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Required RC Jacket Thickness and Reinforcement Ratio for Repairing RC Tied Rectangular and Circular Concrete Columns

Tamer Al-Afandy[1] & Magdy Bakry[2]

[1] Housing and Building National Research Center, tamer_elafandy@yahoo.com
[2] Department of Civil Engineering, Al-Azhar University, drmagdy_amb@hotmail.com

ملخص البحث

يستخدم قميص العمود الخرساني المسلح القائم لاسترجاع مقاومته الأصلية أو لزيادة مقاومته للأحمال وزيادة الممطولية. فى هذا البحث بناءً على الكود الأمريكي ACI 318-11 تم عمل حزمة من الإكسل شيتس لايجاد سمك القميص الخرساني المطلوب للعمود الخرساني المستطيل والدائري غير المقيد بكانات حلزونية وكذلك نسبة الحديد المطلوبة لاسترجاع مقاومة العمود الأصلية دون أي زيادة فى كفاءته لتحمل أحمال رأسية أكبر من تلك الواقعة عليه فعلياً كذلك تم إعطاء قيم لحجم الكانات المطلوبة وذلك لمقاومة خرسانة للعمود الأصلي تتراوح من f'_c = 10- 20 MPa وإجهاد خضوع للحديد من f_y = 360 and 415 MPa وذلك لمعظم مقاسات الأعمدة الموجودة عملياً ولمستوى أحمال يصل إلى P_u= 30000 KN وكذلك تم اشتقاق جميع المعادلات الحسابية المطلوبة لتصميم سمك القميص الخرساني وحديد التسليح والكانات لأى عمود قائم تحت أى حمل رأسى عليه لأول مرة فى هذا البحث.

Abstract

Conventional RC jacketing techniques are widely used in repairing, strengthening, retrofitting and rehabilitation of RC column either for the purpose of restoring its original strength/capacity or increasing strength, ductility or both of them. Depending on axial loading level applied on a column, there is no distinct recommendations for how much should thickness of RC jacket be or what is the required jacket reinforcement ratio. RC jacketing offer an economical alternative to other repair techniques like steel and FRP plating when open space permits it's application. In case of RC columns partially or totally damaged a need for repair technique to restore the original column capacity (without any increase in original strength) is strongly needed. In this paper based on ACI 318-11 code for concrete buildings and by developing several excel sheets for both tied rectangular and circular columns the required RC jacket thickness, percentage of vertical reinforcement ρ and transverse reinforcement ρ_s (ties/stirrups) for practically all different grades of existing column's concrete strength encountered in engineering practice (f'_c = 10-20 MPa) and for steel yield strength values f_y of 360 and 415 MPa have been given. The present study also covers all possible sizes of existing tied rectangular and circular reinforced columns in typical concrete buildings under practically all ultimate vertical loads levels up to P_u = 30000 KN. It should be noted that in the present study the width of rectangular column has been taken between 300 mm – 600 mm.

Key words: Reinforced Concrete, Tied Columns, Repair, Jacket.

1. Introduction

In the present study it has been assumed that the range of existing column's concrete strength f_c' = 10-20 MPa and the yield strength of vertical and transverse reinforcement f_y = 360 MPa and 415 MPa; the vertical reinforcement ratio ρ in existing columns has been assumed a minimum 1%. On the other hand concrete strength of RC jacket has been taken as f_c' = 24 MPa (f_{cu} = 30 MPa) and steel ratio ρ as 0.5% which is the minimum for oversized tied columns according to ACI 3118-11 code. Also in the present study, steel yield strength f_y values of 360 MPa and 415 MPa have been adopted for RC jacket's vertical and transverse reinforcement.

2. Section Enlargement or Jacketing

In this method the entire height of the column section is increased and a cage of additional main reinforcement bars with shear stirrups is provided right from the foundation as per the requirement of additional load, etc. However, there are many instances where the column section is increased with additional reinforcement bars only on one face, and that too starting from the floor slab level of a particular floor and only up to the height of deterioration of the column .The enlargement should be bonded to the existing concrete to produce a monolithic member. Cement mortar is used for these enlargements.

The section enlargement method is relatively easy to construct and economically effective. The disadvantages of this method are a high risk of corrosion of embedded reinforcing steel and concrete deterioration. These problems are associated with relative dimensional incompatibility between existing and new concrete. The restrained volume changes of new material are inducing tensile stresses that may lead to cracking and delaminating when the induced tensile stresses are greater than tensile strain capacity of new material.

The way to make this strengthening technique effective in the future is to use materials with higher tensile strain capacity, with low shrinkage properties.

