Seismic Retrofitting and Repair Manual for Buildings

Earthquake Vulnerability Reduction Project (EVRP)

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Seismic Retrofitting and Repair Manual for Buildings

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Repair and Retrofitting Manual

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Foreword

The Kashmir earthquake claimed over 73000 lives, affected over 2.5 million people and exposed serious shortcomings in the construction trends of the country. Historically, Pakistan's approach to tackle disasters has always remained pre-dominantly reactive, however the havoc wrecked by Kashmir earthquake stimulated planning around pro-active disaster risk reduction approach and the focus shifted from Emergency Response to Prevention and Mitigation of Disaster Risks. To cater for the challenges in implementing this pro-active approach, National Disaster Management Authority (NDMA) was established with institutionalization of allied policy and legal instruments as to enable the lead institution to function as per mandate. This new system of Disaster management is supported by legal and institutional arrangements at the Federal, Provincial and District level.

NDMA in collaboration with UNDP's Bureau for Crisis Prevention and Recovery (BCPR) has launched a programme, titled as Earthquake Risk Reduction and Recovery Preparedness Programme (ERRP) in Pakistan. This programme is within the fold of regional initiative, and is being replicated in four other South Asian countries i.e. Bangladesh, Bhutan, India, Nepal. The programme addresses the critical issues around institutional capacities, public education & awareness; enhance community capacities to undertake risk reduction, practical application of risk reduction principles through demonstration projects.

One of the components of ERRP was to develop "Seismic Retrofitting and Repair Manual for Buildings". It has been observed that the buildings damaged in the 2005 Earthquake have been superficially repaired. Needless to say that this simple and surface repair to buildings will not restore the lost strength; it will only hide the cracks, leaving the building in a weakened state. Such buildings become vulnerable to the next earthquake, even with lesser Magnitude.

This manual will provide the much needed information to Engineers, NGOs and house owners so as to enable them to ensure long-time safety of rehabilitated houses and community buildings.

Lt. Gen. (Retd.) Farooq A. Khan
Chairman
National Disaster Management Authority (NDMA)

Introduction

Experience from recent earthquakes has demonstrated that structures which have been properly designed and constructed are able to withstand severe earthquakes without collapse. However, these same earthquakes have shown that old buildings as well as recently constructed buildings can be seriously damaged or can collapse causing loss of life to the occupants. Studies of the structural performance during these recent earthquakes have clearly demonstrated that structural systems must not only have sufficient strength to resist lateral forces, but they also must have sufficient ductility, or the ability to maintain their integrity when stressed beyond their yield point in order to protect human life.

Repair is the re-establishment of the initial strength of damaged structural members and the re-establishment of the function of damaged nonstructural elements. Properly repaired structural members will possess approximately the same strength as before they were damaged but will probably have a somewhat reduced stiffness in concrete and masonry structures due to very fine cracks which are caused by the earthquake and are impossible to restore.

Strengthening is the judicious modification of the strength and/or stiffness of structural members or of the structural system to improve the structure's performance in future earthquakes. Strengthening generally includes increasing the strength or ductility of individual members or introducing new structural elements to significantly increase the lateral force resistance of the structure. On occasion, strengthening can also involve making selected structural members weaker to improve the interaction of the structural members and prevent premature failure of a weaker adjacent member.

Each structure is a unique system and its damage in an earthquake will be different from other structures, requiring custom repair and strengthening solutions and details. The decision of the rehabilitation (repair and/or strengthening) method and the appropriate construction technique depends on many factors, such as local site conditions, type and age of the structure, type and degree of damage, available time, equipment and staff for specific rehabilitation work, architectural requirements, cost, and the required level of seismic safety. The decision-making is one of the most responsible tasks in the rehabilitation process of a damaged structure.

This manual is intended to provide guidance to designers for repair and strengthening of structures for seismic resistance. While ***repair*** is generally a function following a damaging earthquake, ***strengthening*** can be done either prior to or following an earthquake.
For the preparation of this manual, the following source has been utilized:

1. *Repair and Strengthening of Reinforced Concrete, Stone and Brick-Masonry Buildings*, United Nations Development Programme, 1983.

To help facilitate the assessment of damages inflicted to engineering structures by the earthquakes, a Damage Assessment pro forma has been developed and attached with this Manual as Appendix.

Repair and Retrofitting of Masonry Structures

2.1 Repair of Walls

2.1.1 General

Masonry walls may commonly show cracks due to excessive shear and tensile forces both in the wall and near the wall intersections
Considering cracks in the wall, typical crack-pattern observed are:

i. Diagonal cracks, partially or completely through the masonry width due to diagonal tensile stresses (Figure 2.1a).

ii. Diagonal cracks in masonry piers between window openings, due to diagonal tensile stresses (Figure 2.1b).

iii. Horizontal cracks in masonry piers between window openings, due to alternating bending moments (Figure 2.1c).

iv. Diagonal cracks above the wall openings, due to shearing and arch- type, load-carrying mechanism together with possible cracks in reinforced concrete lintels (Figure 2.1d).

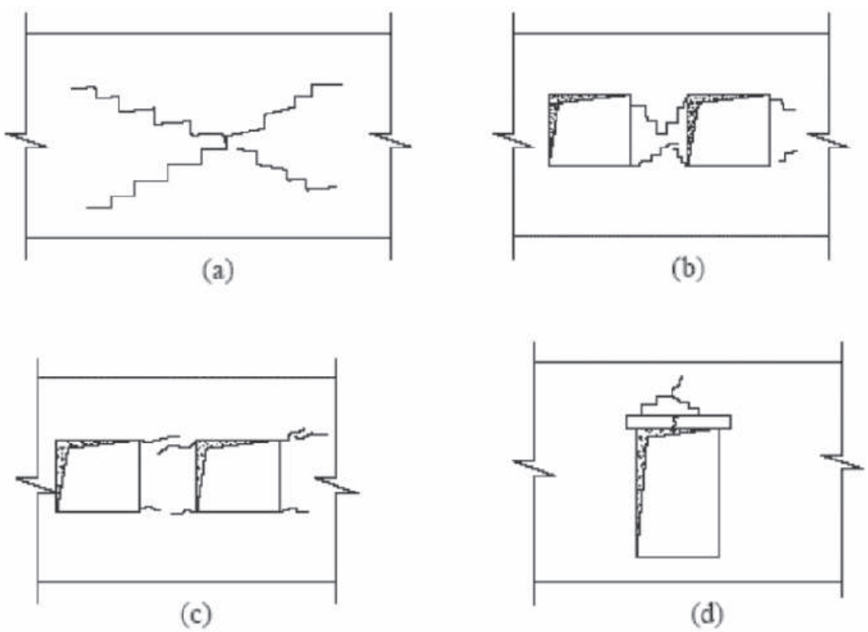

Figure 2.1 Various types of cracks observed in masonry walls

Considering the crack pattern near wall intersections, cracks are typically vertical and result of an insufficient interlocking between connecting walls. Such cracks may occur in an interior wall near the junction with an often heavier exterior wall, or in the corner connection of two exterior walls. The repair of wall intersections is covered in Section 2.2

Depending on the size of cracks, different repair methods can be used, namely:

i. Injection repair

ii. Limited or extensive removal and replacement of bricks and stones along the length of the crack, or

iii. The replacement of entire wall sections.

2.1.2 Injection Repair of Cracks

Cracks with widths exceeding 0.012 in. (0.3 mm) but less than 1/8 in. (3.2 mm), shall be repaired by injection using fluid cement mortar. In special cases, epoxy materials can be considered. For all strengthening procedures except wall jacketing, cracks should generally be repaired.

The sequence of operations in crack injection repair should be as follows:

- Remove the finish coatings, including plaster, from cracked zones and then remove loose mortar or material, dust or other impurities from cracks by air or water jet.
- Bore holes along the crack paths, 12 in. to 24 in. (305 mm to 610 mm) intervals, depending on the crack width. Introduce sleeves or nipples about 2 in. (50 mm) deep into the holes and fasten them with cement mortar (Figure 2.2)

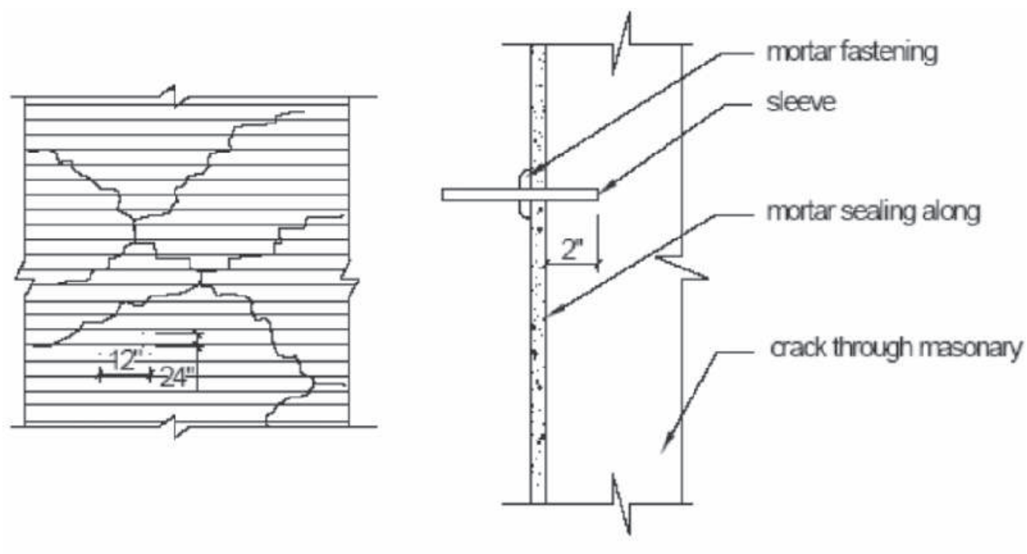

Figure 2.2 Injection repair of cracks in masonry wall

- Seal cracks with cement mortar, along their whole length. Close the sleeves or nipples with stoppers. By removing sleeve stoppers in pairs, the cracks should be cleaned again by air jet and the continuity of injection route checked by introduction of water

- Inject cement milk or fluid mortar with a pressure of 450 psi (3.1 MPa). Manual pumps may be used for small quantities, otherwise mechanical equipment is needed. Successive sleeve stoppers are removed in pairs and the fluid is injected through the lower sleeve until it overflows from the upper one. The operation is continued until the filling of cracks is complete.
- Remove sleeve and reapply finish material to conceal crack repairs.

