMAGE AND/OR COLLAPSE OF WALLS IS CAUSED BY OUT-OF-PLANE LOADING AND IN-PLANE LOADING. HOWEVER, THE MAIN CAUSE IS OUT-OF-PLANE LOADING. BESIDES THAT, THE DAMAGE IS ALSO CAUSED BY POOR MATERIALS QUALITY, POOR WORKMANSHIP, AND LACK OF MAINTENANCE.

4.1. UNREINFORCED MASONRY (UNCONFINED MASONRY)

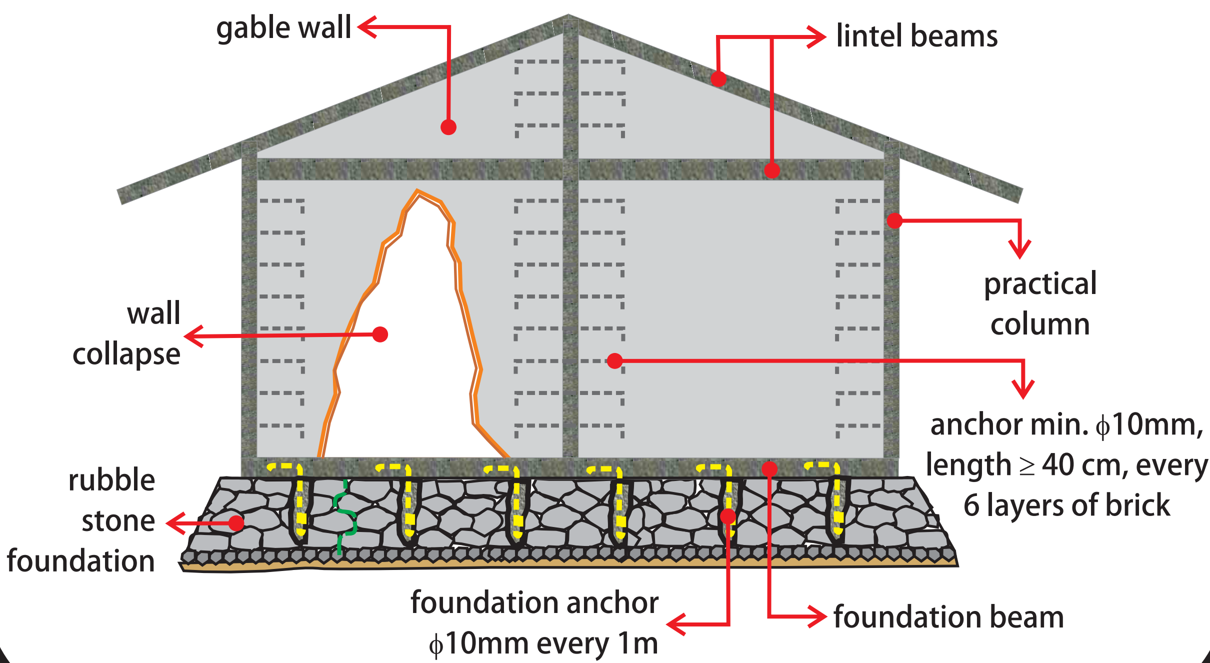
THE CAUSES OF DAMAGE ARE:

1. RELATIVE HEAVY
2. BRITTLE (NO DUCTILITY)
3. CAN NOT WITHSTAND TENSION FORCES THAT OCCURRED DUE TO OUT-OF-PLANE EARTHQUAKE FORCE

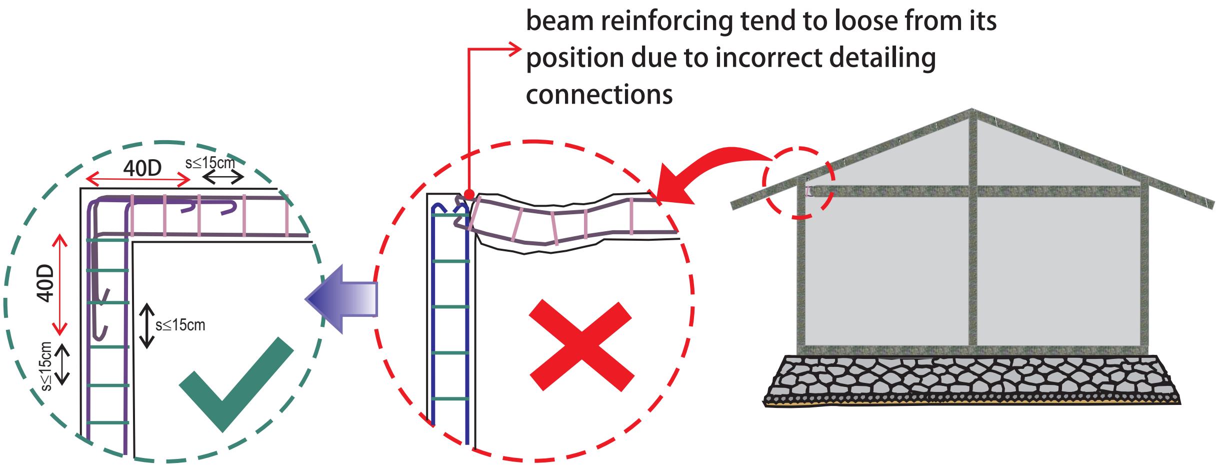
4.2. REINFORCED MASONRY (CONFINED MASONRY)

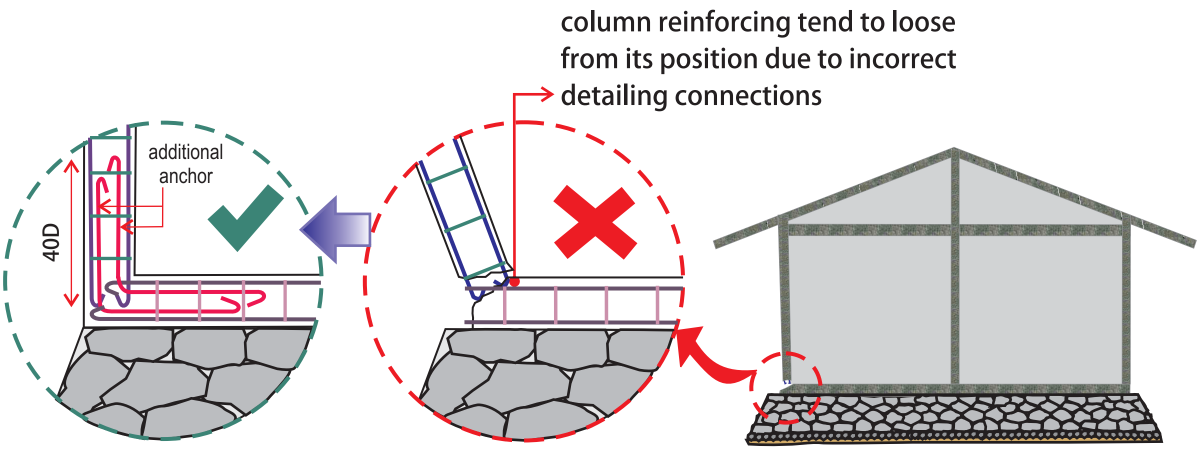
THE CAUSES OF DAMAGE ARE:

1. NO ANCHORAGE TO TIE THE WALLS TO THE CONCRETE FRAMES.
2. NO CONCRETE FRAMING FOR WALLS WITH AREA $\geq 6\ M^2$.



3. INCORRECT REINFORCING DETAILING AT CONNECTIONS OF CONCRETE FRAMES.





4. POOR QUALITY OF CONCRETE FRAMES (PRACTICAL COLUMNS, RING BEAMS, AND FOUNDATION BEAMS)

- THE MINIMUM RECOMMENDED CONCRETE MIX:

  1 CEMENT : 2 SAND : 3 GRAVEL

- SAND AND GRAVEL SHOULD BE CLEAN AND ADD APPROPRIATE AMOUNT OF WATER (1 CEMENT : 2 SAND : 3 GRAVEL : ½ WATER). WATER SHOULD NOT CONTAIN MUD.

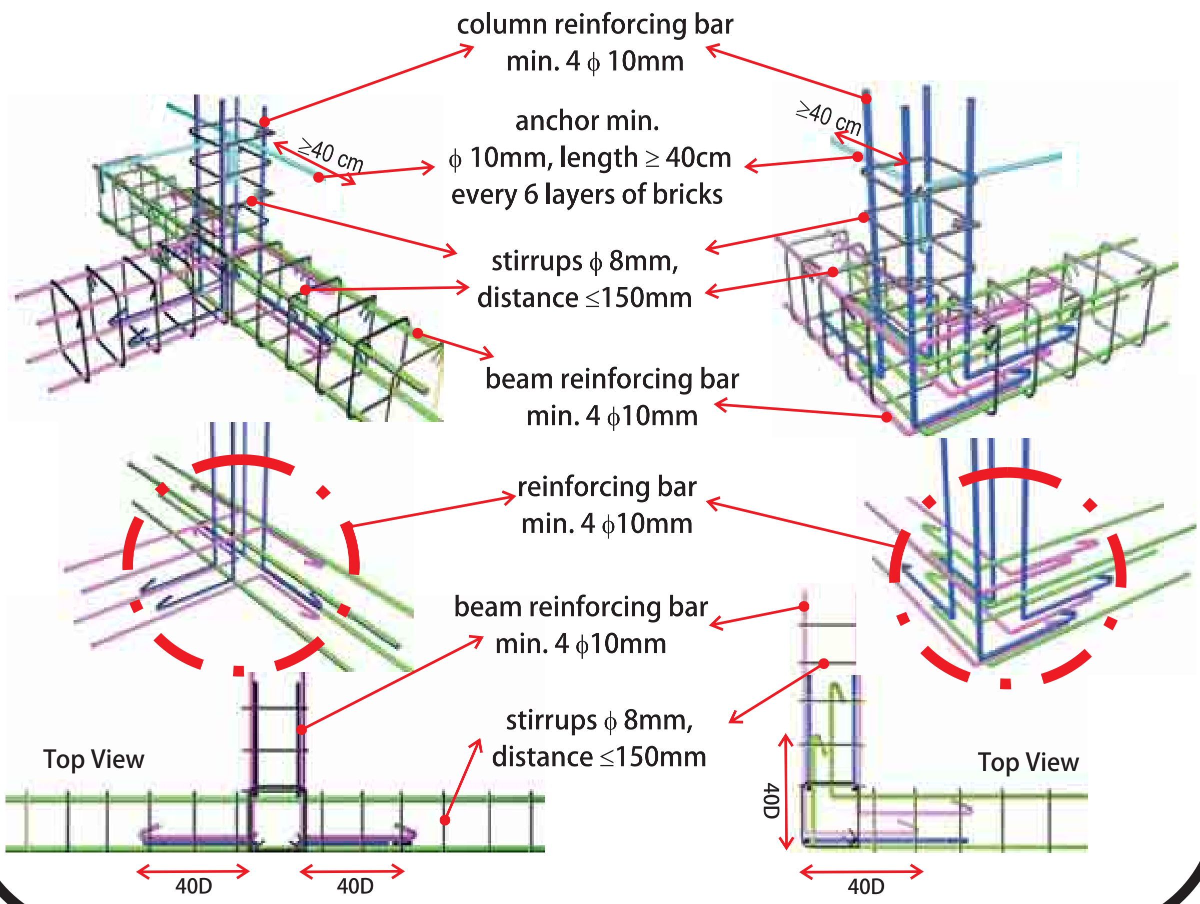
- THE CONCRETING OF PRACTICAL COLUMNS, RING BEAMS, AND FOUNDATION BEAMS SHOULD BE DONE CONTINUOUSLY. (CONCRETING IN STAGES IS NOT RECOMMENDED.)

MINIMUM CONCRETE MIX

5. THE EXISTING DIAMETER AND TOTAL AREA OF REINFORCING BARS IS TOO SMALL AND THE SPACING OF STIRRUPS IS TOO FAR.

   RECOMMENDED MINIMUM REINFORCING BARS:

   - FOR BEAMS: EACH TOP AND BOTTOM OF LONGITUDINAL REINFORCING IS 2ϕ10 MM. MINIMUM STIRRUPS ARE ϕ8 - 150 MM.
   - FOR COLUMNS: MINIMUM LONGITUDINAL REINFORCING IS 4ϕ10 MM. MINIMUM STIRRUPS ARE ϕ8 - 150 MM.



V. CATEGORY OF DAMAGE

CATEGORY 0: NO DAMAGE (N)

EXTENT OF DAMAGE IN GENERAL:

NO DAMAGE.

SUGGESTED POST-EQ ACTIONS:

NO ACTION REQUIRED.

CATEGORY I: SLIGHT - NON-STRUCTURAL DAMAGE (L)

EXTENT OF DAMAGE IN GENERAL:

THIN CRACKS IN PLASTER, FALLING OF PLASTER BITS IN LIMITED PARTS.

THE WIDTH OF THIN CRACK IS LESS THAN 0.075 CM.

SUGGESTED POST-EQ ACTIONS:

BUILDING NEED NOT BE VACATED. ONLY ARCHITECTURAL REPAIRS NEEDED.

CATEGORY II: SLIGHT STRUCTURAL DAMAGE (L)

EXTENT OF DAMAGE IN GENERAL:

SMALL CRACKS IN WALLS, FALLING OF PLASTER IN LARGE BITS OVER LARGE AREAS; DAMAGE TO NON-STRUCTURAL PARTS, PROJECTING CORNICES, ETC. THE LOAD CARRYING CAPACITY OF THE STRUCTURE IS NOT REDUCED APPRECIABLY.

SUGGESTED POST-EQ ACTIONS:

BUILDING NEED NOT BE VACATED. ARCHITECTURAL REPAIRS REQUIRED TO ACHIEVE DURABILITY.

CATEGORY III: MODERATE STRUCTURAL DAMAGE (M)

EXTENT OF DAMAGE IN GENERAL:

LARGE AND DEEP CRACKS IN WALLS; WIDESPREAD CRACKING OF WALLS, COLUMNS, PIERS. THE LOAD CARRYING CAPACITY OF STRUCTURE IS PARTIALLY REDUCED.

SUGGESTED POST-EQ ACTIONS:

BUILDING NEEDS TO BE VACATED, TO BE RE-OCCUPIED AFTER RESTORATION AND STRENGTHENING. STRUCTURAL RESTORATION AND SEISMIC STRENGTHENING ARE NECESSARY AFTER WHICH ARCHITECTURAL TREATMENT MAY BE CARRIED OUT.

CATEGORY IV: SEVERE STRUCTURAL DAMAGE (H)

EXTENT OF DAMAGE IN GENERAL:

GAPS OCCUR IN WALLS; INNER OR OUTER WALLS COLLAPSE; FAILURE OF TIES TO SEPARATE PARTS OF BUILDINGS. APPROXIMATELY 40 PERCENT OF THE MAIN STRUCTURAL COMPONENTS FAIL. THE BUILDING TAKES A DANGEROUS STATE.

SUGGESTED POST-EQ ACTIONS:

BUILDING HAS TO BE VACATED. EITHER THE BUILDING HAS TO BE DEMOLISHED OR EXTENSIVE RESTORATION AND STRENGTHENING WORK HAS TO BE

CATEGORY V: COLLAPSE

EXTENT OF DAMAGE IN GENERAL:

A LARGE PART OR WHOLE OF THE BUILDING COLLAPSES.

SUGGESTED POST-EQ ACTIONS:

CLEARING THE SITE AND RECONSTRUCTION.

VI. RETROFITTING (REPAIR, RESTORE, STRENGTHENING)

PROBLEM CLASSIFICATION

1. BEFORE A DAMAGING EARTHQUAKE:

   THE REQUIRED STRENGTHENING TO BE DETERMINED BY A SURVEY AND ANALYSIS.

2. JUST AFTER A DAMAGING EARTHQUAKE:

   TEMPORARY SUPPORTS & EMERGENCY REPAIRS ARE TO BE CARRIED OUT.

   THOSE ACTIONS ARE NEEDED SO THAT THE BUILDINGS CAN BE RE-FUNCTION AND NOT COLLAPSED DUE TO AFTERSHOCKS.

3. AFTER A DAMAGING EARTHQUAKE WHEN THINGS START SETTLING DOWN:

   DISTINCTION TO BE MADE IN THE TYPE OF ACTION REQUIRED:

   - REPAIR
   - RESTORATION
   - STRENGTHENING

REPAIR, RESTORATION, & STRENGTHENING

1. REPAIR

THE MAIN PURPOSE IS TO BRING BACK THE ARCHITECTURAL SHAPE OF THE BUILDING SO THAT ALL SERVICES START WORKING & THE FUNCTIONING OF BUILDING IS RESUMED QUICKLY.

THE ACTIONS WILL INCLUDE THE FOLLOWING:

A. PATCHING UP OF DEFECTS SUCH AS CRACKS, AND FALL OF PLASTER

B. REPAIRING DOORS, WINDOWS, REPLACEMENT OF GLASS PANES

C. CHECKING AND REPAIRING ELECTRIC WIRING.

D. CHECKING AND REPAIRING GAS PIPES, WATER PIPES & PLUMBING SERVICES

E. REBUILDING NON-STRUCTURAL WALLS, BOUNDARY WALLS, ETC.

F. RE-PLASTERING OF WALLS AS REQUIRED

G. REARRANGING DISTURBED ROOFING TILES

2. RESTORATION

THE MAIN PURPOSE IS TO CARRY OUT STRUCTURAL REPAIRS TO LOAD BEARING COMPONENTS TO RESTORE ITS ORIGINAL STRENGTH.

THE ACTIONS WILL INCLUDE THE FOLLOWING:

A. INJECTING EPOXY LIKE MATERIAL, WHICH IS STRONG IN TENSION, INTO THE CRACKS IN WALLS, COLUMNS, BEAMS, ETC..

B. ADDITION OF REINFORCING MESH ON BOTH FACES OF THE CRACKED WALL, HOLDING IT TO THE WALL THROUGH SPIKES OR BOLTS & THEN COVERING IT SUITABLY.

C. REMOVAL OF PORTIONS OF CRACKED MASONRY WALLS & PIERS AND REBUILDING THEM IN RICHER MORTAR. USE OF NON-SHRINKING MORTAR WILL BE PREFERABLE.

D. REMOVE THE DAMAGE COLUMN OR BEAM, FIX THE REINFORCING, ADD REINFORCING IF NEEDED, AND RE-CONCRETING.

3. STRENGTHENING

THE MAIN PURPOSE IS TO MAKE BUILDINGS STRONGER THAN BEFORE.

THE ACTIONS WILL INCLUDE THE FOLLOWING:

A. DEMOLISH THE WEAKNESS SOURCES OR SOURCES THAT CAN MAKE STRESS CONCENTRATION IN SEVERAL PARTS:

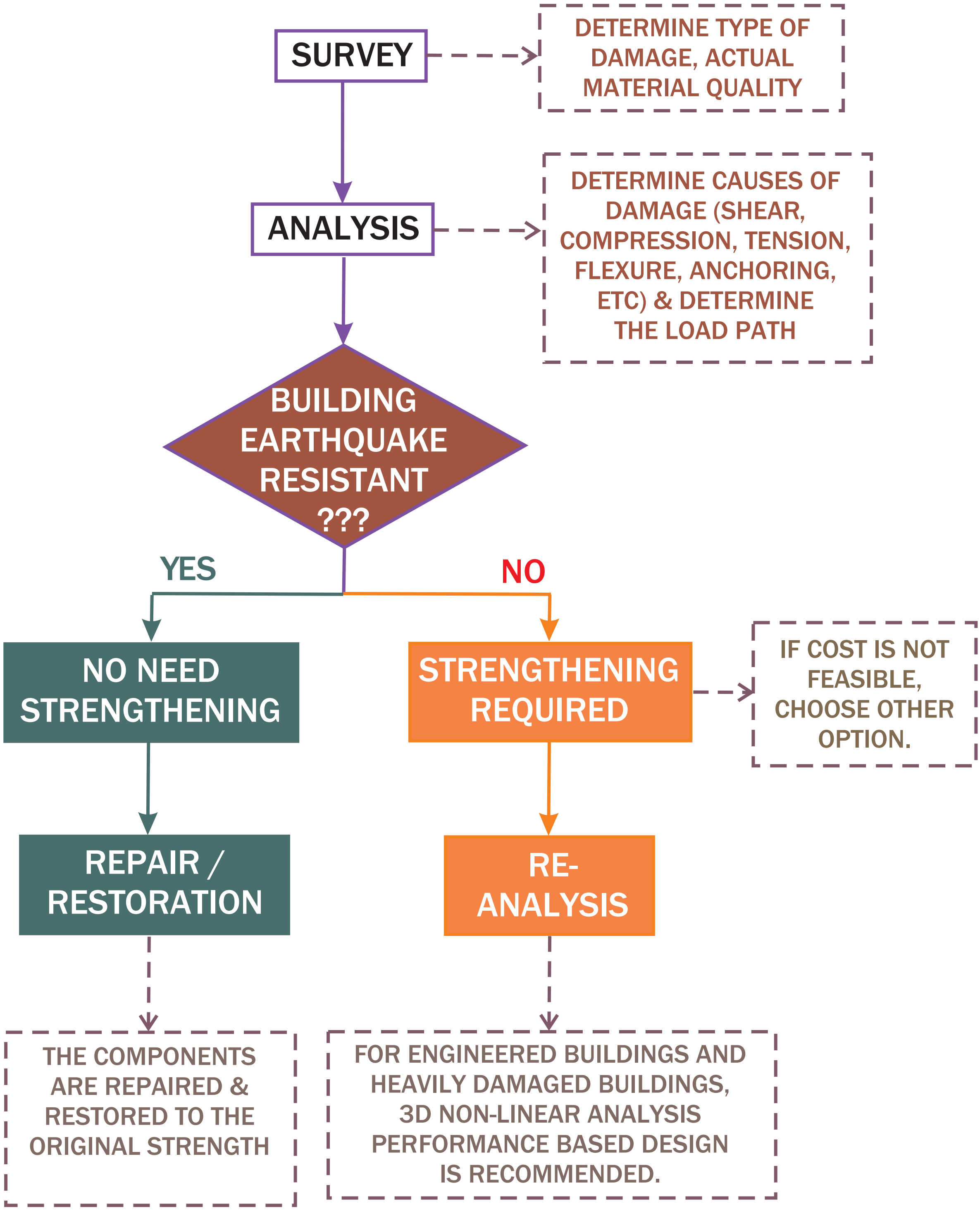
- COLUMNS DISTRIBUTION ARE NOT SYMMETRIC
- WALLS DISTRIBUTION ARE NOT SYMMETRIC
- DIFFERENT STIFFNESS FROM ONE TO ANOTHER FLOORS
- EXCESSIVE OPENINGS

B. MAKE THE BUILDING AS A UNITY BY TYING TOGETHER ALL COMPONENTS OF BUILDING

C. AVOID BRITTLE FAILURE BY RE-ARRANGING, ADDING REINFORCING BARS, AND MAKE THE DETAILS IN ACCORDANCE WITH DUCTILITY REQUIREMENT.

D. INCREASING THE LATERAL STRENGTH BY ADDING WALLS, COLUMNS, ETC.

VII. RETROFITTING STEPS



STEPS OF RETROFITTING:

1. DETERMINE AS ACCURATE AS POSSIBLE HOW THE BUILDING BEHAVE WHEN SHAKEN BY AN EARTHQUAKE:
    - CHECK THE BUILDING
    - CHECK BUILDING MATERIAL QUALITY
    - LIST ALL COMPONENTS OF THE BUILDING THAT ARE DAMAGED
2. PERFORM A DYNAMIC ANALYSIS FOR THE BUILDING TO GET AN IDEA OF THE CAUSES OF DAMAGE AND DETERMINE THE LOAD PATHS WHEN SHAKEN BY THE EARTHQUAKE.
3. DETERMINE THE CAUSES OF DAMAGE OF COMPONENTS; CAUSED BY SHEAR, COMPRESSION, TENSION, FLEXURE, ANCHORING, ETC.
4. AS SOON AS THE TYPE OF DAMAGE CAN BE IDENTIFIED, REPAIR AND RESTORATION OF THE COMPONENTS CAN BE DONE SEPARATELY IN ORDER THAT THE ORIGINAL STRENGTH OF THE COMPONENTS CAN BE RESTORED.
5. IF RESULTS OF ANALYSIS INDICATE THAT THE BUILDING WITH RESTORED COMPONENTS CAN WITHSTAND THE MAXIMUM EXPECTED EARTHQUAKE FOR THAT AREA BASED ON THE LATEST CODE, THEN THERE IS NO NEED TO STRENGTHEN.
6. HOWEVER, IF THE BUILDING WITH RESTORED COMPONENTS WAS NOT DESIGNED OR DESIGNED FOR A LOWER THAN THE MAXIMUM EXPECTED EARTHQUAKE SPECIFIED BY THE LATEST CODE, THEN THE BUILDING NEEDS TO BE STRENGTHENED.
    - FOR STRENGTHENING, THE RESTORED BUILDING MUST BE RE-ANALYZED TO IDENTIFY WHICH COMPONENTS MUST BE STRENGTHENED.
    - FOR ENGINEERED BUILDINGS WITH SEVERE DAMAGE AND IF THE BUILDING NEEDS TO BE STRENGTHENED, 3D NON-LINEAR ANALYSIS PERFORMANCE BASED DESIGN SHOULD BE DONE.
    - IF COST FOR STRENGTHENING THE BUILDING TO ITS ORIGINAL FUNCTION IS NOT FEASIBLE, ONE OPTION THAT CAN BE CHOSEN IS TO CHANGE THE BUILDING FUNCTION WITH LESS STRINGENT REQUIREMENT. THEREFORE, THE COST WILL BE REDUCED.
7. AFTER THE STRENGTHENING WORKS IS COMPLETED, THE BUILDING MUST BE RE-ANALYZED TO ENSURE THAT THE STRENGTHENED BUILDING IS EARTHQUAKE RESISTANT.