3. ACI 318-08 Proposed Equation for Calculation of RC Jacket's Cross Sectional area and Vertical Reinforcement

The required cross sectional area of column's jacket is given by ACI equation

$$A_{g\,jacket} = \frac{P_u}{0.6375\ [(0.85\, f_c') + \rho\,(f_y - 0.85\, f_c')]} \qquad \textbf{(1)}$$

Where

P_u = applied ultimate load on column or jacket

$A_{gjacket}$ = gross sectional area of RC jacket;

ρ = vertical steel ratio, taken 0.5%

f_y = yield strength of steel

For circular column total gross sectional area of concrete column including jacket

$$A_{g\,t} = \frac{\pi D_i^2}{4} + A_{g\,jacket} \qquad \textbf{(2)}$$

Where D_i is existing column diameter

Also, after sizing RC jacket thickness t_{jacket} actual A_{gt} becomes

$$A_{g\,t} = \frac{\pi \left(D_i + 2\,t_{jacket}\right)^2}{4} \qquad \textbf{(3)}$$

$$4t^2_{jacket} + 4D_i t_{jacket} + \left(D_i^2 - 1.273\ A_{gt}\right) = 0 \qquad \textbf{(4)}$$

$$aY + bY + c = 0 \quad (5)$$

$$t_{jacket} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad (6)$$

$$t_{jacket} = \frac{4D_i \pm \sqrt{16D_i^2 - 16(D_i^2 - 1.273A_{gt}}}{8} \quad (7)$$

Vertical steel reinforcement ratio ρ is taken

$$A_{sjackt} = 0.005\, A_{gjackt} \quad (8)$$

For tied rectangular column

$$A_{gjacket} = (b_i + t_{jacket})(t_i + t_{jacket}) - b_i t_i \quad (9)$$

$$A_{gjacket} - ((b_i + t_i)t_{jacket}) - t_{jacket}^2 = 0 \quad (10)$$

$$t_{jacket}^2 + ((b_i + t_i)t_{jacket}) - A_{gjacket} = 0 \quad (11)$$

$$t_{jacket} = \frac{-(b_i + t_i) \pm \sqrt{(b_i + t_i)^2 + 4A_{giacket}}}{2} \quad (12)$$

Where

b_i = *is the width of existing column without RC jacket*

t_i = *is the length of existing column without RC jacket*

Vertical steel reinforcement ratio ρ is taken

$$A_{sjackt} = 0.005\, A_{gjackt} \quad (13)$$

4. Cases of existing columns conditions in need to RC jacketing as a repair technique

FIB 24 stated that a member may be chosen to be repaired – instead of repaired and also strengthened – if its damage is judged to be slight or moderate. A member with severe or heavy damage, consisting of significant disintegration of the concrete core inside the stirrups or ties, and/or buckled or fractured reinforcing bars, cannot be restored to effectively its initial strength and deformation capacity with simple repair means and in all likelihood will be chosen to be jacketed instead.

4.1. Columns showing buckled shape / major cracking or severe steel corrosion (more than 25%) and loss of confinement.

It should be pointed out that in case of an existing column suffer from severe vertical (axial capacity failure) and/or horizontal (buckling failure) and/or diagonal cracks (shear failure) and/or excessive deflection and in case that the residual capacity of existing column is less than 45% of its original strength due to diagonal shear cracks, the existing column should be fully jacketed and according to ACI 318-14 for oversized tied reinforced column the minimum jacket 's steel ratio is ρ 0.5% and the minimum number of longitudinal bars is 6 for tied circular column and 12 for tied rectangular column.

4.2. Columns showing total destruction and/or complete failure

Columns showing total destruction (concrete cover spall, crushing of concrete core, tearing of stirrups and fracture/buckling of vertical reinforcement) need to be reconstructed based on the original design of the building and ρ is also taken 0.5% as a minimum and the minimum number of longitudinal bars is 6 for tied circular column and 12 for tied rectangular column.

In both study cases the RC jacket has been assumed to carry the entire applied axial load on existing column.

5. Reinforced Concrete Jacketing Detailing

According to Shri Pravin B Waghmare (6) reinforced concrete jacketing can be employed as a repair or strengthening scheme. Damaged regions of the existing members should be repaired prior to their jacketing. There are two main purposes of jacketing of columns:

(i) Increase in the shear capacity of columns in order to accomplish a strong column-weak beam design and

(ii) To improve the column's flexural strength by the longitudinal steel of the jacket made continuous through the slab system are anchored with the foundation. It is achieved by passing the new longitudinal reinforcement through holes drilled in the slab and by placing new concrete in the beam column joints as illustrated in figure 4. Rehabilitated sections are designed in this way so that the flexural strength of columns should be greater than that of the beams. Transverse steel above and below the joint has been provided with details, which consists of two L-shaped ties that overlap diagonally in opposite corners. The longitudinal reinforcement usually is concentrated in the column corners because of the existence of the beams where bar bundles have been used as shown in figure 4. It is recommended that not more than 3 bars be bundled together. Windows are usually bored through the slab to allow the steel to go through as well as to enable the concrete casting process.