In relatively thin masonry walls in smaller structures where stresses are low, crack repair techniques may be simpler involving the insertion of cement grout or mortar into the cracks by troweling or other appropriate techniques.

2.1.3 Repair of Large Cracks

In case cracks are larger than 1/8 in. (3.2 mm) in width, cement grout injection can also be used. However, for cracks larger than 3/8 in. (9.5 mm) in width or when loose stones or bricks are present adjacent to the crack, repair methods more extensive than injection must be used. The repair procedure selected may naturally involve strengthening the wall. Several methods of repair are typically available.

Cracks which are approximately vertical can be repaired by removing loose stones or bricks adjacent to the crack and adding steel bars with concrete or replacement stones or bricks using a rich cement grout as appropriate, filling the void (Figure 2.3). This procedure can be repeated on the opposite side of the wall as necessary.

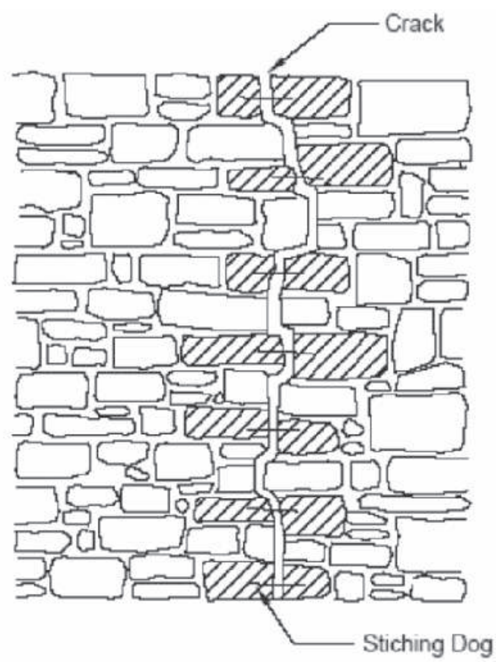

Figure 2.3 Repair of large cracks in masonry wall

Inclined cracks of large widths or a relatively dense arrangement of fine cracks must first be repaired by the injection method or by adding stitching details as described above. Due to their inclined and dense nature, the cracks will not permit reliable stress transmission if only the injection process is utilized, therefore, at properly selected points, pairs of ribs (inside and outside), protruding from the wall face (Figure 2.4) shall be constructed.

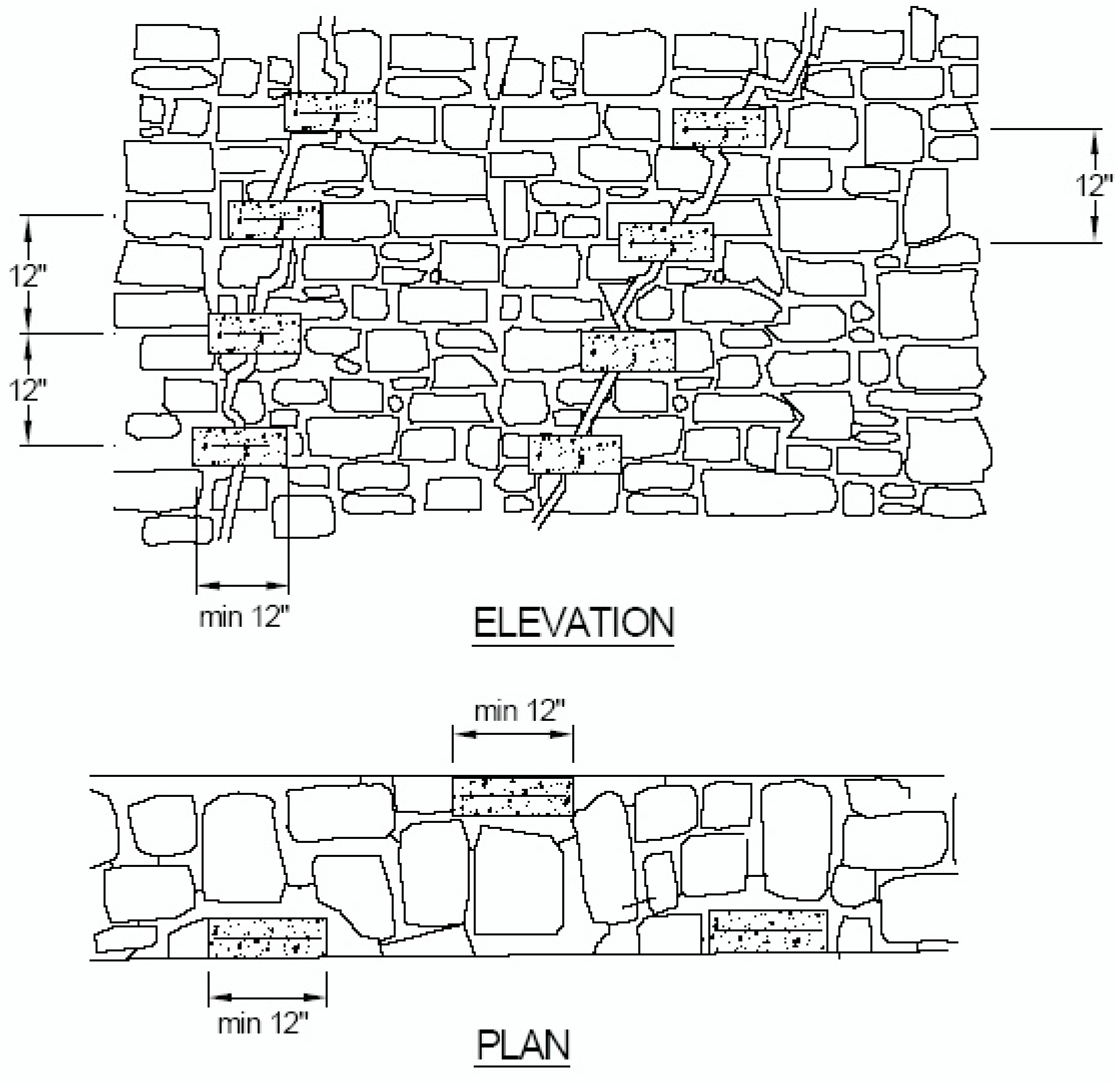

Figure 2.4 Repair of inclined cracks in masonry walls

2.2 Repair and Strengthening of Wall Intersections

2.2.1 General

Wall intersections are particularly vulnerable to earthquake damage, resulting frequently in large vertical cracks or separations as the walls are insufficiently interconnected and lack adequate strength to allow proper interaction. Various repair methods may be considered. Considering the basic weakness of masonry construction under earthquake conditions, repair procedures are most often combined with a local strengthening of the wall intersection.

In case of relatively small vertical cracks, repair can be achieved by a repair of the cracks using techniques described in the previous section, with or without some stitching procedures across the crack.

2.2.2 Separation of Masonry Walls at Junctions

Stone stitching or adding a stone across the crack is one method which can be used (Figure 2.5). Adjacent bricks or stones are removed as denoted by "**1**" and "**2**" and installing a new brick or stone, denoted by "**3**", common to both walls. This new stitching stone should be embedded in rich cement grout, at about 24 in. (610 mm) spacing. The gap formed between the two walls is then filled with a rich cement grout.

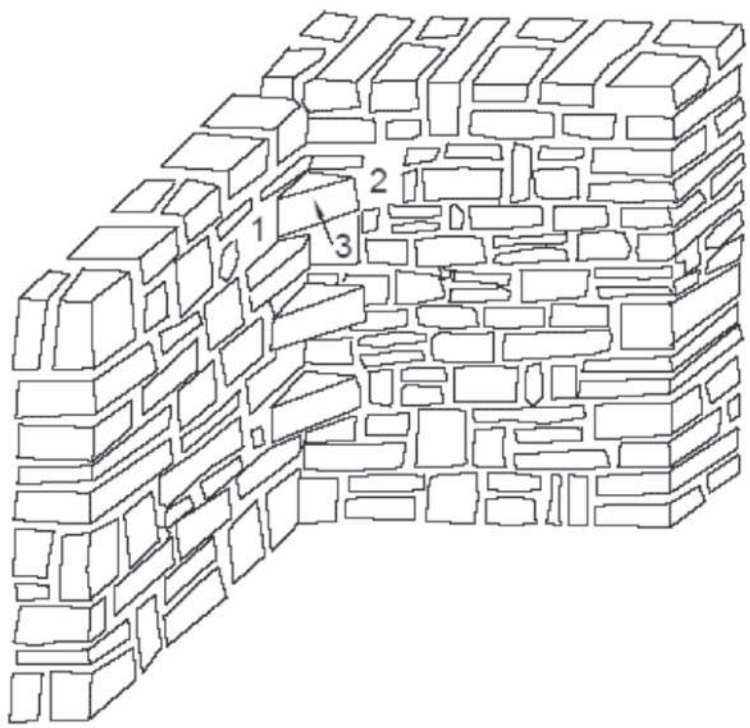

Fig. 2.5 Stiching of walls using through stones

In order to tie the separated wall sections together, tie rods, installed on both sides of the walls, can be used (Figure 2.6). Tightening is carried out by use of bolts and wrench, thus providing a controlled restoration of the walls and tying of the corner. Tie bars must be oil-base painted to resist corrosion. .If aesthetically permissible, the tie rods can remain in place and the typical crack repair would complete this strengthening procedure.