VIII. RETROFITTING STRATEGY & SYSTEM

THIS SECTION DISCUSSES THE GENERAL PRINCIPLES OF RETROFITTING STRATEGY AND SYSTEM WHICH IS APPLICABLE TO NON-ENGINEERED AS WELL AS ENGINEERED BUILDINGS.

RETROFIT IS DONE TO IMPROVE THE SEISMIC SAFETY OF EXISTING BUILDINGS:

- RETROFIT BUILDINGS DAMAGED DURING EARTHQUAKES
- RETROFIT TO COMPLY WITH NEW CODES

SYSTEMATIC RETROFIT APPROACH:

8. 1. RETROFIT STRATEGY:

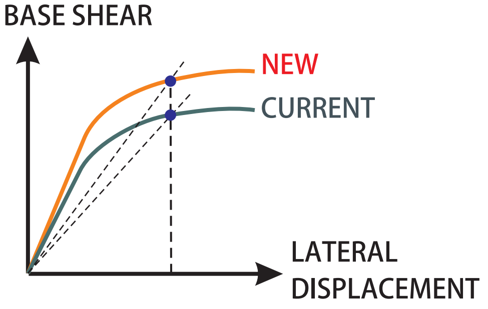
- 8.1.A. INCREASING STIFFNESS AND/OR STRENGTH
- 8.1.B. INCREASING DUCTILITY
- 8.1.C. INCREASING ENERGY DISSIPATION
- 8.1.D. MODIFYING THE CHARACTER OF THE GROUND MOTION TRANSMITTED TO THE BUILDING
- 8.1.E. REDUCING OCCUPANCY EXPOSURE

8.2. RETROFIT SYSTEM:

- 8.2.A. INCREASING STIFFNESS AND/OR STRENGTH
  - 8.2.A.I. ADDITION OF NEW WALLS
  - 8.2.A.II. ADDITION OF BRACED FRAMES
  - 8.2.A.III. THICKENING OF EXISTING SHEAR WALLS
  - 8.2.A.IV. CARBON FIBER REINFORCED PLASTIC (CFRP)
  - 8.2.A.V. PROVIDING BANDAGE
  - 8.2.A.VI. JACKETING
  - 8.2.A.VII. COMBINATION OF THE ABOVE
- 8.2.B. INCREASING DUCTILITY
- 8.2.C. INCREASING ENERGY DISSIPATION
- 8.2.D. MODIFYING THE CHARACTER OF THE GROUND MOTION TRANSMITTED TO THE BUILDING
- 8.2.E. NON-STRUCTURAL COMPONENTS
- 8.2.F. REDUCING OCCUPANCY EXPOSURE

8. 1. RETROFIT STRATEGY

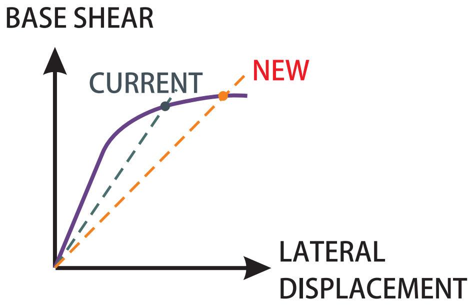
8.1.A. INCREASING STIFFNESS AND/OR STRENGTH



- ESTIMATE NEW PUSHOVER CURVE.
- ASSUME PERFORMANCE LIMIT POINT AT SAME DISPLACEMENT.
- GET NEW BASE SHEAR CAPACITY.
- GET NEW SECANT STIFFNESS AND PERIOD.
- GET NEW BASE SHEAR DEMAND.

STRENGTH INCREASE, NO CHANGE IN DUCTILITY OR DAMPING

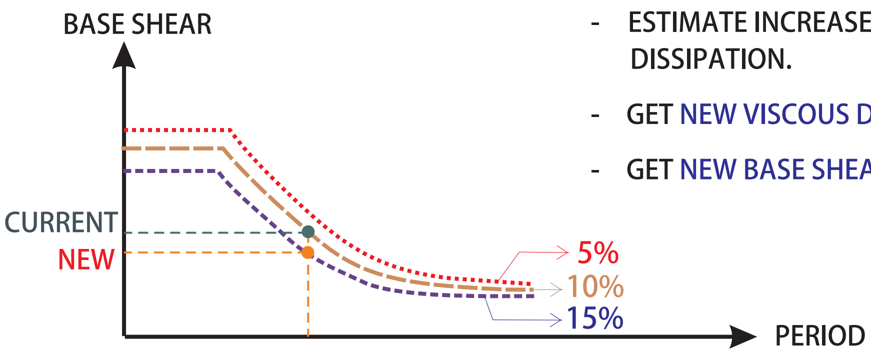
8.1.B. INCREASING DUCTILITY



- ESTIMATE NEW PERFORMANCE POINT.
- GET NEW BASE SHEAR CAPACITY.
- GET NEW SECANT STIFFNESS AND PERIOD.
- GET NEW BASE SHEAR DEMAND.

DUCTILITY INCREASE, NO CHANGE IN STRENGTH OR DAMPING

8.1.C. INCREASING ENERGY DISSIPATION

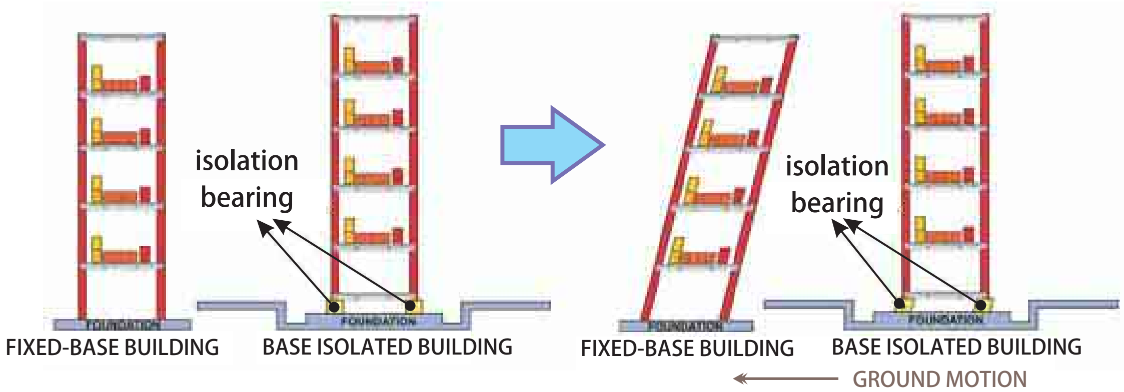


- ESTIMATE INCREASE IN ENERGY DISSIPATION.
- GET NEW VISCOUS DAMPING.
- GET NEW BASE SHEAR DEMAND.

DAMPING INCREASE, NO CHANGE IN STRENGTH OR DUCTILITY

8.1.D. MODIFYING THE CHARACTER OF THE GROUND MOTION TRANSMITTED TO THE BUILDING.

EARTHQUAKE FORCE THAT IMPACT TO THE BUILDING WILL BE REDUCED. THEREFORE THE DISPLACEMENT IN THE BUILDING WILL BE DECREASED. USUALLY BASE-ISOLATION IS APPLIED TO IMPORTANT BUILDINGS SUCH AS HOSPITALS, MAIN FACILITIES THAT MUST BE FULLY FUNCTIONAL AFTER STRUCK BY EARTHQUAKES, AND ALSO HISTORICAL BUILDINGS THAT MUST BE PROTECTED.



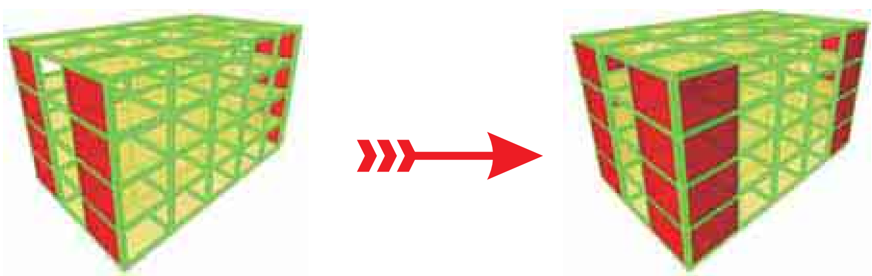
8.1.E. REDUCING OCCUPANCY EXPOSURE

EXAMPLE: THE COST FOR RETROFITTING THE DAMAGE OFFICE BUILDING TO ITS ORIGINAL FUNCTION IS HIGH. THEREFORE, THE BUILDING WILL BE RETROFITTED TO BE A WAREHOUSE WHICH HAS LOWER PERFORMANCE CRITERIA THAN THE OFFICE BUILDING AND THE COST WILL BE LESS THAN RETROFITTED OFFICE BUILDING INTO ITS ORIGINAL FUNCTION.

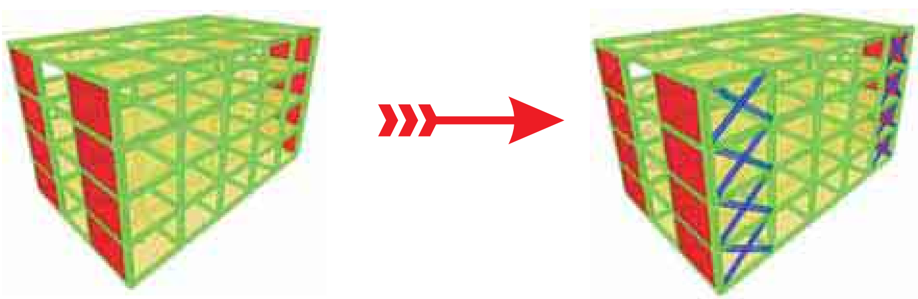
8.2. RETROFIT SYSTEM

8.2.A. INCREASING STIFFNESS AND/OR STRENGTH

8.2.A.I. ADDITION OF NEW WALLS



8.2.A.II. ADDITION OF BRACED FRAMES



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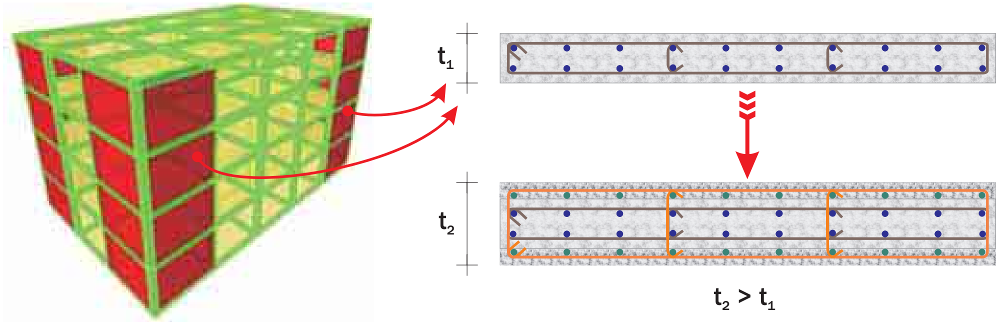
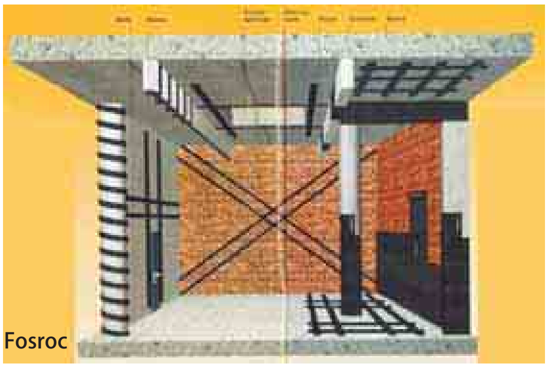
8.2.A.III. THICKENING OF EXISTING SHEAR WALLS



8.2.A.IV. CARBON FIBER REINFORCED PLASTIC (CFRP)



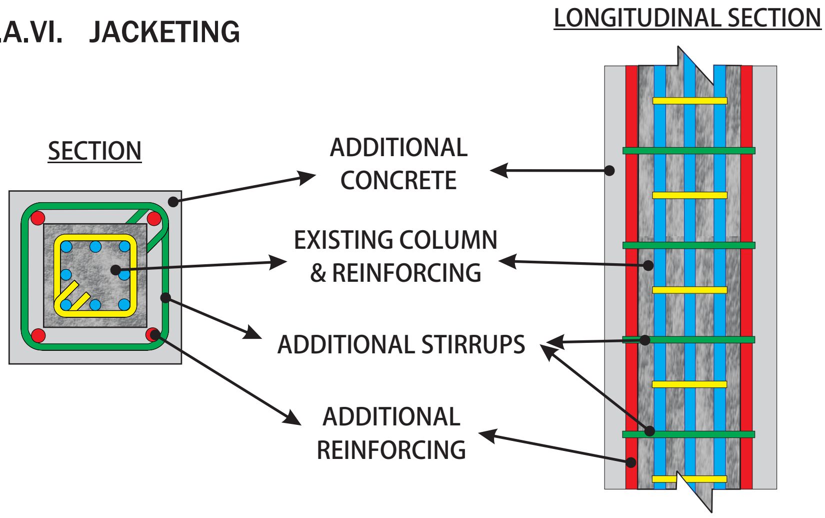
FIBER-WRAPPED SHORT COLUMNS
Courtesy Saif Hussain, Coffman Engineers

8.2.A.V. PROVIDING BANDAGE

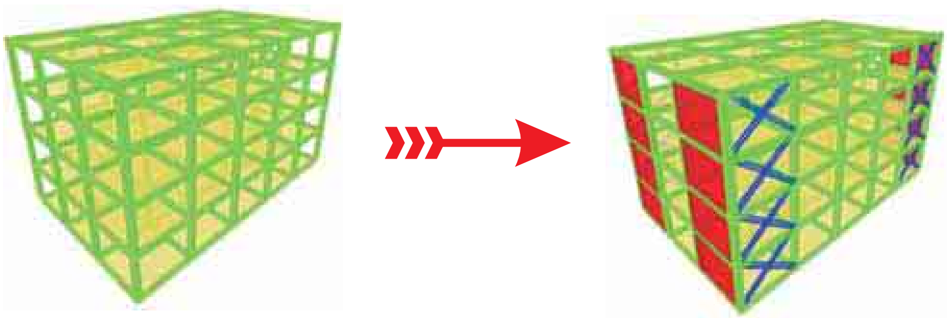
RETROFITTING SCHOOL BUILDING IN SOREANG, SOUTH OF BANDUNG USING WIRE MESH

BANDAGING USING WIRE MESH

8.2.A.VI. JACKETING



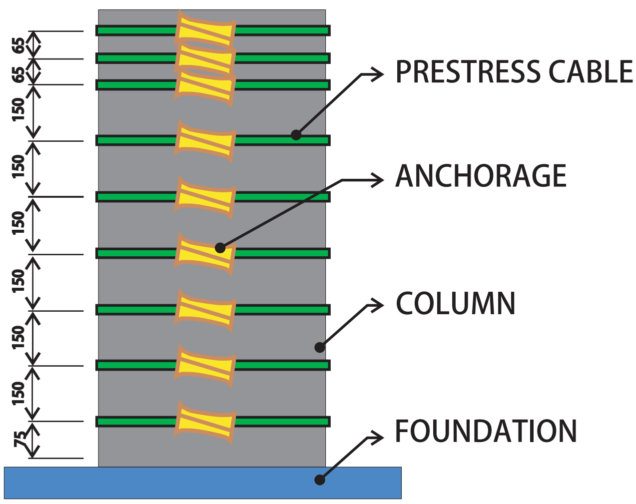
8.2.A.VII. COMBINATION OF THE ABOVE



8.2.B. INCREASING DUCTILITY

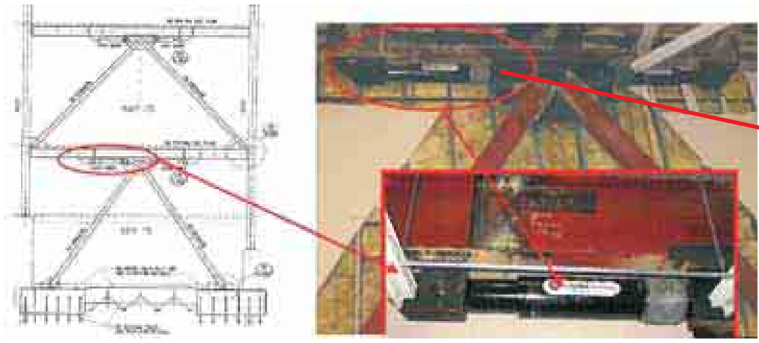
BESIDES INCREASING THE STRENGTH OF A STRUCTURAL COMPONENT, BANDAGING, CARBON FIBER REINFORCED PLASTIC (CFRP) AND JACKETING CAN ALSO BE USED TO INCREASE DUCTILITY.

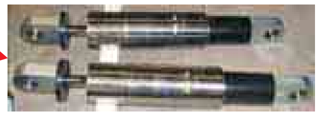
EXTERNAL PRE-STRESSING ALSO CAN BE USED TO INCREASE THE DUCTILITY OF A STRUCTURAL COMPONENT.



EXTERNAL PRE-STRESSING TO INCREASE DUCTILITY.

8.2.C. INCREASING ENERGY DISSIPATION





VISCOUS FLUID DAMPERS

BUCKLING RESTRAINED BRACED FRAME

Pictures Courtesy Saif Hussain, Coffman Engineers

8.2.D. MODIFYING THE CHARACTER OF THE GROUND MOTION TRANSMITTED TO THE BUILDING USING BASE-ISOLATION

LOS ANGELES REGIONAL TRANSPORTATION MANAGEMENT CENTER

LOS ANGELES CITY HALL

Pictures Courtesy Saif Hussain, Coffman Engineers

EXAMPLE OF A BUILDING USING BASE-ISOLATION.

8.2.E. NON-STRUCTURAL COMPONENTS

THE AIM OF RETROFITTING NON-STRUCTURAL COMPONENTS BESIDES THE STRUCTURAL COMPONENTS IS TO MAKE SURE THAT THE BUILDING IS FULLY FUNCTIONAL AND OPERATIONAL AFTER AN EARTHQUAKE.

FROM 35 YEARS OF OBSERVATION OF EARTHQUAKE DAMAGES, MANY BUILDINGS ARE STRUCTURALLY INTACT, HOWEVER IT IS NOT FUNCTIONAL AND OPERATIONAL BECAUSE OF THE NON-STRUCTURAL COMPONENTS ARE DAMAGED.

NON-STRUCTURAL COMPONENTS CONSIST OF :

I. ARCHITECTURAL COMPONENTS, EXAMPLE: PARTITION WALLS, IN-FILL WALLS, CEILINGS, FACADES / WINDOWS, DOORS, ETC.

II. BUILDING SERVICES, EXAMPLE: PIPING, ELECTRICAL, WATER TANKS, PUMPS, LIGHTING SYSTEM, DLL.

III. BUILDING CONTENTS, EXAMPLE: DESKS, CHAIRS, ELECTRONIC EQUIPMENTS, CABINETS, DLL.

EXAMPLE OF NON-STRUCTURAL COMPONENTS IN NON-ENGINEERED BUILDINGS

EXAMPLE OF NON-STRUCTURAL COMPONENTS IN ENGINEERED BUILDINGS

EXAMPLE OF SOME NON-STRUCTURAL COMPONENTS THAT SHOULD BE CHECKED AND RETROFITTED SO THAT SO THAT ALL SERVICES START WORKING & THE FUNCTIONING OF BUILDING IS RESUMED QUICKLY




EXAMPLE OF NON-STRUCTURAL COMPONENTS DAMAGE BY EARTHQUAKE.

8.2.F. REDUCING OCCUPANCY EXPOSURE

EXAMPLE: THE COST FOR RETROFITTING THE DAMAGE OFFICE BUILDING TO ITS ORIGINAL FUNCTION IS HIGH. THEREFORE, THE BUILDING WILL BE RETROFITTED TO BE A WAREHOUSE WHICH HAS LOWER PERFORMANCE CRITERIA THAN THE OFFICE BUILDING AND THE COST WILL BE LESS THAN RETROFITTED OFFICE BUILDING INTO ITS ORIGINAL FUNCTION.

8.3. MATERIALS USED FOR RETROFITTING

- MOST COMMON MATERIALS FOR DAMAGE REPAIR WORKS:
  - CEMENT, STEEL
  - FRP
- MOST COMMON MATERIALS FOR TEMPORARY SUPPORTS:
  - BAMBOO
  - WOOD
- SPECIAL MATERIAL AND TECHNIQUES FOR REPAIR, RESTORE AND STRENGTHENING OPERATIONS:
  - SHOTCRETE
  - EPOXY RESIN & EPOXY MORTAR
  - GYPSUM CEMENT MORTAR
  - QUICK SETTING CEMENT MORTAR
  - MECHANICAL ANCHORS
  - FIBRE REINFORCED POLIMER (FRP)

IX. TECHNIQUES OF REPAIR & STRENGTHENING

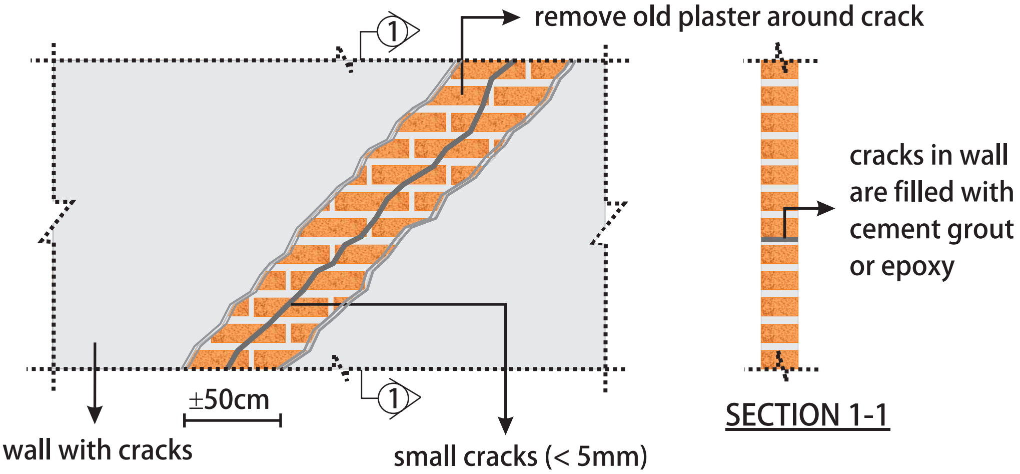
9.1. REPAIR OF CRACKS IN WALLS

EXAMPLE OF CRACKS AT CORNERS OF OPENING AND DIAGONAL CRACKS IN WALLS.

9.1.A. FOR SMALL CRACKS (CRACKS WIDTH IS LESS THAN 5 MM):

I. THE OLD PLASTER AROUND THE CRACK IS REMOVED ± 50CM, AND THEN INJECTED WITH CEMENT GROUT OR EPOXY.

II. AFTER THE CRACK IS SEALED, APPLY NEW PLASTER MADE OF MORTAR 1PC:3PS.



9.1.B. FOR LARGE CRACKS (CRACK WIDER THAN 5MM):

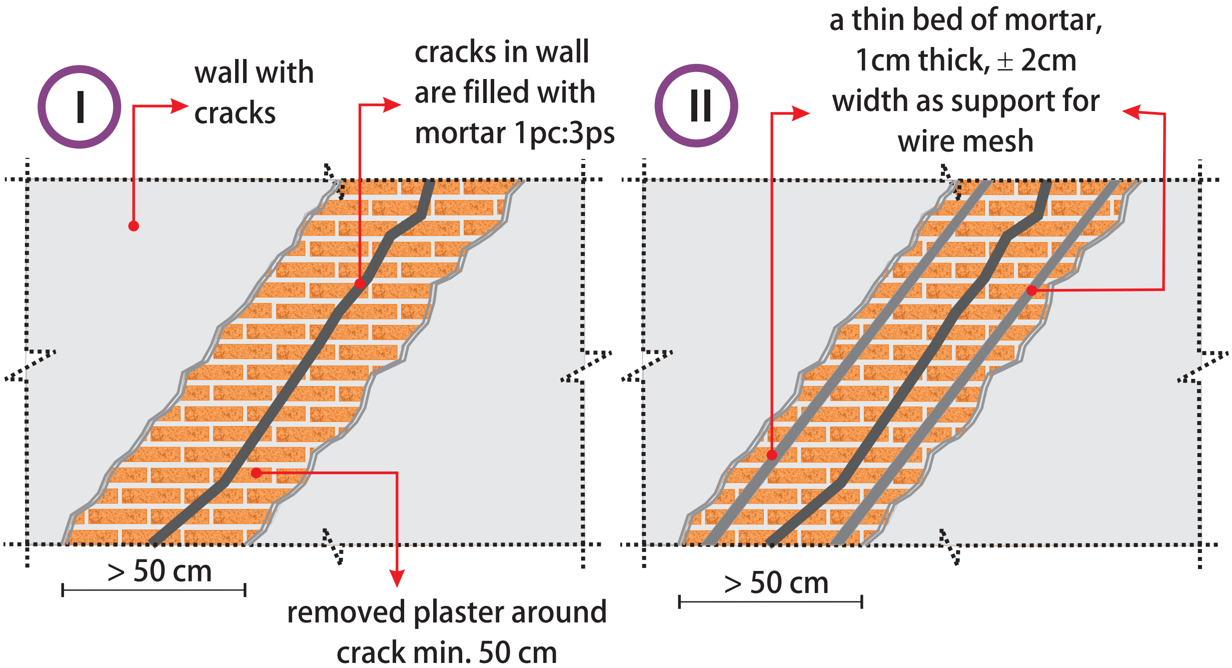
I. THE OLD PLASTER AROUND THE CRACK IS REMOVED MINIMUM 50CM, AND THEN INJECTED WITH CEMENT GROUT OR EPOXY.