Properties of jackets	• Match with the concrete of the existing structure. • Compressive strength greater than that of the existing structures by 5 N/mm^2 or at least equal to that of the existing structure.
Minimum width of jacket	• 10 cm for concrete cast-in-place and 4 cm for shotcrete. • If possible, four-sided jacket should be used. • A monolithic behaviour of the composite column should be assured. • Narrow gap should be provided to prevent any possible increase in flexural capacity.
Minimum area of longitudinal reinforcement	• $3Af_y$, where, A is the area of contact in cm^2 and f_y is in kg/cm^2 • Spacing should not exceed six times of the width of the new elements (the jacket in the case) up to the limit of 60 cm. • Percentage of steel in the jacket with respect to the jacket area should be limited between 0.015and 0.04. • At least, 12 mm bar should be used at every corner for a four sided jacket.
Minimum area of transverse reinforcement	• Designed and spaced as per earthquake design practice. • Minimum bar diameter used for ties is not less than 10 mm or 1/3 of the diameter of the biggest longitudinal bar. • The ties should have 135-degree hooks with 10bar diameter anchorage.

	• Due to the difficulty of manufacturing 135-degree hooks on the field, ties made up of multiple pieces, can be used.
Shear stress in the interface	• Provide adequate shear transfer mechanism to assured monolithic behaviour. • A relative movement between both concrete interfaces (between the jacket and the existing element) should be prevented. • Chipping the concrete cover of the original member and roughening its surface may improve the bond between the old and the new concrete. • For four-sided jacket, the ties should be used to confine and for shear reinforcement to the composite element.
Connectors	• Connectors should be anchored in both the concrete such that it may develop at least 80% of their yielding stress. • Distributed uniformly around the interface, avoiding concentration in specific locations. • It is better to use reinforced bars (rebar) anchored with epoxy resins of grouts.

Professor Stehanos E Dritsos (7) has stated the following:

1- The placing of new concrete in contact with an existing element (by shotcreting. And specially by pouring)will require prior aggravation of the old surface to a depth of at least 6 mm this should be performed by sandblasting or by using suitable mechanical equipment (for example, a scabbler and not just simply a hammer and a chisel). This is to remove the exterior weak skin of the concrete and to expose the aggregate.

2- When placing a new concrete jacket around an existing column, it is not always possible to follow code requirements and place internal rectangular stirrups to enclose the middle longitudinal bars, as shown in the figure 5 in this case, it is proposed to place two middle bars in each side of the jacket, so that octagonal stirrups can easily be placed as demonstrated in figure 5. In this case where column has a cross section with large aspect ratio, the middle longitudinal bars can be connected by drilling holes through the section in order to place a S shaped stirrup, as shown in figure 6. After placing the stirrup, the remaining voids can be filled with epoxy resin. In order to ease placement, The S stirrup can be prefabricated with one hook and, after placing, the second hook can be performed by hand.

3- If a thin concrete jacket is to be placed around a vertical element and the 135 degree hooks at the ends of the stirrups are impeded by the old column, it would be acceptable to decrease the hook anchorage from 10 times the bar diameter to 5 or 6 times the bar diameter as shown in figure 7a. Otherwise, at the ends the stirrups should be welded together or connected with special contacts (clamps), as presented in figure 7b that have now appeared on the market.

4- When constructing a jacket around a column it is important to also strengthen the column joint. As shown in figure 8, this can be accomplished by, where possible, extending the longitudinal reinforcement bars around the joint. In addition, as also shown in figure 8, stirrups must be placed in order to confine the concrete of the jacket around the joint. In the case where the joint has been found to be particularly weak, a steel diagonal collar can be placed around the joint before placing the reinforcement, as shown in figure 9.

5- It is preferable that when a new concrete jacket is placed continuously from the foundation to the top of the building. If this is not possible (due to maintaining the functioning of the building), it is usual to stop the jacket at the top of the ground floor level. In this case, there is a need to anchor the jacket's longitudinal bars to the existing column. This can be achieved by anchoring a steel plate to the base of the column of the floor level above and then welding the longitudinal bars to the anchor plate as shown in figure 10.

6- In the case where there is a need to reconstruct a heavily damaged column, after first shoring up the column, all the defective concrete must be removed so that only good concrete remains, as shown in figure 11. Any buckled reinforcement bars must be cut and removed and new reinforcement bars must be welded to the existing bars. Finally, the column can be recast by placing a special non-shrink concrete.

6. Sizes and Spacing of Main Bars and Ties

I. Clear distance between longitudinal bars shall be not less than $\mathbf{1.5}\boldsymbol{d_b}$ nor 40 mm.

II. Use 10mm diameter ties for 32 mm bars or smaller and at least 12 mm in size for 36 mm and bundled longitudinal bars.

III. Vertical spacing of ties shall be the smallest of the following:

1. 16 x $\boldsymbol{d_b}$ ($\boldsymbol{d_b}$=longitudinal bar diameter).
2. 48 x tie diameter.
3. Least dimension of the column (equivalent or average thickness)

$$t_{eqv(averge)} = \frac{2tt_{jacket}+2b_i t_{jacket}}{t} \quad (14)$$

$$Where$$

$$t = is\ the\ outside\ length\ of\ the\ existing\ column\ with\ RC\ jacket$$

$$b_i = is\ the\ width\ of\ existing\ column\ without\ RC\ jacket$$

IV. Ties shall be arranged such that every corner and alternate longitudinal bar shall have lateral support provided by the corner of the tie with an included angle of not more than 135° and no bar shall be farther than 150 mm clear on each side along the tie from such a laterally supported bar. Where longitudinal bars are located around the perimeter of a circle, a complete circular tie is allowed.