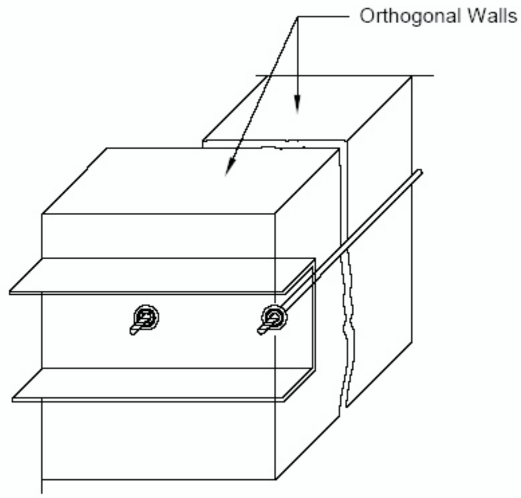

Figure 2.6 Anchoring of separated walls

Particularly in case of stone masonry, the total collapse of a corner region is not uncommon. In such an instance, repair or strengthening requires the introduction of temporary support for the roof or structure above, removal of additional masonry around the damaged area, preparation and cleaning of the contact surface and careful rebuilding (Figure 2.7). Attention could be paid to properly bond the rebuilt part of the wall onto the contact surface. Horizontal reinforcing bars shall be provided in both walls at a spacing of 24 in. (610 mm) in the vertical direction. The reinforcing bars shall be two in numbers and 1/4 in. in diameter. They shall be well extended into the intersecting walls in order to strengthen the corner.

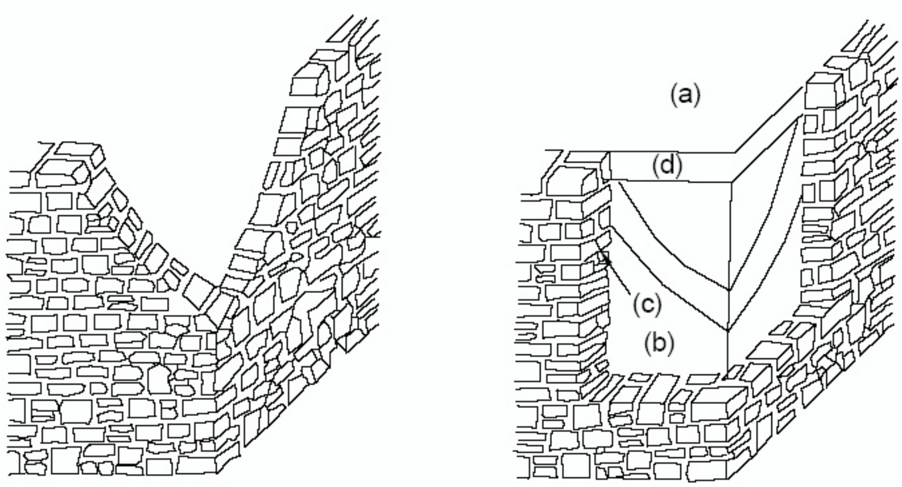

Figure 2.7 Partial reconstruction of masonry walls at corners (a - Removal or support of part or the roof, b - Additional wall removal, c - Contact surface preparation and careful rebuilding)

2.3 Strengthening of Walls

2.3.1 Reinforced Cement Jacketing

For cracks in masonry walls wider than 3/8 in. (9.5 mm), the cracked wall shall be reconstructed. In cases where reconstruction is not feasible, reinforced cement jacketing can be applied (Figure 2.8).

The following steps shall be followed for fixing reinforced cement jackets:

- Remove the damaged plaster, if present.
- Clean the surfaces of the masonry.
- Wash the cracks with water.
- Seal the cracks on one face of the wall with cement-sand mortar.
- Drill holes through the wall at a spacing of 24 in. (610 mm) in both directions to accommodate steel cross ties. The cross ties shall be ¼ in. (6.4 mm) in diameter and have a 90^{o} hook at one end. Holes shall preferably be made in the masonry joints.
- Pass the cross ties through the holes and then grout the hole with cement grout or epoxy resin.
- Install the reinforcing wire mesh to the cracked area of the wall with the help of cross ties. The mesh shall be made of galvanized steel (GS) wires having diameter up to 1/8 in. (3.2 mm) and opening size up to 4 in. (102 mm). Also install the reinforced wire mesh on the other face of the wall and provide a 90^{o} hook at the other end of the cross tie.
- Apply the thin cement slurry on to the wall surface.
- Apply 5/8 in (16.0 mm) of cement-sand plastering over the wire mesh. The proportion of the mortar for plastering shall be 1:3. Also apply the plastering on the other face of the wall.
- Provide a minimum lap length 12 in. (305 mm) wherever necessary.

2.3.2 Strengthening of Damaged Walls at Junctions/Corners

The following steps shall be followed for the repair of damaged junctions/corners of the masonry walls:

- Remove the heavily cracked portion of the damaged masonry.
- Clean the exposed portions of the masonry walls.

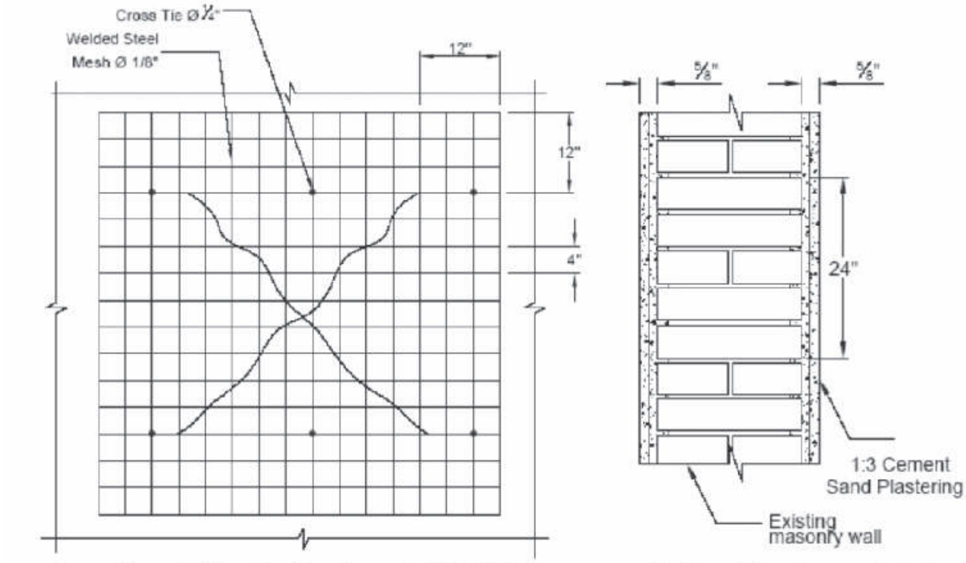

Figure 2.8 Repair of heavily cracked brick/block masonry wall with reinforced cement jacketing

- Wash the exposed portions of the masonry walls with water.

- Reconstruct the portion of the wall which has been removed. Use the masonry units of the same type and dimensions as the existing ones. Use cement-sand mortar for the reconstruction work. Connect the masonry walls at the junction/corner by proper toothing.

- Properly cure the reconstructed masonry for 15 days.

- Drill holes through the new walls at a spacing of 24 in. (610 mm) in both directions to accommodate steel cross ties. Also drill holes at the same spacing in old walls up to a minimum distance of 24 in. (610 mm) from where the new masonry starts.

- Insert the steel cross ties through the holes and then grout the holes with cement grout or epoxy resin. The cross ties shall be ¼ in. (6.4 mm) in diameter and have a 90o hook at one end.

- Install the reinforcing wire mesh to the masonry wall with the help of cross ties. The mesh shall be made of galvanized steel (GS) wires having diameter up to 1/8 in. (3.2 mm) and opening size up to 4 in. (102 mm). Also install the reinforced wire mesh on the other face of the wall and provide a 90o hook at the other end of the cross tie.

- Apply the thin cement slurry on to the exposed surfaces of the masonry wall.

- Apply 5/8 in (16.0 mm) of cement-sand plastering over the wire mesh. The proportion of the mortar for plastering shall be 1:3. Also apply the plastering on the other face of the wall.

- Provide a minimum lap length 12 in. (305 mm) wherever necessary.

Repair and Retrofitting of Concrete Structures

3.1 General

Repair of reinforced concrete elements is often required after a damaging earthquake to replace lost strength. Strengthening of reinforced concrete structural elements is one method to increase the earthquake resistance of damaged or undamaged buildings. Thus, the strength of the structures can be moderately or significantly increased and the ductility can be improved.

Depending on the desired earthquake resistance, the level of the damage, the type of elements and their connections, members can be repaired and/or strengthened by injections, removal and replacement of damaged parts or jacketing.

Establishing sound bond between the old and the new concrete is of great importance. It can be provided by chipping away the concrete cover of the original member and roughening its surface, by preparing the surfaces with glues (for instance, with epoxy prior to concreting), by additional welding of bent reinforcement bars or by formation of reinforced concrete or steel dowels.

Perfect confinement by close, adequate and appropriately shaped stirrups and ties contributes to the improvement of the ductility of the strengthened members. Detailed consideration of the possibility of significant redistribution of the internal forces in the structures due to member stiffness changes is very important.