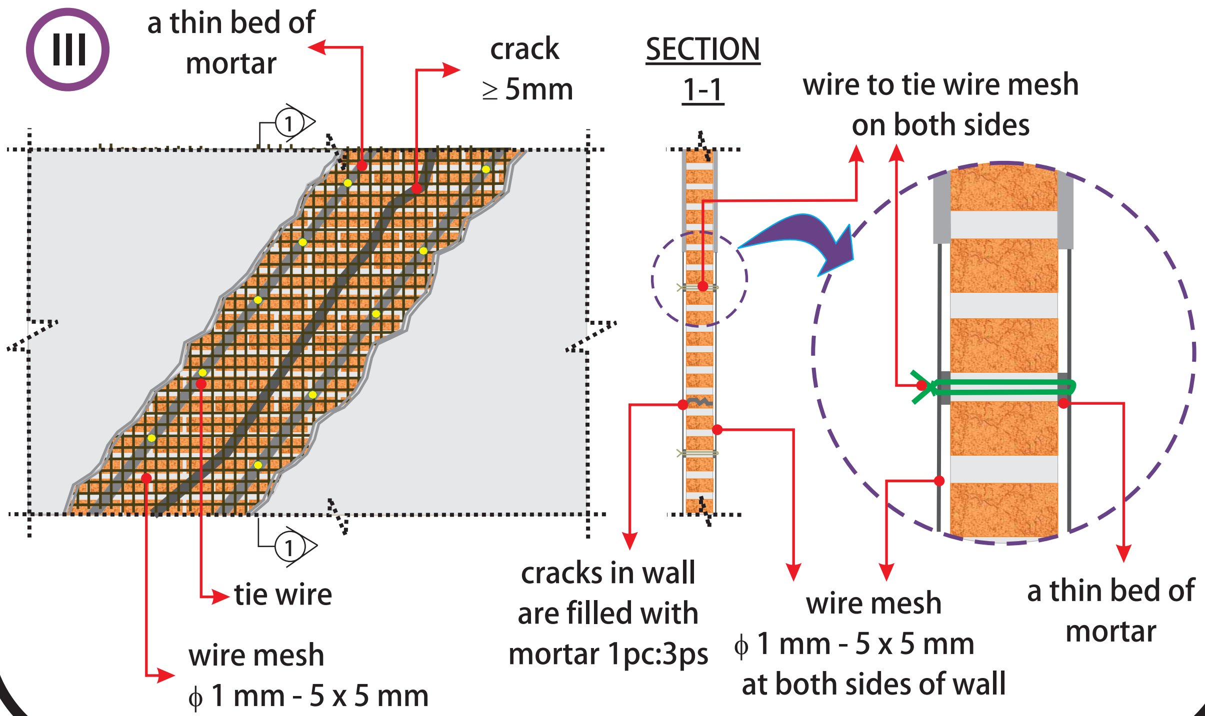
NOTE FOR CHAPTER IX:
ALL DIMENSION OF FOUNDATION, BEAM, COLUMN, AND REINFORCING INDICATED IN THIS CHAPTER ARE MINIMUM REQUIREMENTS. ACTUAL DIMENSION MUST BE IN ACCORDANCE WITH SEISMICITY OF EACH AREA.

II. AFTER THE CRACK IS SEALED, A THIN BED OF MORTAR, 1CM THICK, AND ± 2CM WIDTH MUST BE MADE. A THIN BED OF MORTAR SERVES AS THE SUPPORT FOR THE WIRE MESH.

III. PLACE WIRE MESH ON BOTH SIDES OF THE WALL AND TIE THOSE WIRE MESH TO EACH OTHER.

IV. THE WALL IS RE-PLASTERED WITH MORTAR 1 PC : 3 PS.

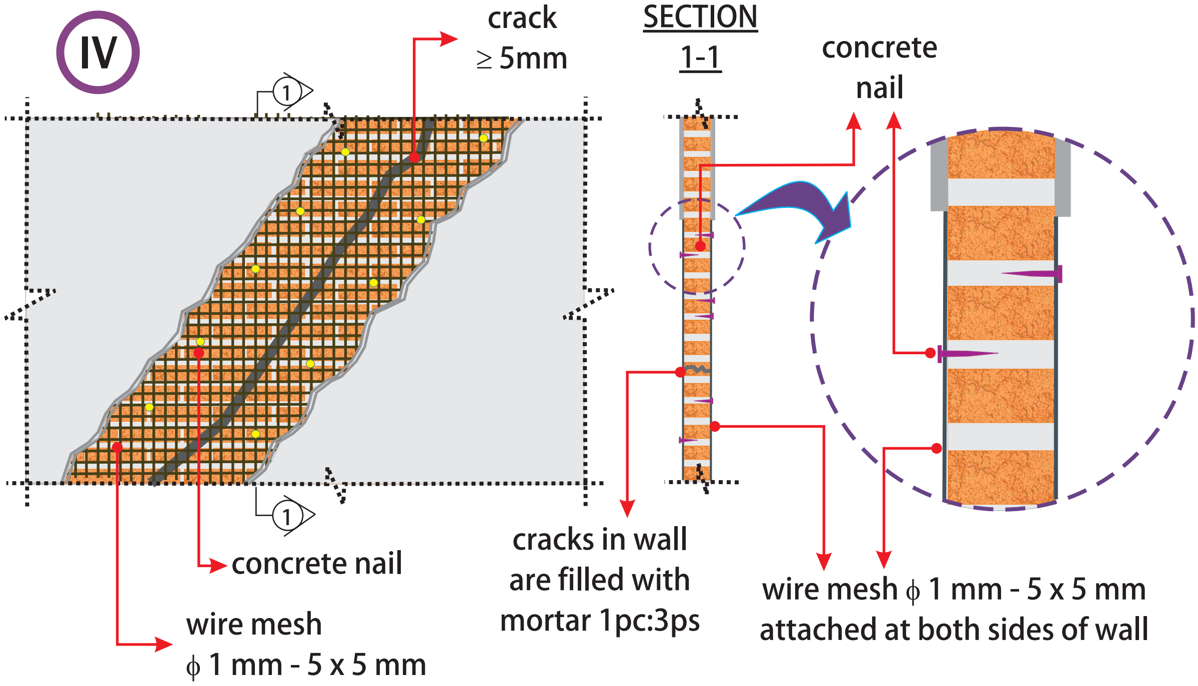




NOTE:

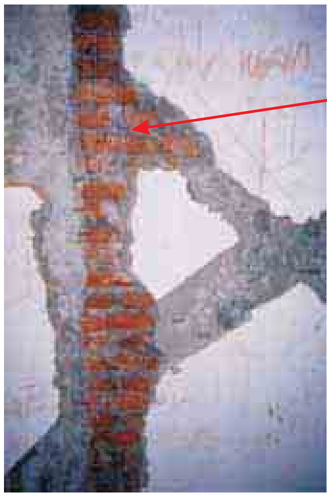
- IF THE WALL IS CONFINED WITH BEAMS AND COLUMNS, THE WIRE MESH TO STRENGTHEN THE CRACKED WALL CAN BE PLACED DIRECTLY ON THE WALL. WIRE MESH ON BOTH SIDES CAN BE NAILED WITH CONCRETE NAILS (SEE FIGURE IV). HOWEVER, THE BEST IS AS DESCRIBED BELOW.
- UNCONFINED MASONRY WALLS WHEN STRENGTHENED USING WIRE MESH:

  THE WIRE MESH MUST BE PLACED ON A THIN BED OF MORTAR AND WIRE MESH ON BOTH SIDES MUST BE TIED (SEE FIGURE III). IN THIS CASE, BOTH SIDES OF WIRE MESH WITH THE PLASTERS AND THE BRICK WALL ACT AS "SANDWICH" CONSTRUCTION.



UNCONFINED MASONRY WALLS WHEN STRENGTHENED USING WIRE MESH.

WIRE MESH MUST BE PLACED ON A THIN BED OF MORTAR AND WIRE MESH ON BOTH SIDES MUST BE TIED.



FOR CONFINED MASONRY, THE WIRE MESH TO STRENGTHEN THE CRACKED WALL CAN BE PLACED DIRECTLY ON THE WALL, NO NEED TO PROVIDE A THIN BED OF MORTAR.

EXAMPLE OF RETROFITTING SCHOOL BUILDINGS IN BENGKULU, DAMAGED BY JUNE 4, 2000 EARTHQUAKE

DAMAGED DUE TO JUNE 4, 2000 EQ

AFTER THE SEPTEMBER 12, 2007 EQ

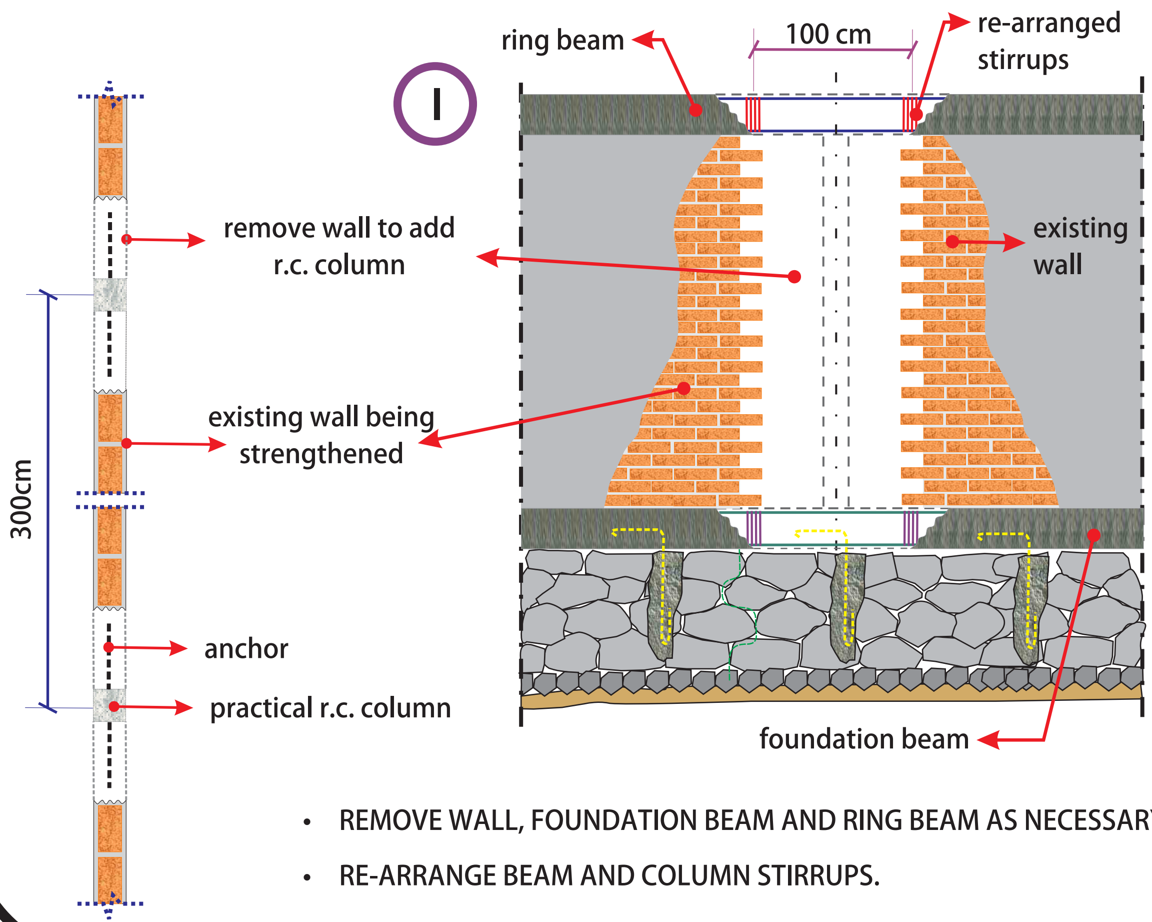
EXAMPLE OF RETROFITTING BUILDINGS IN BANDA ACEH, DAMAGED BY DECEMBER 26, 2004 EARTHQUAKE

9.2. RETROFITTING COLLAPSED WALL AND ADDITION OF PRACTICAL COLUMNS

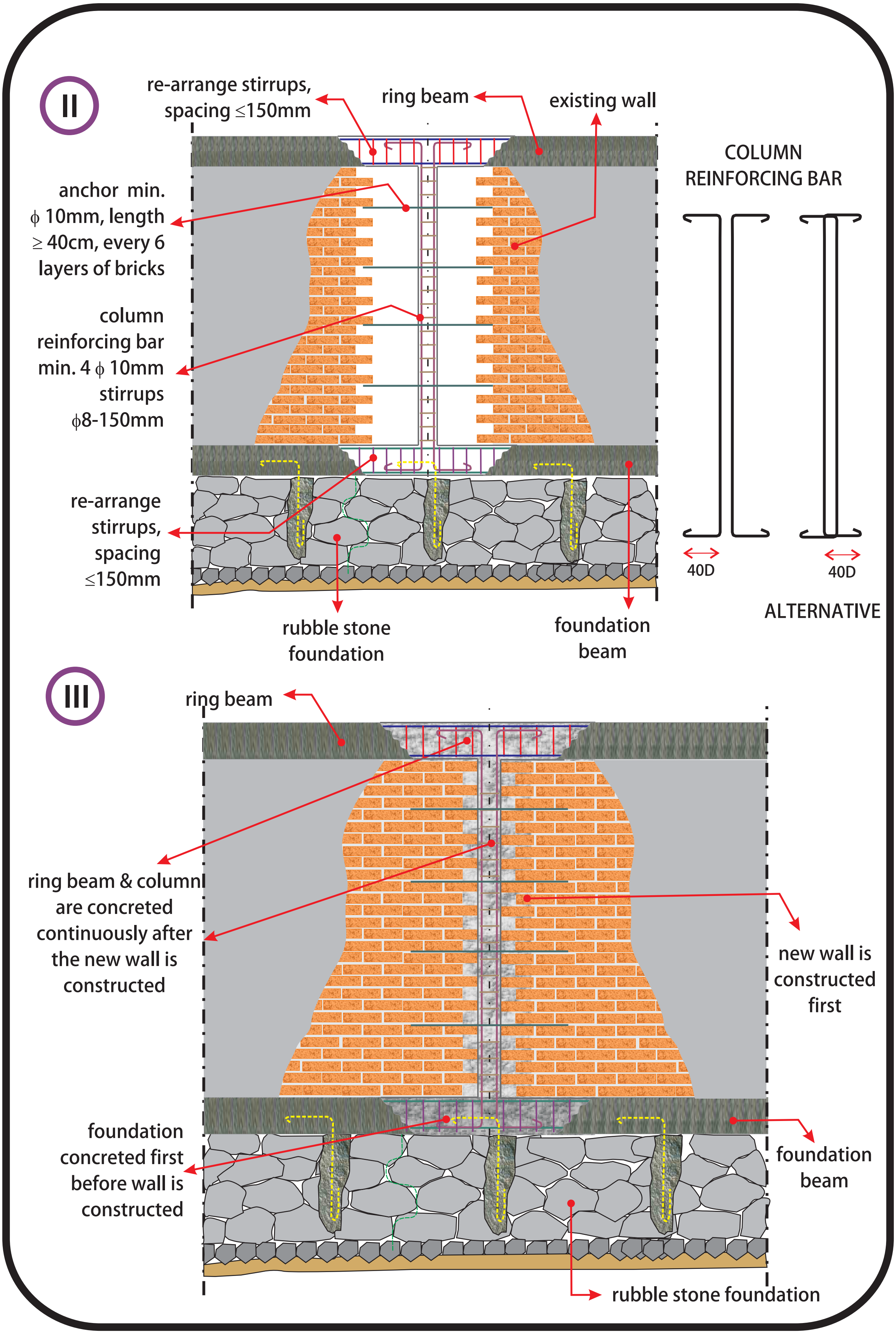

EXAMPLE OF WALL COLLAPSE

NOTE:

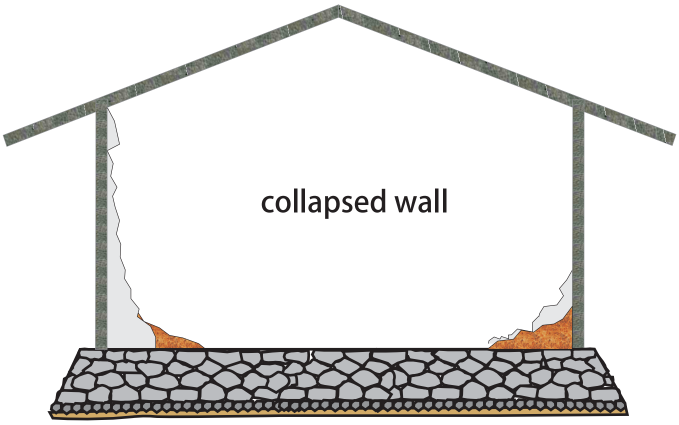
- BEAMS & COLUMNS THAT CAN BE CHIPPED EASILY IS AN INDICATION OF LOW CONCRETE QUALITY.
- ALL LOW CONCRETE QUALITY MUST BE REPLACED.
- THE BEAM AND COLUMN STIRRUPS MUST BE ADDED IF THE SPACING > 150MM OR NO STIRRUPS.
- JOINT DETAILING OF REINFORCEMENT MUST COMPLY WITH EARTHQUAKE RESISTANT REQUIREMENTS.

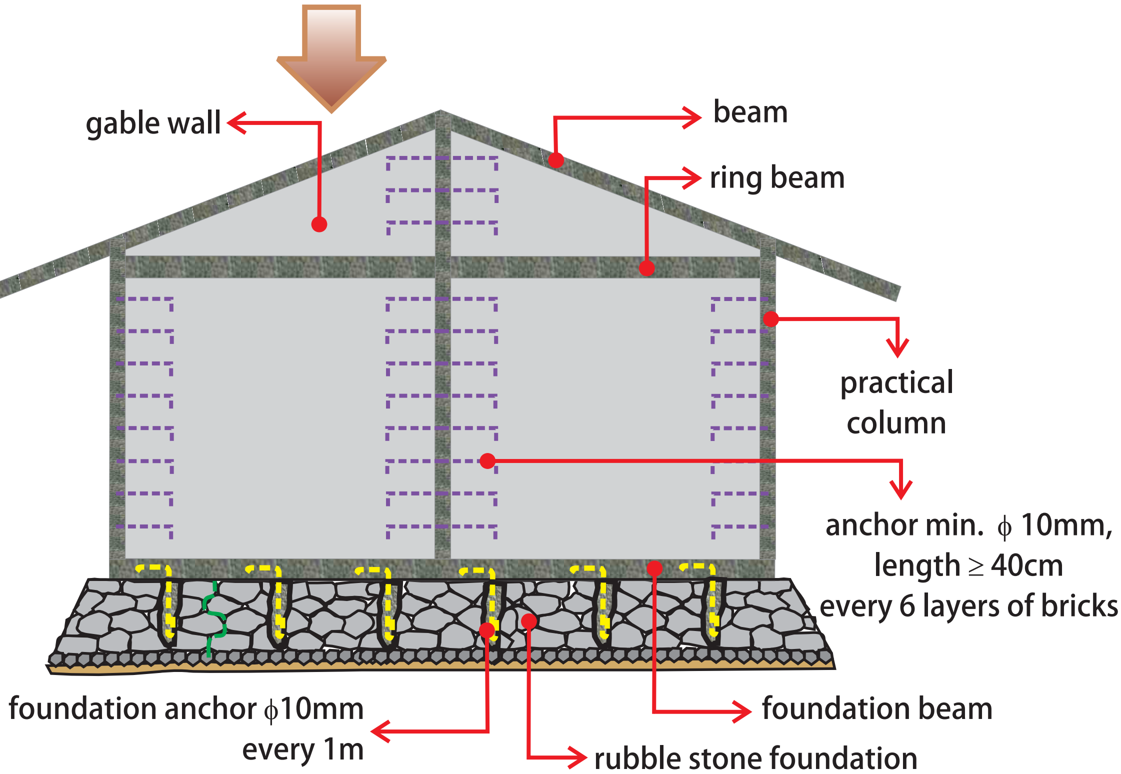


- REMOVE WALL, FOUNDATION BEAM AND RING BEAM AS NECESSARY.
- RE-ARRANGE BEAM AND COLUMN STIRRUPS.


II
re-arrange stirrups, spacing ≤150mm
ring beam
existing wall
anchor min. ϕ 10mm, length ≥ 40cm, every 6 layers of bricks
column reinforcing bar min. 4 ϕ 10mm stirrups ϕ8-150mm
re-arrange stirrups, spacing ≤150mm
rubble stone foundation
foundation beam
COLUMN REINFORCING BAR
40D
40D
ALTERNATIVE
III
ring beam
ring beam & column are concreted continuously after the new wall is constructed
new wall is constructed first
foundation concreted first before wall is constructed
foundation beam
rubble stone foundation

FOR TOTALLY COLLAPSED WALLS, A NEW WALL MUST BE CONSTRUCTED AND IT IS RECOMMENDED TO PROVIDE CONFINEMENT CONSISTING OF FOUNDATION BEAM, RING BEAM AND COLUMNS. WALL ANCHORING MUST ALSO BE PROVIDED MIN ϕ10MM LENGTH > 40 CM, FOR EVERY 6 LAYERS OF BRICKS.





EXAMPLE OF RETROFITTING A COLLAPSED WALL

9.3. RETROFITTING OF DAMAGED BEAMS AND COLUMNS

CRACKS IN CONCRETE:

1. HAIR-LINE CRACKS IN CONCRETE (WIDTH LESS THAN 0.2 MM) OR NO VISIBLE CRACKS INDICATE INSIGNIFICANT DAMAGE.
2. GENERALLY, CRACKS UP TO 2 MM WIDE IN CONCRETE COMPONENTS ARE NOT CONSIDERED SIGNIFICANT (AND MAY SIGNIFY LOW DAMAGE).
3. CRACKS UP TO 5 MM WIDE IN CONCRETE COMPONENTS MAY INDICATE MODERATE DAMAGE.
4. CRACKS GREATER THAN 5 MM INDICATE HEAVY DAMAGE (WITH SIGNIFICANT LOSS OF STRENGTH).
5. BUCKLING OF REINFORCEMENT IN CONCRETE COMPONENTS SIGNIFIES HEAVY DAMAGE, IRRESPECTIVE OF CRACK WIDTH IN CONCRETE.

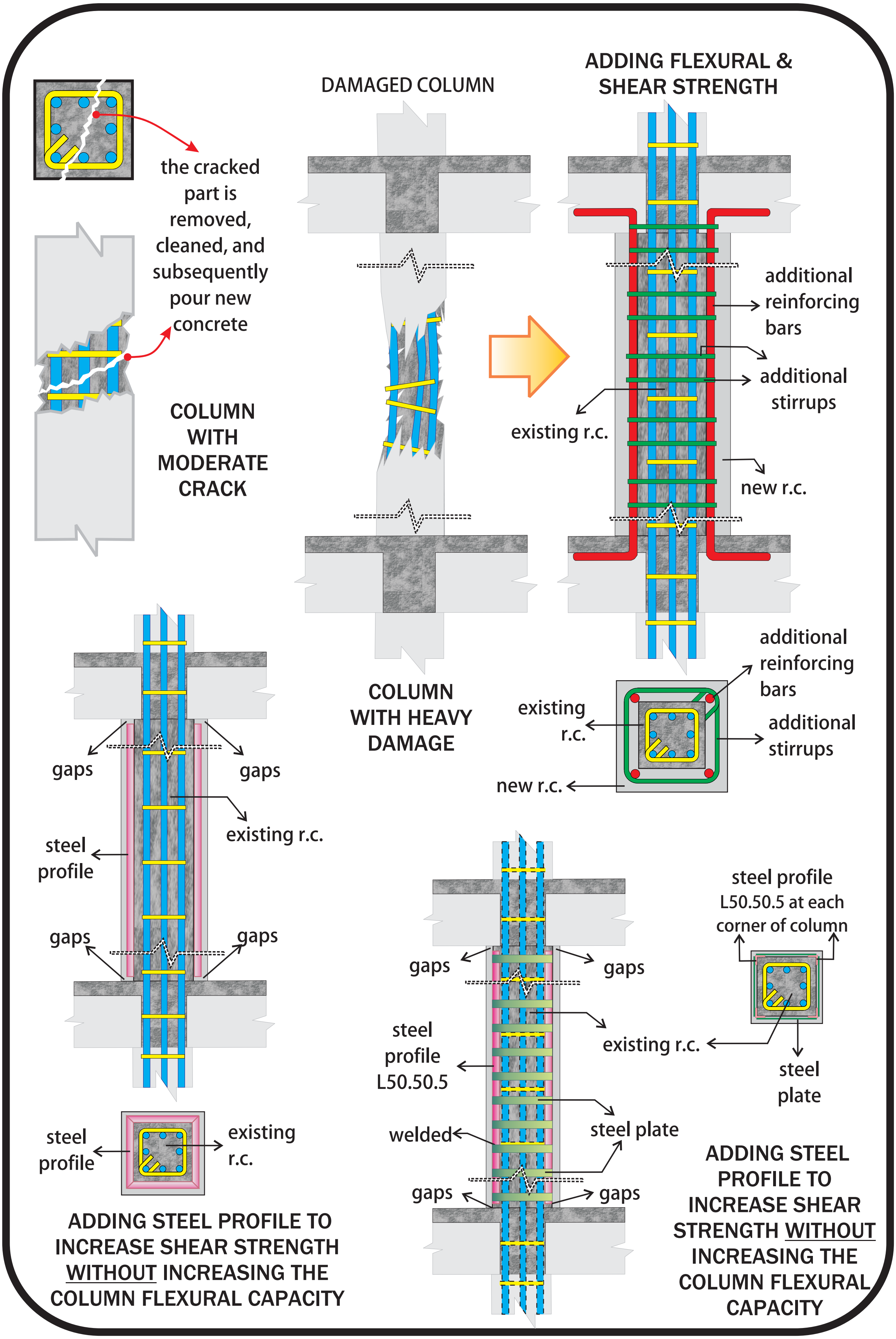
GENERALLY, THE TECHNIQUES TO STRENGTHEN CONCRETE COLUMN / BEAM ARE AS FOLLOWS:

1. TO ADD REINFORCEMENT AND STIRRUPS OUTSIDE THE CONCRETE COLUMN / BEAM AND SUBSEQUENTLY COVER BY CONCRETE.
2. TO BANDAGE THE CONCRETE COLUMN / BEAM WITH WELDED WIRE FABRIC AND SUBSEQUENTLY PLASTER WITH MORTAR.
3. TO COVER THE CONCRETE COLUMN WITH RECTANGULAR STEEL PROFILE OR PIPE AND SUBSEQUENTLY THE GAP BETWEEN CONCRETE AND STEEL IS GROUTED.
4. TO BANDAGE WITH STEEL PLATE WELDED TO 4 STEEL ANGLE PROFILES PLACED IN EACH CORNER OF THE COLUMN AND SUBSEQUENTLY THE GAP BETWEEN CONCRETE AND STEEL IS GROUTED.