It should be noted that tied circular column jacket can be treated as a tied hollow square column jacket of equivalent area, i.e.

Thickness of square column t

$$t = \left\{\sqrt{\frac{3.14\,D^2}{4}} - \sqrt{\frac{3.14\,D_i^2}{4}}\right\}/2 \quad (15)$$

Regarding Reinforcement for Hollow Rectangular Compression Members Caltrans (8) stated the following:

1- The area of longitudinal reinforcement in the cross section shall not be less than 0.01 times the gross area of concrete in the cross section.

2- Two layers of reinforcement shall be provided in each wall of the cross section, one layer near each face of the wall. The areas of reinforcement in the two layers shall be approximately equal.

3- The center-to-center lateral spacing longitudinal reinforcing bars shall be no greater than 1.5 Longitudinal Reinforcement times the wall thickness, or 18 inches, whichever is less.

4- The center-to-center longitudinal spacing of lateral reinforcing bars shall be no greater than 1.25 times the wall thickness, or 12 inches, whichever is less.

5- Cross ties shall be provided layers of reinforcement in each wall. The cross ties shall include a standard 135 degree hook at one end, and a standard 90 degree hook at the other end. Cross ties shall be located at bar grid intersections, and the hooks of all ties shall enclose both lateral and longitudinal bars at the intersections. Each longitudinal reinforcing bar and each lateral reinforcing bar shall be enclosed by the hook of a cross tie at a spacing not to exceed 24 inch.

6- Lateral reinforcing bars may be joined at the corners of the cross section by overlapping 90-degree bends. Straight lap splices of lateral reinforcing bars are not permitted unless the overlapping bars are enclosed over the length of the splice by the hooks of at least four cross ties located at intersections of the lateral bars and longitudinal bars.

7- When details permit, the longitudinal reinforcing bars in the corners of the cross section shall be enclosed by closed hoops. If closed hoops cannot be provided, then pairs of "U" shaped bars with legs at least twice as long as the wall thickness, and oriented 90 degrees to one another, may be substituted.

7. Minimum tie percentage ρ_s min of RC jacket.

The volumetric transverse reinforcement ratio $\boldsymbol{\rho_s}$ for hollow jacket is defined as follows:

Percentage of stirrups ($\boldsymbol{\rho_s}$) = volume of stirrups in one pitch / volume of concrete core for a pitch s

$$\rho_s = \frac{4\,a_s\,(D - d_s)}{s\,(D^2 - D_i^2)} \geq 0.25\% \qquad (16)$$

or

$$\rho_s = \frac{4\,a_s\,(D_c - d_s)}{s\,(D_c^2 - D_{ci}^2)} \geq 0.25\% \qquad (17)$$

where

a_s is the cross sectional area of ties,

d_s is the diameter of the tie bar,

D is the outside diameter of the existing column with RC jacket,

D_i is the diameter of existing column without RC jacket,

s is pitch of stirrups,

D_c is diameter of the outer core out to out of the outer stirrups,

D_{ci} is diameter of the inner core out to out of the inner stirrups

8. Practical recommendations for RC Jacket thickness

Based on the present study, it has been been found that for existing column strength $\boldsymbol{f_c'}$ = ranges from 10 MPa to 20 MPa and for steel yield strength $\boldsymbol{f_y}$ values of 360 MPa and 415 MPa and making jacket concrete strength $\boldsymbol{f_c'}$ = 24 MPa the following findings could be utilized for sizing RC jacket thickness accurately.