3.2 Columns

The aim of rehabilitation is to improve the earthquake resistance of the buildings. Increasing column flexural and shear strength, improving column ductility and rearrangement of the column stiffness can be achieved by repair and/or strengthening techniques as covered in this section.

Column flexural strength increases with the enlargement of the concrete area and by adding new longitudinal reinforcement. Shear strength, and especially ductility, is improved by better confinement with close transverse reinforcement, ties or steel strips. Equalizing of column stiffness by rearrangement, like separating columns from spandrel walls, improves the compatible behavior of all columns of the structure.

Damage of reinforced concrete columns without a structural collapse will vary, such as a slight crack (horizontal or diagonal) without crushing in concrete or damage in reinforcement, superficial damage in the concrete without damage in reinforcement, crushing of the concrete, buckling of reinforcement, or rupture of ties. Based on the degree of damage, techniques such as injections, removal and replacement, or jacketing can be provided.

3.2.1 Local repairs

Resin injections are applied only for repair of damaged columns with slight cracks without damaged concrete or reinforcement. Epoxy resin injection batched or mixed in the head of the equipment is suitable for cracks with width from 0.004 in. to 0.25 in. (0.1 to 6.4 mm). The epoxy resin is injected into ports placed in drilled holes, spaced from 8 in. to 36 in. (203 mm to 914 mm) (Figure 3.1). Cement grout injections can be applied for larger cracks having widths from 1/12 in. to ¼ in. (2.1 mm to 6.4 mm). The injecting procedure initiates from the column bottom and proceeds upward.

Removal and replacement should be performed for heavily damaged columns with crushed concrete, buckled longitudinal bars or ruptured ties.

When the concrete is only slightly damaged, the loose concrete is removed, the surfaces are roughened and dust is cleaned. Depending on the amount of concrete removed, some additional ties or reinforcement may be added. Before concreting, the existing column should be saturated with water as necessary.

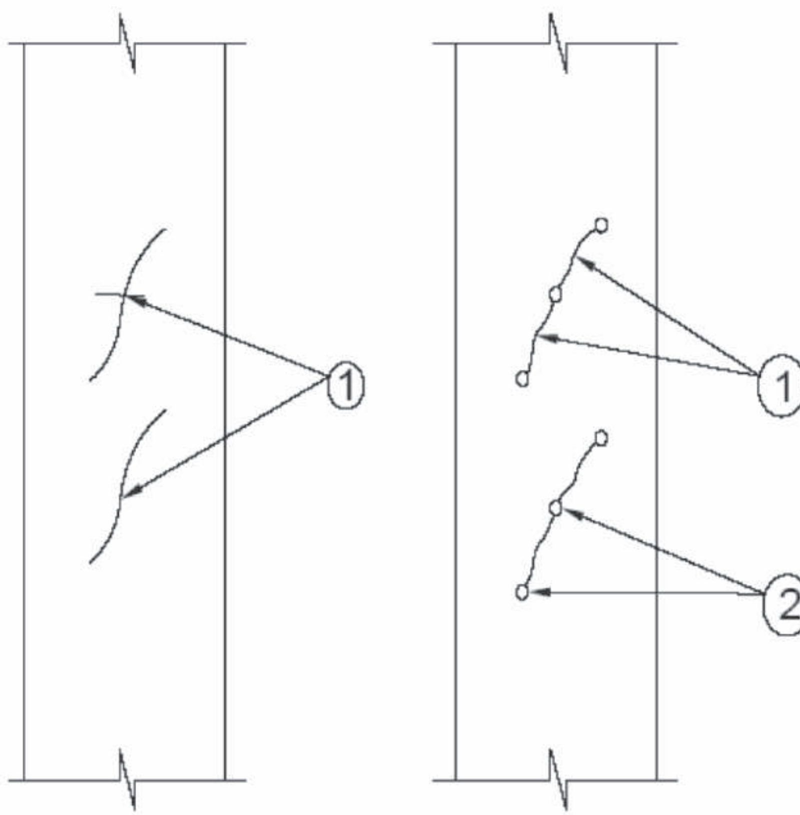

Figure 3.1 Repair of damaged columns with slight cracks (1. Cracks; 2. Injection ports)

Temporarily, the form and the concrete should be placed higher than the final repaired top level in order to compact the concrete sufficiently. After one day, the form can be removed and the fresh concrete that is beyond the normal configuration can be chipped away (Figure 3.2).

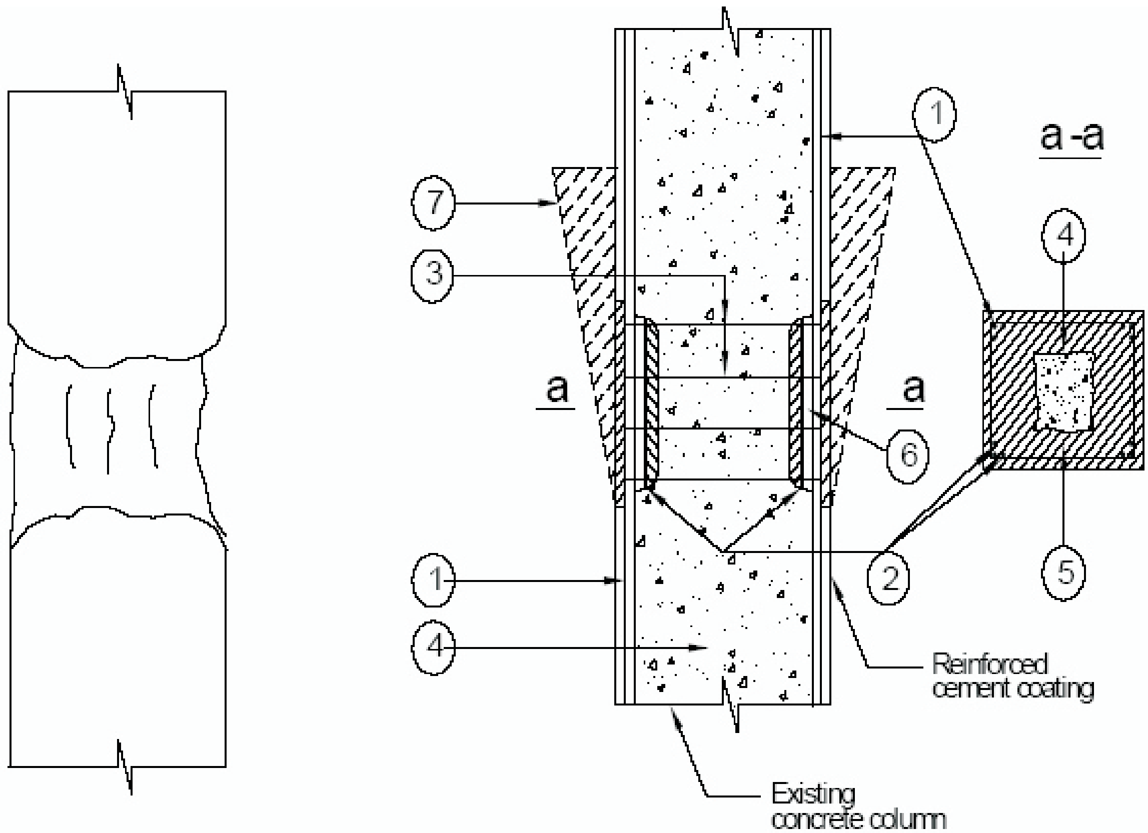

Figure 3.2 Repair of concrete columns with slight damage (1. Existing reinforcement; 2. Added new reinforcement; 3. Added new ties; 4. Existing concrete; 5. New concrete; 6. Welding; 7. Temporary castform)

When the longitudinal reinforcement is buckled, the ties are ruptured and the concrete is crushed. Total removal and replacement of the damaged parts must be carried out (Figure 3.3). If only repair is required, the original cross sections size will be maintained. If strengthening is necessary, the area of the column must be increased. Damaged and loose concrete should be removed, new longitudinal reinforcement inserted and welded to the existing reinforcement and new additional close ties placed. Non-shrinkage concrete or concrete with low shrinkage properties should be placed. Special attention must be paid to achieving good bond between the new and the existing concrete.