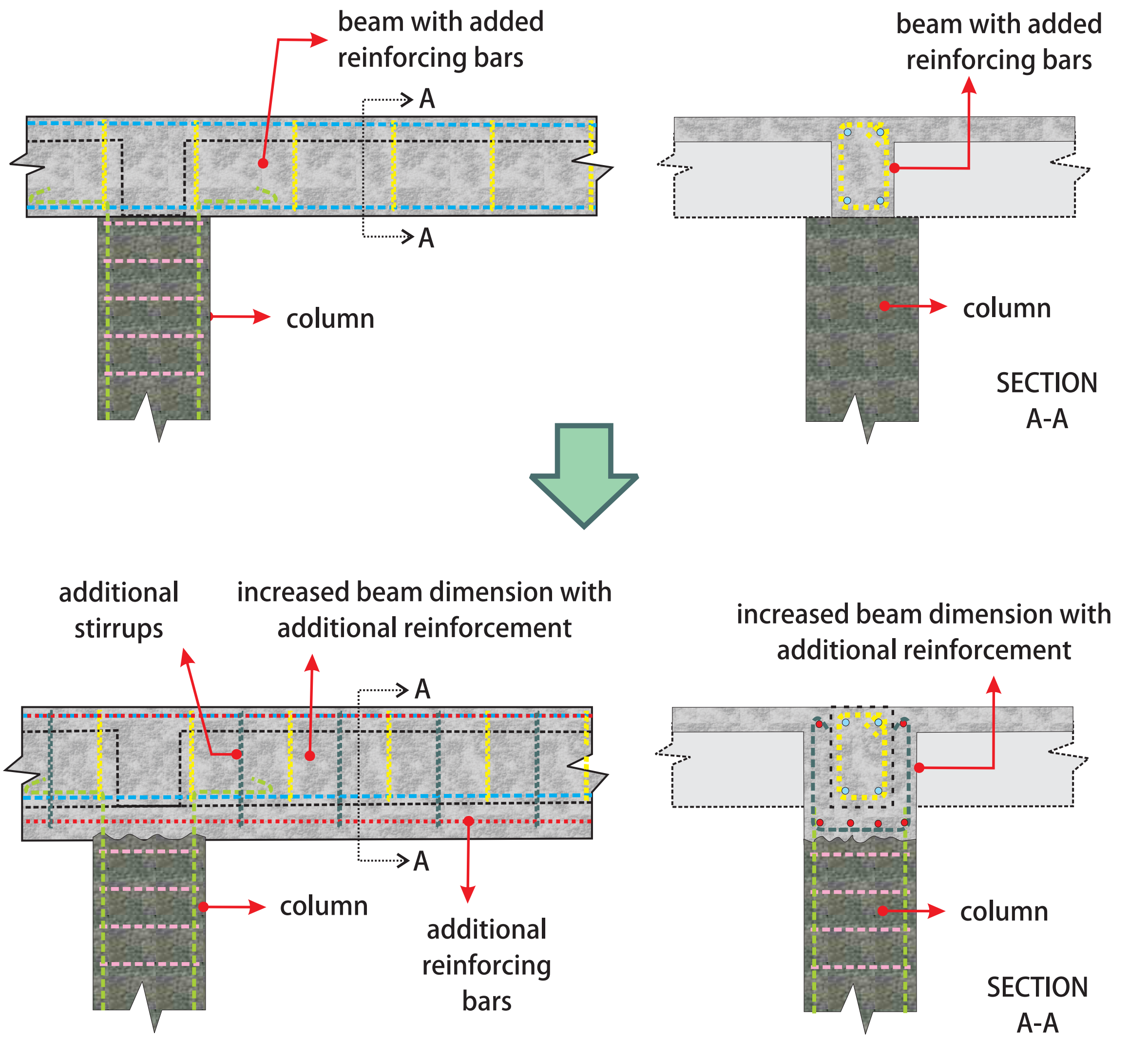
TO INCREASE THE COLUMN SHEAR STRENGTH WITHOUT INCREASING ITS FLEXURAL CAPACITY, A GAP MUST BE PROVIDED AT THE TOP AND BOTTOM OF THE COLUMN. THEREFORE, THE ADDITIONAL REINFORCEMENT IS NOT ANCHORED TO THE BEAM.

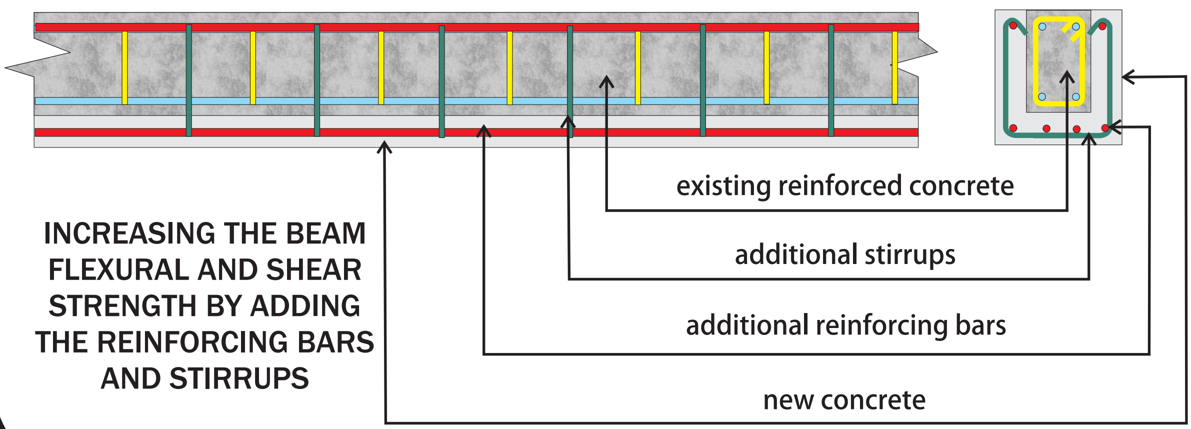
FOR COLUMNS WITH MODERATE CRACKS, REMOVE THE DAMAGE PART, CLEAN, AND POUR NEW CONCRETE. COLUMNS MUST BE SUPPORTED DURING RETROFITTING WORKS. (SEE EXPLANATION 9.4.)

FOR HEAVILY DAMAGED COLUMNS, NAMELY COLUMNS WHERE ITS STRENGTH IS SUBSTANTIALLY REDUCED (BASED ON OBSERVATION AS WELL AS ANALYSIS). THE DAMAGED PART IS REMOVED AND IF THE ANALYSIS SHOWS THAT ADDITIONAL REINFORCEMENT MUST BE PLACED, ONE OF THE ABOVE EXPLAINED METHOD CAN BE APPLIED. BEFORE REMOVING THE DAMAGED PART OF THE COLUMN, BEAMS AND SLABS AROUND THE COLUMN MUST BE SUPPORTED.

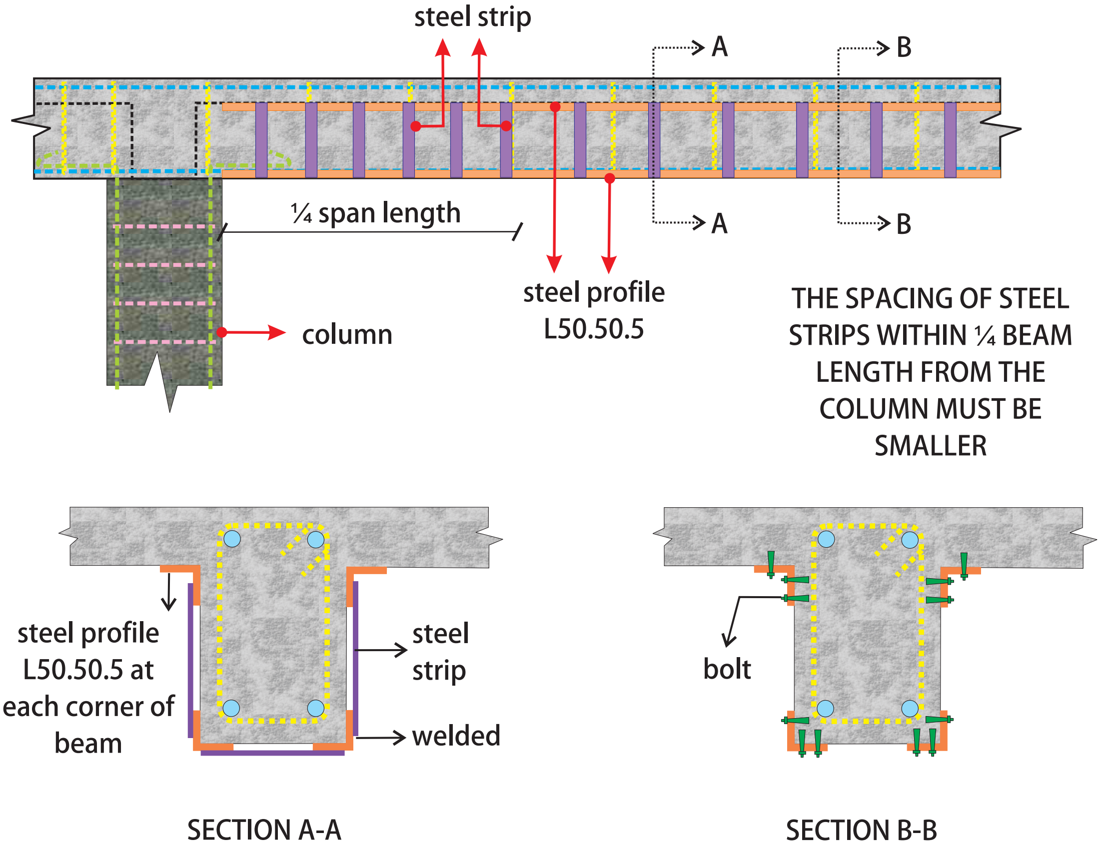

the cracked part is removed, cleaned, and subsequently pour new concrete
COLUMN WITH MODERATE CRACK
DAMAGED COLUMN
COLUMN WITH HEAVY DAMAGE
ADDING FLEXURAL & SHEAR STRENGTH
additional reinforcing bars
additional stirrups
existing r.c.
new r.c.
additional reinforcing bars
existing r.c.
additional stirrups
new r.c.
gaps
gaps
existing r.c.
steel profile
gaps
gaps
steel profile
existing r.c.
ADDING STEEL PROFILE TO INCREASE SHEAR STRENGTH WITHOUT INCREASING THE COLUMN FLEXURAL CAPACITY
gaps
gaps
steel profile L50.50.5
existing r.c.
welded
steel plate
gaps
gaps
steel profile L50.50.5 at each corner of column
existing r.c.
steel plate
ADDING STEEL PROFILE TO INCREASE SHEAR STRENGTH WITHOUT INCREASING THE COLUMN FLEXURAL CAPACITY

IF THE ANALYSIS SHOWS THAT THE BEAM REINFORCEMENT IS NOT ADEQUATE, ADDITIONAL REINFORCEMENT MUST BE PLACED AND THE DIMENSION OF THE BEAM CAN BE INCREASED (JACKETING).





INCREASING THE BEAM FLEXURAL AND SHEAR STRENGTH BY ADDING THE REINFORCING BARS AND STIRRUPS



ADDING STEEL PROFILE & STIRRUPS TO INCREASE THE BEAM SHEAR STRENGTH WITHOUT INCREASING ITS FLEXURAL STRENGTH

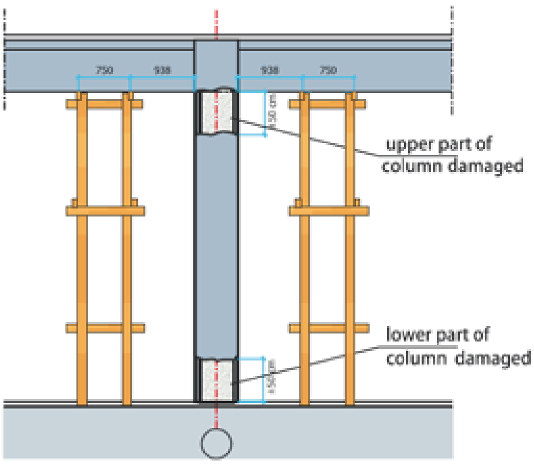
9.4. RETROFITTING OF TOP & BOTTOM OF COLUMNS THAT ARE DAMAGED AND PLACING ADDITIONAL STIRRUPS OF BEAMS AND COLUMNS

EXAMPLE OF UPPER & LOWER PARTS OF COLUMNS THAT ARE DAMAGED

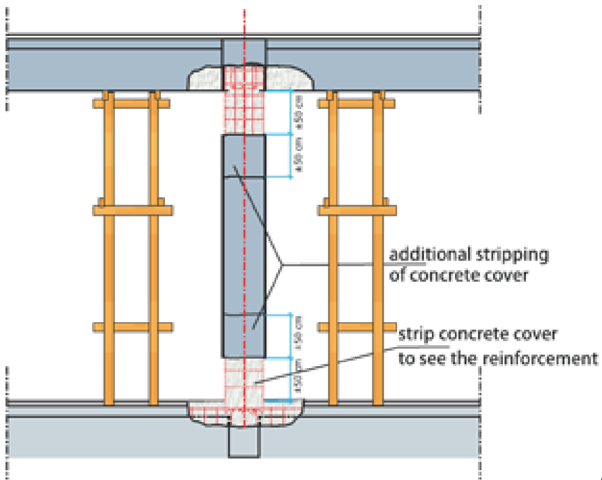
IMPLEMENTATION OF RETROFITTING:

1. SUPPORT THE BEAMS AROUND THE COLUMN TO BE RETROFITTED WITH TIMBER POSTS 2X8/10 CM AT SUITABLE INTERVALS. TIMBER SIZE TO BE ADJUSTED BASED ON THE LOAD TO BE SUPPORTED. STEEL SUPPORT CAN ALSO BE UTILIZED. (FIGURE I)
2. STRIP THE CONCRETE COVER OF COLUMNS / BEAMS TO KNOW THE NUMBER OF REINFORCEMENT & STIRRUPS. (FIGURE II)
3. IF ANALYSIS SHOWS THAT THE NUMBER OF COLUMN & BEAM REINFORCEMENT & STIRRUPS ARE NOT SUFFICIENT, ADDITIONAL REINFORCEMENT MUST BE PLACED. (FIGURE III.A.)
4. IF THE DETAIL OF THE COLUMN-BEAM JOINT REINFORCING IS NOT IN ACCORDANCE WITH THE SEISMIC RESISTANT REQUIREMENTS, ADDITIONAL ANCHORING FROM COLUMN TO BEAM MUST BE PLACED. IN THIS CASE, PART OF THE BEAM CONCRETE MUST BE REMOVED FOR ANCHORING. (FIGURE III.B.)

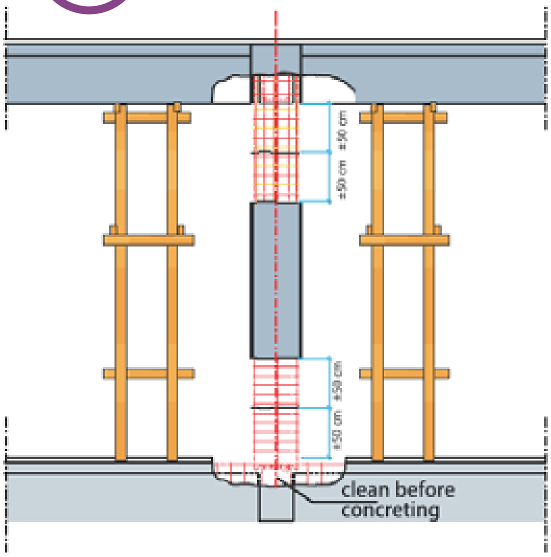
I



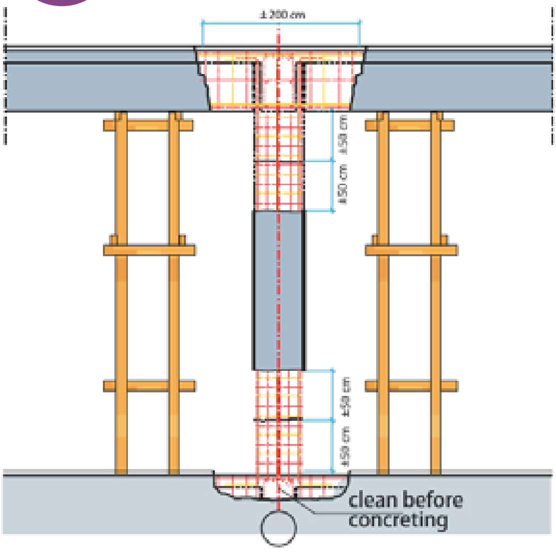
II



III.A



III.B

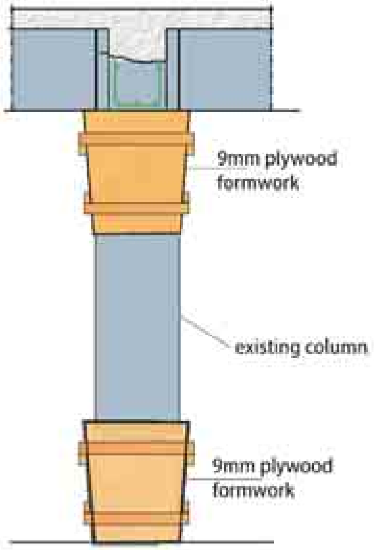


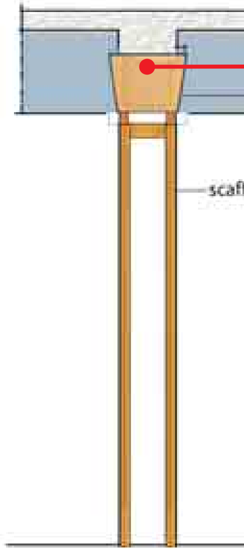
IF ADDITIONAL BEAM STIRRUPS IS NECESSARY:

- CONCRETE MUST BE REMOVED ± 2M.
- PLACE STIRRUPS WITH SUITABLE SIZE & SPACING IN ACCORDANCE WITH THE ANALYSIS RESULT.

5. IF THE COLUMN / BEAM REINFORCEMENT IS NOT ADEQUATE, THERE ARE 2 CHOICES THAT CAN BE IMPLEMENTED:
   A. REMOVE THE ENTIRE COLUMN / BEAM CONCRETE & INSTALL THE ADDITIONAL REINFORCEMENT.
   B. ADDITIONAL REINFORCEMENT IS INSTALLED OUTSIDE THE COLUMN / BEAM AND CONCRETED (JACKETING).
6. IF NO ADDITIONAL REINFORCEMENT FOR THE COLUMN IS NECESSARY, BUT THE DETAILING OF THE JOINTS MUST BE RECTIFIED, THE BEAM CONCRETE MUST BE REMOVED ±2M AND INSTALL THE NECESSARY ANCHORING. FOR ADDITIONAL COLUMN STIRRUPS, STRIP THE COLUMN CONCRETE COVER MIN. 1M LENGTH AND SUBSEQUENTLY PLACE THE STIRRUPS WITH SUITABLE SIZE & SPACING IN ACCORDANCE WITH THE ANALYSIS RESULT. (FIGURE III.B.)
7. FOR PLACING NEW CONCRETE, THE FORMWORK MUST BE SHAPED LIKE A CONE (FIGURE IV.A. & IV.B.). THE UPPER PART OF CONE FORMWORK MUST EXCEED THE BOUNDARY OF OLD & NEW CONCRETE.
8. POUR CONCRETE WITH THE DESIRED STRENGTH UP TO THE TOP OF THE CONE.
9. IF THERE IS NOT ENOUGH SPACE, CONCRETING CAN BE DONE BY DRILLING A HOLE IN THE SLAB. (FIGURE IV.B.)
10. AFTER 24 HOURS, THE FORMWORK CAN BE REMOVED AND THE PROTRUDING CONCRETE PART (DUE TO THE CONE SHAPE) CAN BE CHIPPED. (FIGURE V. A. & V.B.)

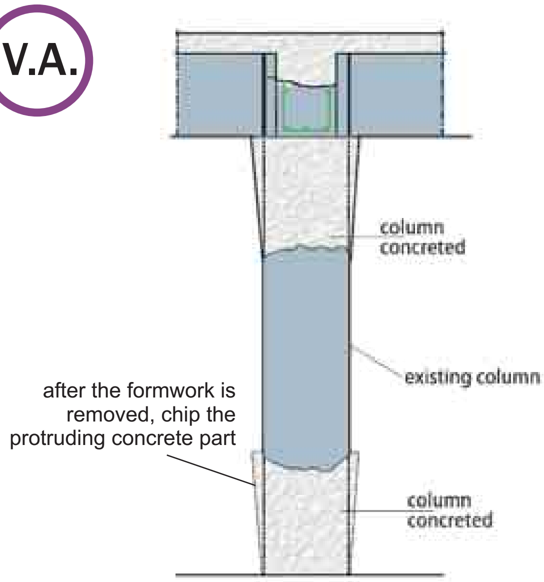
IV.A.

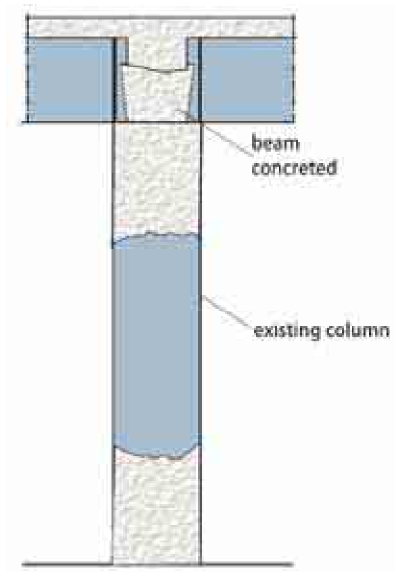




EXAMPLE OF FORMWORK USED FOR BEAM CONCRETING

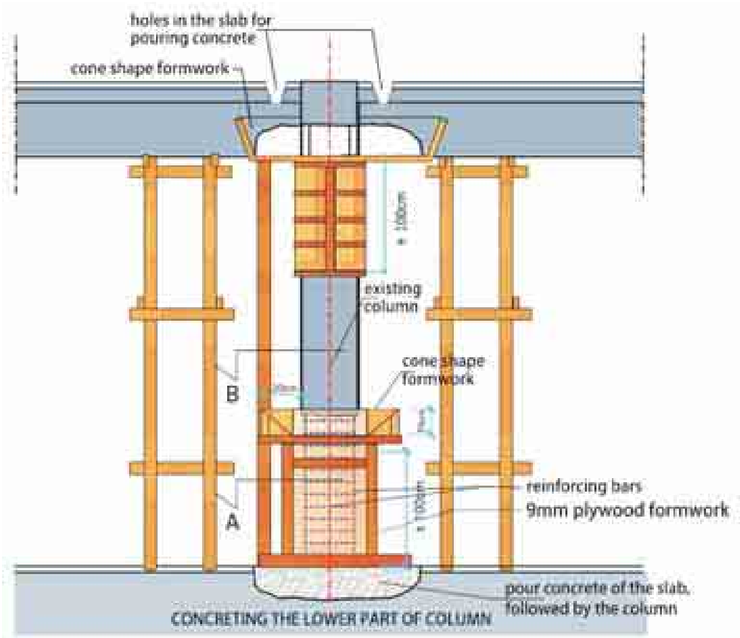
V.A.