For tied rectangular column

$$for \quad P_u \leq 600\,ton \qquad t_{jacket} = 10\,cm$$

$$for \quad 600\,ton < P_u \leq 3000\,ton \qquad t_{jacket} = 12.5\,cm$$

For tied circular column

$$for \quad P_u \leq 500\,ton \qquad t_{jacket} = 15\,cm$$

$$for \quad 500\,ton < P_u \leq 900\,ton \qquad t_{jacket} = 20\,cm$$

$$for \quad 900\, ton < P_u \leq 1800\, ton \quad t_{jacket} = 27.5\, cm$$

$$for \quad 1800\, ton < P_u \leq 2700\, ton \quad t_{jacket} = 32.5\, cm$$

$$for \quad 2700\, ton < P_u \leq 3000\, ton \quad t_{jacket} = 35\, cm$$

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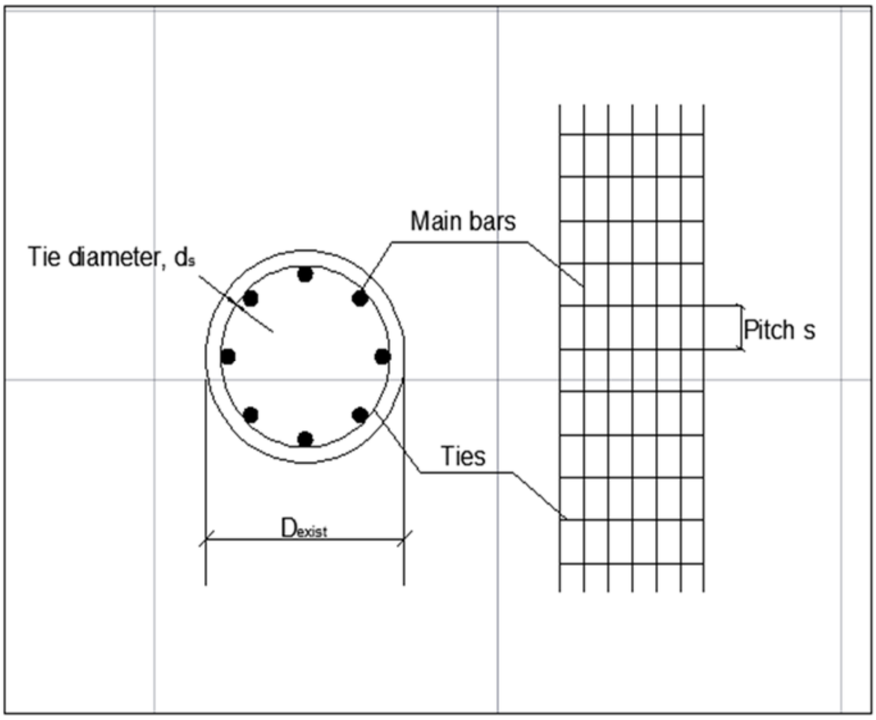


Figure 1 Tide Circular Column

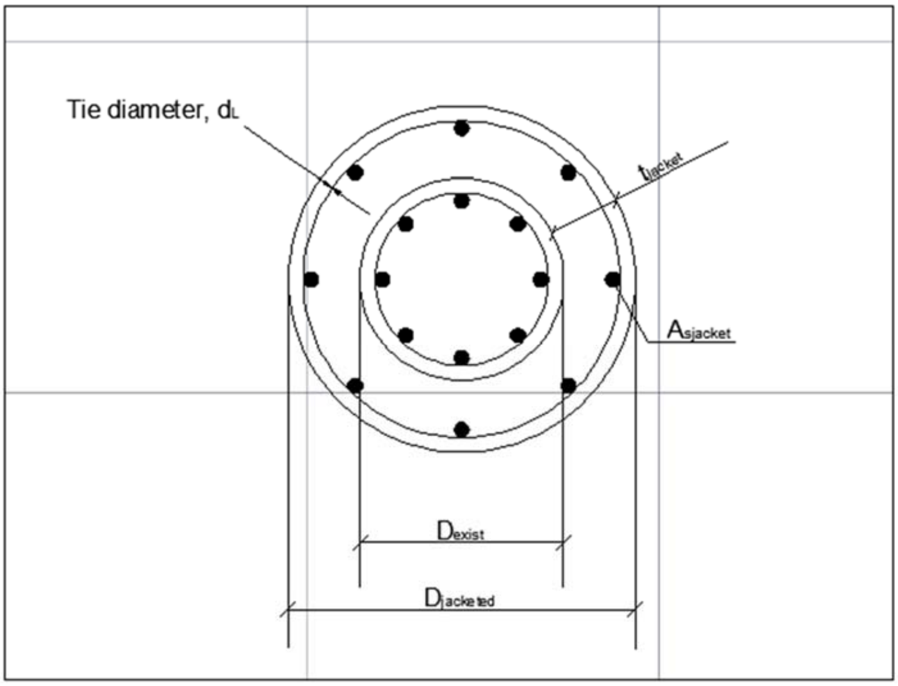
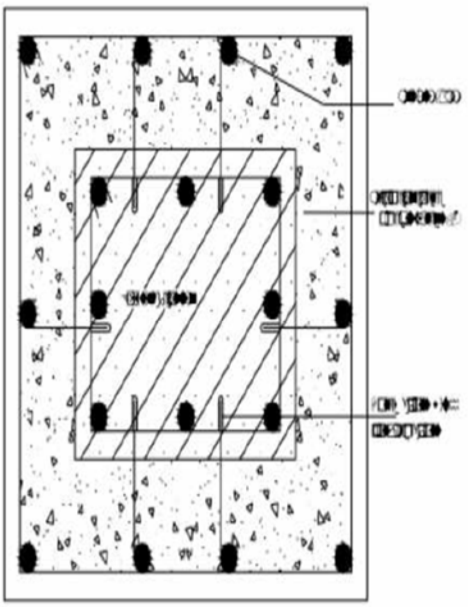