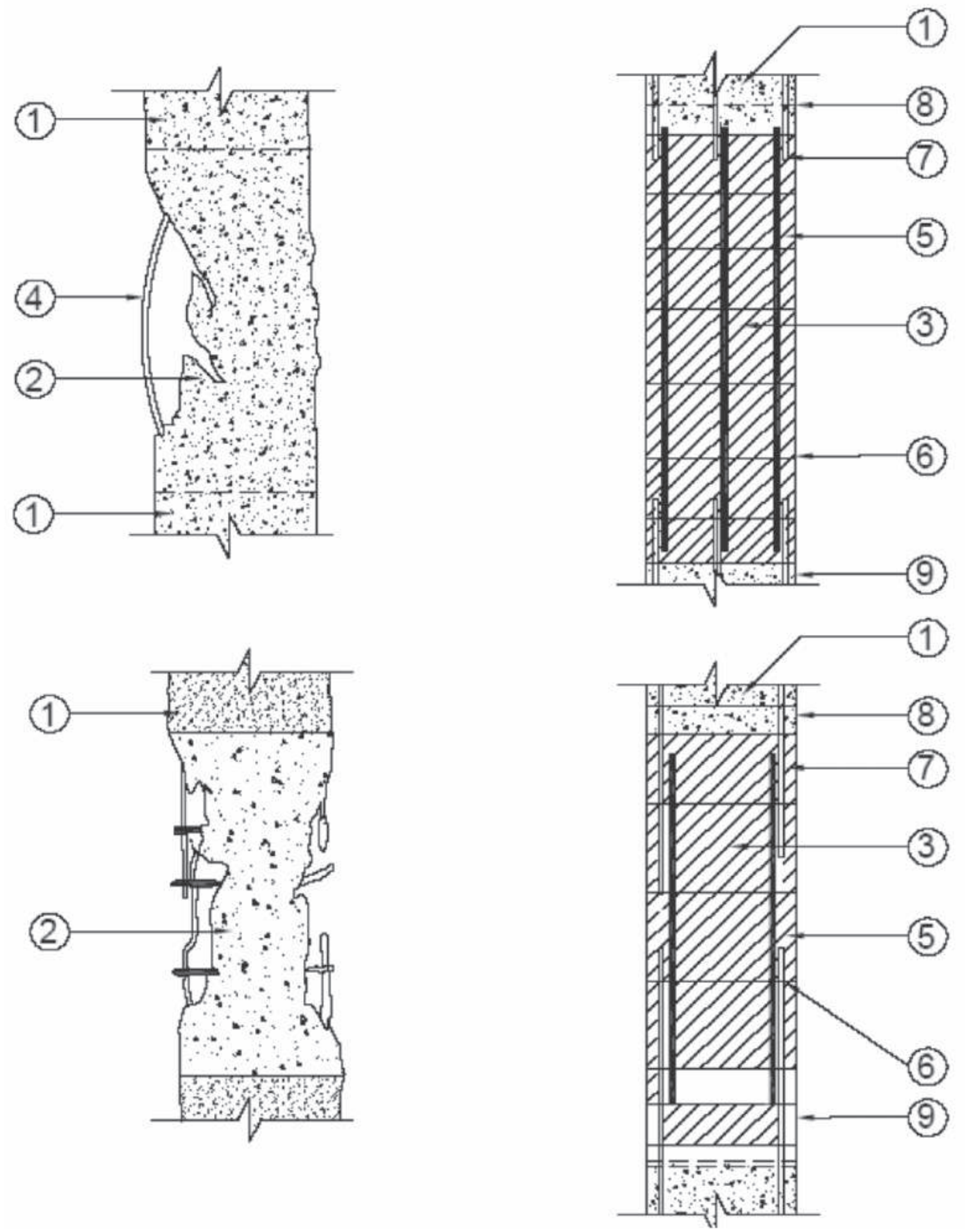

Figure 3.3 Repair of concrete columns with broken ties (1. Existing non-damaged concrete; 2. Existing damaged concrete; 3. New concrete; 4. Buckled reinforcement; 5. New reinforcement; 6. New ties; 7. Welding; 8. Existing ties; 9. Existing reinforcement)

3.2.2 Reinforced Concrete Jacketing

Jacketing should be applied in cases of heavily damaged columns or in cases of insufficient column strength. Because of the increased capacity of the columns, this is really a strengthening procedure although it can also provide repair. Jacketing can be performed by means of adding reinforced concrete. Reinforced concrete jacketing according to the available space conditions around the column can be performed by adding jacketing to one, two, three or four sides of concrete column sections (Figure 3.4).

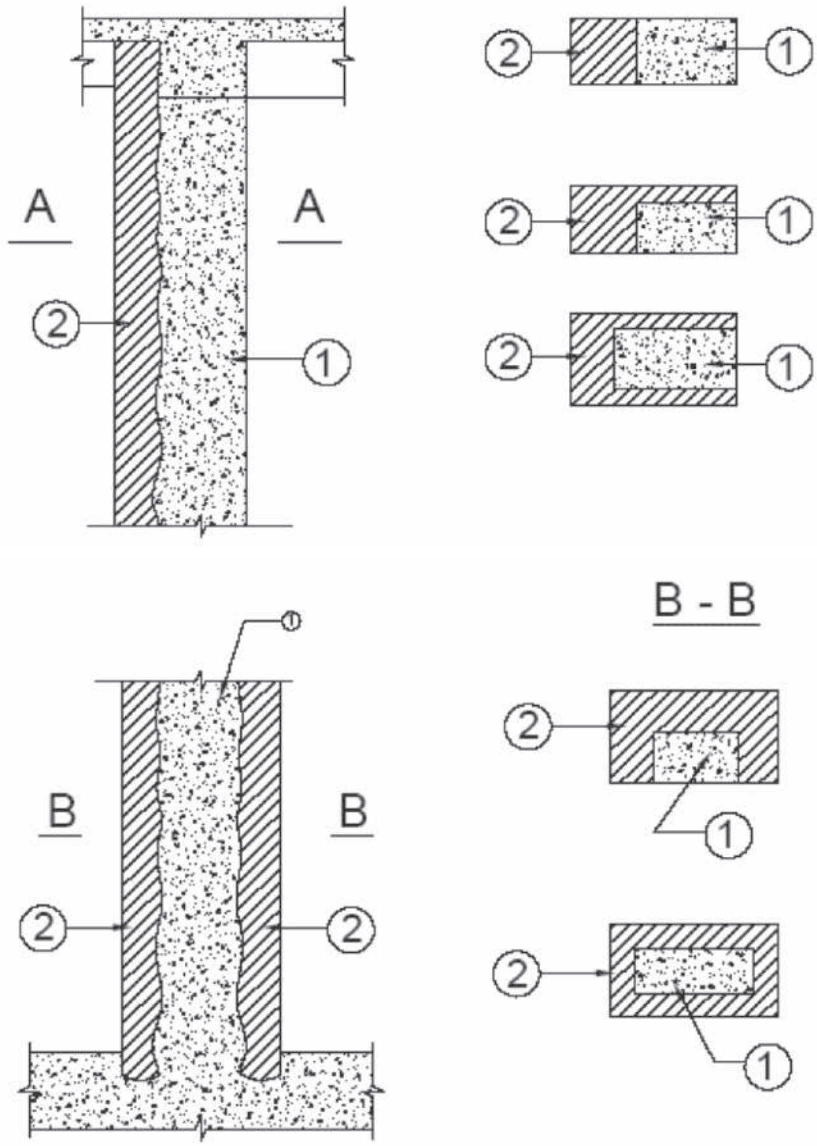

Figure 3.4 Repair of concrete column by jacketing (1. Existing column; 2. Jacketing concrete)

It is strongly recommended that columns be jacketed on all four sides for best performance in future earthquakes. In order to achieve the best bond between the new and the existing concrete, four-sided jacketing is also most desirable. In case one, two or three sided jacketing is all that is possible, the concrete cover in the jacketed parts of the existing column must be chipped away so new ties can be welded to existing ties. In case of a four-sided jacketing, only roughening of the surface of the existing column may be required unless greater load transfer is desired.

Jacketing only in the story space without reinforcement penetrating through the floor structure can improve the local axial and shear strength of the column (Figures 3.4 and 3.5.a). However, the flexural column strength is not improved and the column-to-beam joint is not strengthened. Thus, the total frame structure may show poor behavior in future earthquakes. Jacketing only within the story is a local strengthening which does not improve seismic response unless significant shear walls are also added. Adequate column flexural strength can be achieved by passing the new longitudinal reinforcement through holes drilled in the slab and placing new concrete in the beam-column joint region (Figure 3.5.b)

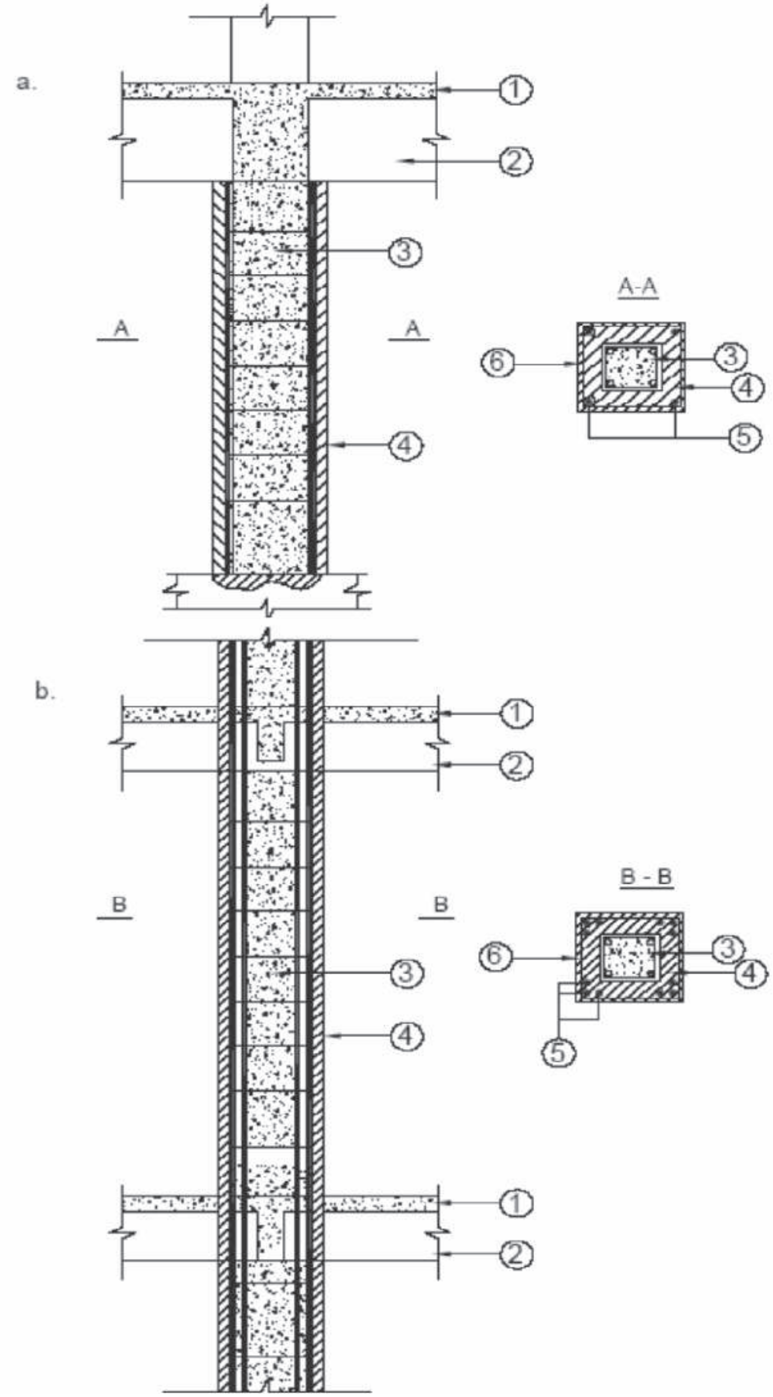

Figure 3.5 Repair of concrete columns by (a) local and (b) Global jacketing (1. Slab; 2. Beam; 3. Existing column; 4. Jacket; 5. Added longitudinal reinforcement; 6. Added ties)