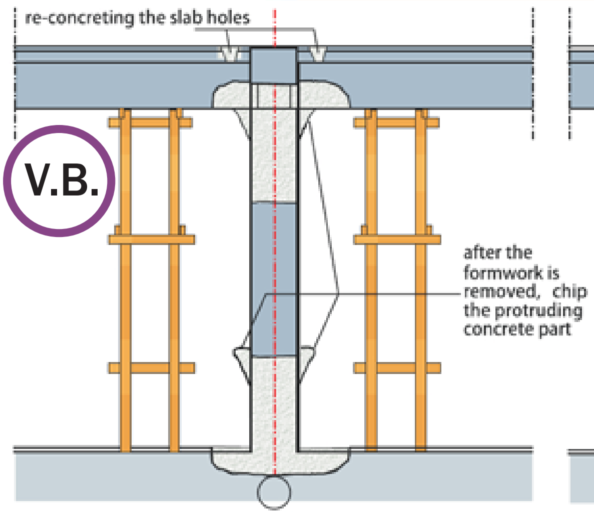


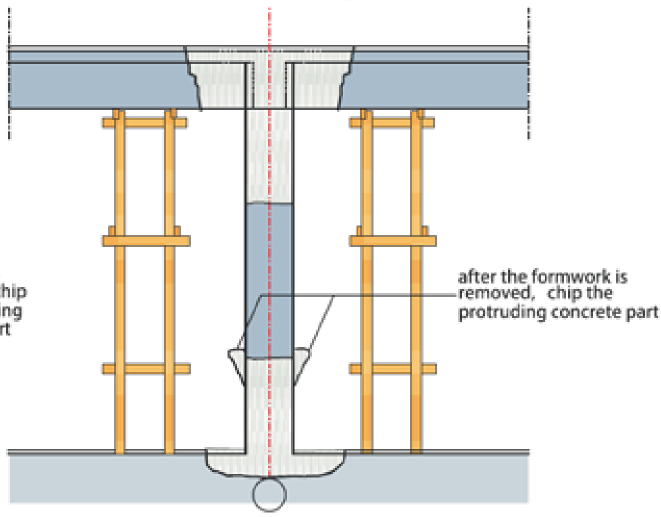
EXAMPLE OF CONCRETING UPPER & LOWER PARTS OF COLUMN

IV.B.



V.B.






DAMAGED COLUMN, STIRRUPS & ANCHORING ARE NOT ADEQUATE

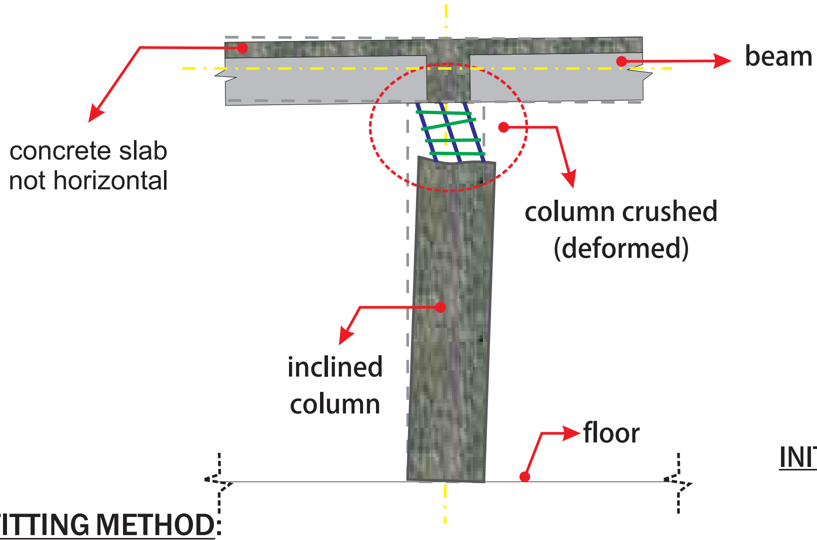

ADDITION OF STIRRUPS & ANCHORING


FORMWORK


FORMWORK REMOVED AFTER CONCRETING

EXAMPLE OF COLUMN RETROFITTING

9.5. RETROFITTING OF INCLINED COLUMNS DAMAGED AT THE TOP



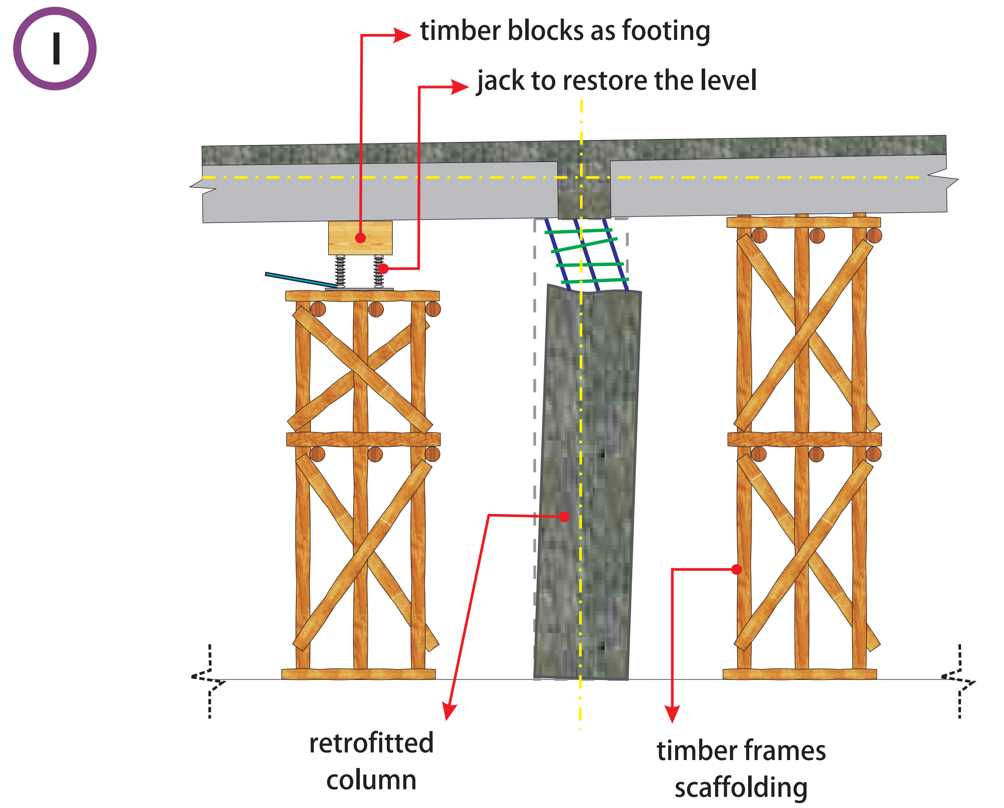
INITIAL CONDITION

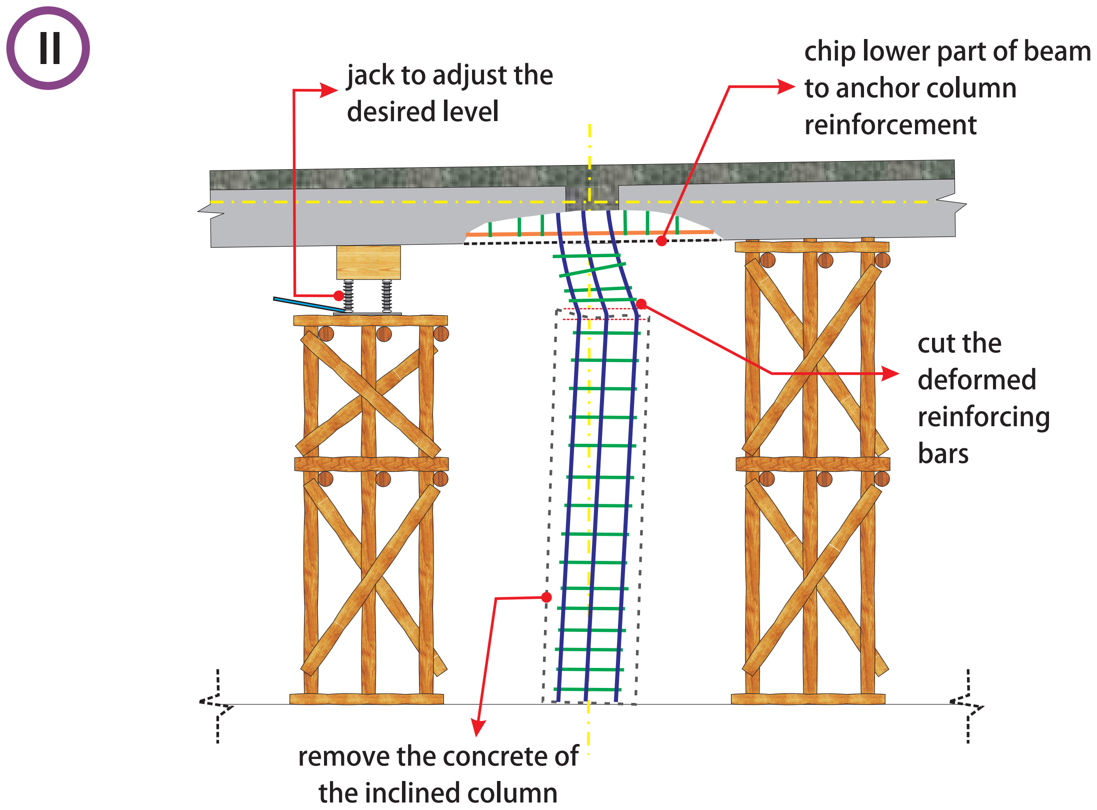
RETROFITTING METHOD:

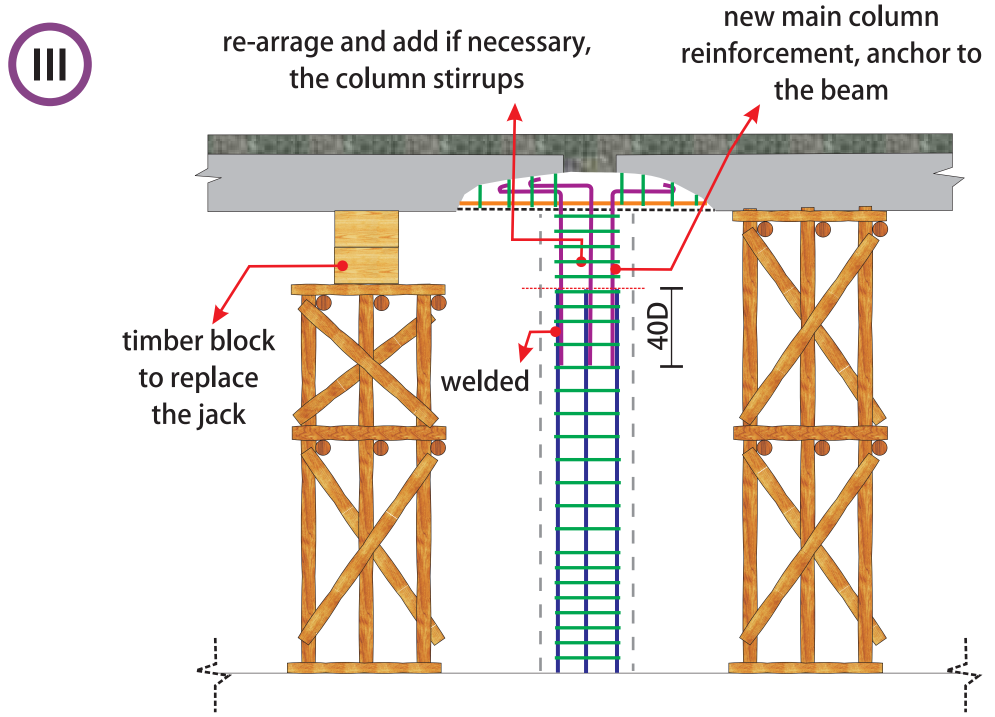
1. SUPPORT THE BEAMS AROUND THE COLUMN TO BE RETROFITTED DURING CONSTRUCTION.
2. THE SLANTED BEAM MUST BE SUPPORTED AND JACKED-UP TO RESTORE THE LEVEL. (FIGURE I)

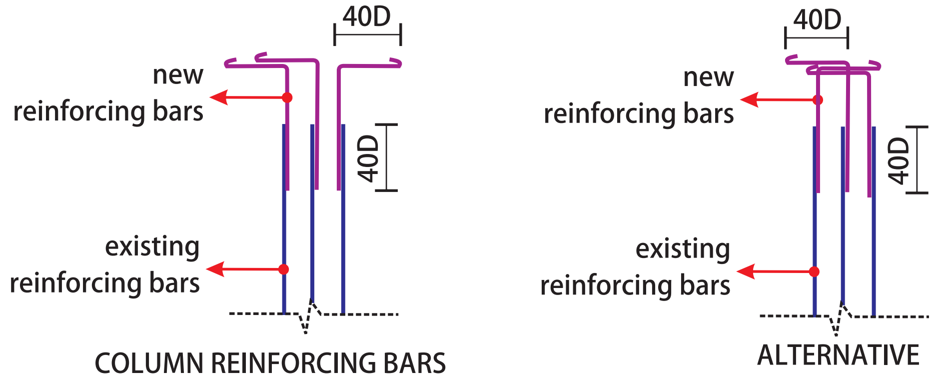
   NOTE: IF JACKING IS DIFFICULT, THE DEFORMED COLUMN REINFORCEMENT CAN BE CUT FIRST.
3. REMOVE THE CONCRETE OF THE INCLINED COLUMN.
4. CUT THE DEFORMED REINFORCING BARS. (FIGURE II)
5. JACK-UP THE BEAM UNTIL THE DESIRED LEVEL.
6. REMOVE THE CONCRETE OF THE LOWER PART OF THE BEAM AND FOR IMPROVING THE JOINT REINFORCEMENT DETAIL. (FIGURE II)
7. AFTER THE STRUCTURE IS HORIZONTAL AT THE DESIRED LEVEL, THE JACKS ARE REPLACED WITH TIMBER OR CONCRETE BLOCKS. (FIGURE III)
8. INSTALL THE NEW COLUMN REINFORCEMENT AND SPLICE WITH THE EXISTING ONE. THE LENGTH OF SPLICE BETWEEN THE EXISTING AND THE NEW REINFORCEMENT IS MINIMUM 40D. (FIGURE III)

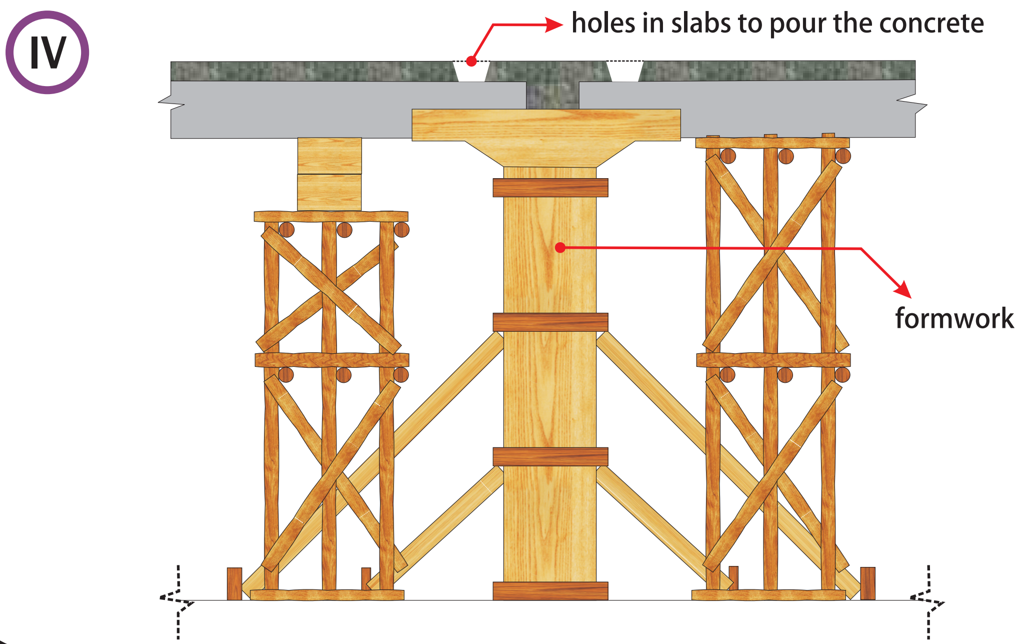
   RE-ARRANGE AND ADD, IF NECESSARY, THE COLUMN STIRRUPS.
9. CONSTRUCT THE FORMWORK OF 9 MM THICK PLYWOOD. THE FORMWORK MUST BE SHAPED LIKE A CONE. (FIGURE IV)
10. IF THERE IS NOT ENOUGH SPACE, CONCRETING CAN BE DONE BY DRILLING A HOLE IN THE SLAB. (FIGURE IV)
11. PLACE THE CONCRETE AS SOON AS THE FORMWORK IS READY.
12. AFTER 24 HOURS, THE FORMWORK CAN BE REMOVED AND THE PROTRUDING CONCRETE PART (DUE TO THE CONE SHAPE) CAN BE CHIPPED.


I
timber blocks as footing
jack to restore the level
retrofitted column
timber frames scaffolding


II
jack to adjust the desired level
chip lower part of beam to anchor column reinforcement
cut the deformed reinforcing bars
remove the concrete of the inclined column


III
re-arrage and add if necessary,
the column stirrups
new main column
reinforcement, anchor to
the beam
timber block
to replace
the jack
welded
40D


40D
new
reinforcing bars
40D
existing
reinforcing bars
COLUMN REINFORCING BARS
40D
new
reinforcing bars
40D
existing
reinforcing bars
ALTERNATIVE


IV
holes in slabs to pour the concrete
formwork

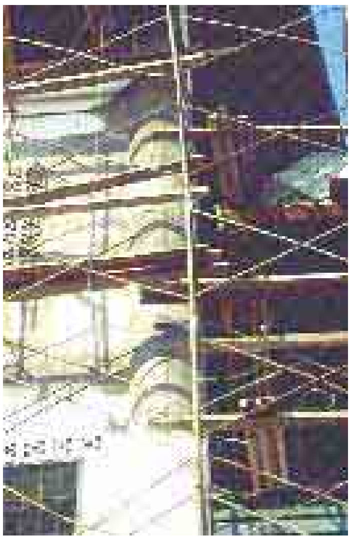
EXAMPLE RETROFITTING OF SCHOOL BUILDINGS IN BENGKULU, DAMAGED BY JUNE 4, 2000 EARTHQUAKE







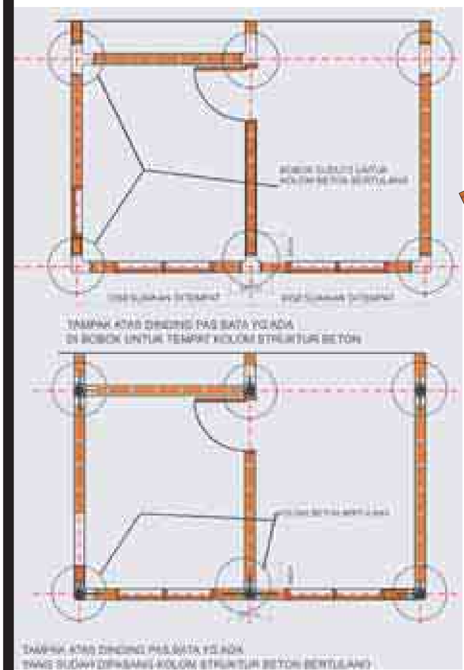

EXAMPLE RETROFITTING OF BUILDINGS IN BANDA ACEH, DAMAGED BY DECEMBER 26, 2004 EARTHQUAKE

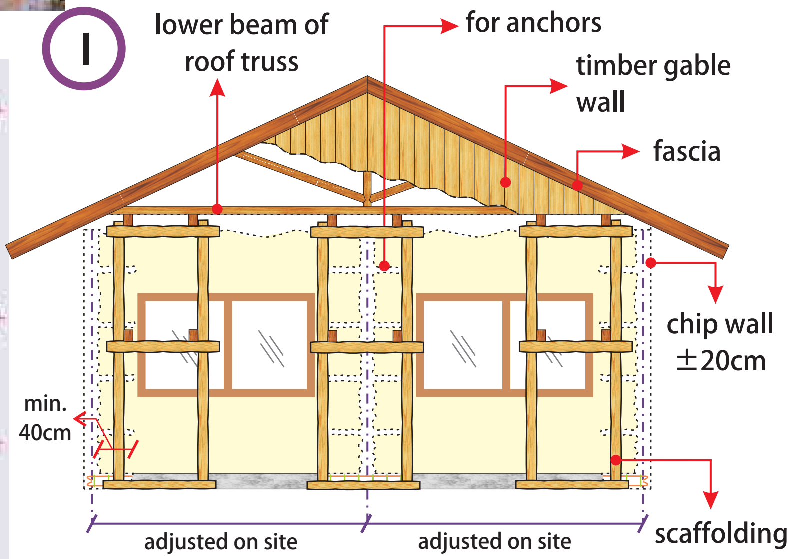


9.6. EXAMPLE RETROFITTING OF UNCONFINED MASONRY HOUSE WITH R.C. PRACTICAL COLUMNS & BEAMS

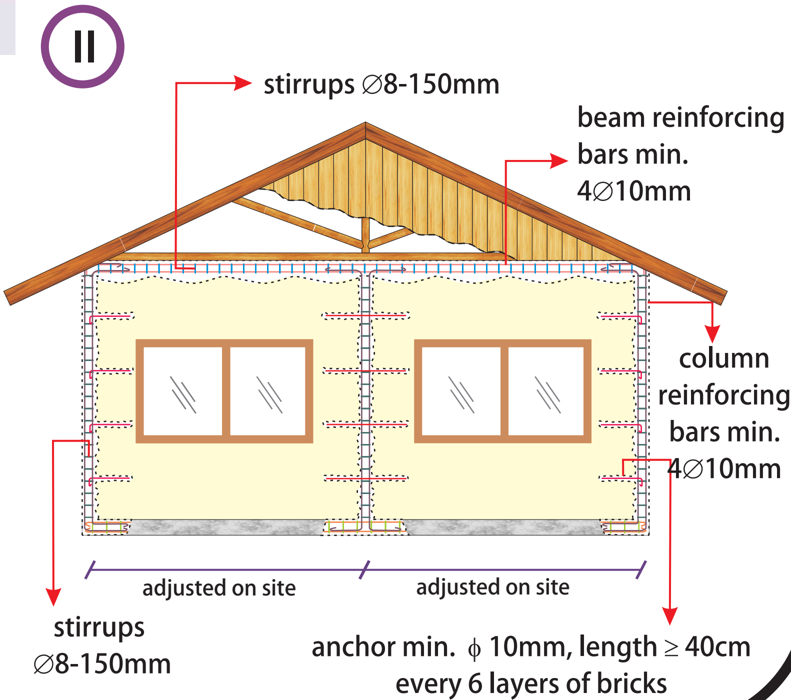
EXAMPLE OF UNCONFINED MASONRY HOUSE:

1. CRACKS IN WALLS
2. NO R.C PRACTICAL COLUMNS & BEAMS





NOTE: THE ACTUAL MEASUREMENT SHOULD BE CHECKED ON SITE.



RETROFITTING METHOD:

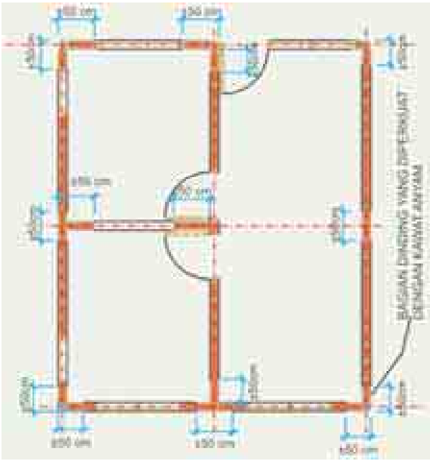
1. ERECT SCAFFOLDING IN PLACES WHERE THE WALLS ARE CHIPPED TO CONSTRUCT THE R.C. PRACTICAL COLUMNS & BEAMS.
2. THE JUNCTION OF WALLS MUST BE CHIPPED ±20 CM TO CONSTRUCT THE R.C. PRACTICAL COLUMNS.
3. THE MORTAR IS REMOVED EVERY 6 LAYERS OF BRICKS FOR ANCHORS.