Figure 2 Tide Circular Column with RC Circular Jacketing

Figure 3 Additional Reinforcement & Micro concreting



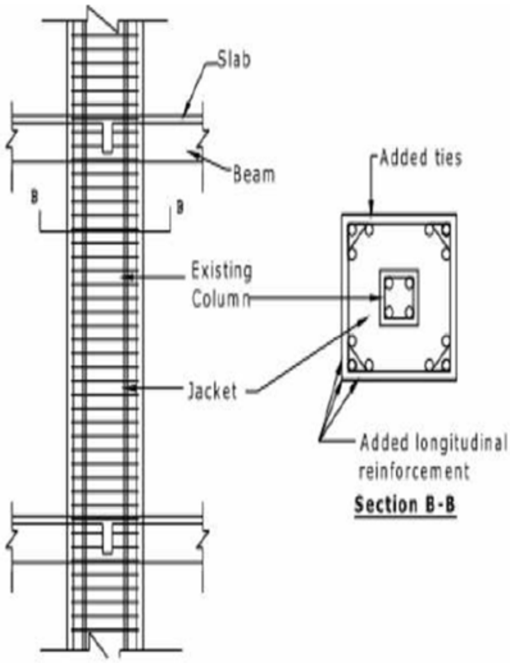


Figure 4 Construction Techniques for Column Jacketing

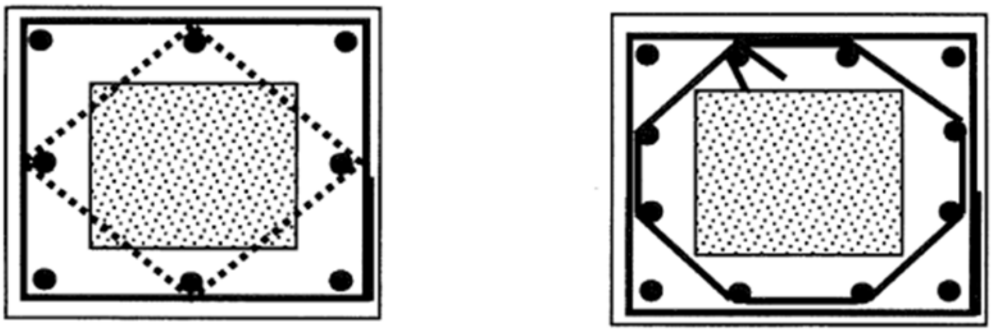


Figure 5 Placements of Internal Stirrups in Rectangular Cross Section

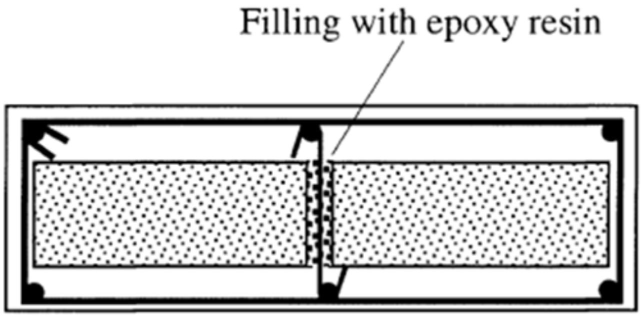


Figure 6 Placement of Internal Stirrups in Rectangular Cross Section With a Large Aspect Ratio

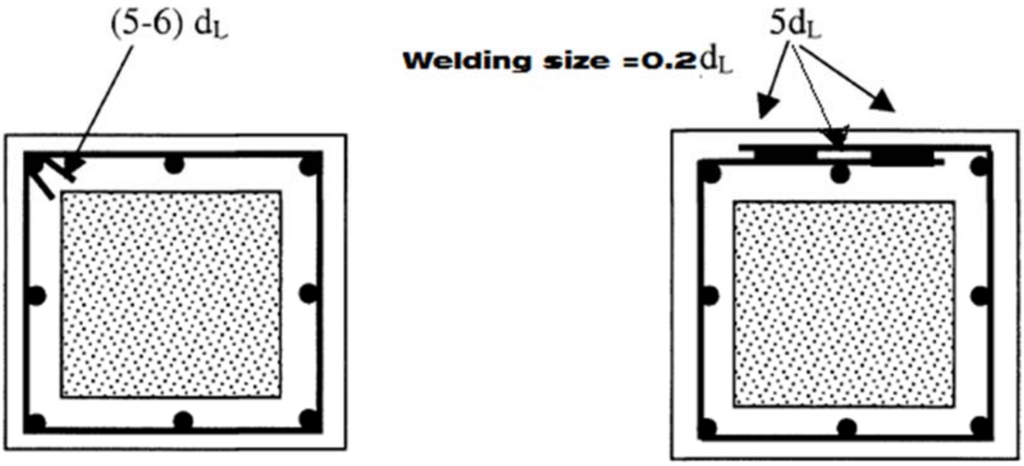


Figure 7 Reducing hook length and welding the ends of stirrups.