In the case of a one-sided jacket, adequate connection between existing and new concrete must be achieved by good detailing and closely spaced, well anchored, additional transversal reinforcement (Figure 3.6). This can be achieved by providing anchorage with ties to the existing longitudinal reinforcement

(Figure 3.6). Welding is not necessary, but chipping free space for passing the hooks of the additional ties is necessary.

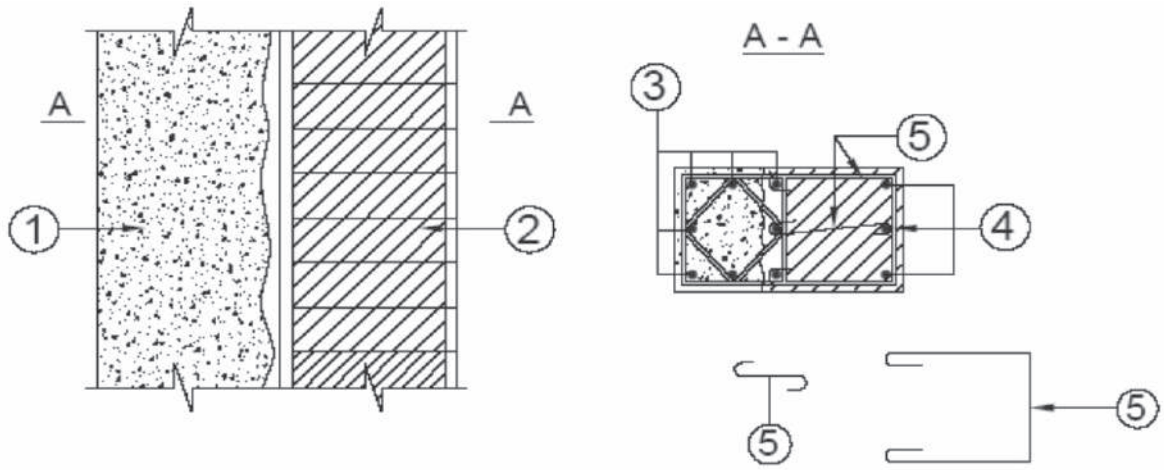

Figure 3.6 Repair of concrete columns by one-sided jacketing (1. Existin column; 2. Jacket; 3. Existing reinforcement; 4. Added longitudinal reinforcement; 5. Added ties)

Similar detailing is applied in case of two or three-sided lateral jacketing. In the usual case of four-sided jacketing, jacketing with ties is recommended (Figure 3.7). Concentration of the newly-added longitudinal reinforcement at the corners of the cross section allows an adequate confinement of all longitudinal bars. The jacket should be of sufficient thickness with closely spaced ties to provide confinement. With the new longitudinal reinforcement passing through holes, drilled in the slab, this procedure provides a continuous connection of the jackets to the upper story and lower story columns.

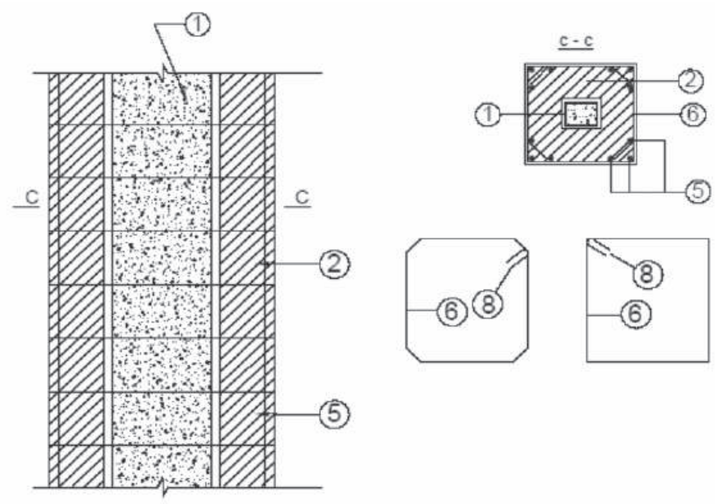

Figure 3.7 Repair of concrete columns by four-sided jacketing (1. Existing column; 2. Jacket; 3. Key; 4. Bent bars; 5. Added reinforcement; 6. Ties; 7. Welding; 8. Alternative corners)

Reinforced concrete jacketing should also conform to the following provisions:

- The strength of the new materials must be equal or greater than those of the existing column.
- Concrete strength should be at least 500 psi (3.45 MPa) greater than the strength of the existing concrete.
- The thickness of the jacket should be at least 1½ in. (38.1 mm) for shotcrete application or 4 in. (102 mm) for cast-in-situ concrete.
- The area of longitudinal reinforcement should not be less than 0.01 and no more than 0.06 times the gross area of the jacket section. The reinforcement should not be less than four bars for four-sided jacketing and bar diameter should be at least 5/8 in. (16 mm).
- Ties should be arranged so that every corner and alternate longitudinal bar should have lateral support provided by corners of the ties with an included angle of no more than 135 degrees. No intermediate bar should be farther than 4 in. (102 mm) from corners of the ties. In some cases, it will be necessary to drill into the core of the existing column and epoxy hooked ties into the hole or drill completely through the existing column core to install new ties.
- The diameter of ties (except welded wire fabric) should be minimum 3/8 in. (9.5 mm), but not less than 1/3 of the longitudinal bar diameter.
- Vertical spacing of ties shall not exceed 4 in. (102 mm). In addition, it is advisable that the spacing of ties should not exceed the thickness of the jacket.
- Jackets can be installed either as conventional or special cast-in-situ concrete or by shotcrete (gunite). For both methods, the existing concrete surface must be thoroughly roughened by chipping and cleaned of all loose material, dust and grease. The surface should be thoroughly moistened before placing the concrete or shotcrete.

3.3 Beams

The aim of repair and/or strengthening of beams is to provide adequate strength and stiffness of damaged or undamaged beams which are deficient to resist gravity and seismic loads. It is very important that the rehabilitation procedure chosen provides proper strength and stiffness of the beams in relation to adjacent columns in order to avoid creating structures of the "strong beam - weak column" type which tend to force seismic hinging and distress into the column, which must also support major gravity loads.

Depending on the type of damage (cracking, crushing of concrete, and rupture of reinforcement or ties) and the necessary level of strengthening, the techniques for repairing and strengthening beams are quite similar to techniques used for columns.

3.3.1 Local Repairs

Injections are applied for repair of damaged beams with slight cracks only. Epoxy or cement grout injections are made similar to such repairs for columns.

Removal and replacement should be applied when heavy damage like crushing of concrete, deterioration of bond or rupture of reinforcement occurs. Before the removal of crushed concrete or rupture reinforcement, the damaged beam must be temporarily supported. The replacement procedure of beams is similar to that of columns. More attention must be paid to compact the new concrete under existing beams or slabs.

3.3.2 Reinforced Concrete Jacketing

Reinforced concrete jacketing can be performed by adding concrete on one, three or four sides of a beam. In order to create adequate bond between original and new concrete and for welding of the added reinforcement to the existing reinforcement, the concrete cover must be chipped away. An irregular shaped concrete surface by the roughening of the concrete combined with anchoring by welded stirrups provides good shear and tensile connection of the jacket to the existing beam.

According to the type of strengthening (flexural or shear), the longitudinal or the transverse reinforcement predominates. Reliable anchorage of longitudinal reinforcement bars in joint areas by sufficient development length is of great importance. Adequate shear and ductility improvement should be provided by additional stirrups distributed on all sides of the existing beams. The legs of the stirrup should penetrate through drilled holes in the slab in the top part of the jacket, where they must be sufficiently anchored.

One-sided jackets (Figure 3.8) or adding strength only to the beam soffit should be used only when it is necessary to increase the flexural strength in the mid-span of a beam. The connection between the existing and the new longitudinal reinforcement is achieved by welded connection bars (Figure 3.8). The concrete cover should be chipped away to the existing longitudinal reinforcement and higher at existing stirrups. Additional stirrups welded to the existing ones provide the connection between the existing beam and the newly-added concrete. The longitudinal reinforcement bars should be anchored in the support region, which may be by welding of the reinforcement to a collar of steel angle profile.