9.7. EXAMPLE RETROFITTING OF UNCONFINED MASONRY HOUSE USING WIRE MESH PLASTERED WITH SAND & CEMENT MORTAR

EXAMPLE OF UNCONFINED MASONRY HOUSE:

1. CRACKS IN WALLS

2. NO R.C PRACTICAL COLUMNS & BEAMS



LAYOUT OF WALLS STRENGTHENED USING WIRE MESH

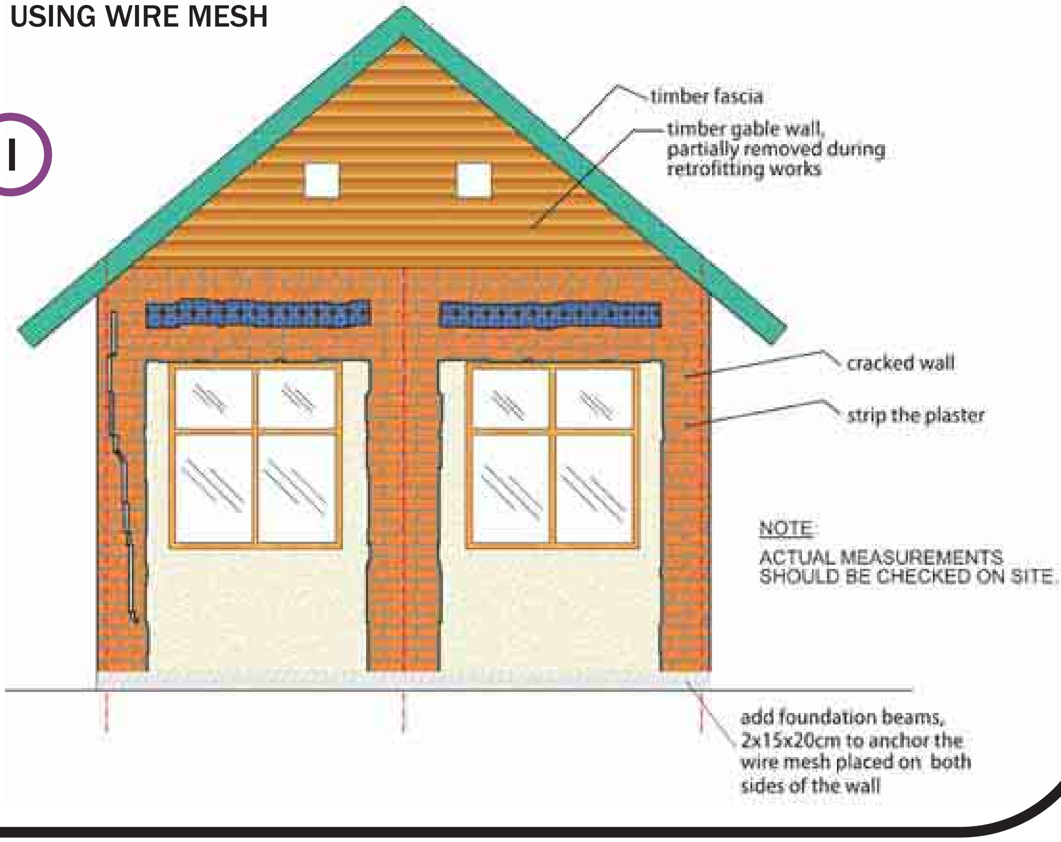
RETROFITTING METHOD:

1. REMOVE THE INNER AS WELL AS OUTER PLASTER OF THE WALL ± 40CM IN THE VERTICAL AS WELL AS HORIZONTAL DIRECTIONS WHERE THE WIRE MESH WILL BE INSTALLED. (FIGURE I)

   THE INNER AS WELL AS OUTER PLASTER OF WALLS JUNCTION MUST ALSO BE REMOVED.

2. THE CRACKS ARE SEALED WITH CEMENT & SAND MORTAR.

I



3. IF THE EXISTING MORTAR OF THE WALLS CONSIST OF LIME & SAND OR LIME, RED-BRICK POWDER & SAND, WITHOUT CEMENT, BEFORE STRENGTHENING WITH WIRE MESH, IT IS RECOMMENDED TO INJECT CEMENT WATER INTO THE MORTAR STARTING FROM THE LOWER PART OF THE WALL.

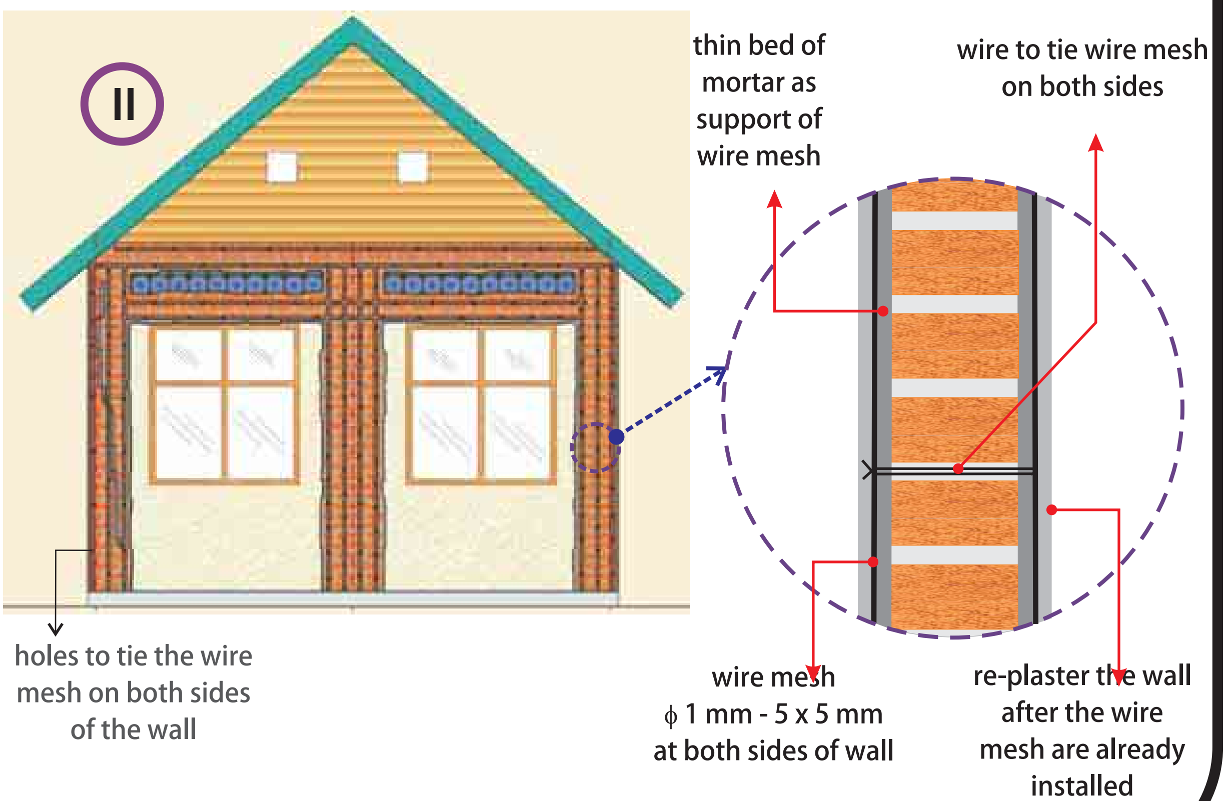
4. SEVERAL THIN BEDS OF MORTAR, 1CM THICK, ± 2CM WIDTH, AND WITH SPACING ± 10 CM MUST BE MADE THAT SERVES AS THE SUPPORT FOR THE WIRE MESH. (FIGURE IV)

   USE 9MM THICK & 2CM WIDTH PLYWOOD STRIPS TO BE USED AS FORMWORK TO PREPARE THE THIN BEDS OF MORTAR.

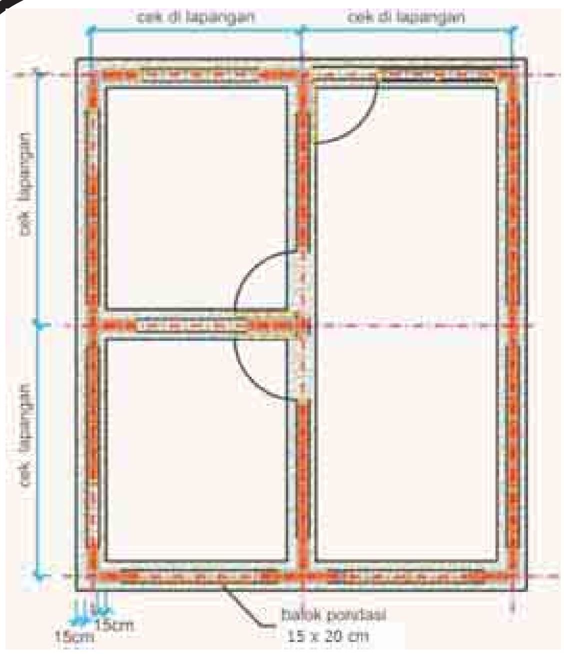
5. WIRE MESH ON EACH SIDE OF THE WALL SHALL BE TIED. FOR THE PURPOSE, HOLES ARE DRILLED ON THE THIN BEDS OF MORTAR EVERY ± 15-20CM. (SEE DRAWINGS OF RETROFFITING OF CRACK WALLS 9.1.)

6. CONSTRUCT 2 FOUNDATION BEAMS 15X20CM ON EACH SIDE AT THE LOWER PARTS OF THE WALLS BELOW THE FLOOR. THE WIRE MESH MUST BE ANCHORED INTO THE FOUNDATION BEAMS. (FIGURE III)

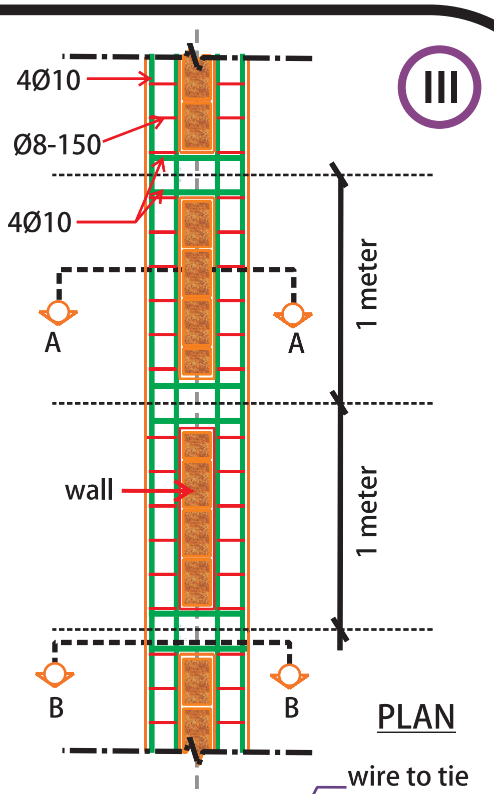
7. THE FOUNDATION BEAM MUST BE CONSTRUCTED FIRST. AFTER THAT RE-PLASTER THE WALLS WHERE THE WIRE MESH ARE ALREADY INSTALLED WITH MORTAR OF CEMENT & SAND.



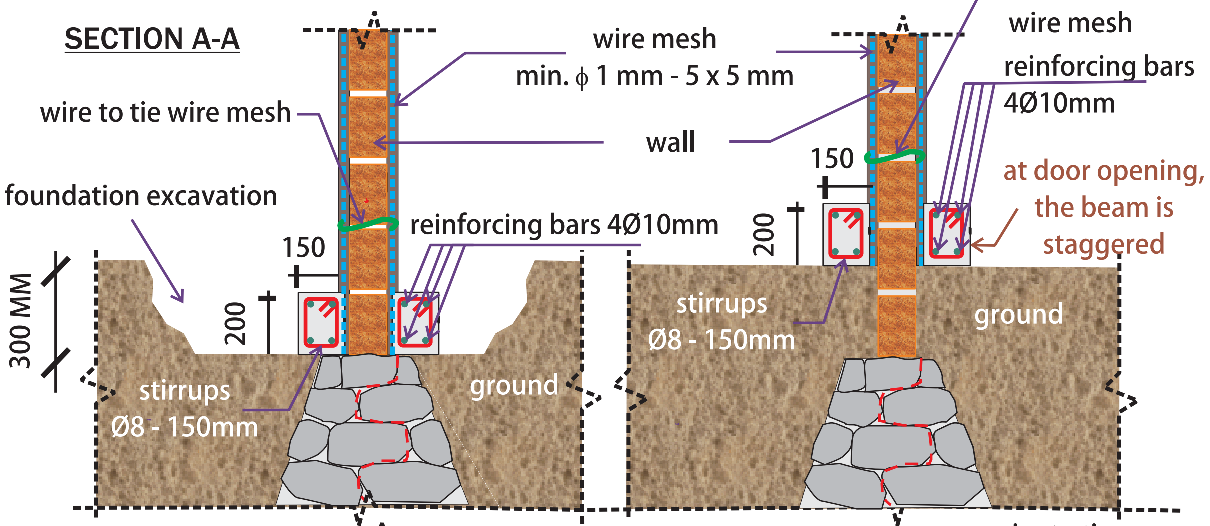
III

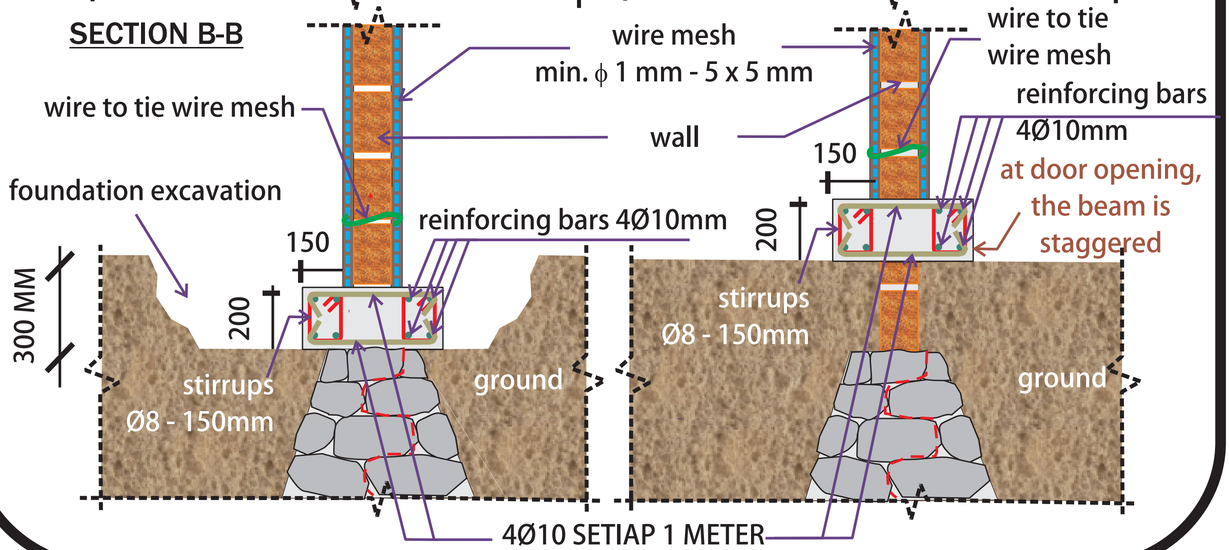


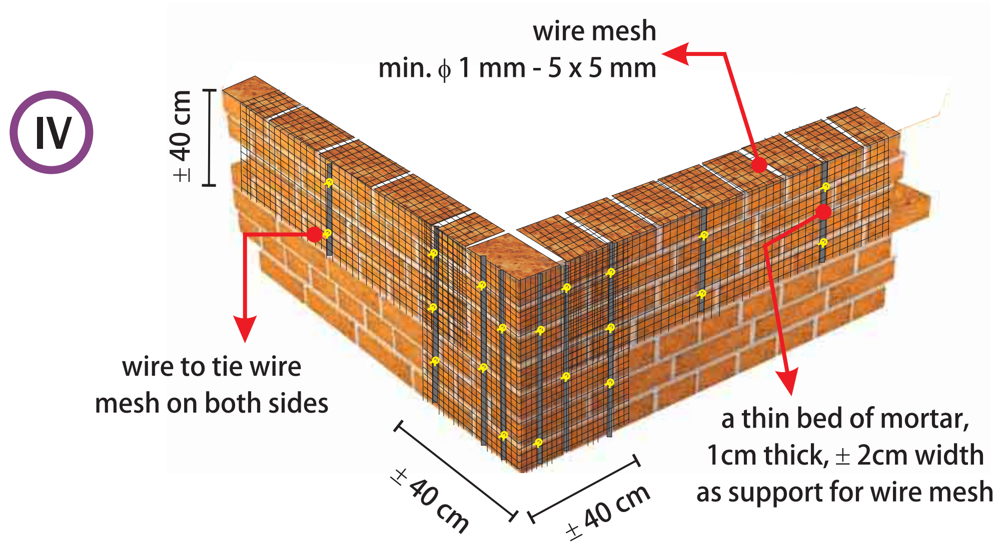
LAYOUT OF FOUNDATION BEAM TO ANCHOR THE WIRE MESH



PLAN

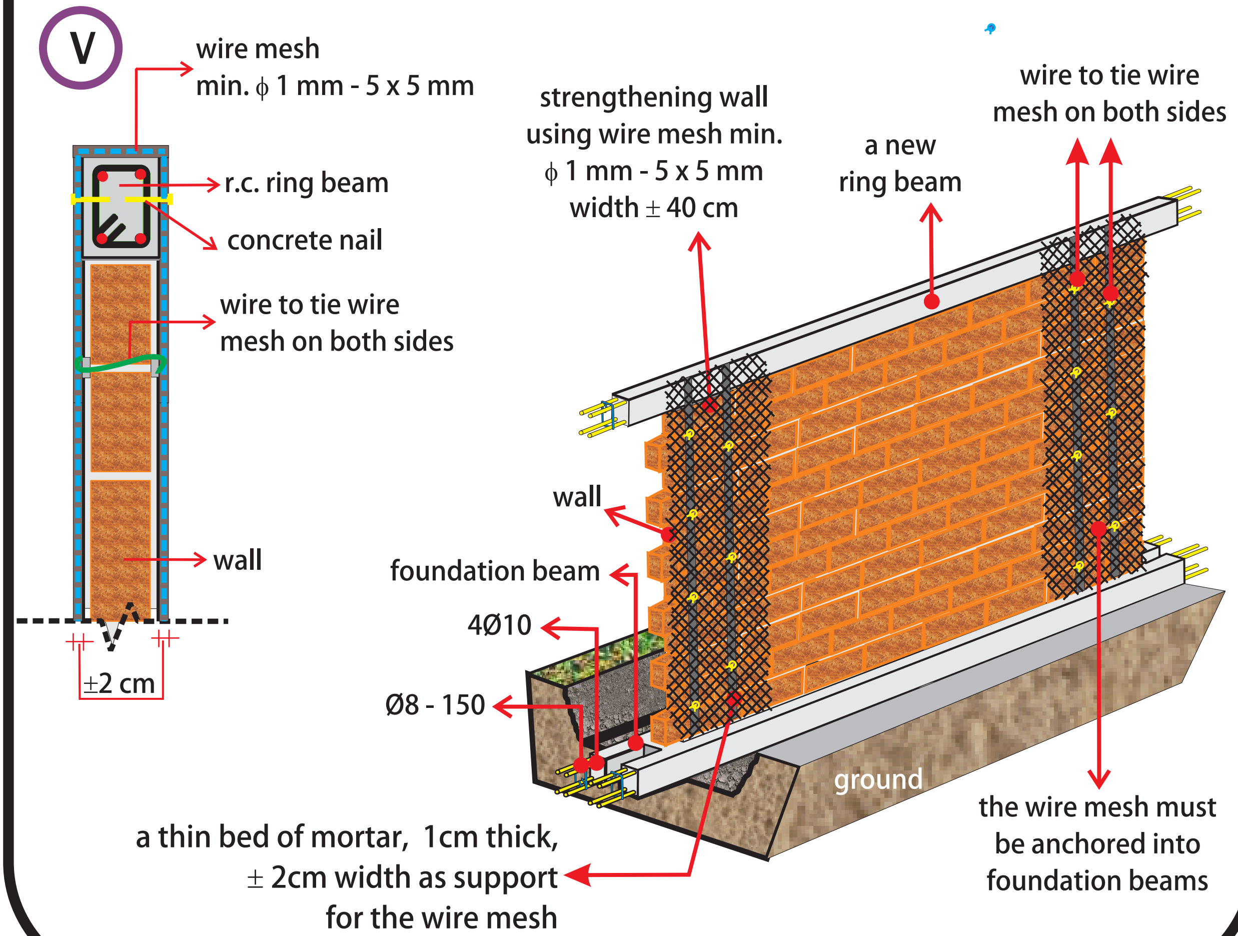






WALL STRENGTHENING USING WIRE MESH

IF PREFERRED, AN R.C. RING BEAM ABOVE THE WALL CAN BE CONSTRUCTED INSTEAD OF BANDAGING USING WIRE MESH.



9.8. RETROFITTING OF R.C. SHOP-HOUSES

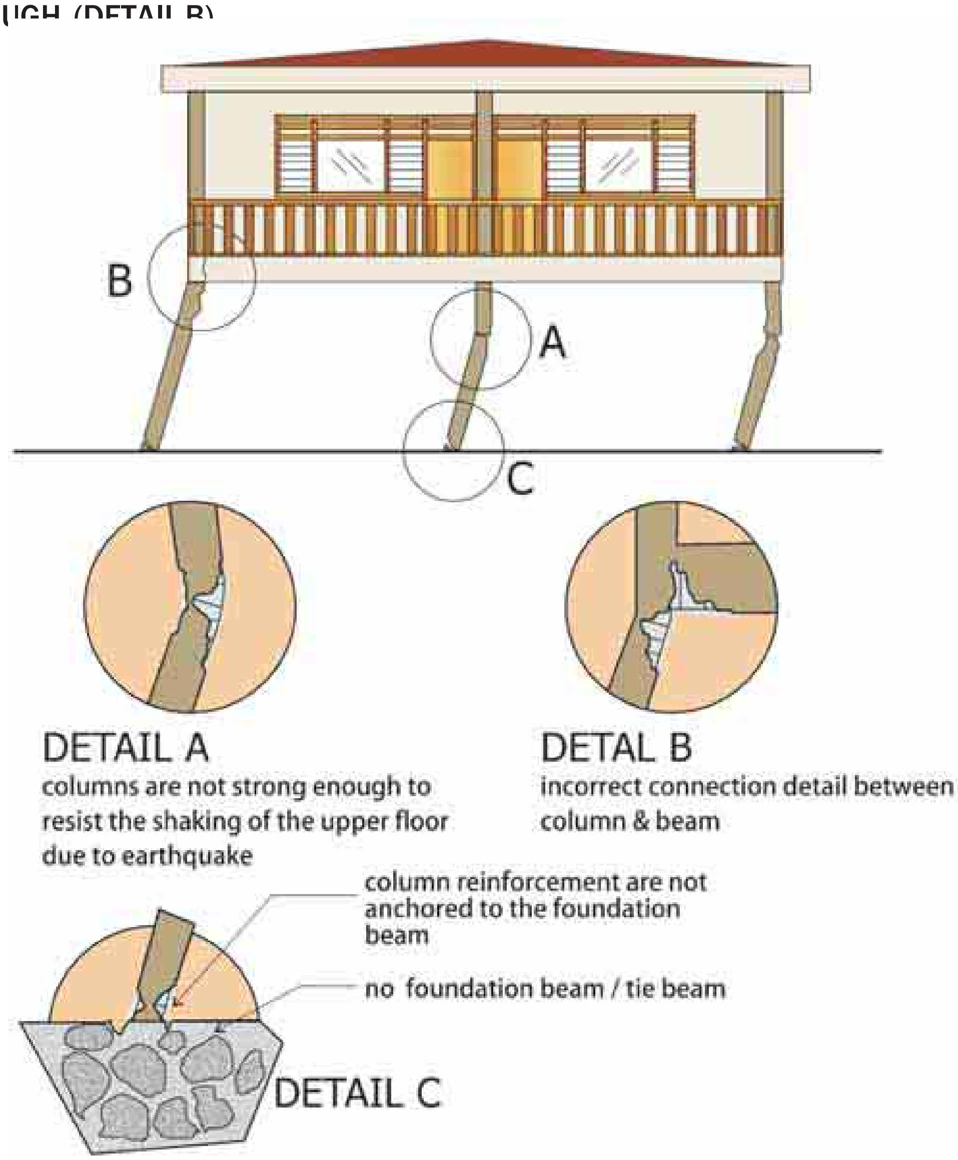
GENERALLY, THE GROUND FLOOR COLUMNS OF SHOP HOUSES ARE DAMAGED DURING EARTHQUAKES, NAMELY THE TOP AND THE BOTTOM OF COLUMNS. THE STRUCTURE OF THE UPPER FLOOR USUALLY DOES NOT SUFFER ANY SIGNIFICANT DAMAGE.