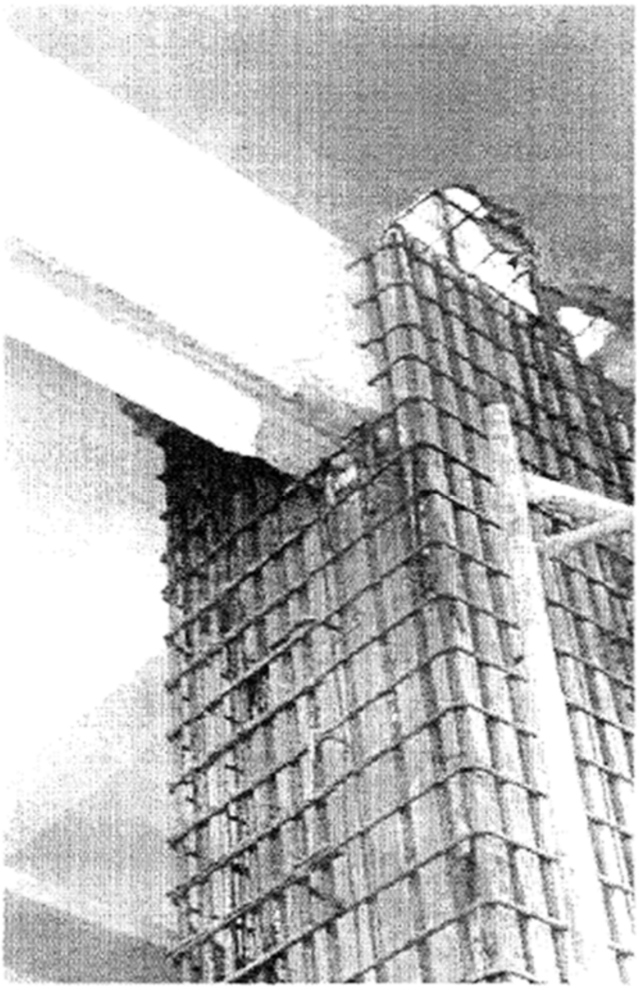


Figure 8 Strengthening the Column Joint.

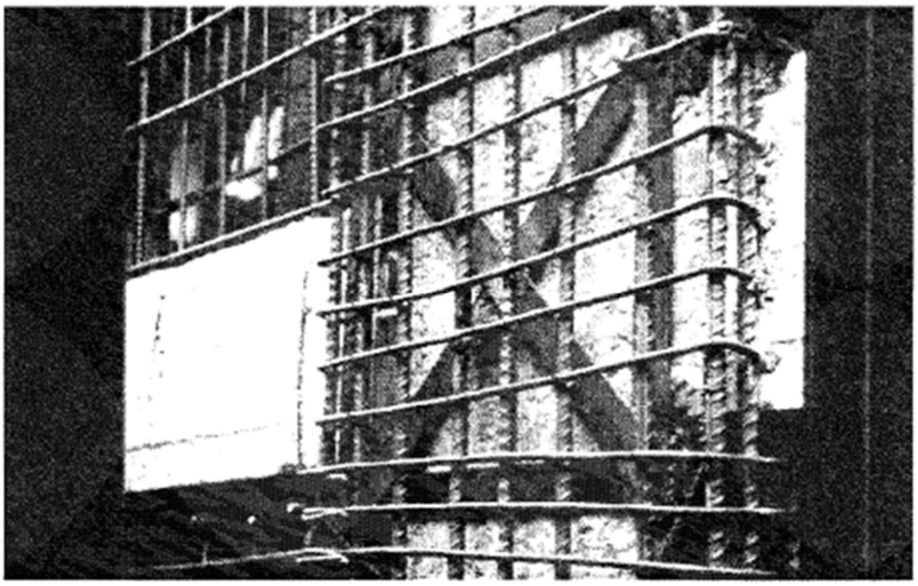


Figure 9 Placing a Steel Diagonal Collar around a Weak Column Joint.

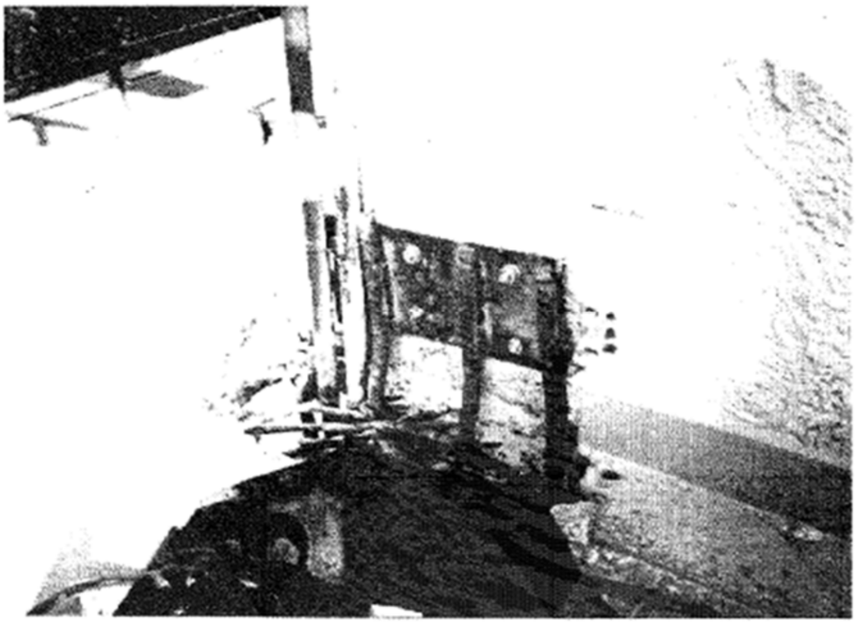


Figure 10 Welding Longitudinal Bars to an Anchor Plate.