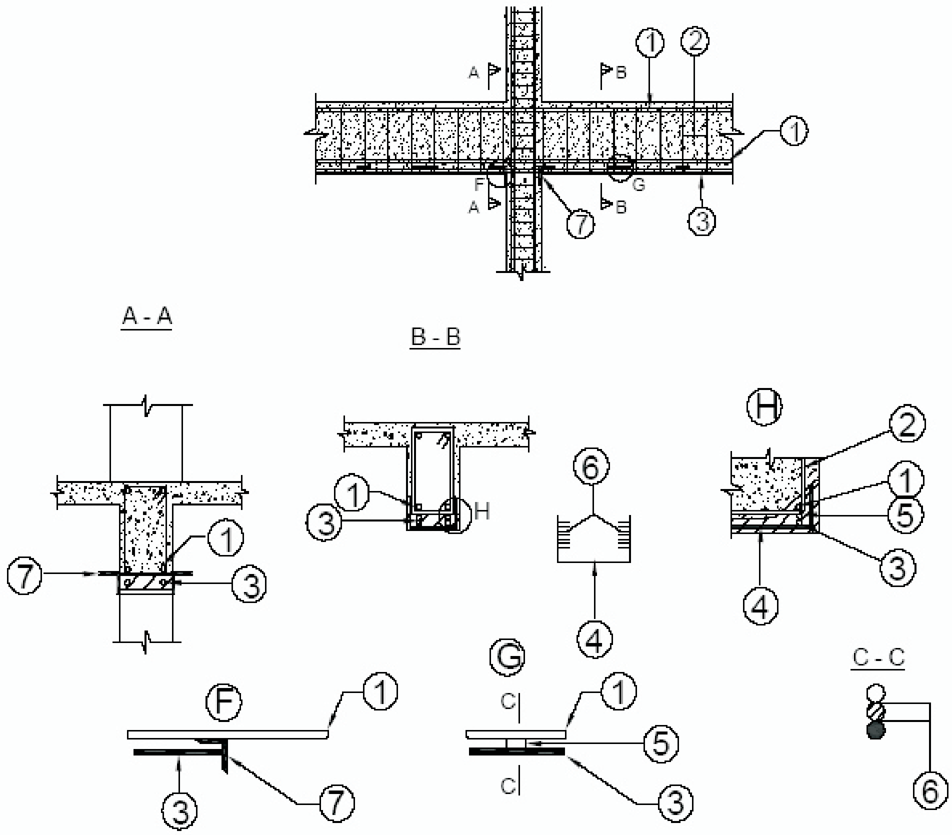

Figure 3.8 Strengthening of concrete beams by one-sided jacketing (1. Existing reinforcement; 2. Existing stirrups; 3. Added longitudinal reinforcement; 4. .Added stirrups; 5. Welded connecting bar; 6. Welding; 7. Collar of angle profile)

Four-sided jacketing (Figure 3.9) or encasement of a beam adds considerable flexural and shear strength because of the increase of the reinforcement area and concrete cross section dimensions (depth and width). The additional longitudinal reinforcement should be connected with the existing reinforcement by diagonally welded bent bars or small steel plates. The stirrups pass through holes drilled in the slab and surround the whole beam. These holes can also be used to place the concrete in the part of the jacket beneath the slab. Additional reinforcement for negative bending moments must be added over the slab surface in the beam region and outside of the existing column. Special attention must be paid to the anchorage of the longitudinal bars in the joint region of the column jacket.

Jacketing on three sides of the beam can also be installed beneath the soffit of the slab, as shown in Figure 3.10. Shotcrete is the most feasible method of installing this type of jacket and its primary weakness is the anchorage of the new stirrups at the top of the sides of the jacket.

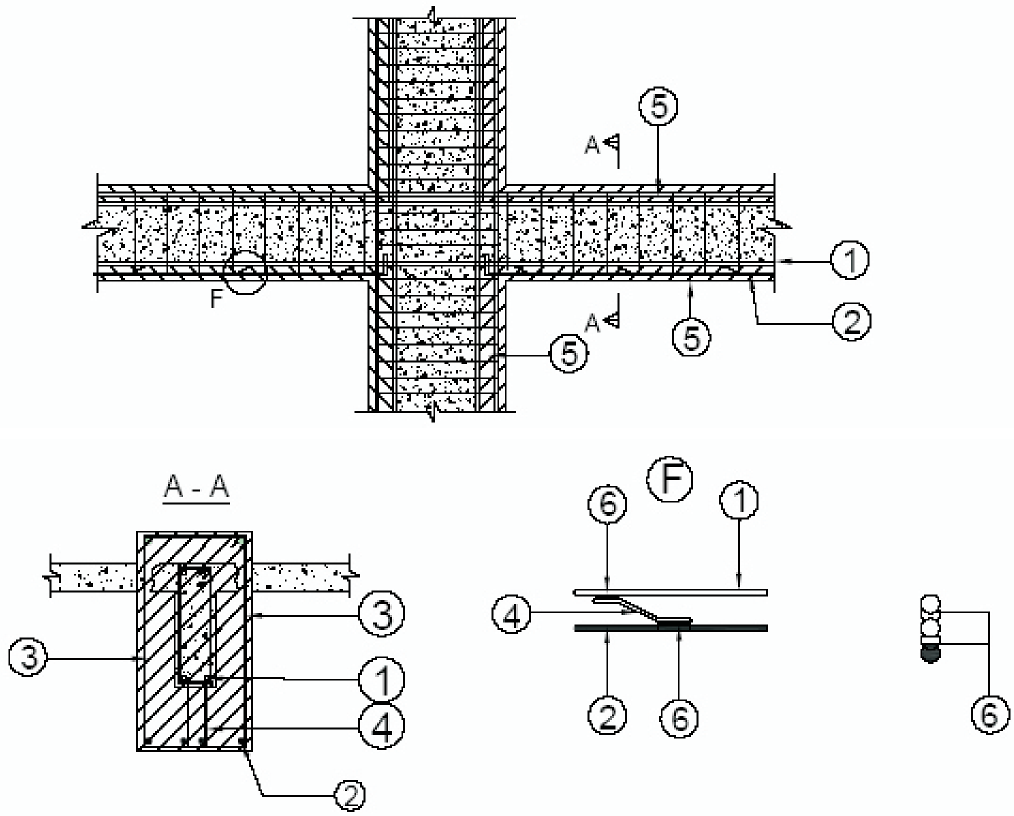

Figure 3.9 Strengthening of concrete beams by one-sided jacketing (1. Existing reinforcement; 2. Added longitudinal reinforcement; 3. Added stirrups; 4. Welded connecting bar; 5. Concrete jacket. 6. Welding;)

This detail is inferior to that shown in Figure 3.9 as the effectiveness of the detail depends on the dynamic strength of the power driven nails and the stiffness of the strand to provide effective anchorage for the new stirrups. Increased strength might be achieved by using a continuous steel plate with epoxy resin bolts installed in the concrete with the new stirrups welded to or hooked around the steel plate.

Reinforced concrete jacketing should conform to the following provisions, as well:

- The strength of the now materials should not be less than those of the existing beam.
- The thickness of the jacket should not be less than 1½ in. (38.1 mm) for shotcrete application or 3 in. (76.2 mm) for cast-in-situ concrete.
- The beam reinforcement of moment resisting frames should be continuous in the top and bottom of the beam and not less than 0.005 times gross area of beam at support regions.

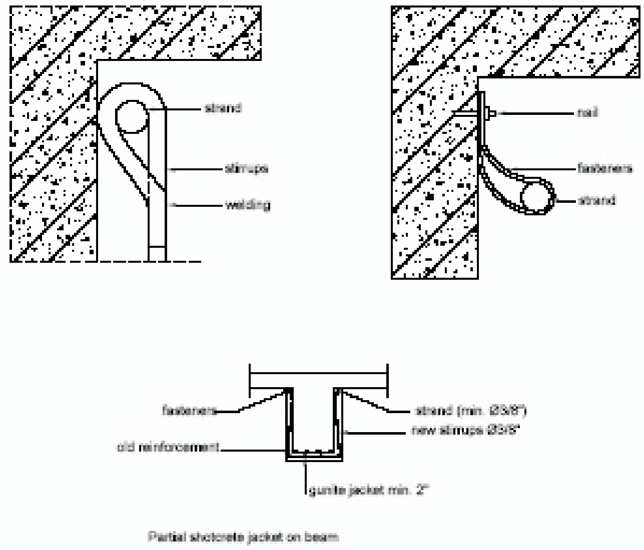

Figure 3.10 Strengthening of concrete slab-beam system by three-sided jacketing

- Top and bottom reinforcement should be anchored within column joint area with full development length, beginning from the face of the column, or continuous through the joint region.
- At support regions for a length equal to 4 times the overall beam height, the stirrup spacing must not be more than ¼ of the beam height. Outside this region, the stirrup spacing can be doubled.

3.3.3 Repairing Gravity Load Capacity of Beams

Steel rods can be used for improving the shear resistance of damaged or undamaged beams. It can be performed by vertical external clamps (Figure 3.11a) or by diagonal ones (Figure 3.11b). The clamps consist of round rods with threads at the end which are tightened with nuts. At the beam, bottom vertical clamps are fixed on angle profiles, but diagonal clamps are welded to longitudinal reinforcement to resist the longitudinal component of force. If load reversals are anticipated, four- sided jacketing is the preferred method of strengthening.