THE CAUSES OF THE DAMAGE OF R.C. SHOP-HOUSES ARE AMONG OTHERS THE FOLLOWING:

1. THE DIFFERENCE OF MASS AND RIGIDITY BETWEEN THE GROUND FLOOR AND THE UPPER FLOOR.

   THE UPPER FLOOR IS MORE HEAVY AND RIGID COMPARED TO THE GROUND FLOOR SO THAT WHEN SHAKEN BY EARTHQUAKES, THE COLUMNS AND WALLS AT THE GROUND FLOOR ARE NOT STRONG ENOUGH TO WITHSTAND THE SHAKING OF THE UPPER FLOOR. (DETAIL A)

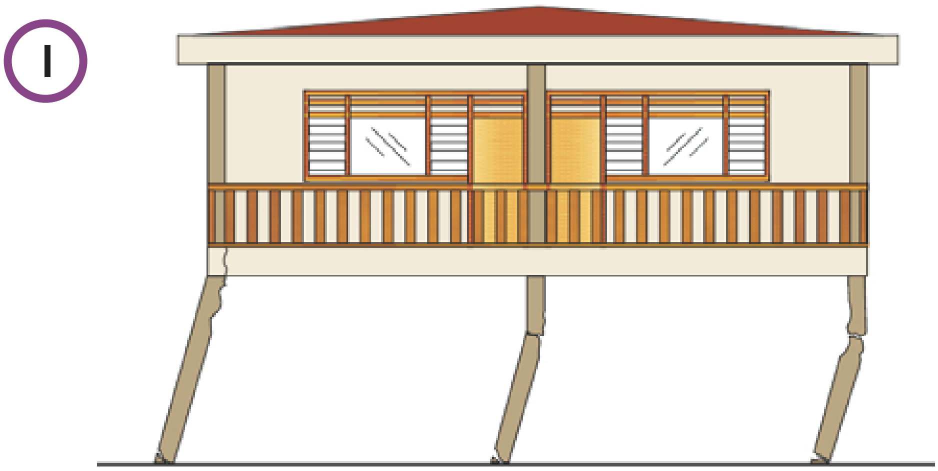
2. THE JOINT BETWEEN COLUMN AND BEAM AT THE GROUND FLOOR IS NOT RIGID ENOUGH. (DETAIL B)



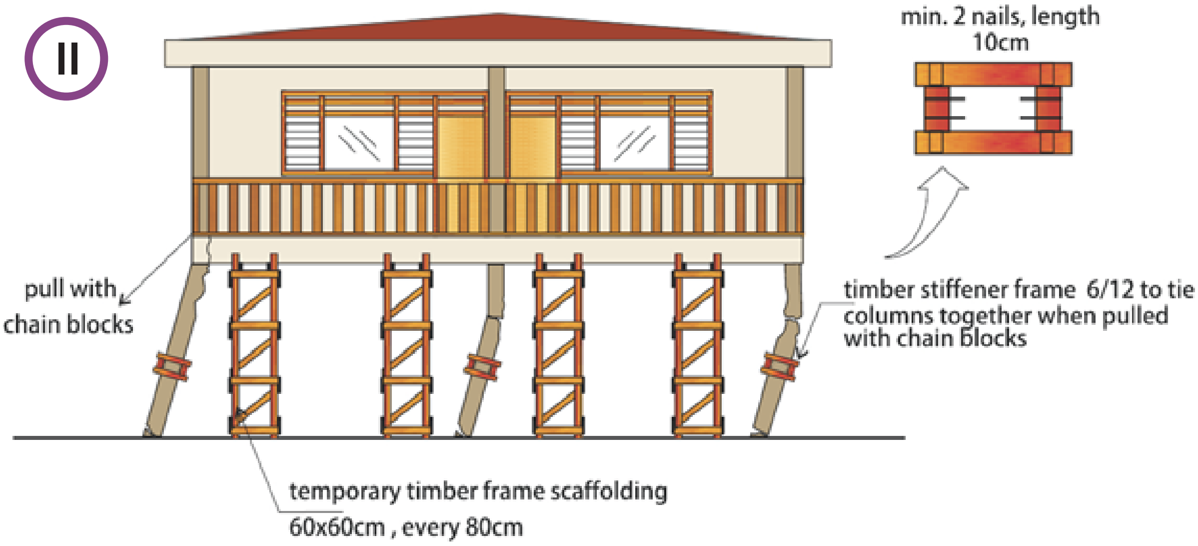
3. USUALLY COLUMNS ARE NOT INTERCONNECTED TO ACT AS ONE RIGID UNIT BECAUSE THERE IS NO FOUNDATION BEAMS / TIE BEAMS. (DETAIL C)

4. DUE TO THE NON EXISTANCE OF FOUNDATION BEAMS, THE BEAM-COLUMN CONNECTION ARE NOT RIGID ENOUGH. (DETAIL C)

5. THERE ARE NO PRACTICAL BEAMS AND PRACTICAL COLUMNS FOR WALLS WITH AN AREA > $6M^2$.

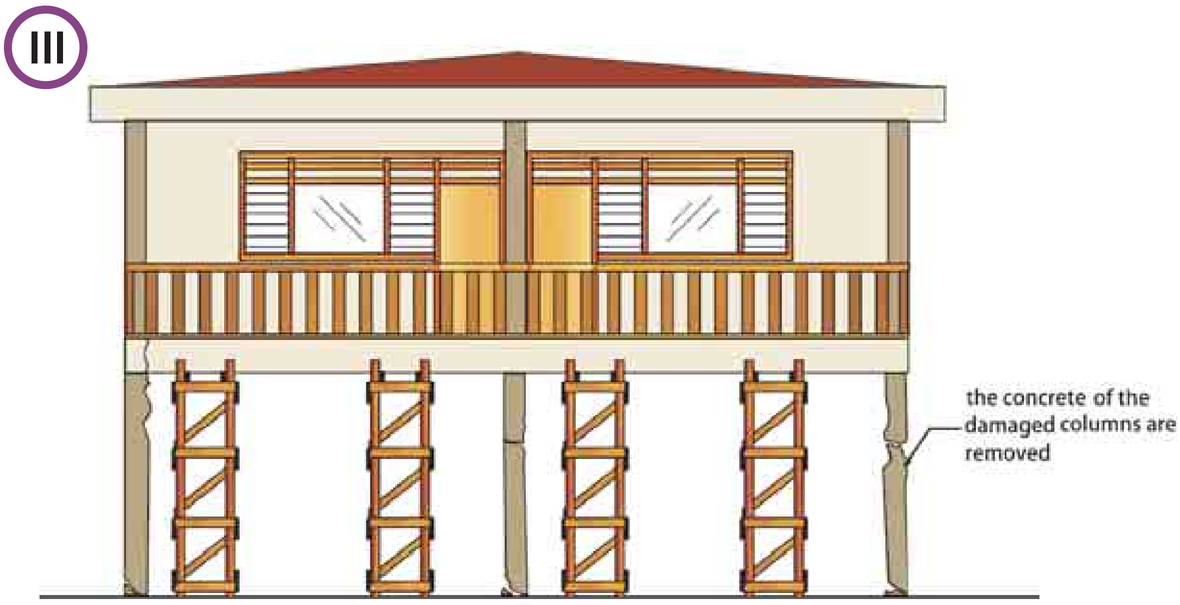


shop-house condition after the earthquake



INSTALL TEMPORARY TIMBER FRAME SCAFFOLDING EVERY 80CM.

THE BUILDING MUST MOVE AS ONE UNIT WHEN PULLED USING CHAIN BLOCKS. THEREFORE, COLUMNS AT THE GROUND FLOOR MUST BE FRAMED TOGETHER WITH TIMBER FRAMES 6/12 CM AS CAN BE SEEN IN THE FIGURE II ABOVE.

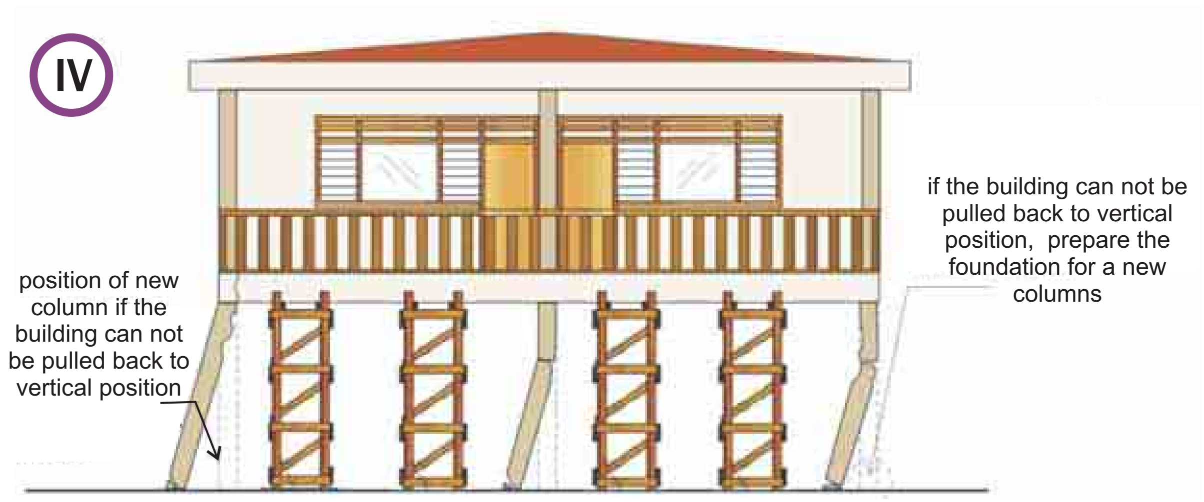


REMOVE THE CONCRETE OF THE DAMAGED COLUMN PARTS. IF THE COLUMN REINFORCEMENT IS STILL INTACT, IT CAN BE RE-USED AFTER RE-ARRANGING.

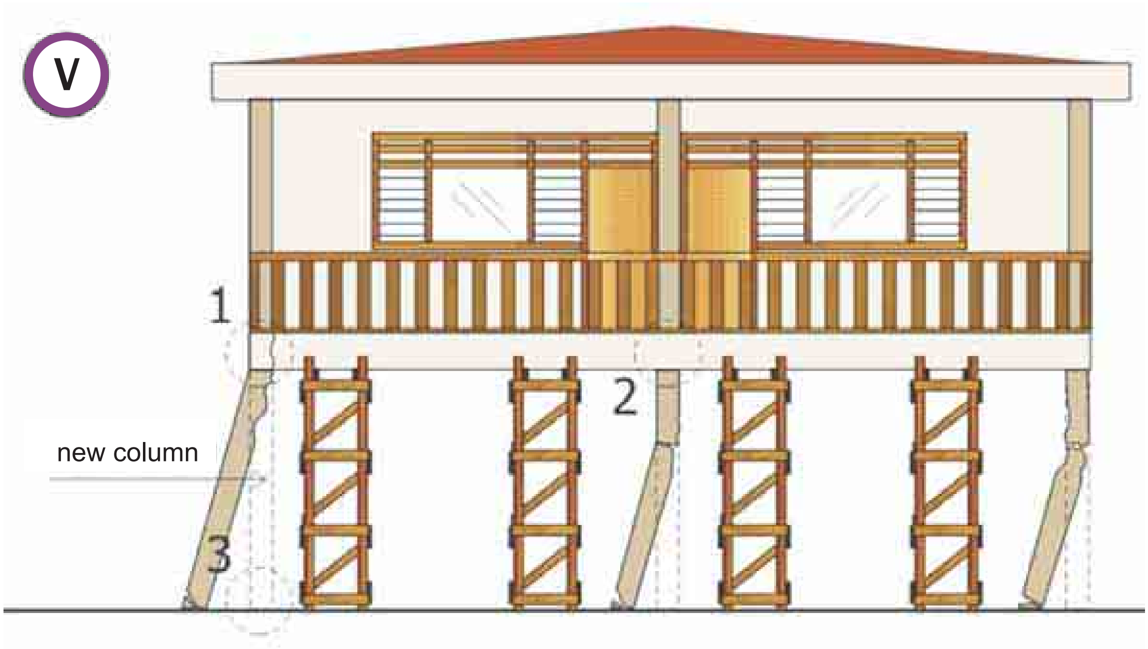
THE NEW COLUMN REINFORCEMENT SHALL BE MINIMUM 4∅16MM, ADJUSTED IN ACCORDANCE WITH THE SEISMICITY OF THE AREA. STIRRUPS SPACING 100MM UP TO 40D FROM THE TOP AND BOTTOM OF THE COLUMN. STIRRUPS SPACING FOR THE MIDDLE PART IS 150MM.

THE COLUMN & BEAM REINFORCING BARS AT THE BOUNDARY OF CONCRETE THAT IS REMOVED MUST BE RE-ARRANGED.

FOUNDATION BEAM (TIE BEAM) MUST BE CONSTRUCTED FIRST BEFORE CONCRETING COLUMNS.



IF COLUMNS CAN NOT BE PULLED BACK TO VERTICAL POSITION, THE DAMAGED / INCLINED COLUMNS MUST BE REMOVED. PREPARE FOUNDATIONS FOR NEW COLUMNS. THE NEW FOUNDATIONS MUST BE INTEGRATED WITH THE EXISTING ONE.

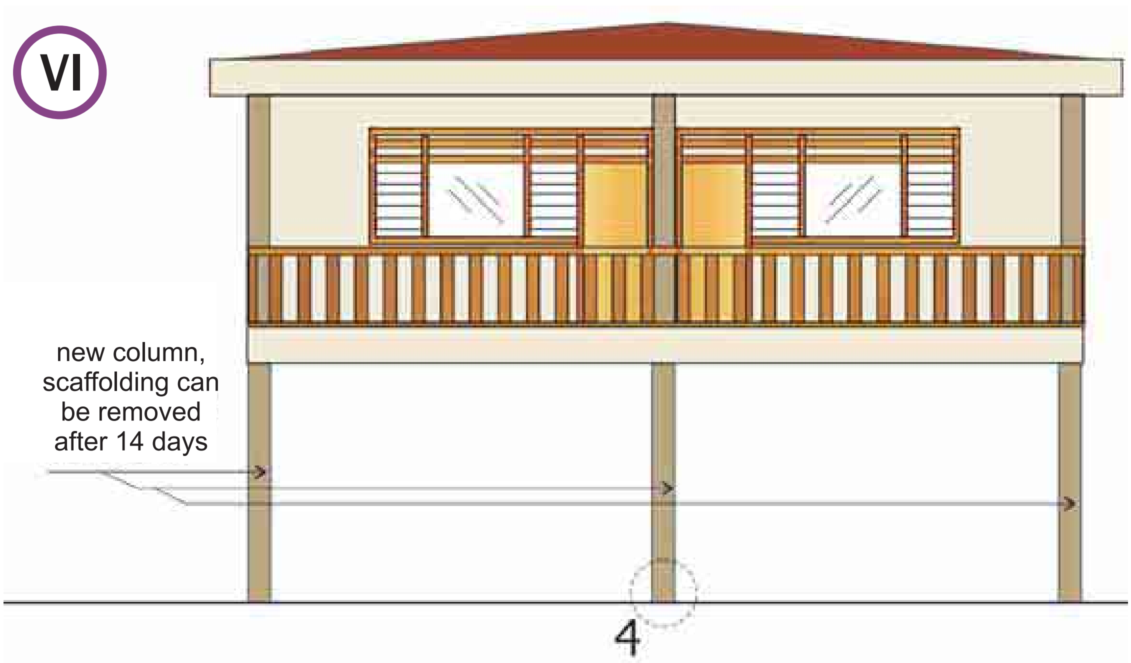


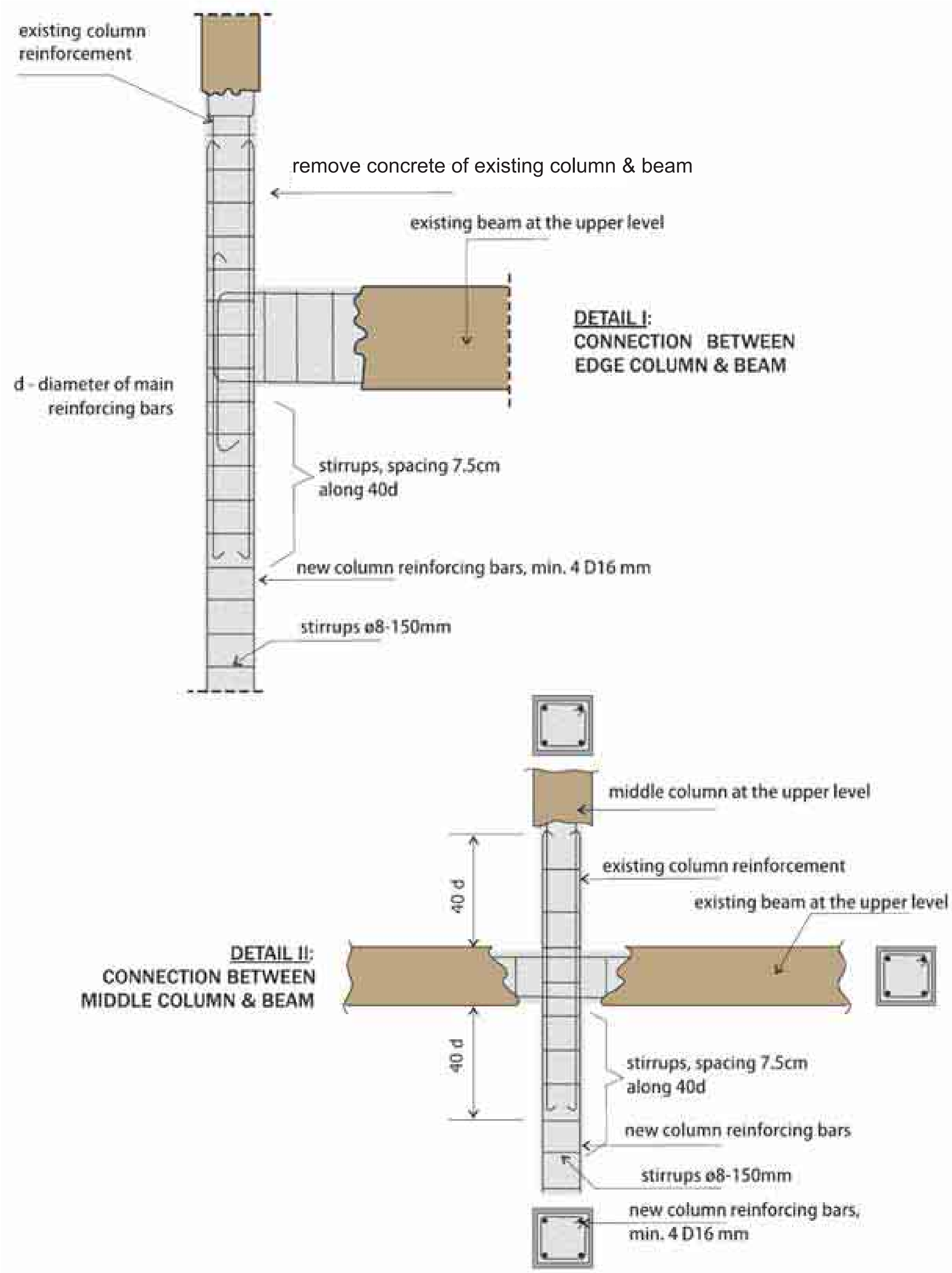
PREPARE REINFORCING BARS AND FORMWORKS FOR NEW COLUMNS.

POUR WITH CONCRETE MINIMUM 1 CEMENT : 2 SAND : 3 GRAVEL AND ADEQUATE WATER.

AFTER 3 DAYS, THE FORMWORK CAN BE REMOVED.

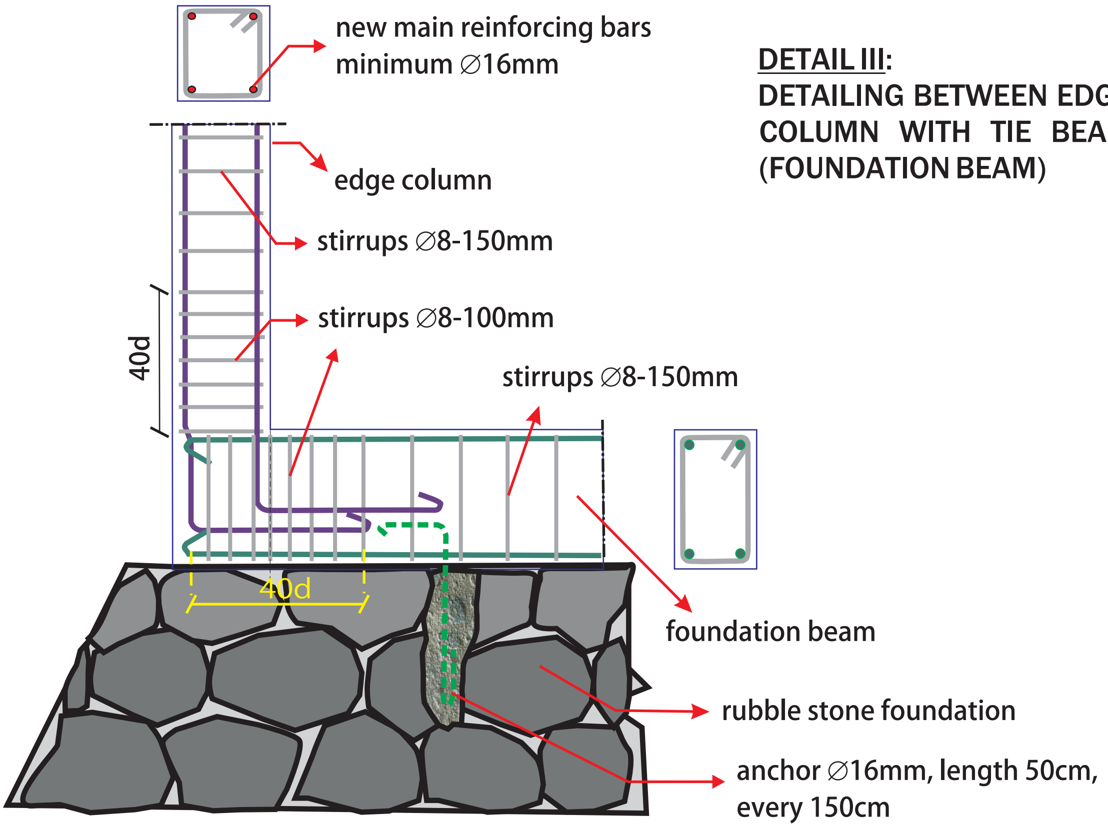
THE SCAFFOLDING CAN BE REMOVED MINIMUM 14 DAYS AFTER ALL COLUMNS ARE CONCRETED.



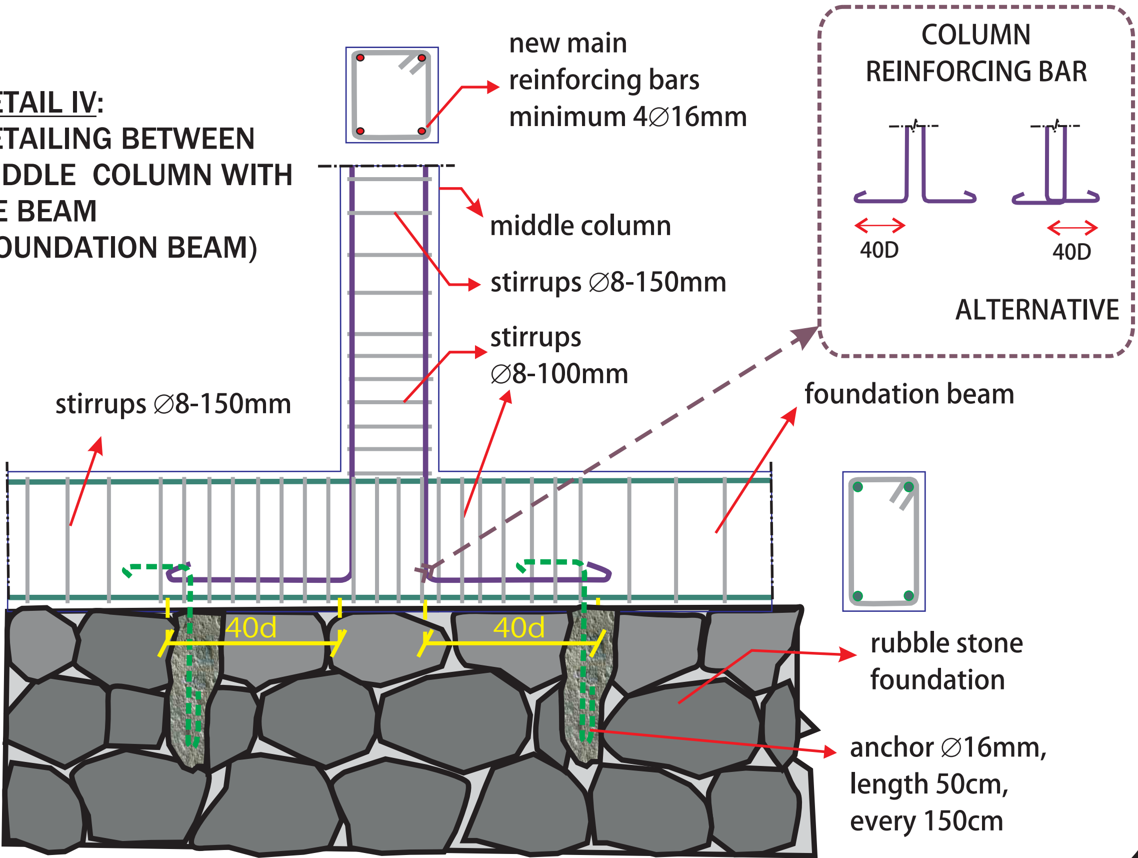


existing column reinforcement
remove concrete of existing column & beam
existing beam at the upper level
DETAIL I:
CONNECTION BETWEEN EDGE COLUMN & BEAM
d - diameter of main reinforcing bars
stirrups, spacing 7.5cm along 40d
new column reinforcing bars, min. 4 D16 mm
stirrups ø8-150mm
middle column at the upper level
existing column reinforcement
existing beam at the upper level
40 d
DETAIL II:
CONNECTION BETWEEN MIDDLE COLUMN & BEAM
40 d
stirrups, spacing 7.5cm along 40d
new column reinforcing bars
stirrups ø8-150mm
new column reinforcing bars, min. 4 D16 mm

DETAIL III:
DETAILING BETWEEN EDGE COLUMN WITH TIE BEAM (FOUNDATION BEAM)



DETAIL IV:
DETAILING BETWEEN MIDDLE COLUMN WITH TIE BEAM (FOUNDATION BEAM)

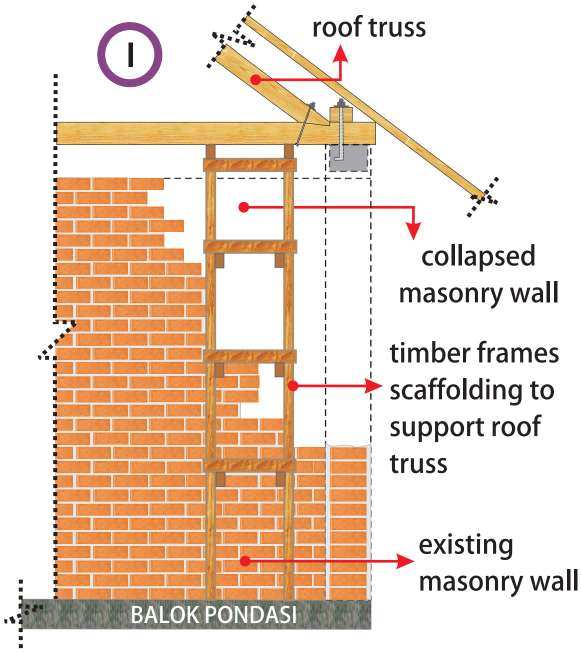


9.9. RETROFITTING OF WALLS COLLAPSED AT THE CORNERS

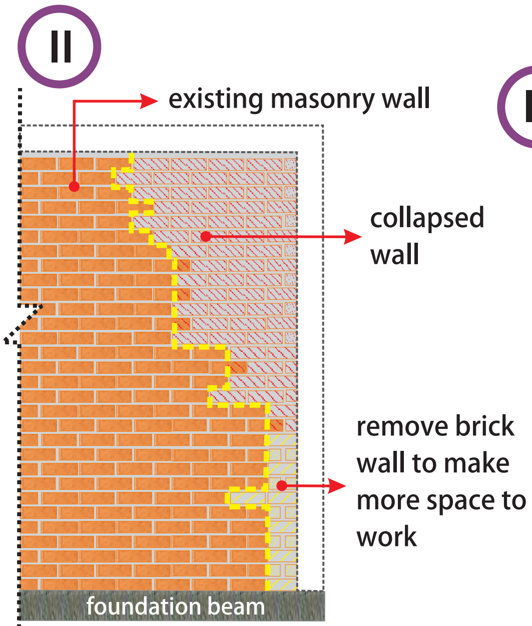

EXAMPLE FAILURE OF WALLS AT THE CORNERS

RETROFITTING METHOD:

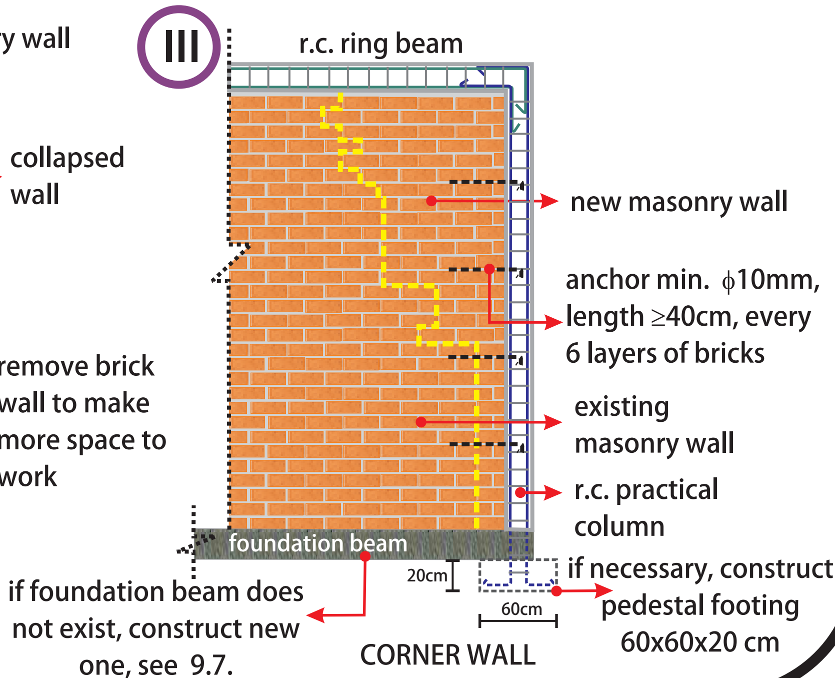
1. INSTALL SCAFFOLDING TO SUPPORT THE ROOF TRUSS.
2. IF NECESSARY, REMOVE PART OF EXISTING WALL TO MAKE MORE SPACE TO WORK.
3. INSTALL COLUMN & RING BEAM REINFORCEMENT.
4. THE COLUMN & RING BEAM ARE CONCRETED WITH MINIMUM CONCRETE MIX 1 CEMENT : 2 SAND : 3 GRAVEL, WITH ADEQUATE WATER.
5. INSTALL THE NEW WALL UP TO THE RING BEAM LEVEL.