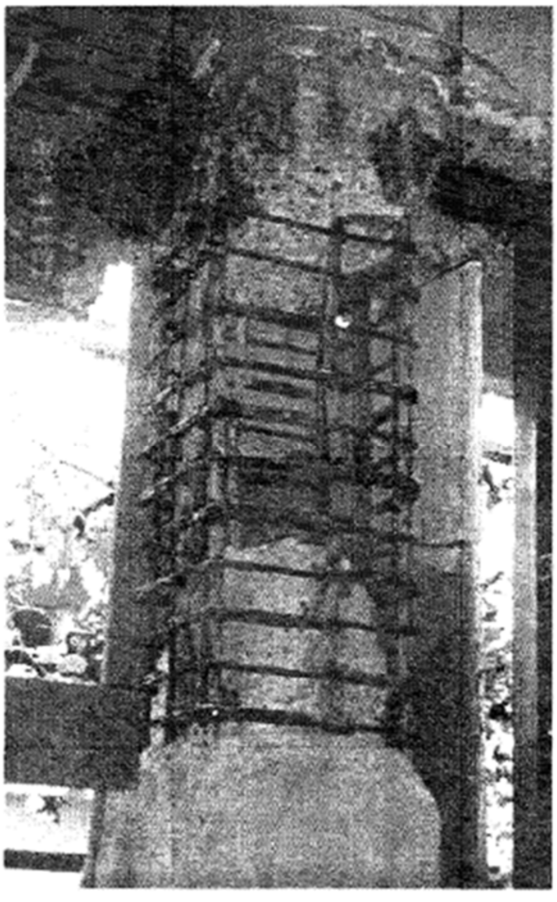


Figure 11 Removal of Defected Concrete from a Heavily Damaged Column.

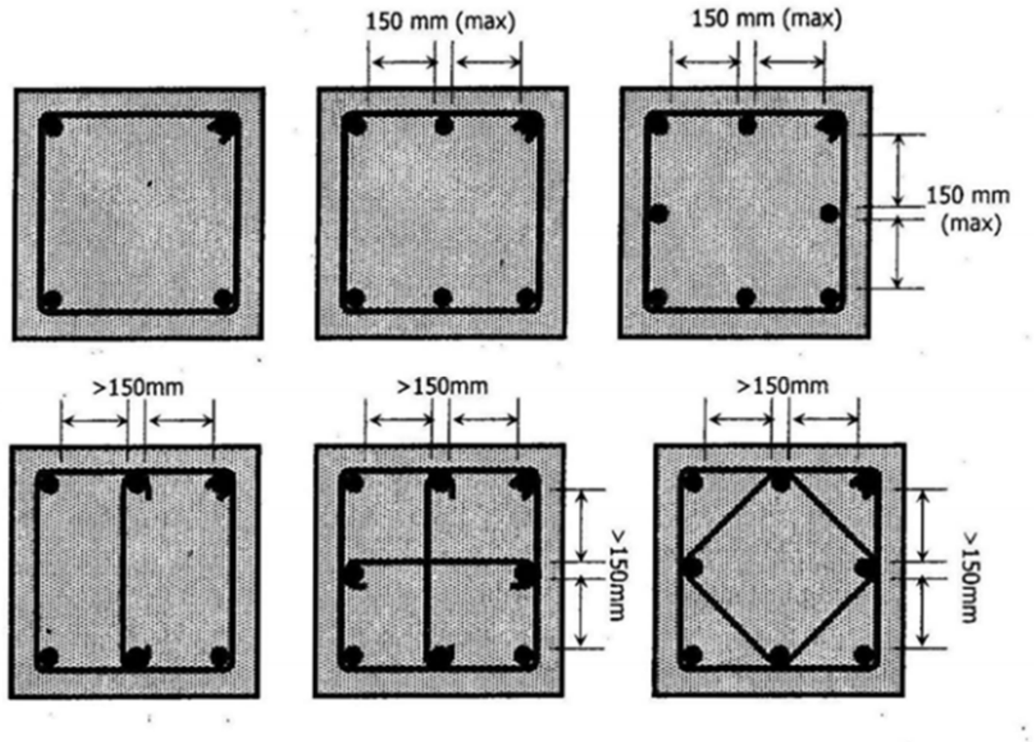


Figure 12 Typical Tie Arrangement