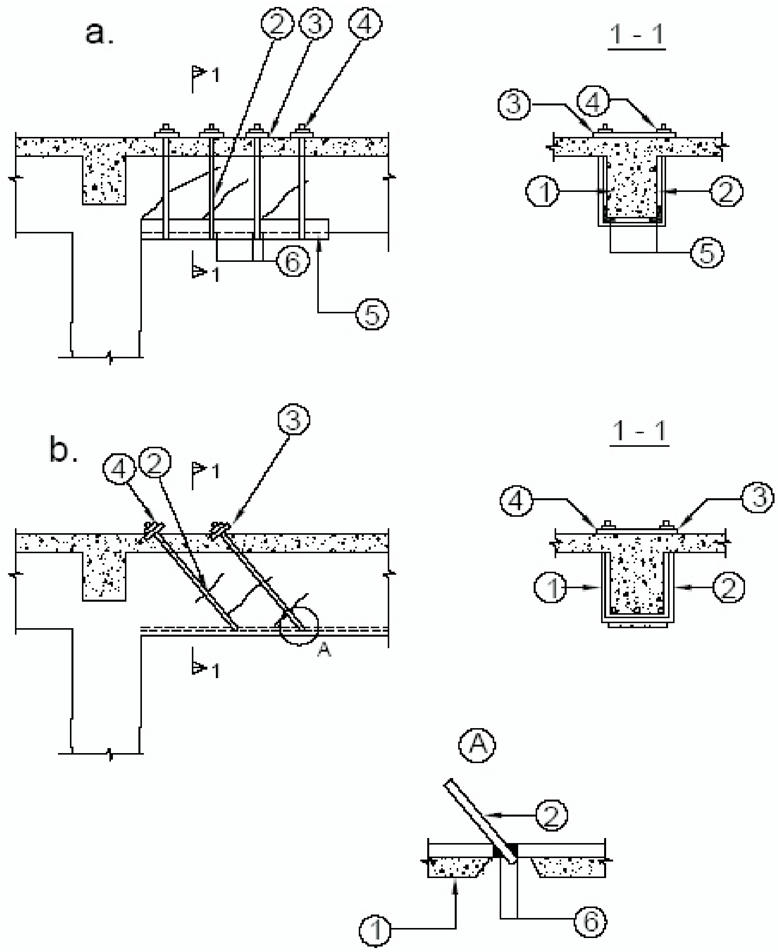

Figure 3.11 Repairing Gravity Load Capacity of Beams (1. Existing beam 2. Steel clamp; 3. Steel plate; 4. Nut; 5. Angle profile; 6. Welding)

Acknowledgement

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United Nations Development Program

Damage Assessment Proforma

First Level Form for Damage Evaluation, Quick Interventiuons and Usability of Buildings in the Seismic Emergency

Surveyor ☐☐ Form No. ☐☐☐☐☐ Date ☐☐ (Day) ☐☐ (Month) ☐☐ (Year)

SECTION 1 Building Identification

Province: ________________________ Township/City: ___________________________

Locality: _________________________

Address

House No. ______________________

Street: __________________________

Road: ___________________________

Owner of building:____

Position

Isolated Internal

End Corner

Plan and Elevation of building if available

SECTION 2 Building Description

Total No. of stories	Average story height (m)	Average floor area	(m²)	Age of building	Use	No. of units in use	Utilization percentage	
1	□2.50	□50	800 ~ 1300	□19	Living area	1 to 2	> 65%	No one
2	2.50 ~ 3.50	50 ~ 80	1300 ~ 2100	20 ~ 45	Production	3 to 5	30 to 65%	□10
3	3.50 ~ 5.0	80 ~ 130	2100 ~ 3300	46 ~ 60	Business	6 to 9	< 30%	11 to 20
4	> 5.0	130 ~ 210	3300 ~ 5000	61 ~ 71	Offices	10 to 15	Not Utilized	21 to 40
5		210 ~ 330	5000 ~ 8000	72 ~ 81	Pub. Ser.	16 to 24	In Const.	41 to 80
6	Basement floor	330 ~ 500	8000 ~ 10000	82 ~ 91	Storage	> 25	Unfinished	81 to 160
7	0	500 ~ 800	> 10000	> 91	Strategical		Abandoned	□160
8	1							
9	2					Ownership		
10	□3						Public	Private

SECTION 3 Typology (Multi-Choice with max 2 options)

Horizontal Structures \ Vertical Structures	Not identified	Masonry Structures: Irregular and bad masonry – Without tie beams	Irregular and bad masonry – Without tie beams	Regular and good masonry – Without tie beams	Regular and good masonry – Without tie beams	Isolated coulmn	Mixed with RC
Not identified		☐	☐	☐	☐	No	
Flexible diaphragm (GI sheet with steel / wooden truss)		☐	☐	☐	☐	Yes ☐	
Rigid Diaphragm (Concrete slab)		☐	☐	☐	☐	☐	

Other Structures	
RC Frame	☐
RC Walls	☐
Steel Frame	☐

Regularity	Not regular	Regular
Plan or elevation	☐	☐
Curtain wall disposition	☐	☐

SECTION 4 Damage to STRUCTURAL ELEMENTS and provisional interventions already carried out

Structural Components / Pre-existing damage \ Level / Extension	DAMAGE(1): D4-D5 Very Seriuos > 2/3	D4-D5 1/3 to 2/3	D4-D5 < 1/3	D2-D3 Seriuos > 2/3	D2-D3 1/3 to 2/3	D2-D3 < 1/3	D1 Light > 2/3	D1 1/3 to 2/3	D1 < 1/3	None		MEASURES TAKEN: None	Demolitions	Tie-beams	Restorations	Props	Barriers and passage protections
Vertical Structures	☐	☐	☐	☐	☐	☐	☐	☐	☐	○		○	☐	☐	☐	☐	☐
Horizontal Structures	☐	☐	☐	☐	☐	☐	☐	☐	☐	○		○	☐	☐	☐	☐	☐
Stairs	☐	☐	☐	☐	☐	☐	☐	☐	☐	○		○	☐	☐	☐	☐	☐
Roofing	☐	☐	☐	☐	☐	☐	☐	☐	☐	○		○	☐	☐	☐	☐	☐
Curtain walls, partitions	☐	☐	☐	☐	☐	☐	☐	☐	☐	○		○	☐	☐	☐	☐	☐
Pre-exsiting damage	☐	☐	☐	☐	☐	☐	☐	☐	☐	○		○	☐	☐	☐	☐	☐

(1)-For each level provide the extent of damage only if present. If the object on the line is not damaged, tick off **None.**

SECTION 5 Damages to NON STRUCTURAL ELEMENTS and provisional interventions already carried out.

Type of Damage \ Interventions	Damage Present	MEASURES TAKEN: None	Removal	Props	Restoration	No Access	Barriers and Passage
1) Detachment of plaster, coverings, false Ceilings	○	○	☐	☐	☐	☐	☐
2)Fall of roof Tiles, chimneys…	○	○	☐	☐	☐	☐	☐
3)Fall of Cornices, Parapets…	○	○	☐	☐	☐	☐	☐
4)Fall of other internal or external objects	○	○	☐	☐	☐	☐	☐
5)Damage to Plumbing, Sewage or Heating systems	○	○			☐	☐	☐
6)Damage to electrical or gas system	○	○			☐	☐	☐

SECTION 6 External Danger Caused by other buildings and interventions already carried out.

Type of Damage \ Interventions	DANGER ON: Building	Internal Streets	Access	MEASURES TAKEN: No Access	Barriers and Passage Protection
1) from the ollapse of other Buildings	☐	☐	☐	☐	☐
2) from the fall of elements of other buildings.	☐	☐	☐	☐	☐

SECTION 7 Land and Foundation

MORPHOLOGY OF THE SITE				SETTLEMENTS OF SOIL OR FOUNDATION PRESENT OR POSSIBLE			
1)To○	2)Stro○ Slope	3)Slig○Slope	4) Ho○zontal	A) Abs○nt	B)Create○y EQK	C) Incre○ed by EQK	D)Pre-○isting

Surveyor	No. of Form	Date

SECTION 8 Safety assessment

RISK ASSESSMENT

Risk	STRUCTURAL (Sect.3 to 4)	NON STRUCTURAL (Sect 5)	EXTERNAL (Sect 6)	GEOTECHNICAL (sect 7)
LOW	○	○	○	○
LOW WITH MEASURES	○	○	○	○
HIGH	○	○	○	○

SAFETY RESULT

A	**SAFE** BUILDING	○
B	**SAFE WITH QUICK INTERVENTIONS** BUT TEMPORARILY NOT SAFE	○
C	**PARTIALLY UNSAFE** BUILDING	○
D	**TEMPORARILY UNSAFE** TO BE CAREFULLY REVIEWED	○
E	**UNSAFE** BUILDING	○

UNSAFE UNITS,FAMILY AND PEOPLE EVACUATED

N. OF UNSAFE UNITS				FAMILIES EVACUATED					N. OF PEOPLE					

LIMITED (*) OR EXTENSIVE (**) MEASURES TAKEN TO (CASE B)

	*	**	MEASURES SUGGESTED		*	**	MEASURES SUGGESTED
1	☐	☐	Application of reinforcement	7	☐	☐	Removal of cornices,parapets, projecting elements
2	☐	☐	Repairs of light damage of curtain wall and partitions	8	☐	☐	Removal of internal and external objects.
3	☐	☐	Roofing restorations	9	☐	☐	Barriers and passage Protections
4	☐	☐	Props on Stairs	10	☐	☐	Repairs to systems
5	☐	☐	Removal of wallings, coverings, false ceilings	11	☐	☐	
6	☐	☐	removal of tiles, chimneys, parapets	12	☐	☐	

SECTION 9 OTHER OBSERVATIONS

Inspection accuracy 1 Out Side Only 2 Partial 3 Complete (>2/3)

On the damage, on interventions, usability, etc

Subject	Notes	Photograph	Pin

SURVEYOR(IN BLOCK LETTERS)	**SIGNATURE**

For Details:

National Disaster Management Authority Pakistan
Prime Minister's Secretariat
Islamabad, Pakistan
Ph: +92-51-9206544, 9205086
Website: http://ndma.gov.pk