INSTALL SCAFFOLDING TO SUPPORT ROOF TRUSS



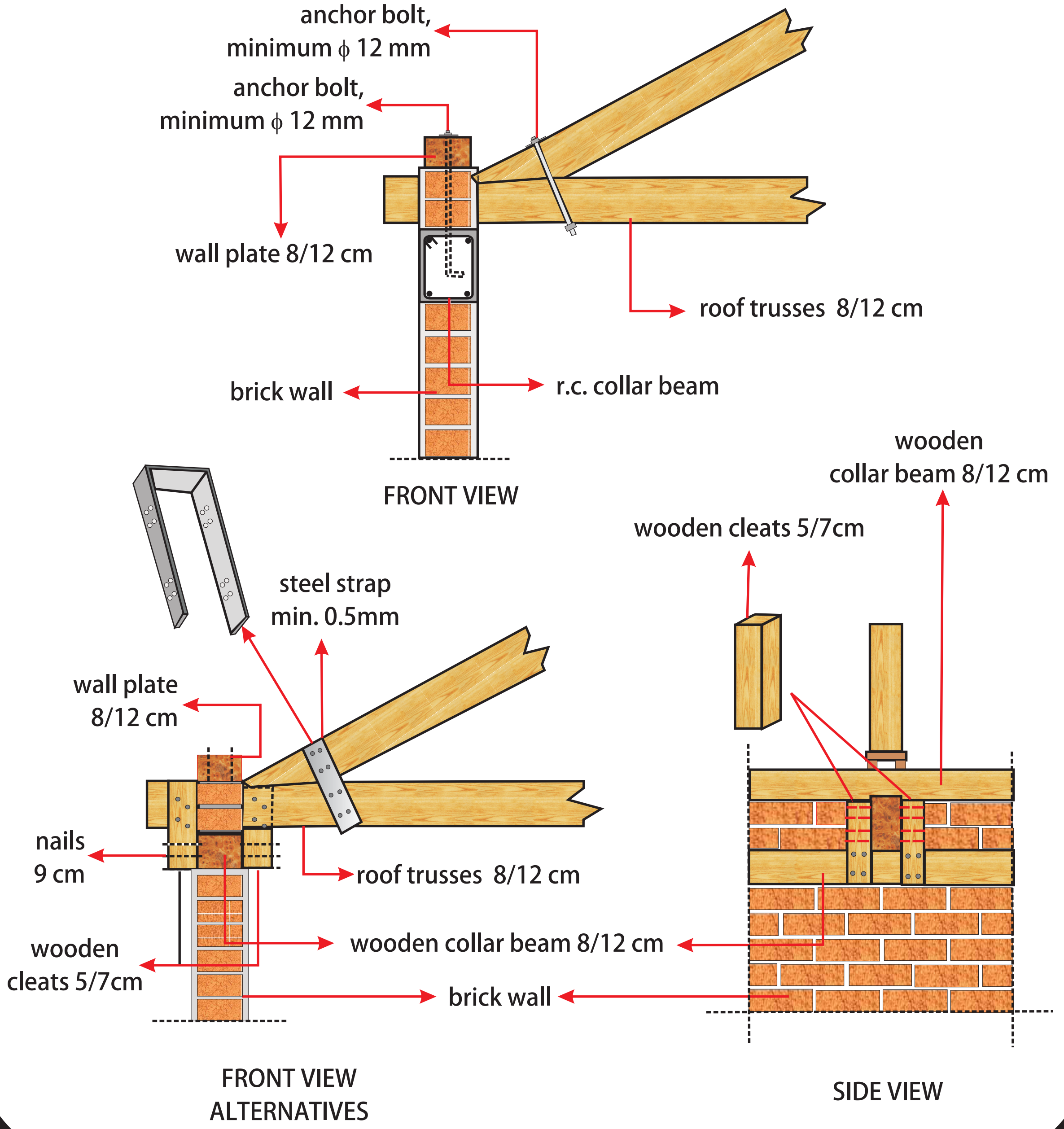
CORNER WALL

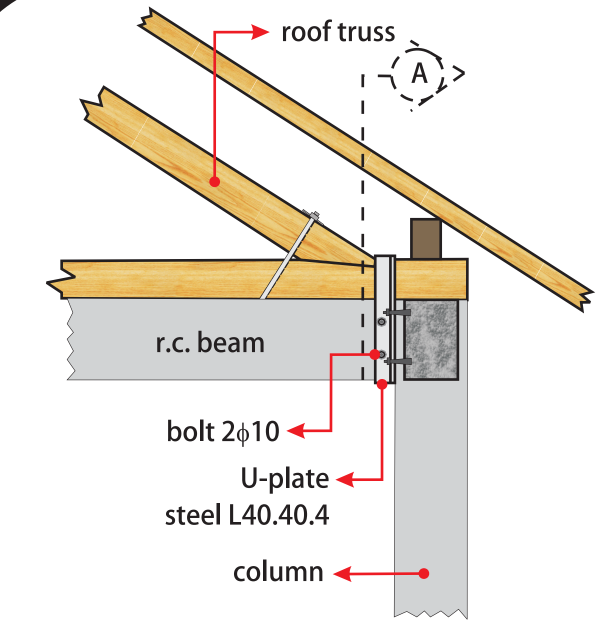


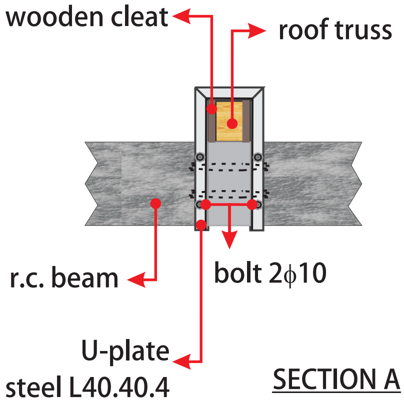
CORNER WALL

9.10. RETROFITTING OF DISLODGED ROOF TRUSSES

EXAMPLE OF DISLODGED ROOF TRUSSES



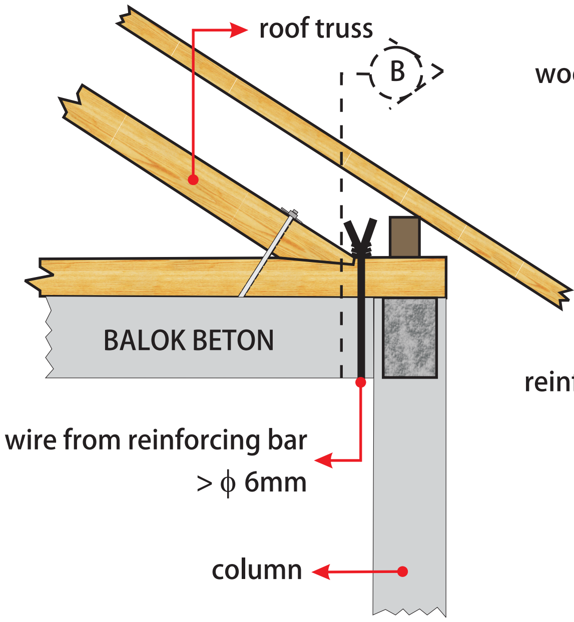


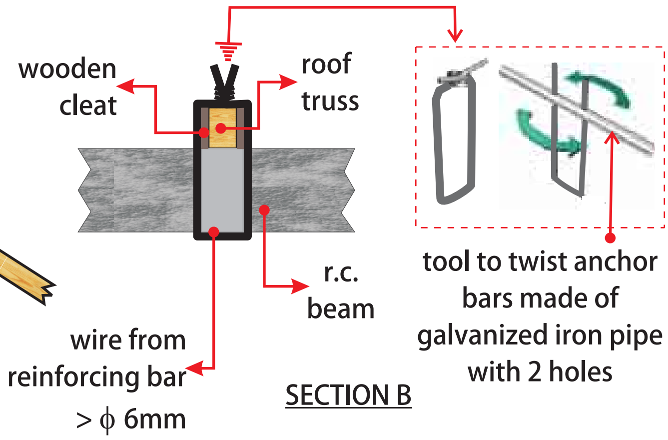


SECTION A

ALTERNATIVE I

CONNECTION BETWEEN
ROOF TRUSS AND R.C. BEAM

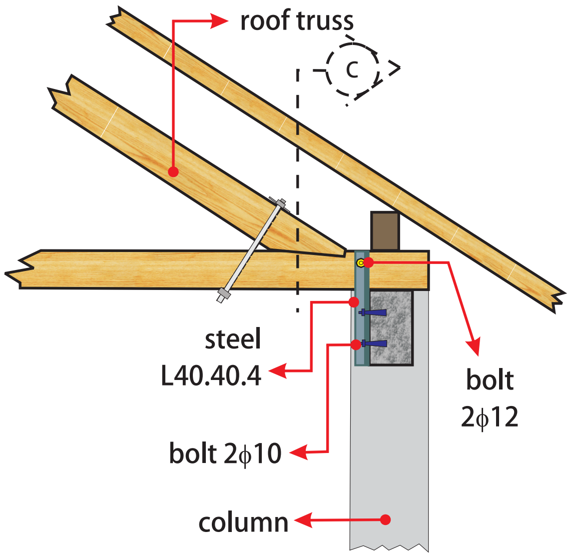


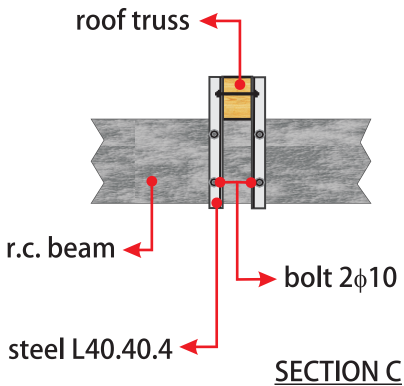


SECTION B

ALTERNATIVE II

CONNECTION BETWEEN
ROOF TRUSS AND R.C. BEAM





SECTION C

ALTERNATIVE III

CONNECTION BETWEEN
ROOF TRUSS AND R.C. BEAM

9.11. SECURING NON-STRUCTURAL COMPONENTS BEFORE EARTHQUAKES OCCUR

NON-STRUCTURAL COMPONENTS DAMAGE IS OF CONCERN BECAUSE OF THE THREE TYPES OF RISKS ASSOCIATED WITH IT:

1. RISK TO LIFE:

   BUILDING OCCUPANTS CAN BE INJURED OR KILLED BY FALLING NON-STRUCTURAL COMPONENTS PAST EARTHQUAKES HAVE SHOWN THE DANGERS OF BROKEN GLASS, FALLING CEILINGS, RUPTURED GAS PIPING, FALLING BRICKWORK, AND COLLAPSE OF MASONRY PARTITION OR IN-FILL WALLS.

2. RISK TO PROPERTY:

   PROPERTY LOSSES MAY BE THE RESULT OF DIRECT DAMAGE TO A NON-STRUCTURAL ITEM OR CONSEQUENTIAL DAMAGE. EXAMPLE: WHEN THE EARTHQUAKE OCCURS, THE GAS STOVE IN THE KITCHEN IS OVERTURNING. THE FIRE IS BROKEN OUT, BURNING ALL OF THE BUILDING CONTENTS AND MAY CAUSE A HUGE LOSS OF PROPERTY.

3. RISK TO FUNCTION AS SOON AS THE EARTHQUAKES OCCUR:

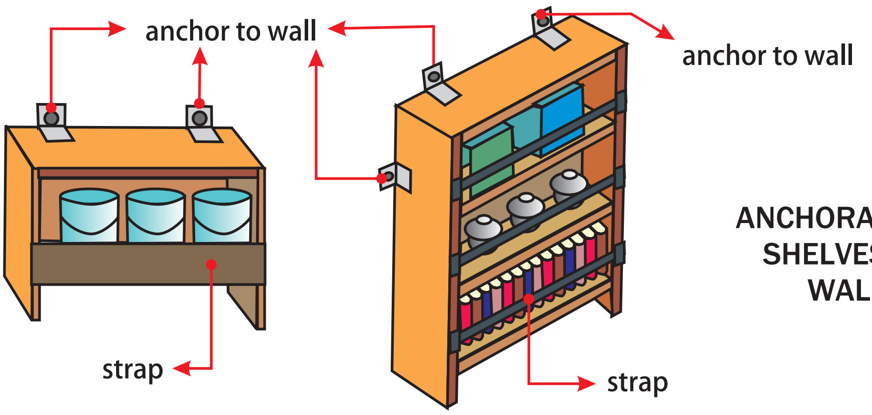
   DISRUPTION TO NORMAL FUNCTIONS WILL CAUSE POST-EARTHQUAKE DOWN TIME AND LOSS OF FUNCTION JUST WHEN THE COMMUNITY'S DEMAND FOR SERVICES MAY BE EXTREME.

   MANY EXTERNAL FACTORS CAN CAUSE INTERRUPTION TO FUNCTIONS AFTER AN EARTHQUAKE, INCLUDING ELECTRIC POWER OUTAGE, WATER OUTAGE, AND DAMAGE TO INFRASTRUCTURE.

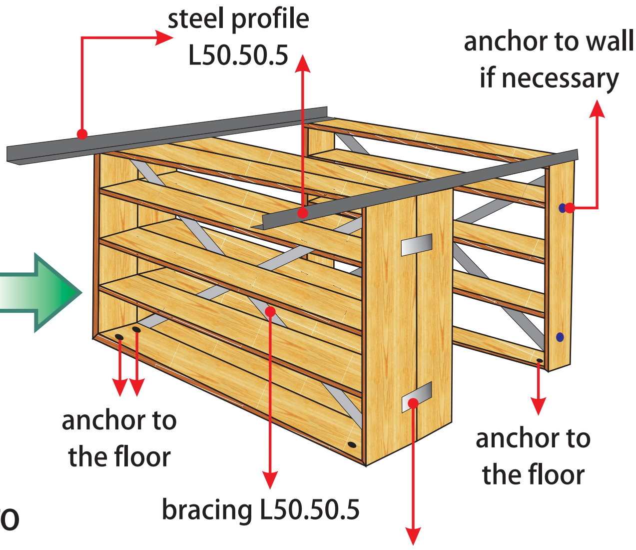
THEREFORE, THE NON-STRUCTURAL COMPONENTS MUST BE CHECKED AND SECURED BEFORE EARTHQUAKES STRUCK.

NOTE:

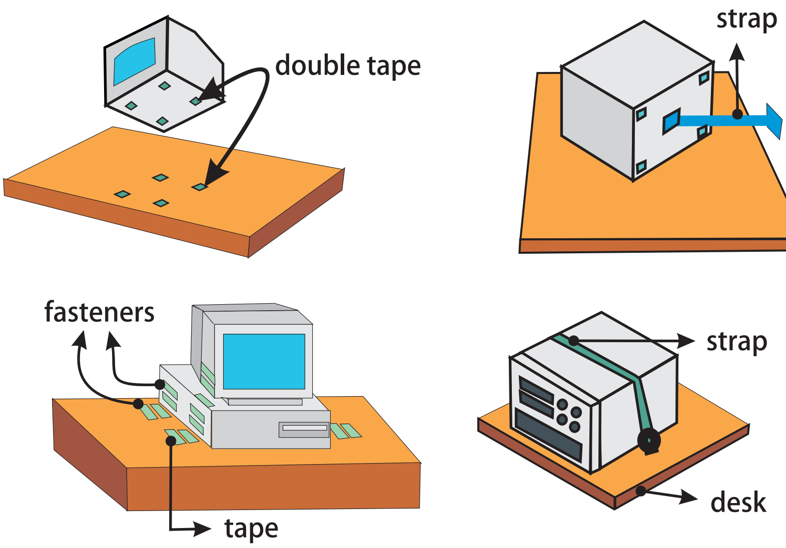
THIS MANUAL ONLY DISCUSSES THE NON-STURCTURAL COMPONENTS FOR NON-ENGINEERED BUILDINGS, SUCH AS COMMON-PEOPLE HOUSES, SCHOOLS, AND SHOP-HOUSES. THE NON-STURCTURAL COMPONENTS FOR ENGINEERED BUILDINGS (HIGH-RISE BUILDING) ARE MORE COMPLICATED AND IS NOT DISCUSSED IN THIS MANUAL.



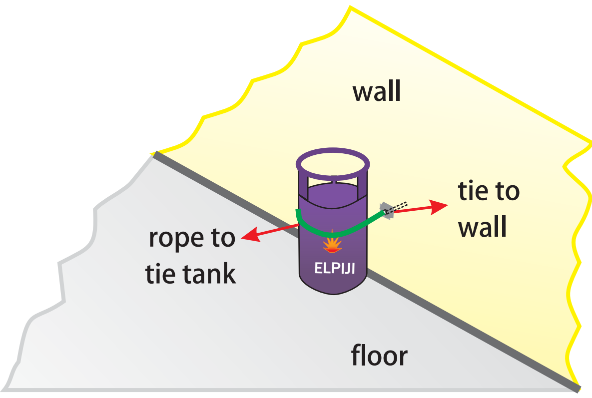
ANCHORAGE OF SHELVES TO WALL



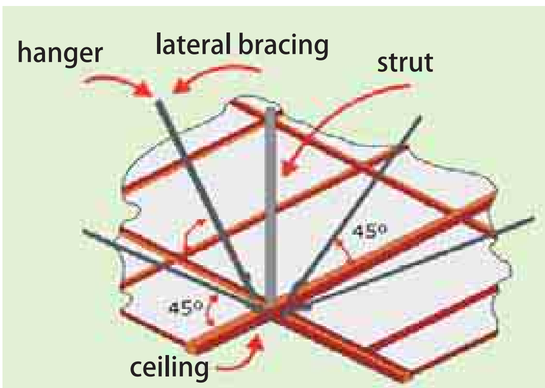
CABINETS MUST BE SAFE-GUARDED TO RESIST EARTHQUAKE SHAKING



SAFE-GUARDING COMPUTERS TO RESIST EARTHQUAKE SHAKING



SAFE-GUARDING GAS TANK TO WITHSTAND EARTHQUAKE SHAKING

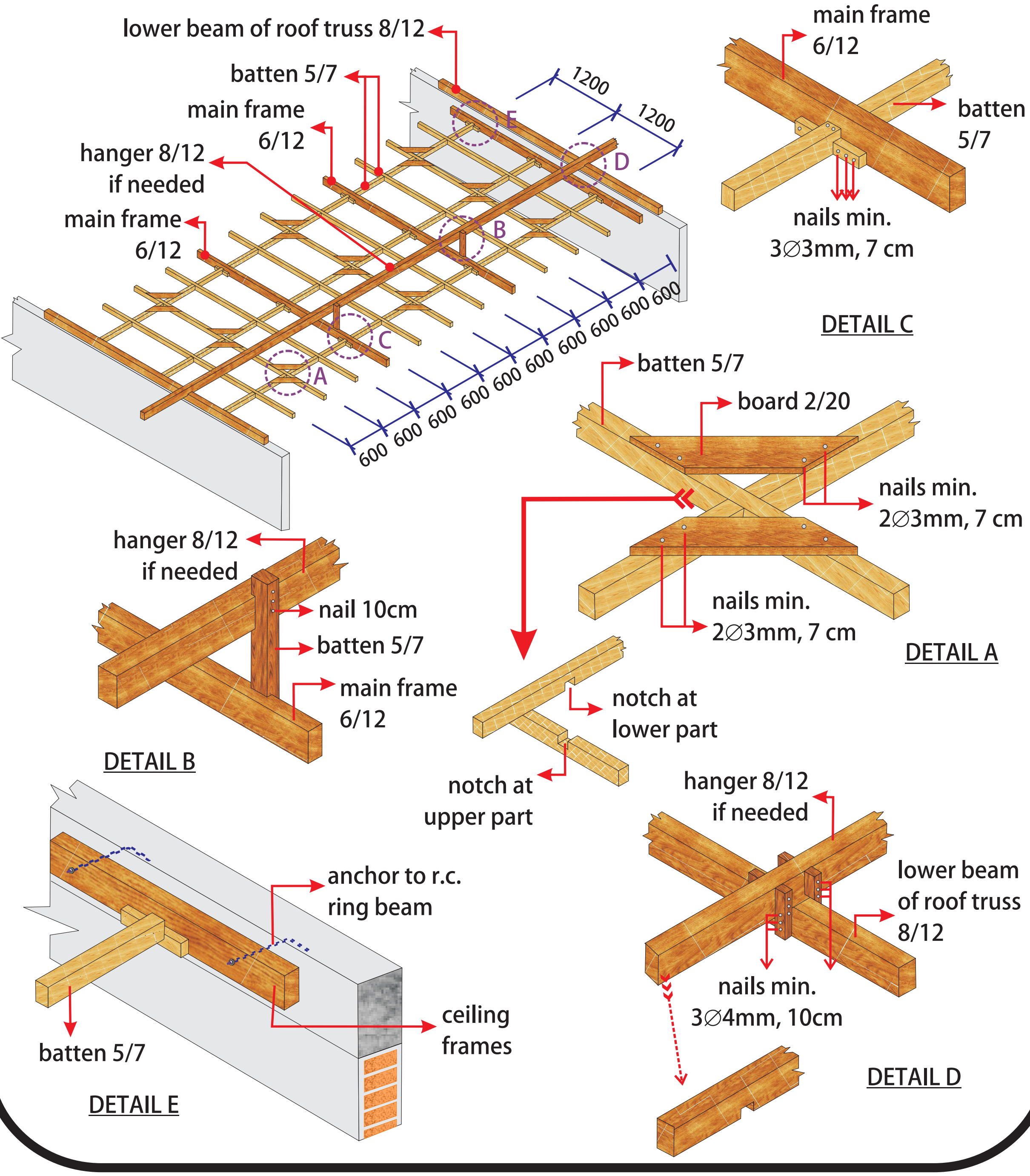


METAL CEILING FRAME HANGER

9.12. RETROFITTING OF SUSPENDED CEILINGS

EXAMPLE OF SUSPENDED CEILINGS

CEILINGS FRAMING FUNCTION AS DIAPHRAGM TO DISTRIBUTE LOADS UNIFORMLY. THEREFORE, IT MUST BE RIGID AND STRONG. METAL CEILINGS HANGERS MUST ALSO BE RIGID.



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